Water Main Geothermal:

Could Existing Water Pipes Replace Dirty Energy Utilities?

By Lilli Ambort and John Farrell

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INSTITUTE FOR Local Self-Reliance

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Related publications from ILSR's Energy Democracy Initiative:

- **The Secret to Low Cost, Low Carbon Home Heating? Your Water Pipes**: in this episode of the Local Energy Rules podcast, host John Farrell speaks with Jay Egg, a geothermal expert, about successful water main geothermal projects in Canada and the triumphs and challenges of projects in the U.S. (2020).
- **Utility Franchise Fee Update**: this post takes a deep dive into franchise fees, an oft-overlooked strategy for cities to fund their climate and energy goals (2020).
- **Inclusive Financing**: a report detailing how utilities can knock down major barriers to energy efficiency and renewables by allowing customers to make site-specific investments and recovering utility costs through an opt-in tariff (2016).
- **Energy Self-Reliant States III:** this national overview of state renewable electricity potential finds that 47 states could meet 100% of their electricity needs using in-state renewables (2020).
- **Investigating City Commitments to 100% Renewable Energy**: this report uses survey results to identify 11 key recommendations city leaders can use to transition to 100% renewable energy (2020).

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Executive Summary

This brief explores a novel, affordable concept to reduce greenhouse gas emissions and other pollutants from home heating and cooling: water main geothermal. Air source heat pumps can replace existing fossil-powered systems, but struggle to compete cost-effectively in cold climates. Water main geothermal combines the efficiency and technical capability of ground-source geothermal in cold climates with costs competitive to fossil gas furnaces. Using a heat exchanger attached to the water main (or a short spur), this mechanism replaces expensive well drilling or expansive loop fields to deliver thermal energy to a building's geothermal heat pump.

This analysis shows that water main geothermal could provide a viable, cost-effective alternative to traditional home heating and cooling systems. Homeowners benefit from lower heating and cooling costs, water utilities benefit from a new source of income, and cities benefit from reaching their climate commitments. It is our hope that U.S. cities — that almost universally own their public water utility — use the results of this brief to conduct a feasibility study to explore deployment of water main geothermal to homes and businesses in their jurisdiction.

Introduction

The United States' annual average temperature has increased by **1.2 degrees Fahrenheit** between 1986 to 2016 relative to the period of 1901 to 1960, with the most recent decade being the warmest in 1,500 years. As temperatures increase and extreme weather events become more frequent, Americans are going to use more electricity for air conditioning, and a combination of gas, oil, and electricity for heating. Home heating and cooling alone accounts for about **441 million tons** of carbon dioxide emissions annually in the United States, posing a serious challenge to cities (and countries) pursuing lower emissions. Homeowners could save energy, reduce costs, and lower emissions by switching to more efficient systems, like geothermal heating and cooling.

Geothermal systems, in use since the 1940s in the U.S., are one of the most efficient home heating and cooling systems. Geothermal heat pumps use the ground as a heat source or sink to heat and cool buildings. Since ground temperatures remain relatively constant, ranging from **45 degrees Fahrenheit to 75 degrees Fahrenheit** (depending on latitude), an average heat pump may use one unit of electricity to extract and distribute several units of heating or cooling.

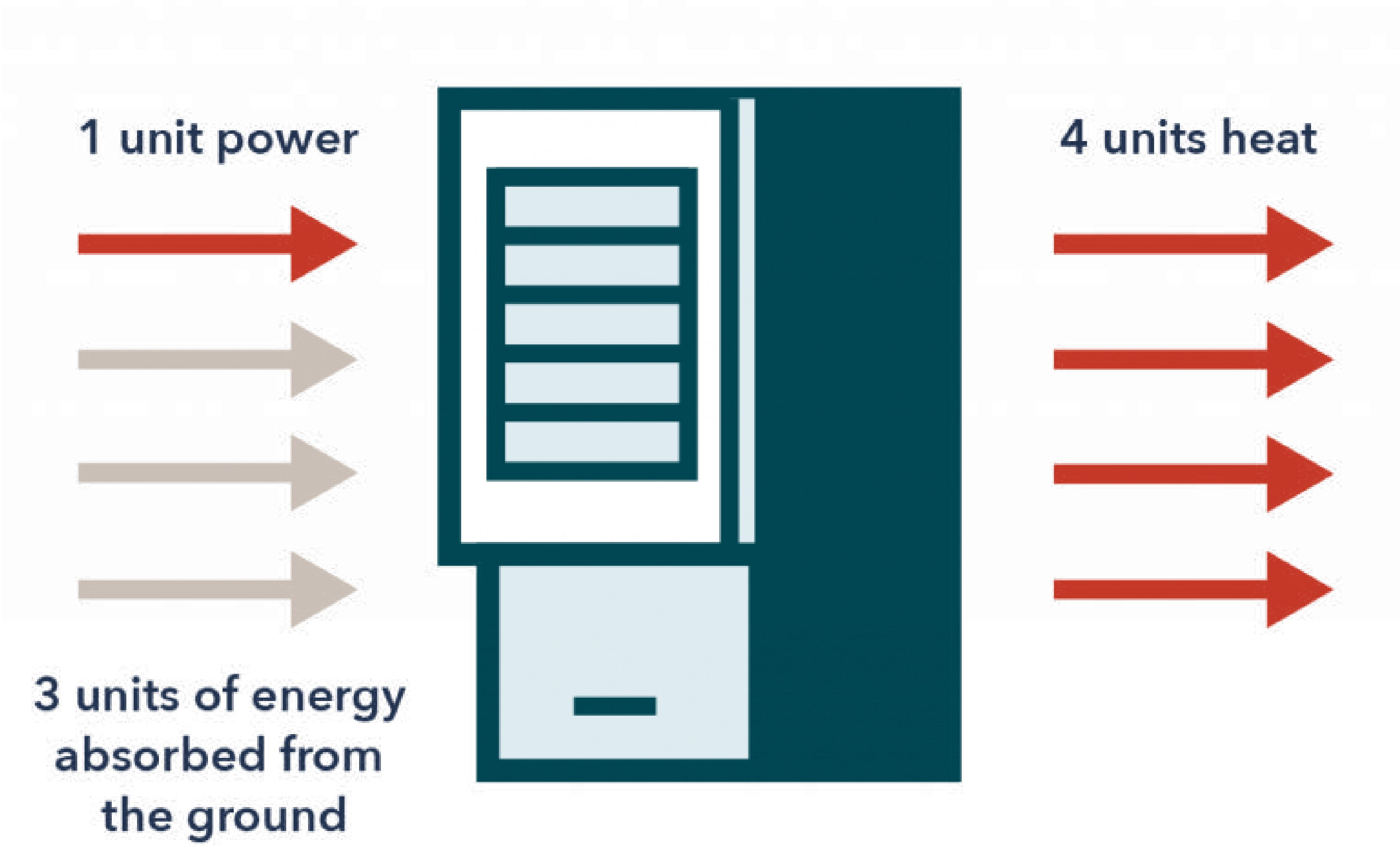


Photo via Dandelion Energy

Despite the high cost of installing geothermal, U.S. customers install approximately 50,000 systems each year. Due to the energy savings compared to many fuel sources such as oil, propane, or electric resistance heating, they can recover the upfront costs **5-10 years**.

Oak Ridge National Laboratory completed an assessment of geothermal heat pump potential across the entire U.S. residential sector. The South has the highest potential, due to its cooling demand and use of electric resistance water heating. The Midwest comes in at a close second. If the entire residential sector converted to geothermal heating and cooling, nationwide energy savings would amount to 42.2 percent and summer peak energy demand reduction would be 144 gigawatts. To put that in perspective, 144 gigawatts is equivalent to **450 million solar panels, 59,328 wind turbines**, or **288 coal plants** worth of peak demand energy savings. Annual energy expenditures savings would be $57.8 billion, and carbon emissions would be reduced by 42.4 percent annually.

