

OVERVIEW AND STATUS OF U.S. DOE'S NEW GROUND-SOURCE HEAT PUMP PROGRAM INITIATED IN 2009

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Abstract: The U.S. Energy Policy Act of 2005 authorized the U.S. Department of Energy (DOE) to promote the deployment of ground-source heat pumps (GSHPs). DOE subsequently funded two independent studies to investigate the market status of GSHPs, barriers to their adoption, and actions needed to overcome the barriers. Using funding appropriated by the American Recovery and Reinvestment Act of 2009 (ARRA) DOE has initiated its first new GSHP activity since 1999. The activity is aimed at the top three barriers identified in the studies — high initial cost, lack of consumer and policymaker knowledge and confidence, and limitations of the delivery infrastructure. ARRA funds totaling \$67 million have been allocated for activities including 26 technology demonstration projects at U.S. residential, commercial, and institutional facilities, data-gathering and analysis activities, and development of a national certification standard for personnel involved in design and installation of GSHP systems. This paper reviews the barriers identified by the two independent studies, describes the new DOE activity and how it is addressing the barriers, and discusses alternative paths forward for the technology.

Key Words: ground-source heat pumps, clean energy, buildings, U.S. DOE

1 INTRODUCTION

Many policymakers in the United States consider energy to be the defining challenge of our time. It is a major driver for climate change, national security, economic competitiveness, and quality of life. To address this challenge, by 2008 the United States was investing federal dollars in a diverse portfolio of clean energy technologies including demand-side energy efficiency; power generation from solar, wind, geothermal, and biomass resources; and strategies to de-carbonize traditional electricity generation sources and reduce our dependence on foreign oil through bio-fuels, hydrogen, and efficiency gains including lightweighting and the electrification of personal transportation. Noticeably missing from the portfolio was any significant activity focused on ground-source heat pumps (GSHPs) to reduce the use of non-renewable primary energy in buildings.

DOE funded two modest GSHP programs from 1994 through 1999 (Hughes and Pratsch 2002), but there was no DOE GSHP activity from 1999 through 2009. Even so, over the past decade GSHP systems demonstrated performance improvement, and achieved a growing

*Notice: This manuscript has been authored by UT-Battelle, LLC, under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the years, beginning in 2003, GSHP unit shipments displayed double-digit increases over the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

share in U.S. markets for building heating, cooling, and water heating equipment. For five previous years. This coincided with a boom in residential construction and significant increases in energy prices. By 2008 GSHPs were believed to be installed in 1 of every 38 new U.S. homes — a 2.6 percent market share for the segment (Kaarsberg et al. 2010). Even though new home starts have declined, a newer study concluded that market share has continued to grow, with GSHPs installed in 1 of every 28 new U.S. homes in 2010 (Ellis 2011). U.S.-based GSHP manufacturers shipped about 115,000 units worldwide, averaging 3.5 tons capacity apiece, in 2009 (EIA 2011).

Although there was no DOE GSHP activity over the last decade, there has been GSHP federal policy support of other kinds. Since 2007 one segment of the utility industry, the rural electric cooperatives (RECs), have been able to obtain long-term loans with terms of up to 35 years at the cost of government funds from the U.S. Department of Agriculture Rural Utilities Service (USDA/RUS) to provide the outside-the-building portion of GSHP systems to customers in exchange for a tariff on the utility bill (FESA 2007). In December 2007 Congress directed the General Services Administration (GSA) to accelerate the use of more cost-effective energy saving technologies and practices in GSA facilities, starting with lighting and GSHPs (EISA 2007). Tax credits effective through 2016 for home and business owners purchasing GSHP systems were enacted in October 2008 (EESA 2008). At that time the tax credits were for 30 percent of the cost of a residential GSHP system capped at \$2000, and a full 10 percent of system cost for commercial buildings. The \$2000 cap for homeowners was eliminated by ARRA in 2009. Additionally, a growing number of U.S. states and local governments offer tax credits or other incentives for GSHP systems (DSIRE 2011).

The U.S. built environment — consisting of residential, commercial, and institutional buildings — accounts for about 40 percent of primary U.S. energy consumption and greenhouse gas (GHG) emissions, 73 percent of U.S. electricity consumption, and 34 percent of U.S. natural gas consumption directly (or 55 percent if accounting for gas used to generate electricity consumed in buildings) (DOE 2009). A recent study by McKinsey & Company found that reducing the consumption of energy in buildings is the least costly way to achieve large reductions in carbon emissions (McKinsey & Company 2007). It is unlikely that the United States will be able to make significant progress toward reducing energy consumption and GHG emissions without aggressively pursuing building energy efficiency opportunities.

