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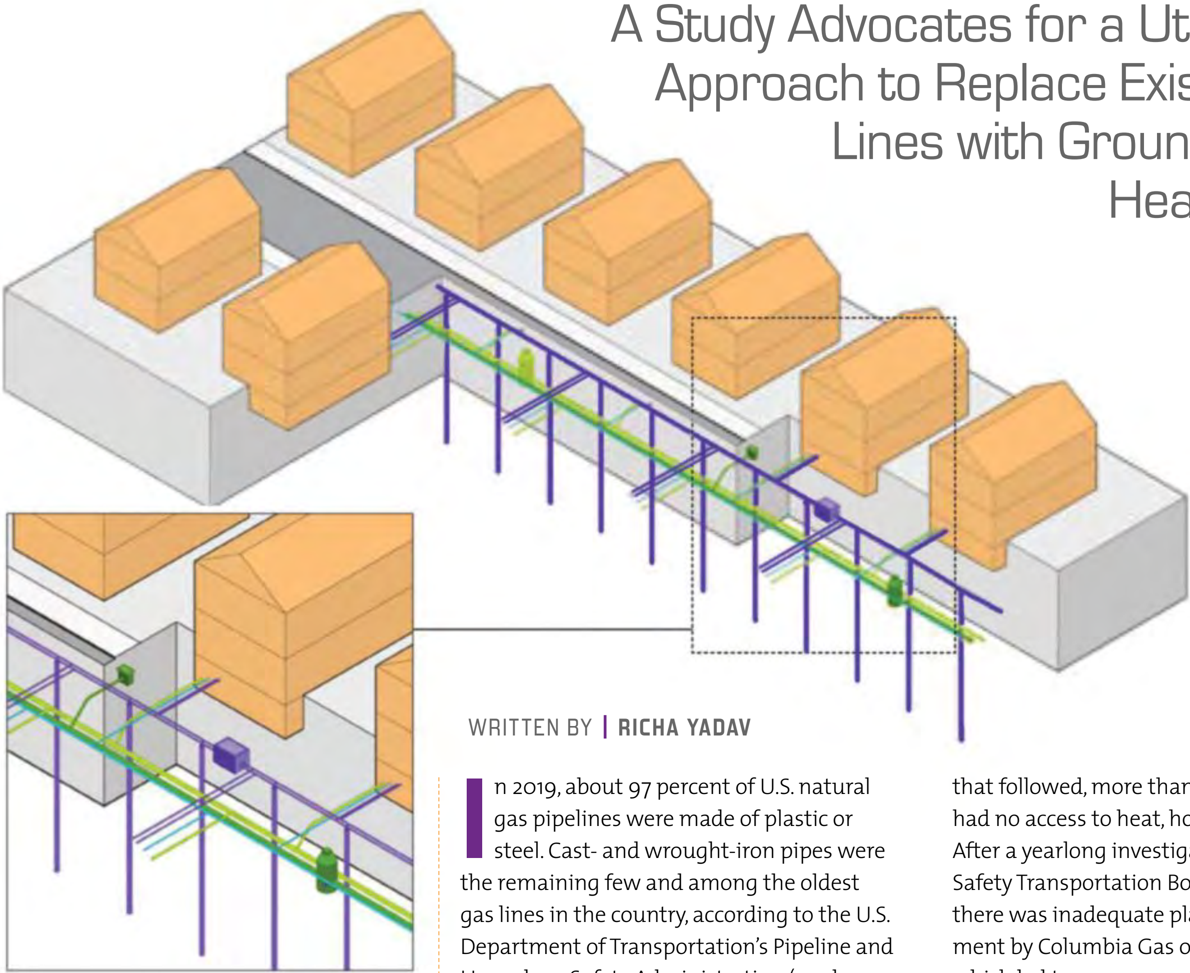
GEOMICRODISTRICTS

A Study Advocates for a Utility-scale Approach to Replace Existing Gas Lines with Ground-source Heat Pumps



GeoMicroDistrict: Ground-source heat pump closed vertical systems could be installed in a single row along an existing utility corridor. Vertical boreholes and service connections could be located between existing infrastructure.

WRITTEN BY | RICHA YADAV

In 2019, about 97 percent of U.S. natural gas pipelines were made of plastic or steel. Cast- and wrought-iron pipes were the remaining few and among the oldest gas lines in the country, according to the U.S. Department of Transportation's Pipeline and Hazardous Safety Administration (read more at bit.ly/2UwHgdM). Nearly half of all iron pipes are concentrated in four states, including Massachusetts, New Jersey, New York and Pennsylvania. If cast-iron (and bare-steel pipelines) are left in the ground beyond their service life, utilities have to spend millions of dollars repairing leaks on old pipelines. When left unattended, leaking gas pipes release methane, which is a highly combustible gas that poses significant health, public safety and environmental risks.