Technical Potential of Residential GHPs

Benefits	Technical Potential				
	Northeast	Midwest	South	West	Nation
Annual primary energy savings	0.9	1.2	1.9	0.6	**4.6**
Percentage savings	42.9%	39.7%	46.5%	35.3%	**42.2%**
Annual CO2 emissions reduction (million metric tons)	62.7	72.4	125.0	36.5	**296.6**
Percentage savings	44.2%	39.1%	46.6%	35.1%	**42.4%**
Summer peak electrical demand reduction (GW)	28.9	46.3	56.1	12.7	**144.0**
Percentage savings	53.8%	47.1%	36.8%	50.4%	**42.2%**
Annual energy expenditures savings (billion $)	15.5	13.8	22.2	0.4	**57.8**
Percentage savings	47.2%	45.1%	48.3%	37.2%	**45.7%**

Source: Oak Ridge National Laboratory

A major barrier to geothermal systems is the large "loop field" needed to transfer ground temperature to the heat pump. The loop field consists of many loops or coils of hose filled with a benign heat transfer fluid, such as antifreeze glycol. Whether the loop field is horizontally or vertically placed, it requires the space of about half a football field and a willingness to tear up landscaping or spending thousands of dollars to drill bore-holes. About **21 percent** of homes in the U.S. cannot install traditional geothermal systems because their lots are too small. Many others can't recover the upfront costs because of artificially low fossil gas prices (due to producers being able to offload the health and environmental costs of production and combustion onto the public).

One building in New York, however, found a promising workaround to the loop field and cost recovery barrier that could revolutionize home heating and cooling: connecting their geothermal system to the city water main.

Water Main Geothermal

William L. Buck Elementary School in Valley Stream, N.Y., in partnership with American Water, was the first building in the United States to connect its geothermal system to the city water main in February of 2015. Instead of drilling several boreholes to install a traditional geothermal system, the school **saved $600,000** by connecting the pilot project to the city water main with a **pair of saddle taps**. The system has **two separate compartments**, one loop coming from the water main and one water/glycol loop for the school. The lines are separated by a double plated heat exchanger that the two loops run through simultaneously, with the water/glycol loop using the water main as either a heat sink or source. The graphic below illustrates the system.

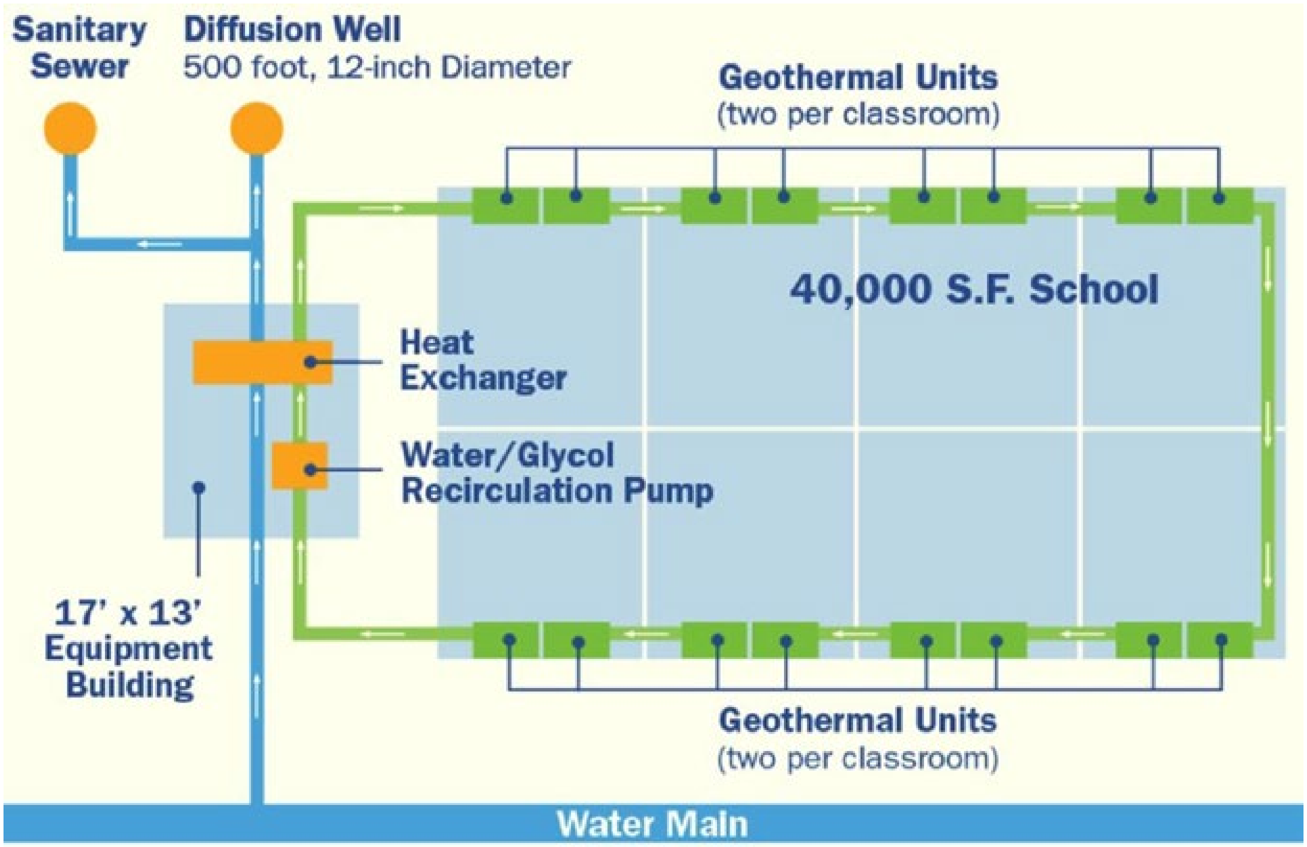


Photo via engineering.com

The water from the main flows into the heat exchanger (blue lines), which extracts heat (in the winter) or cooling (in the summer) for the glycol loop serving the building (green lines). The heated or cooled water/glycol solution then travels to the geothermal heat pump units serving classrooms. After the heat exchanger extracts or returns heat, the water from the main goes to the sanitary sewer and a diffusion well that returns the water to the local aquifer.

Photo via California Geo

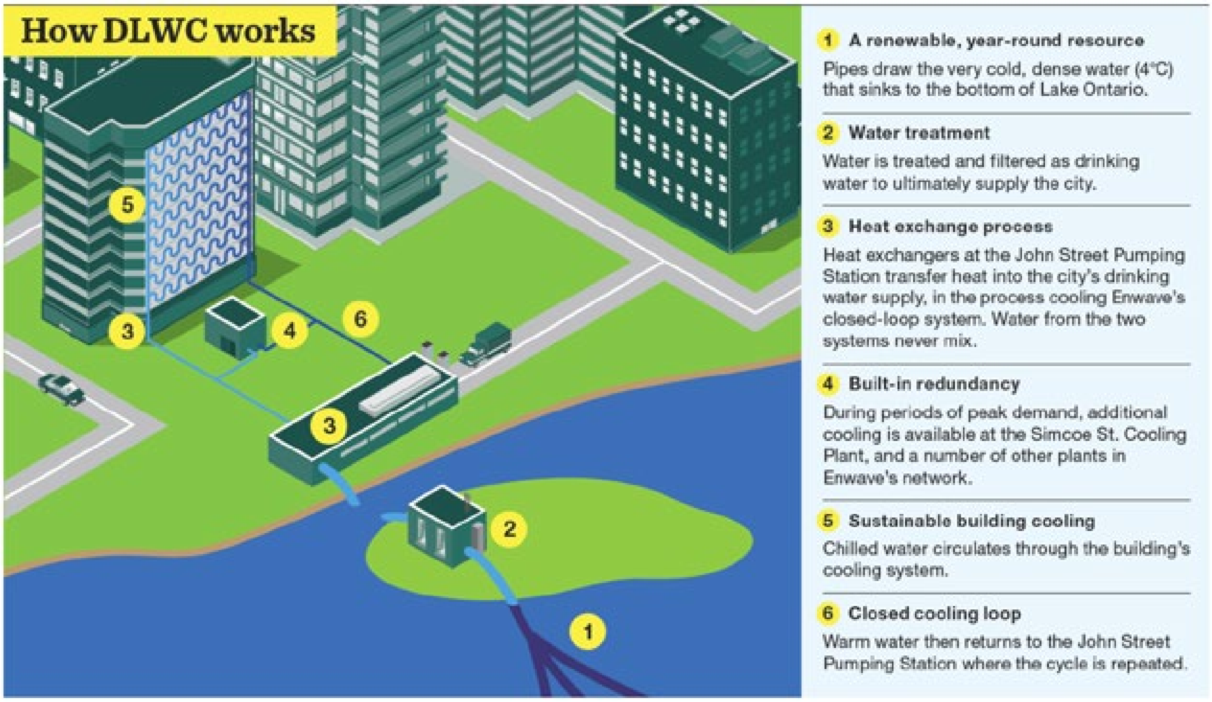
Before the geothermal pilot project, the 63-year-old, 40,000-square-foot school did not have air conditioning, making the building hot and uncomfortable for students late in the spring semester. Now, the geothermal system provides heating and cooling year round. For heating alone, the school saw a **56 percent reduction** in energy consumption per square foot and a 6 percent reduction in energy costs, saving $40,000 a year.