GSHPs have been proven capable of producing large reductions in energy use and peak demand in buildings. For example, after the buildings in an entire city with a population of about 12,000 people were retrofitted with GSHPs, the whole-city energy savings was 33 percent, the whole-city summer peak demand was reduced by 43 percent, and the electric utility serving the city experienced an improvement in whole-city annual load factor from 0.52 to 0.62 (Hughes and Shonder 1998).

These observations lead us to question why the United States has pursued a portfolio of clean energy options that does not include GSHPs. Have policymakers overlooked GSHPs, or are GSHPs simply unable to make a major contribution to the national goals? In 2008 DOE commissioned two independent studies to address GSHP markets. Although the studies differed in many details, some of which are summarized later in this paper, the conclusion drawn by DOE was that GSHPs merited reconsideration.

The American Recovery and Reinvestment Act (ARRA 2009) became law in 2009, designed to create jobs while helping to lift the faltering U.S. economy. Energy provisions were a prominent feature of ARRA, which provided more than \$42 billion for energy programs, \$36 billion of that going to DOE. Congress directed that \$400 million of the DOE funding should be committed for geothermal energy, and DOE used this opportunity to revisit GSHPs.

The influx of ARRA money allowed DOE to design a new deployment activity to address barriers identified in the two aforementioned studies, while also achieving the ARRA-specific goals of creating new jobs and stimulating the economy.

In June 2009 a DOE GSHP solicitation was issued requesting proposals in three topical areas: Technology Demonstration Projects, Data Gathering and Analysis, and National Certification Standards (FOA 2009). In October 2009 DOE announced the selection of 37 awardees including 27 for federally cost-shared demonstrations, 9 for data and analysis activities, and 1 for work on a national certification standard (GSHP 2011). Later two demonstration projects dropped out due to lack of cost-share, and one was added. Across the remaining 36 projects, about \$67 million in federal funds is being invested. This exceeds the sum total of all previous DOE investment in GSHP technology and exceeds any previous single-year DOE investment by a factor of 10.

The rest of this paper reviews the recent studies, describes the new ARRA-funded DOE activity and how it is addressing the barriers identified in the studies, and discusses alternative paths forward for the GSHP activity after the ARRA projects are complete.

2 RECENT STUDIES

2.1 Oak Ridge National Laboratory Study

The scope of the ORNL study included: 1) determining the status of global GSHP markets and the U.S. GSHP industry and technology, 2) assembling and updating previous estimates of GSHP energy savings potential, 3) identifying key barriers to application of GSHPs, and 4) identifying actions that could accelerate market adoption of GSHPs in the United States. The findings are documented in detail elsewhere along with conclusions and recommendations (Hughes 2008). Information from the study most germane to this paper is summarized below.

At the time of the ORNL study, U.S. buildings consumed about 40 quads of non-renewable primary energy annually and were projected to consume 49.5 quads by 2030 (DOE 2008). Based on previous analyses updated and summarized in the study report (EIA 1990, TIAx 2002, Fischer 2006), aggressive GSHP deployment could save 3.4 to 3.9 quads annually by 2030, defraying 35 – 40 percent of the projected growth in U.S. building energy usage and saving consumers \$33 – 38 billion annually. The energy savings of 3.4 – 3.9 quads also corresponds to a reduction of 91 – 105 GW in summer peak electric demand, assuming the same relationship between demand reduction and primary energy savings that was measured in the whole-city GSHP demonstration (Hughes 2008). Expressed in another way, GSHPs could potentially avoid 42 – 48 percent of the 218 GW of growth in generating capacity (from 982 to 1200 GW) that is predicted to be needed by 2030 (EIA 2008). The study concluded that GSHPs appear able to make a major contribution to U.S. national energy goals.

The ORNL study identified three principal barriers to GSHP application: 1) initial cost, 2) lack of consumer and policymaker knowledge and confidence, and 3) limitations of the delivery infrastructure. The following addresses these barriers and what the study suggested could be done to overcome them.

To enable GSHPs to realize a significant portion of their savings potential, their high initial cost to consumers must be aggressively reduced. A common policy option for reducing technology cost and improving performance is to invest in R&D. Creative business models also are needed that allow the costs of ground heat exchangers (or loops) to be shared between individual consumers and the general public. Ground heat exchangers, like buried natural gas distribution pipelines, generally outlive many generations of space conditioning

and water heating equipment and even the building itself. However, consumers are not required to pay the initial cost of the gas pipeline as part of the cost of their gas-fired space conditioning systems. No other competitive HVAC/water heating system has a major portion of its initial cost locked up in a component that could easily outlive the building. One solution to the high initial cost of GSHP systems would be policies that encourage utilities or other market actors to provide consumers access to ground heat exchangers for a monthly fee. The \$33 – 38 billion in annual energy cost savings would be ample to cover the debt service plus profit on investments required to provide every building in America access to a ground heat exchanger.