In September 2018, a natural-gas leak resulted in 131 fires and three explosions in three communities in Merrimack Valley, Mass. Thousands of people from the city of Lawrence and towns of Andover and North Andover were forced to evacuate their homes. About 25 people were injured and one person died in the incident. In the winter months that followed, more than 8,000 customers had no access to heat, hot water and gas. After a yearlong investigation, the National Safety Transportation Board determined there was inadequate planning and management by Columbia Gas of Massachusetts, which led to over pressurization in the valley's aging cast-iron gas pipes. (Read a synopsis of NTSB's report at bit.ly/3ajO59i.)

Massachusetts Rethinks Gas Infrastructure

Massachusetts has the second-oldest gas infrastructure system in the country with 6,000 miles of aging and leak-prone pipes, which make up 26 percent of the state's gas system. In recent years, natural-gas companies have faced a great deal of backlash caused by pipeline failures and methane leaks from aging pipelines. Gas companies are therefore actively replacing aging pipelines with corrosion-resistant high-density polyethylene plastic pipelines. It is estimated that repairing and replacing the state's leaking gas system can cost taxpayers more than $9 billion during the next 20 years. This does not include the price of lost gas that customers and businesses already pay in their monthly bills, which is estimated at $90 million per year in the greater Boston area alone. (Learn more from a research article published by the Proceedings of the National Academy of Sciences of the United States of America, www.pnas.org/content/112/7/1941.)

Currently, nearly 70 percent of Massachusetts' electricity and 50 percent of heating energy loads are met by natural gas, all of which is imported from other regions in the U.S. and overseas. During peak winter season, the state faces massive gas shortages, increasing the wholesale price of gas, as well as the cost of power production. To address this energy-security problem and overarching climate issues, the state has required electric utilities to use more renewable energy each year and has heavily invested in energy-efficiency programs. At the current pace, clean-energy alternatives are poised to undercut gas prices in coming years, per Rocky Mountain Institute, rmi.org/insight/clean-energy-portfolios-pipelines-and-plants.

The decreasing cost of renewables will likely accelerate the pace of renewable deployment and building electrification, which will decrease gas consumption. If gas consumption declines, the utilization of gas pipelines will drop, inadvertently increasing the financial burden of maintaining the pipelines on a shrinking pool of gas customers. Although it is imperative to maintain gas lines for public safety, continually replacing leaking pipelines with new ones will not only cost taxpayers billions of dollars but also lock some gas customers into another 40 to 70 years of fossil-fuel dependency. The macroeconomics have forced Massachusetts policymakers and industry leaders to rethink future expansion of gas infrastructure.

Following the aftermath of Merrimack Valley, the Home Energy Efficiency Team (HEET), a local environmental non-profit, began exploring potential substitutes for gas infrastructure. Long known for its work on energy-efficiency retrofits and methane-leak studies in Massachusetts, HEET wanted to explore an alternative business model where customers could purchase renewable thermal energy, instead of natural gas. In early 2019, HEET selected Buro Happold to lead a feasibility study for replacing aging natural-gas infrastructure with a network of ground-source heat pumps (GSHPs). (For a quick lesson about GSHPs, see “Understanding GSHP Systems”, page 46.)

Viability of GeoMicroDistricts

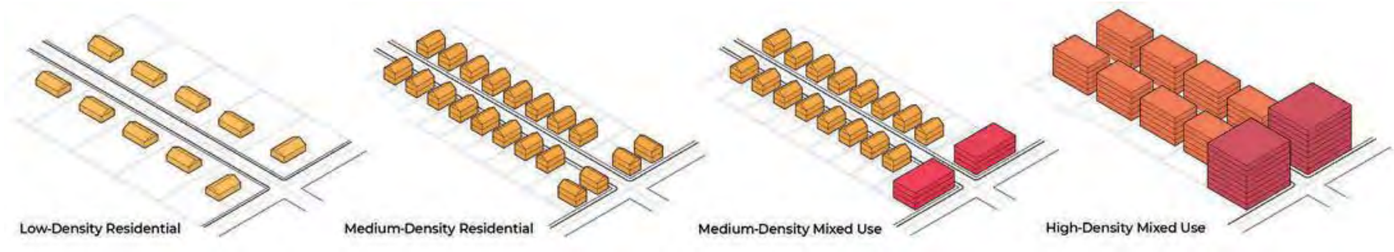
During the development of the study, the term “GeoMicroDistrict” was coined to refer to the GSHP network that serves a street segment—the length of street between two intersections or an intersection and a dead end. The GeoMicroDistrict would contain a shared loop running through an array of boreholes installed within public rights-of-way. The ambient water circulating in the shared loop would serve as the heat-exchanging medium between the ground and heating and/or cooling distribution systems housed within individual buildings. In theory, the concept is to incrementally replace leaking gas pipes with GeoMicroDistricts that are eventually interconnected to create a district-scale energy system.