Other Models of Geothermal With Water

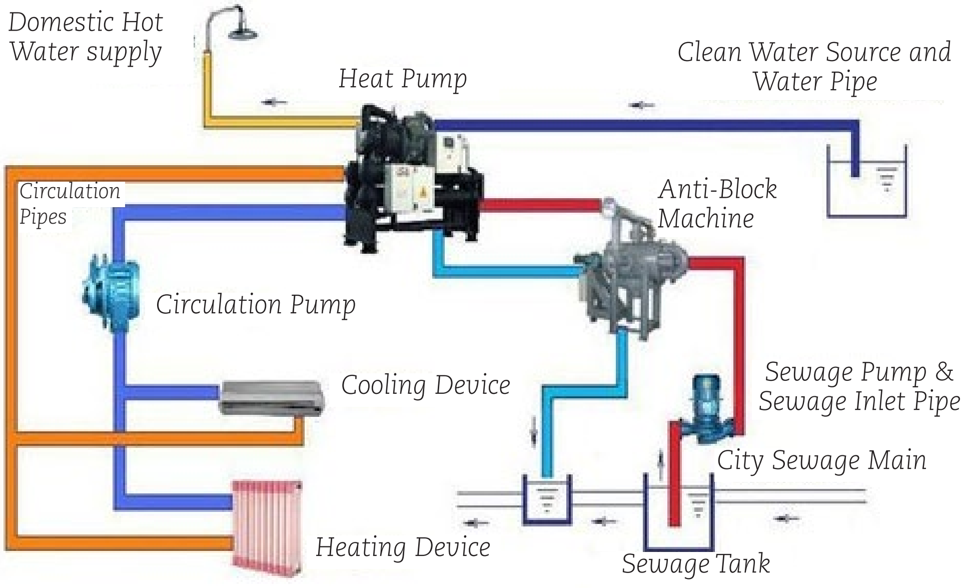
The William L. Buck Elementary School pilot project demonstrated the missed energy opportunity running beneath city streets. Other cities, including Toronto and Philadelphia, have already tapped water mains as a low-cost, low-carbon alternative to heating and cooling buildings.

Toronto's **Deep Lake Water Cooling project** provides air conditioning using cold lake water and a district chilled water cooling system. The natural low water temperature from Lake Ontario helps to air condition 51 buildings comprising 29 million square feet of high-rise building space in downtown Toronto. This alternative reduces CO2 emissions by 79,000 tons and reduces electricity consumption by 90 percent, as compared to conventional chilling. Three intake pipes remove water from Lake Ontario and run it through a standard water treatment process to become regular drinking water. As the cool water runs through the downtown area to provide drinking water, heat exchangers simultaneously use a separate water main to provide air conditioning. The coldness of the city's water is used to cool the warm water via heat exchangers, ensuring the city's potable water never touches the project's distribution system. Once cooled, the project's water is recirculated through the closed-loop distribution system to downtown cooling customers.

Figure 1: DLWC Process (Source: Toronto Hydro)



A few cities and provinces have turned to wastewater instead of potable water for energy. In February of 2012, the Philadelphia Water Department's **wastewater geothermal installation** came online at the Southeast Water Pollution Control Plant. The system uses the wastewater to heat the plant's compressor building and gallery space. As the **diagram below** shows, the system pumps the wastewater through an anti-block machine to prevent buildup. Afterward, the wastewater runs through a heat pump to facilitate the heat exchange needed to heat or cool the building. The project consists of a **one million BTU per hour unit** in the basement of the plant. NovaThermal initially estimated **$216,000 in savings** over 15 years; current savings are around **$18,000 annually**, with up to $270,000 in savings over 15 years. The plant's system, modelled below, is the first commercial scale geothermal system to use domestic wastewater in the United States.



The **Renewable Resource Recovery Corporation** (R3C) in Ontario has a solution to make wastewater geothermal systems available for residential homes. R3C has patented a precast concrete sewer pipe that has a heat extraction system embedded within. The pipe extracts geothermal heat from the ground and from within the pipe. The company used its geothermal technology to heat a **2,000 square foot home** in Sudbury, Ontario, one of the coldest Canadian cities, for the entire winter using only their pipe system to supply a heat pump.

While this paper primarily focuses on the potable water supply, the United States sewer water distribution system has untapped potential for energy recovery. According to the Department of Energy, the United States alone discards **350 billion kilowatt-hours** of hot water, or recoverable energy, down the drain each year; enough energy to heat **5 billion average-sized homes for an entire day in the middle of winter**.

With several examples of water-based geothermal in action, U.S. cities have an opportunity to consider how it could reduce energy use and costs, and cut emissions from building heating and cooling.

A New Energy Utility

Water main geothermal presents a compelling opportunity to address an existing infrastructure problem and a pressing climate threat.

The U.S. Environmental Protection Agency estimates that the country needs to invest **$600 billion** into its crumbling water infrastructure over the next 20 years to maintain its reliability. Currently, repairs and replacements move far too slowly — an average of **0.8 percent** of pipe infrastructure is replaced annually, equal to a 125-year replacement schedule. With water main geothermal, water utilities will have an opportunity to provide new services as they replace or upgrade existing water distribution infrastructure.

NEW INCOME

Unlike basic water main upgrades, selling heat provides a new revenue source for city water utilities. Instead of consumers paying the gas or electric utility (most often privately owned) for their heating and cooling, they would pay their water utility. Municipal water utilities could charge a flat rate based on the thermal needs of individual homes or earn revenue by financing utility-owned heat exchangers that serve one or more properties. Although most cities have public water utilities, cities with private water utilities could still benefit by charging the utility a right of way fee for delivering thermal energy, similar to what cities do with **electric utilities and utility poles**. For example, the City of Toronto receives **$1 million annually** as an energy transfer fee for the use of city infrastructure and as a shareholder dividend from the company that runs the system. Income from right of way fees could support more rapid expansion of water main geothermal or help fund citywide climate initiatives.

INSTITUTIONAL CHANGE

Water main geothermal also changes the power dynamic of building decarbonization initiatives by giving cities an alternative to gas utilities. Oil and gas heat most buildings, especially in northern climates. With a financial future tied to fuel sales, the private utilities selling fossil fuels to heat buildings have little incentive to help address the climate threat of burning oil and gas. Additionally, many states have granted these private utilities a monopoly, preventing competitors from challenging their business model or political hegemony.