Limited consumer knowledge and confidence is another major barrier. Actions to address this barrier include assembling statistically valid data from independent studies of the installed base of GSHP systems and conducting an independent assessment of the national benefits of GSHPs. Without irrefutable hard data and documented benefits, policymakers, regulators, and consumers are unlikely to advocate for and commit to actions such as investing in R&D to reduce cost and improve performance of GSHPs, or encouraging utilities or others to provide consumers access to ground heat exchangers for a monthly fee. In general, a higher volume of GSHP projects improves affordability, but this cannot be achieved without policymaker, regulator, and consumer support.

If U.S. GSHP markets were to expand rapidly, most of the segments of the industry would be able to expand accordingly without creating bottlenecks, but GSHP system design and installation infrastructures would be strained. Currently these infrastructures only exist in some localities. Actions to address this barrier include improving training materials for design of the various types of GSHP systems and training more architects, commercial HVAC designers, and design-support organizations serving residential contractors. Improvements are also needed in training materials and certification for installation of GSHP systems, along with training of more drilling rig and excavation equipment operators, loop installers, residential HVAC contractors, commercial mechanical contractors, and commercial design/build contractors. These activities to strengthen GSHP delivery infrastructure should be targeted to localities where GSHP project activity is growing (e.g., where there are utility-sponsored programs to provide loop access for a monthly fee). The goal would be to create enough project activity so that robust, competitive, and self-sustaining infrastructures can develop and become fully capable with a wider range of GSHP applications in more areas. Such infrastructure has successfully established itself in a few applications and localities already (e.g., K-12 schools in Dallas/Fort Worth).

2.2 Navigant Consulting Study

The scope of the Navigant study included summarizing the status of GSHP technology and market penetration globally, estimating the energy saving potential of GSHPs in the United States, identifying and describing the key market barriers that inhibit wider market adoption of GSHPs, and recommending initiatives that can be implemented or facilitated by DOE to accelerate market adoption (Navigant 2009). Information from the study on whether GSHPs are able to make a major contribution to U.S. national energy goals is summarized below

This study utilized a traditional analytical approach to estimating the U.S. energy savings potential of GSHPs. The entire U.S. space conditioning market was approximated by 18 unique space-conditioning-load files derived from modeling based on prototypical single-family homes and small office buildings and one weather file for each of nine census sub-regions. These 18 loads were used to estimate space conditioning energy use for conventional and GSHP systems. Average regional energy rates were applied to estimate annual energy costs. Installed costs for conventional and GSHP space conditioning systems were estimated. Simple pay back periods for GSHPs versus conventional systems were estimated, and finally market penetration curves were used that relate years to payback to an

estimate of market penetration (ADL 1995). An estimate of regional energy savings was obtained by multiplying baseline energy consumption of the conventional space conditioning system in the region by percent savings from displacing the conventional system with GSHPs, and then multiplying that product by the estimated percentage of market penetration. Summing across regions yields a national estimate.

Several baseline conventional systems and scenarios were considered, and the resulting estimate from this analysis was that the national primary energy savings potential of GSHPs in the United States was a meager 0.15 quads. This result reinforces the concern that GSHP initial cost is the primary barrier to greater market acceptance. Without a solution to the initial cost problem, GSHPs simply are unable to make a major contribution to the national goals. The Navigant study mentioned several incremental paths to improvement but was silent on solutions to the initial cost problem.

3 ARRA-FUNDED DOE ACTIVITY

With the influx of funding through ARRA, DOE was able to design a new activity, within the constraints of ARRA, that addresses the top three barriers identified in the studies — initial cost, lack of consumer and policymaker knowledge and confidence, and limitations of the delivery infrastructure. In June 2009, a DOE GSHP solicitation was issued requesting proposals in three topical areas: Technology Demonstration Projects, Data Gathering and Analysis, and National Certification Standards (FOA 2009).

The technology-demonstration component of the activity addresses the initial cost barrier in several ways. Demonstration projects had a lower limit on size (>50 tons) so that each project would be of sufficient scale to attract competitive bidding among construction subcontractors and otherwise demonstrate reduced costs through economies of scale. “Ground source” was defined broadly to include many options — including the Earth, surface water, recycled gray water, sewage treatment plant effluent, retention basin storm water, harvested rainwater, and water from a subsurface aquifer — whether alone or in combination with outdoor air or other options in a hybrid configuration. This broad definition led to consideration of many ground-source options during project development, not just vertical-bore systems, so that the performance of a broad portfolio of high-value approaches could be examined.

Another innovative feature of the demonstration is the requirement that all projects collect and submit data on cost and performance. In addition, the government cost-sharing requirement was designed to help the demonstration projects overcome local limitations in the infrastructure for GSHP design and installation by, for example, providing the resources to allow the local engineer to bring in a specialized consultant to help design an innovative ground-source system in cases where robust commercially available design tools do not yet exist.