District-scale GSHP systems are not a novel idea. In the U.S., universities like Colorado Mesa, Ball State and Furman, as well as many large-scale residential development projects have successfully installed and operated district-scale GSHP systems for years. However, strategic replacement of natural-gas pipelines with GSHP systems is certainly a unique proposition. For successful execution of this

A FUTURE FOR RENEWABLE ENERGY

Following the public release of the GeoMicroDistrict Feasibility Study, Home Energy Efficiency Team (HEET), a Massachusetts environmental non-profit, and its supporting partners filed an act for utility transition to using renewable energy. Known as the FUTURE Act, the act was developed with legislative leaders to pass laws to improve regulations for gas distribution systems and to accelerate the transition to renewable energy. The FUTURE Act will grant utilities the permission to bill customers for renewable thermal credits (or Btus) instead of gas and proposes a renewable thermal credit market for the gas industry. The act calls for flexible regulations, allowing municipalities to choose energy alternatives, and requests for funding and financial incentives to encourage gas companies to distribute thermal renewable energy instead of gas. The bill was supported by 13 municipalities at the Telecommunications, Utilities and Energy Committee hearing last November. (Learn more about the hearing at malegislature.gov / Bills / 191 / HD3719.) HEET is currently supporting Eversource Gas, a local utility, to pilot the GeoMicroDistrict concept in 2021.

PROTOTYPE STREET SEGMENTS



Layout of prototype street segments (PSS), representing common building and land-use characteristics across Massachusetts.


PHOTO: COURTESY INTERNATIONAL DISTRICT ENERGY ASSOCIATION, ENERGY SAVING TRUST

The Home Energy Efficiency Team (HEET) project aims to develop an innovative GeoMicroDistrict, which can potentially replace natural gas infrastructure with a network of neighborhood-scale district heating systems, supplying heat via a system of insulated pipes to homes, businesses, schools and more.

concept, various risks pertaining to site suitability, building compatibility, high upfront capital costs and operational reliability (energy load and capacity management) need to be mitigated.

To address these constraints, the GeoMicroDistrict Feasibility Study examined the engineering and economic viability of installing shared loops in four prototypical street segments (PSS). The PSS represent distinct building and land-use typologies prevalent in Massachusetts. Each PSS is composed of two contiguous lines of residential and/or commercial properties on either side of a 40-foot-wide, 500-foot-long public right-of-way.

To avoid site conflicts with underground infrastructure systems (potable water, telecom, data cables, sewer, stormwater systems and the like), borehole installation area is limited to the 2-foot-wide gas utility corridor. The engineering layout is informed by the state's geological and seasonal parameters and designed to operate in balanced condition so as to prevent ground overheating or overcooling. The heating and cooling demand profiles of each PSS are then compared with the ground's thermal capacity to assess annual thermal loads met by interconnected GeoMicroDistricts.

Buro Happold's study concluded that interconnected GeoMicroDistricts can provide nearly 100 percent of the annual thermal loads in low- to medium-density residential and mixed-use commercial areas. High-density neighborhoods would require supplemental heating and cooling energy. The study strongly advocates for a utility-scale approach wherein existing gas companies install, operate and maintain the GeoMicroDistricts. It is assumed that any costs associated with systems outside the building are borne by the gas company. As the customer base increases, the load diversity, efficiency and economies of scale would improve. Furthermore, the utility also would be responsible for scaling and managing system capacity while integrating thermal energy storage and backup energy systems, as needed.

At this conceptual stage, it is assumed that

UNDERSTANDING GSHP SYSTEMS

A ground-source heat pump (GSHP) is a heat-exchanging device that transfers heat to or from the ground, groundwater or surface water to provide space heating and cooling. These devices are some of the most energy-efficient and low-carbon space-conditioning technologies available today. The GeoMicroDistrict Feasibility Study discussed in this article focuses on a subset of GSHPs called vertical ground-coupled heat pumps that exchange heat with the ground.