In contrast, cities tend to own their water utilities. Over 150 cities with a combined population of 100 million Americans have pledged to transition to 100 percent renewable energy. Water main geothermal aligns a city's financial and climate interests even as it frees residents and businesses from the dominance of fossil fuel companies. Instead of imploring incumbent fossil gas utilities to sell less product, cities can build a competitive and cost-effective heating (and cooling) solution for homes and businesses. Water main geothermal can provide revenue for a core municipal utility even as it expands service.

MORE EQUITABLE ENERGY

A thermal energy water utility could also aim to solve pressing inequities in energy burden that are often ignored or overlooked by private utilities. Wide-ranging research has acknowledged that low-income households **spend an average of three times more of their income on energy bills** than higher income households (a figure that has not changed over time). Even with similar incomes, problems of high energy burdens and insecurity are on average worse among minority households. For example, black households with children are more likely than any other group to experience energy insecurity even after controlling for income. Across all low-income households, energy burdens are highest but access to energy-saving utility programs is lowest.

Over 150 U.S. cities, home to over 100 million residents, have made bold commitments to shift to cleaner energy. Many of these cities have commitments to make their economies more equitable. Water main geothermal provided by a municipal water utility could give the city the power to help achieve both goals.

ADDITIONAL SERVICES

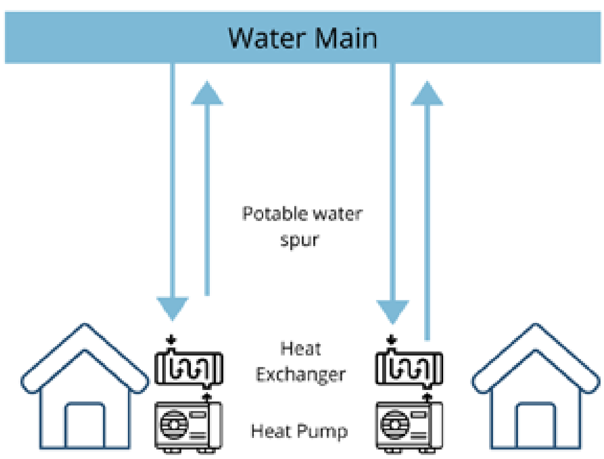
Water utilities selling heating and cooling can also justify financing energy efficiency improvements to homes. **Inclusive energy financing** (also known by its trademark name of Pay As You Save™) is a breakthrough strategy to finance weatherization projects on utility bills that can lower barriers, especially for renters and low-income residents. Few private utilities have adopted this strategy, but several customer-owned cooperatives have. With a city — and its climate commitments — in charge, it may be easier to provide better access to clean energy improvements for all.

A Residential Model?

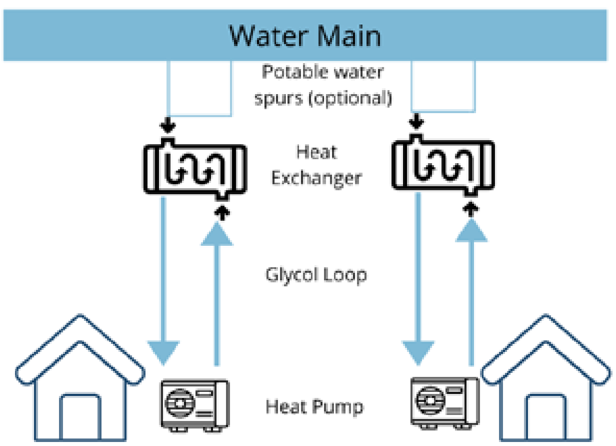
The water main geothermal system at William L. Buck elementary school has provided a potential model for schools or commercial buildings. The pilot program illustrated how water main geothermal works and that water main geothermal could provide energy savings on heating and cooling for other schools. Residential systems, however, may look different.

Every home would need a connection to the water main (or a spur) for access to thermal energy. This could be individualized to a single home or a loop serving an entire block. Each home would need access to a double-plated heat exchanger that would transmit thermal energy from the water main (or spur) — without touching the contents — to a fluid loop that could connect to the home's heat pump.

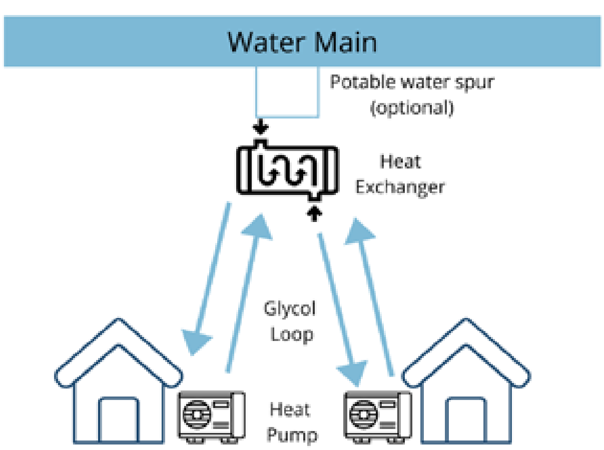
Option 1: Individually owned heat exchangers



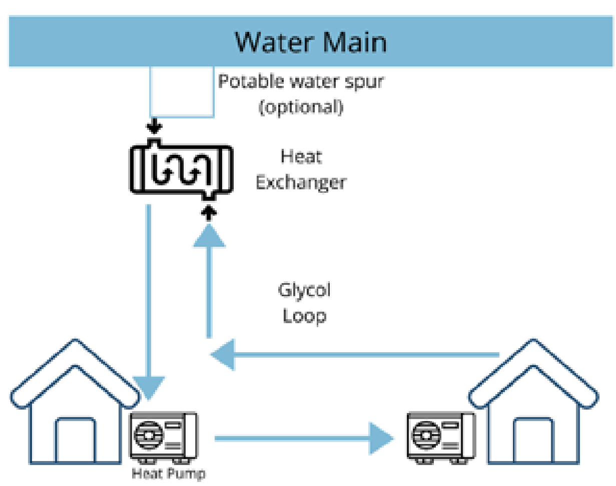
Option 2: Utility owned home heat exchangers



Option 3: Utility owned community heat exchanger



Option 4: Utility owned community heat exchanger, community loop



The graphic above illustrates multiple options for residential water main geothermal options. Under option one, homes would have individual heat exchangers and heat pumps provided by the homeowner. Each heat exchanger would be serviced by a spur running from the water main. In the second option, each home would still have an individual heat pump, but the individual heat exchangers would be owned by the utility and have the potential to be attached to the water main directly or via a spur. The third and fourth options show a sized up heat exchanger owned by the water utility that could serve multiple homes. The difference between these two options is that the third option has individual loops from the heat exchanger to the homes. The fourth option instead uses a community thermal loop that serves multiple homes.

Thermal Supply Technical Issues

To work widely, water main geothermal requires sufficient water flow in the water main to provide enough heating and cooling energy for customers as well as to maintain a consistent temperature in the water main. The spurs used to provide thermal energy to homes would also need to have sufficient flow, potentially requiring a circulation pump to continually draw and return water from the main.

The following simple analysis looks at the issue of temperature management in the water main and in a spur serving a single home. For this analysis, we look at an example of three full days with extreme temperatures, with a base assumption of -30°F for 72 hours. A well-insulated 2,000 square foot home with a three ton geothermal unit will require 25,000 BTU per hour to maintain a temperature difference of 100°F between the inside (70°F) and outside. On average, a one inch spur supplying a home from the water main has 37 gallons flowing through it every minute. To heat a house for 72 hours, the geothermal unit would extract about 1.8 million BTUs of thermal energy from the approximately 160,000 gallons of water that would flow through the one inch pipe. Since each gallon of water requires 8.33 BTUs to change the temperature by 1°F, the thermal load would lower the temperature of the water in the spur by about 0.45°F each day over 3 days. These calculations do not account for inefficiencies in the system, exergy losses[1] from the water to air heat transfer, or reverse thermal loading of the ground. However, it appears that a single home would have a minimal impact on the water temperature in a one-inch spur pipe off of the water main, even in the most extreme circumstances. It's also important to note that the temperature impacts are cumulative downstream of the home, but not for the home itself, which continues to be supplied with fresh water from the main.

1. **Exergy loss** of water to air ground source heat pumps calculations require the rate of heat transfer, environment temperature, and power input of all components of the system. System inefficiencies most often have a moderate effect on exergy loss and energy usage, but not enough to make a big difference on the home's thermal load or the homeowner's energy bill.

The second scenario examines the impact of multiple homes on the water main itself, either drawing off heat or cold to serve the homes' heating or cooling needs. A significant increase in water temperature flowing through the main could result in increased scaling and bacterial growth while too much heat extracted could freeze the water. However, a 6-inch water main (among the smallest) has a flow volume 36 times greater than a single home's supply through a one-inch spur. If we scale up our example to a single block of about 40 homes in a low-density residential neighborhood, the total impact on the water flow through a 6-inch water main would be about 0.5 °F per day. For an entire neighborhood of 1000 homes, the thermal impact would be a worrying 12.5 °F per day. As noted above, this ignores the thermal heat energy that would be recaptured by the buried pipes and exergy losses within the home. At a basic level, a handful of homes connected to the water main for geothermal heating and cooling will have minimal impact on water temperature. At a larger scale, however thermal changes are more significant and more mitigation and management of temperature impacts would be required.

Water main upgrades are a particularly useful tool. A 12-inch water main has four times the flow volume of a six-inch main, for example, reducing the heat impact of 40 homes in the prior example from 0.50°F to 0.13°F per day. In the pilot project at William L. Buck Elementary School, for example, the main needed to be sized up, and the line running from the water main to the school required a constant flow of water. Fundamentally, installing water main geothermal systems is well within the engineering scope of an existing water utility, and could provide cost-effective thermal services and energy savings to municipal customers.

Widespread adoption would require deeper analysis of temperature impacts and potential mitigation measures, as well as more detailed knowledge of the water distribution system in a city. The cumulative impact on the water's temperature as it facilitates heat exchange between multiple homes in a given period of time is a cause of concern but depends on the water flow. In our basic scenarios, we examined the thermal impact per day of a single home, a low-density city block, and an entire residential neighborhood on the temperature of a certain quantity of water flowing through the main. However, it's important to note that these impacts are all downstream of the heat pumps systems. For example, our calculations indicate that the velocity of water through a 6-inch pipe with a rate of 1,100 gallons per minute is about 12.5 feet per second. Assuming the distance between two home's water supply lines is 55 feet per home, the water would need to travel 55,000 feet between 1,000 homes on a single water main in a high density residential area. The water would take 73 minutes to travel between the first and thousandth home. In other words, the thermal impact from participating homes only accumulates for 73 minutes (based on our flow estimate) before the water has passed beyond the final house, not for an entire day.

The more pressing thermal management problem may not be for individual homes, therefore, but system-wide. The impact on water temperature after serving multiple homes will, over time, affect the temperature at the end destination. Whether the unused water is injected back into an aquifer or returned to a river, the accumulated temperature changes from heating and cooling attached homes could meaningfully change the temperature of the aquifer or river. A common issue with traditional geothermal systems, for example, is seasonal balance. If the heating season is more intense than the cooling season (as is true for most of the northern United States), more heat is extracted from the ground in winter than is returned in the summer. With entire city neighborhoods tapping the water system for heating, it could lower groundwater or river temperatures meaningfully over time. Fortunately, there are also management techniques for the long-term impacts. Geothermal systems in cold climates are often supplemented by solar thermal systems to provide supplementary heat. Suffice to say that thermal management is a complex and necessary consideration for water main geothermal systems.

The shortcomings of this report are that the authors do not have enough engineering background to calculate the full effects of thermal offloading from homes on the water main's temperature or the recovery rate of the water's temperature over time. Interested cities would need to conduct an assessment of the thermal load of each building, residential neighborhood composition, the temperature of the water main, and the existing water flow volume per hour. Depending on the water utility's existing infrastructure, certain neighborhoods may already be ideal candidates for the water main geothermal system.

Home Heat Pump Options

The size (or number) of heat pump(s) needed for a home depends on square footage, quality of insulation, and number and size of windows. Compared to traditional furnaces, heat pumps have much lower thermal ratings (as measured in BTUs) for a similar home. This is because gas furnaces are typically oversized, for several reasons. One, to save money, customers tend to lower the home temperature at night or when they're away, requiring more capacity to recover. In contrast, heat pump systems operate most efficiently at a constant temperature. Gas furnaces also come in step sizes, e.g. 40,000, 70,000, or 90,000 BTU. If a house has a maximum thermal load of 72,000 BTU, then a 90,000 BTU furnace would be installed. Installers also make a higher profit on a larger furnace, so they have a financial incentive to sell an oversized system.

Based on data from the Massachusetts Clean Energy Center's **Residential Ground-Source Heat Pump program**, most homes at or below the average size for an American home (2,000 square feet) would be served by a single, standard three-ton heat pump in a climate like Massachusetts. For colder climates and larger homes, additional insulation may be required to manage with a single heat pump.

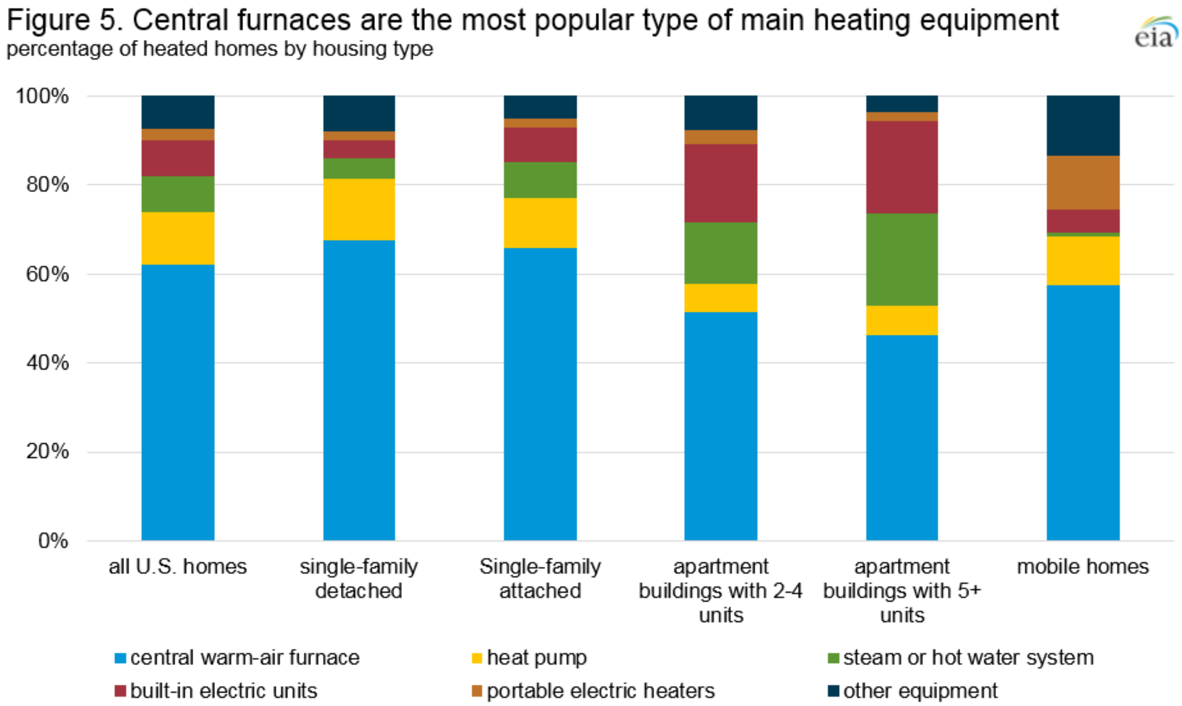


Photo via the U.S. Energy Information Administration

Most, but not all, U.S. homes are good candidates for heat pumps. As shown above, **over 60 percent** of homes in the United States have central warm-air furnaces, making geothermal heat pumps a likely drop-in replacement. Homes that rely on water boilers, heating oil connected to radiators, or hot water baseboard heaters would need to either add duct work or opt for a **high temperature water-to-water heat pump** to serve the water-based system. High temperature water-to-water heat pumps use liquid with a temperature of between 50 degrees Fahrenheit and 122 degrees Fahrenheit. The water-to-water heat pump then takes the preheated liquid and heats it up to 160 degrees Fahrenheit to be used for home heating. Depending on the type of heating delivery — in-floor, radiators, etc. — homes may not need as high a water temperature.