As compared to ambient air, the temperature of the ground remains relatively constant. Vertical ground-coupled systems utilize the temperature difference between the ground and interior spaces to transfer heat. The system consists of one or more heat pumps that are connected to a series of pipes, typically made of high-density polyethylene. These pipes form a closed loop that is buried in vertical boreholes. The boreholes can range from 4 to 6 inches in diameter and 100 to 500 feet in depth, though greater depths and larger diameters are possible.

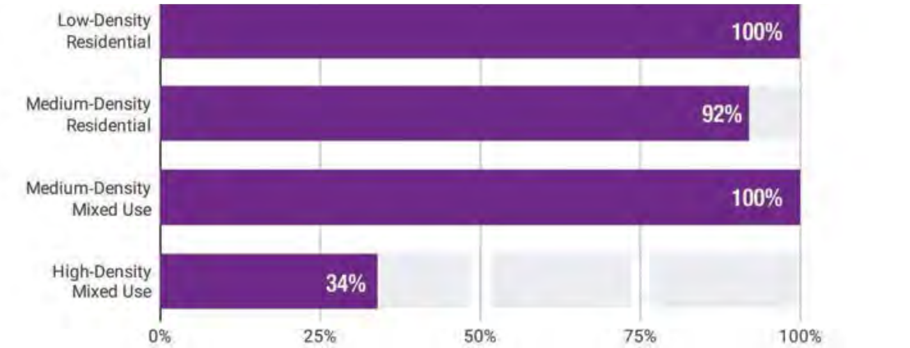
A heat-transfer fluid, typically water or water with a non-toxic antifreeze solution, is circulated through the closed-loop to exchange thermal energy with the ground. The heat pumps regulate the fluid flow to transfer thermal energy to the building's HVAC system. In winter months, the circulating fluid extracts heat from the ground to heat indoor spaces and, in summer, heat is transferred from indoor spaces and rejected to the ground to provide cooling.

Multiple factors must be considered prior to sizing a GSHP system, including building heating and cooling requirements, available land area, and the geological and hydrogeological characteristics of the ground. For optimal performance, it is very critical to maintain stable ground temperature over the long-term. This can be achieved by balancing heat extracted and rejected into the ground (maintaining thermal balance).

The ground can withstand a 10 to 15 percent difference between heating and cooling loads but beyond that the ground may become gradually warmer or colder, reducing the operating efficiency of the GSHP system. To design a GSHP system that meets 100 percent of a building's heating and cooling demands, the system must have enough capacity to perform during extreme winter and summer days. Because heating and cooling demands are rarely identical, supplemental heating or cooling may be needed to meet peak demands while maintaining thermal balance.

customers would pay for monthly thermal energy consumption and any additional costs associated with heat-pump installation or improvements needed inside the buildings with financial support from the state. The performance and cost for retrofitting existing buildings can therefore vary significantly based on their type, size, height, and age of the building and the original space-conditioning system. Installing heat pumps in new buildings is relatively easier than renovating existing buildings. GSHPs in existing buildings are generally more compatible with forced-air and hydronic systems because the distribution system can be reused with minor adjustments in the ducts, pipes and controls. However, buildings utilizing steam distribution systems and electrical baseboards are not well suited to GSHPs and may need a gut rehab. Furthermore, gas-powered appliances, like domestic hot-water heaters, stoves, ovens and clothes dryers, etc., would need to be replaced with electric appliances. It is also critical that existing buildings are made as efficient as possible prior to or during the conversion. This would allow for the installation of smaller and less expensive systems, reducing upfront costs and energy bills for the customer.

TECHNICAL FEASIBILITY: GSHP Closed Vertical Annual Thermal Energy Loads Met (Interconnected)



Safety First

GeoMicroDistricts represent a viable "safety first" alternative to natural-gas heating along with a host of additional benefits, including climate-change mitigation, infrastructure resilience and air-quality improvements. The concept promotes equitable transition to a renewable thermal system that can be deployed in any neighborhood, city or region. Allowing gas utilities to operate GeoMicroDistricts will help them retain their current organization purpose, structure and workforce. Installing GeoMicroDistricts will not be an easy or inexpensive feat and will require significant coordination with public utilities, policymakers and communities. It is safe to say that investing in heat pumps and building electrification is certainly a better utilization of billions of taxpayer dollars that are currently being used for funding an obsolete energy system.