Another option is a **geothermal split system**, a hybrid that can help in homes where electrical service may not have enough capacity. In this case, the geothermal system would provide all of the cooling and most of the home heating, with the furnace as a backup. The split system is more cost effective in homes that would need to increase their electric service capacity to support an all electric system.

Homes with built-in electric resistance heaters, a small fraction of homes, could not as easily be served with geothermal because of the required ductwork or conversion to a water-based system that could be served by a water-to-water heat pump. If a homeowner adds ductwork, the average additional cost would be about **$2,802 per cooling ton**, significantly increasing the cost.

Comparing Costs of Water Main Geothermal

Drilling bore fields is one of the most expensive components of installing a geothermal system. The pilot project in Valley Stream, N.Y., saved $600,000 by not having to drill **over a hundred bore holes**, out of a total project cost of **$3.4 million**. That price tag includes the cost of sizing up the water main, as well as installing a downsized underground loop system to service individual classrooms, a heat exchanger, and two geothermal units in each classroom. The school currently saves **$40,000 a year** in heating costs.

The William L. Buck elementary school project was more expensive than future projects will be for multiple reasons, including:

- School was in session while the system was being installed, so work had to be completed at night and during the weekend and at 1.5 times normal contractor wages, costing $1.7 million in labor alone.
- American Water, the water utility, used its own contractors who required additional training to work on the pilot project.
- Honeywell charged $88,000 to tie into the existing school energy management system.

Improvements could reduce expected costs to $2 million for water main geothermal models similar to the pilot.

The project at William L. Buck Elementary School was paid for by American Water under the premise that the water utility would become the school's heating and cooling utility as well. However, because of regulations set by the New York Department of Health (based on outdated information), the water utility was not allowed to recirculate the water after it had gone through heat exchange at the school. So, instead of receiving the income from both the heat exchange from the water and later for the use of the same water, American Water could only charge for heat exchange. According to Jack DiEnna of Geothermal National and International Initiative (Geo-Nii), the New York Public Service Commission had planned to pay American Water $2.5 to $3 million for the system but backed out of the agreement after a change in leadership. Regulatory barriers prevented the pilot system from proving the full economic potential of water main geothermal.

Traditional geothermal systems have already proven their economic viability for commercial or multifamily buildings. DiEnna completed a traditional geothermal installation at a similarly sized school in Philadelphia that cost $3 million. The payback period on the system was only 7 years because of reduced operation costs and energy savings. The average cost of a water main geothermal system could be up to 50 percent less than the cost of a traditional geothermal system, reducing the payback period even further. Jay Egg, a geothermal expert, estimated that for a 20-story high rise, a regular geothermal system would cost $8 million, but if the system is connected to the water main, it would cost only $4 million.

WATER MAIN VERSUS GROUND-SOURCE GEOTHERMAL

The table below shows the cost to homeowners of replacing their heating and cooling system in three scenarios: a traditional geothermal heat pump with bore holes, a geothermal heat pump connected to the water main, and a water main geothermal heat pump without the cost of a heat exchanger. The table shows the upfront estimated cost of each system, the (optional) cost of adding ductwork, the current potential tax credit, the cost after the tax credit, the energy savings compared to traditional fossil gas or oil heating, and the payback period for homeowners to recoup the cost of the system for each scenario (which is variable based on original fuel type). Based on conversations with geothermal expert Jay Egg, ILSR finds that water main connections cut the cost of geothermal systems by half, and if the water utility pays for the heat exchanger, homeowner costs are even lower.

Cost to Homeowners			
	Traditional Geothermal Heat Pump (GHP)	Water Main GHP	Water Main GHP (heat exchanger paid by utility)
Upfront cost	$20,000	$6,000 to $12,000	$3,300 to $7,000
Energy savings	30 - 70%	30 - 70%	30 - 70%
Added ductwork	$2,802 per cooling ton	$2,802 per cooling ton	$2,802 per cooling ton
Cost + added ductwork (based on 3 ton system)	$28,406	$14,406 to $20,406	$11,706 to $15,406
Tax Credit	26%	26%	26%
Cost-Tax Credit	$14,800	$4,440 to $8,880	$2,442 to $5,180

Source: Earth River Geothermal, Energy Star

According to Don Penn, the engineer for the New York water main geothermal pilot program, the cost of a water main geothermal system for a homeowner (connecting to the municipal water main, installing a standard three ton system with a double wall heat exchanger, and a geothermal heat pump) would be $6,000 to $12,000, depending on the efficiency of the system. Installing traditional geothermal in a typical 2,000 square foot home costs around **$20,000**. Currently, there is a 26 percent tax credit from the IRS on all geothermal system equipment. In 2021, it will decrease to 22 percent and may expire if not renewed by the end of the year. The added financial incentives and tax benefits cut the cost of geothermal systems even further. In connecting geothermal heat pumps to the water main, tax credits cut the cost of installation from over $14,000 to less than $9,000. If the water utility provides the infrastructure necessary for a new spur from the water main and the heat exchanger, the cost of the system decreases to less than $6,000.

The break-even point for a water main geothermal system depends on utility rates, excavation costs, house insulation quality, presence of ductwork, efficiency of the geothermal model, and what incentives the federal government, local government, and utility can provide.

WATER MAIN GEOTHERMAL VERSUS TRADITIONAL HVAC

Connecting geothermal heat pumps to the water main also makes the cost of installation competitive with other heating and cooling systems. For homes with central air conditioning, for example, a water main geothermal system has a comparable upfront cost to a combination of gas furnace and air conditioner. If the heat exchanger is paid for by the utility, water main geothermal systems would be even cheaper. Even in cases where the upfront cost of a water main geothermal system is greater than for alternatives, long-term energy savings would help recoup the cost of the system. Geothermal systems continue to provide cost savings on energy bills long after the system cost has been recovered.

HVAC Unit Installation Costs	
Central Air Conditioner	$3,500 to $7,600
Electric Furnace	$1,500 to $2,500
Gas Furnace	$4,000 to $5,000
Oil Furnace	$5,500 to $6,500
Air Source Heat Pump	$7,500 to $12,500
Water Main GHP	$6,000 to $12,000
Water Main GHP (exchanger paid by utility)	$3,300 to $7,000

Source: University of New Hampshire, Modernize

Lifetime Costs (a cold climate case study)

To evaluate the potential costs for a typical homeowner, we use the example of our co-author John Farrell's Minneapolis home. In Minneapolis, Minn., gas cost approximately 71 cents per therm in January 2020 including fuel, delivery costs, and taxes and fees. The federal **Energy Information Administration** shows national prices for commodity gas for residential gas use at around 95 cents per therm on average over the past decade during the heating season.

Heat pump customers will get their thermal energy from water rather than gas, instead using electricity to convert the thermal energy in the water to heat for the home. For a 2,500 square foot home, geothermal contractor **Dandelion Energy** reports electricity use for heating of approximately 8,150 kilowatt-hours in a year. Crudely adjusted down by 20 percent to match a 2,000 square foot home size used in our heating example, that would be an additional 6,520 kilowatt-hours. At a local price of $0.11 per kilowatt-hour, the annual price of electricity to provide geothermal heating would be around $717.

Geothermal heat pumps also provide efficient air conditioning, reducing energy consumption for cooling in the Dandelion example by 43 percent, about 1,153 kilowatt-hours. With another crude 20 percent adjustment for our example home, we'll assume an electricity savings of 922 kilowatt-hours, and a dollar savings of about $101.

In combination, a geothermal heat pump will unfortunately increase heating and cooling costs for a Minneapolis customer with central heating and air conditioning by about $84 per year, due to low gas prices. If Minneapolis gas prices matched the national average of 95 cents, the equation flips. Heating costs would rise to $713 per year, and the geothermal system would save about $100 per year between heating and cooling. But operating costs aren't the only story.

The midpoint cost estimate for a natural gas furnace and central air conditioner is about $10,000, compared to $6,660 for a water main geothermal system (after 26% tax credit). If both were financed at 5 percent interest for 10 years, the geothermal customer would save an additional $36 per month or $439 per year.

A final element is the cost of the water main connection. The average cost of installing a new water main hookup to a home is **$1,559**. The amount varies depending on the estimated cost of testing, inspection, and installing service to the home, but it's a decent ballpark estimate. ILSR expects that a water utility would finance and bill customers for this cost at low interest (3%) over 20 years, for an annual cost of $105.

The net effect financed equipment and infrastructure costs plus operations costs shows a net savings for water main geothermal compared to fossil gas plus central air conditioning of $250 per year in Minneapolis. If the local gas price was closer to the national average, annual savings would be closer to $400. The two tables below account for the difference in cost per therm of fossil gas in Minneapolis versus the national average. All other costs for a geothermal system considered below remain the same.

Water Main Geothermal Pro Forma for 2,000 s.f. Minneapolis Home

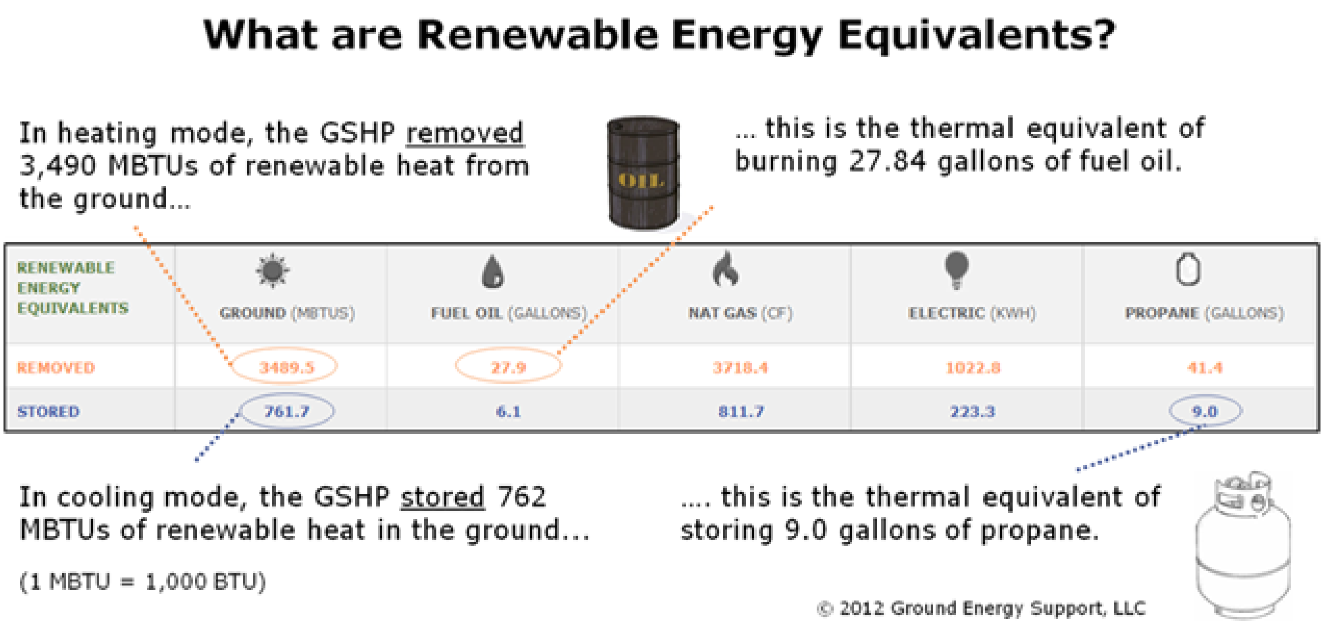
	Annual Energy Use	Annual Cost
Electricity for heat	+6520 kWh	$717
Electricity for cooling	-922 kWh	-$101
Fossil gas @ $0.71 per therm	-750 therms	-$532
Water main connection		$105
Replacement equipment cost		-$439
TOTAL		**-$250**
Other considerations		**Cost impact**
Thermal charge from water utility		+ +
Carbon price		- -

Water Main Geothermal Pro Forma for 2,000 s.f. National Avg. Home

	Annual Energy Use	Annual Cost
Electricity for heat	+6520 kWh	$717
Electricity for cooling	-922 kWh	-$101
Fossil gas @ $0.95 per therm	-750 therms	-$713
Water main connection		$105
Replacement equipment cost		-$439
TOTAL		**-$431**
Other considerations		**Cost impact**
Thermal charge from water utility		+ +
Carbon price		- -

Emissions

In addition to potential economic benefits, geothermal systems cut emissions. Benefiting both cities and residents, geothermal heat pumps produce **75 percent to 85 percent** fewer emissions than gas and oil furnaces (and the benefit only grows as more electricity is produced from renewable resources). Geothermal heat pumps reduce emissions up to 72 percent compared to electric resistance heating with standard air conditioning equipment. Central air conditioning and heat pumps operate similarly, but there's one key difference. Central air conditioners have to produce heat to provide cooling, while heat pumps transfer heat from the air (or water) to provide cooling without producing additional heat. Therefore, heat pumps are more efficient than air conditioners and generate four times more energy than they consume. Geothermal heat pumps are able to provide these reductions in emissions as they use **25 percent to 50 percent less** electricity than conventional heating or cooling systems.



Co-author John Farrell's Minneapolis home uses about 900 therms of gas each year, or just under 11,000 pounds of carbon dioxide equivalent. That's for the furnace, water heating, and a gas dryer, with the latter using about 10-15 therms per month. A geothermal system has the potential to replace the heating and water heating use of about 750 therms or 9,000 pounds of carbon dioxide per year (an 81 percent reduction).

WATER MAIN GEOTHERMAL VERSUS ALTERNATIVES

As another non-gas heating and cooling system alternative, air source heat pumps are not as effective as water main geothermal systems in cold climates, nor as economical.

A ductless air source heat pump installation can cost from **$3,500 to $5,000** per indoor unit, while a central heat pump system can cost between $12,000 and $20,000. These costs are dependent on tax credits, financial incentives, and installation costs. Central systems tend to be more expensive, especially if the home does not already have a duct system, which can add an extra cost of $15,000 to $30,000. Most unducted systems use three or more indoor units, which cost around **$7,500 for 3 units** and up to $12,500 for 5 units. Overall, the installation costs for an air source heat pump are comparable to the costs of installing a geothermal heat pump for a system connected to the water main. The energy savings are similar as well; where air source heat pumps have an average **energy savings of 40 percent**, geothermal heat pumps can cut energy costs by **30 percent to 70 percent** (depending on the efficiency of the system). Geothermal heat pumps can reduce emissions by **up to 44 percent** compared to air source heat pumps.

However, despite similar upfront costs and overall savings, air source heat pumps perform poorly in cold temperatures. When temperatures drop below 5 degrees Fahrenheit, most air-source systems can no longer efficiently provide heat. Homes can use a secondary electric (or gas) heating system to assist during extreme cold, but using backup systems reduces energy and cost savings. Air source heat pumps also do not provide a potential revenue stream to the city water utility.

SUMMARIZING THE ECONOMIC BENEFITS

Water main geothermal systems could cut the cost of installing a geothermal system in half. At this lower price, it reduces costs compared to air source heat pumps and oil furnaces, while providing cost competitive savings compared to gas furnaces. Water main geothermal systems could cut electricity usage between 25 percent to 50 percent and reduce emissions by up to 85 percent compared to traditional HVAC systems. Water main geothermal is one of the most cost effective and environmentally friendly ways to heat and cool residential homes.

Localizing Building Energy Generation

An often-overlooked benefit of electrification, such as transitioning from fossil gas furnaces to heat pumps, is the opportunity to produce the energy for heating and cooling locally or on-site. Approximately **40 percent of American homes** are suitable for solar and every household could own a slice of a **community solar** project nearby. In both cases, the solar electricity could power the heat pump for heating and cooling the building. A typical 5-kilowatt residential solar array in the Midwest would produce enough electricity each year to entirely offset the additional electricity demand for heating from a heat pump.

The heat pump opportunity also suggests a change to solar policy. Electricity customers with solar are often required to size their solar array to the home's electricity use. Net metering, the accounting policy responsible, allows customers to subtract from their electric bill all the electricity they produce, paying just the "net" amount. But size limits associated with net metering (in theory to prevent customers from "overproducing") do not account for the growing use of electricity to power everything. A heat pump increases electricity use even as it reduces overall energy consumption for heating. An electric vehicle does the same. Since customer-sited solar has significant social and environmental benefits, electricity consumers argue for allowing them to be maximized in size to serve existing and future electricity uses.

Jurisdictional and Code Issues

The pilot water main geothermal program in Valley Stream, N.Y., faced regulatory issues with the New York Department of Health (DOH). The N.Y. DOH has a regulation that **prohibits the return of potable water** to the distribution system after heat exchange. The pilot was in contradiction of New York's 10 State Standards and the **U.S. Environmental Protection Agency's guidance document WSG 170**.

The pilot program at William L. Buck Elementary school was able to go ahead with the installation of the geothermal system, but only because it had federal approval. Unlike the original plans to have the water from the system recirculated into the distribution system, the New York Department of Health required that the water from the water main go to an aquifer via a diffusion well and the sanitary sewer instead. Oneonta, N.Y., was inspired by the pilot and **commissioned a feasibility study** to do a similar system at a local hospital to reduce the facility's reliance on gas. Oneonta had to scrap this project because it was also in violation of part 8.10.2 of the 10 State Standards that does not allow potable water to be recirculated after heat exchange. Before the city could rework its plan, the state's health department threatened to pull funding for the municipal water utility if the project went forward.

Could the health department's opposition affect other proposed projects?

The New York Department of Health cited the **U.S. Environmental Protection Agency's guidance document WSG 170** from 2003. The memo comes from the Director for the Office of Ground Water and Drinking Water, citing concerns over the prior decade about water contamination with metal byproducts, oil, and refrigerants, in addition to concerns on temperature changes and bacteria growth from heat pumps. However, the memo acknowledges that at the time there were not satisfactory test results to indicate whether heat pumps would actually create these issues if the water was recirculated to the distribution system. New evidence has shown that potable water heat exchange is perfectly safe and manageable.

In a 2018 study, the Oak Ridge National Laboratory found that using a heat exchanger on a water supply line caused only marginal temperature increases (2.9 degrees Celsius, or 5.2 degrees Fahrenheit) and had no impact on water quality and bacterial growth. The elementary school pilot project's use of a double walled heat exchanger ensures that the water/glycol solution in the geothermal loop will never contaminate the potable water. It is also important to note that geothermal heat pumps are already authorized for use with potable domestic hot water (DHW) systems, such as drinking fountains and dedicated DHW heat pumps. Safe and manageable heat exchange already exists within the water distribution system, so it is time to expand beyond water fountains and into geothermal heat pumps.

Dedicated Potable Water Cooler

Dedicated and passive Domestic Hot Water Generators

Dedicated Hot Water GHP (water-to-water GHP)

Not every state or municipality has regulations in place that prevent the use of municipal water mains for geothermal systems. Individual municipal water districts are free to use the energy in their water lines, and local municipalities must choose how to keep their water safe. Federal approval or approval by the governor's office can supersede state regulations to approve municipal water main geothermal systems. Currently, the federal government does not have any formal rules regulating the installation or use of municipal water mains for geothermal systems.

The plumbing code presents another potential barrier to implementing water main geothermal systems. Both the International Plumbing Code and Uniform Plumbing Code — typically used for city plumbing codes — say that it is unacceptable to place geothermal lines parallel or perpendicular to water mains. Municipalities would need to be willing to modify or grant exceptions to their own municipal plumbing regulations to approve water main geothermal installations. The Valley Stream project illustrates that old regulations and codes discouraging water main geothermal are not based on sufficient evidence of harm. However, early projects may have to overcome these barriers before they can be constructed.

Who Pays?

A water main geothermal project involves several parties, each with a financial interest. The building owner will have to purchase a heat pump system and install piping to serve the heat pump. They may also require a circulator pump to keep water flow sufficient to serve their heating and cooling needs. These costs can be offset or recovered through tax credits, city or state incentives, and energy bill savings. The city or private water utility will need to provide a spur off the water main and the heat exchanger, and potentially an enclosure to ensure that the customer has no way to tamper with pipes that return water to the distribution system. In addition, the city's water mains may require upgrades to ensure sufficient water flow to manage heating and cooling demands as adoption increases. In both cases, the water utility will have additional revenue from selling energy and financing infrastructure.

Water main geothermal systems compete with a gas utility and can replace fossil gas furnaces and water heaters. Expect incumbent gas utilities to lobby to restrict water main geothermal. Geothermal systems have a mixed benefit for electric utilities and are likely to incur less resistance. Some buildings would replace inefficient electric resistance heating with an efficient heat pump, lowering electricity use. However, many more homes would be switching from gas, oil, or propane to electric heat pumps, increasing sales.

Next Steps: A Feasibility Study

Despite the success of the pilot program in Valley Stream, N.Y., every city will need to conduct its own feasibility study to understand the costs and benefits associated with implementing its own water main geothermal systems with buildings other than schools, such as hospitals, corporate buildings, and residential neighborhoods. Some questions that cities should be aware of when conducting a feasibility study are listed below.

1. What state or local rules may impede implementation, including health department regulations or plumbing codes?
2. What is the temperature of the water, size of the water main, and rate of water flow needed for proper heat exchange?
3. What neighborhoods already have existing water infrastructure and flow rates that would handle heat exchange?
4. What parts of the water distribution system are already scheduled for upgrades?
5. What are the estimated costs of upgrading the water mains needed to implement the geothermal connection?
6. How much would it cost to install a double walled heat exchanger (and perhaps a geothermal heat pump) for 100 homes or 1,000 homes? Could the city afford to pay the upfront costs and recoup the cost on the water bill?
7. What kind of technical or financial assistance can be offered to residents for installing a geothermal heat pump and a double walled heat exchanger?
8. What is the best starting point for this system to be implemented in the city? Would it focus on commercial buildings or residential?

9. How long is the cost recovery for water infrastructure upgrades for the water utility?
10. How much revenue would be generated for the water utility?
11. What are the health, safety, and environmental benefits for the city and its residents (such as carbon emissions reductions, indoor air quality, reduced risk of gas leaks)?
12. What are the overall economic and financial benefits for both the city and the residents?

While not comprehensive, the list above provides a good starting point for municipalities to better understand the costs and benefits associated with implementing water main geothermal systems.

Conclusion

William L. Buck Elementary School's pilot program proved that water main geothermal systems are safe and successful in providing energy savings.

By connecting to water mains, cities can sharply reduce the cost of installing a geothermal heat pump system for customers compared to the common practice of drilling boreholes. Water main geothermal systems can also cut emissions from heating and cooling drastically. In addition, water main geothermal can leverage typical city ownership of water utilities to accelerate adoption, reduce customers costs, and raise revenue for the water utility.

Municipalities across the U.S. have an opportunity to leverage the potential energy lying under their streets to reduce pollution, cut energy bills, and affordably transition away from fossil gas. After missing the opportunity to use water main geothermal to take advantage of these benefits for years, all evidence shows that now is the time.