In October 2009 DOE announced the selection of 27 federally cost-shared GSHP Technology Demonstration Projects, and project summaries are available on the internet (GSHP 2011). Two projects later dropped out due to lack of cost-share, and one project was added.

Funding requested from DOE by awardees ranged from \$430,000 to \$5 million; the total DOE demonstration project investment is \$65 million. The individual projects range in size from 73 to 10,000 tons of GSHP capacity and will be installed in a wide variety of residential, commercial, and institutional facilities around the United States. In selecting these awardees, DOE purposely chose a broad range of ground-source options beyond vertical-bore, such as municipal gray water (Figure 1), flooded mine water (Figure 2), a standing-column well (Figure 3), and a river (Figure 4).

For satisfying the building loads most of the awardees use the typical system configuration of per-zone decentralized heat pumps on a common loop in multi-zone applications. However, some of the awardees are interfacing large chiller/heat pump plants to the ground source and serving fan coils or air handlers with hot and chilled water. There are a variety of building applications among the awardees including an ice rink, poultry barn, college campus, housing development, and shopping mall. Innovative business models and financing approaches being used by the awardees include third-party micro-utilities where the investor owns the system and provides energy services for a monthly fee, and energy savings performance contracts.

Each ARRA technology demonstration awardee is required to assemble installed cost information and collect detailed performance data to confirm the expected operating performance of the systems at their sites. Since collecting and analyzing valid data from the demonstration projects is a key objective for this activity, DOE is providing technical assistance to awardees through ORNL and their subcontractor, CDH Energy. The ORNL team will help awardees develop their monitoring plans, set up reliable data collection and transfer processes, load data into an intermediate database for validation and preliminary analysis, and ultimately send this data to DOE's data archive contractor.

The data gathering and analysis component of the program addressed limitations of the GSHP design and installation infrastructure by funding projects to develop design tools and simulation models that are needed to extend the capability to engineer and install a wider range of the ground-source options to a broader group of practitioners. In October 2009, DOE announced the selection of nine data gathering and analysis projects with total funding across all awardees of \$1 million. Ground-source options to benefit from design and modeling tool improvements as a result of these awards include various hybrids, standing-column well, and surface water systems. Several of these awardees also will be assembling independent and statistically valid data on cost, financial incentives, and performance of installed GSHP and hybrid GSHP applications in hot-humid and hot-arid climate zones. This should also help address consumers' and policymakers' limited knowledge and confidence in GSHP systems in those areas.



Figure 1: Municipal gray water



Figure 2: Flooded mine water



Figure 3: Standing-column well

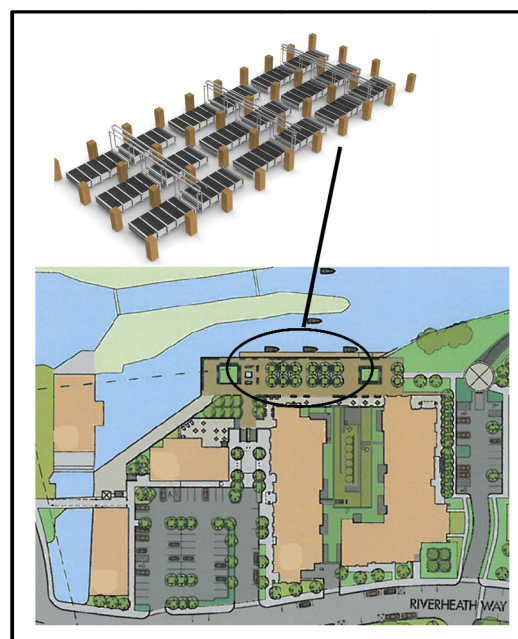


Figure 4: River

Creating a national certification standard for the GSHP industry (for drillers, plumbers, electricians, HVAC specialists, engineers, architects, etc.) is designed to increase consumer and policymaker knowledge and confidence in the technology. The standard will also reduce the potential for improper design and installation of systems and assure product quality and performance. This project does not include development of new curricula or training materials. The standard will draw from existing, nationally recognized curricula developed in conjunction with professional and trade organizations, product manufacturers, and government regulatory authorities.

4 ALTERNATIVE PATHS FORWARD FOR A NATIONAL EFFORT

While a final budget has not been enacted for FY 2011, and the President's FY 2012 budget request will not be sent to Congress until February, it is still useful to consider potential alternative scenarios for the future deployment of this technology. In 2011 we will begin to receive the first performance data from the ARRA GSHP projects. The following represent some hypothetical paths forward for federal government/industry acceleration of GSHP deployment. These are solely for discussion purposes and could be combined in many ways.

4.1 Business as Usual (BAU), Tax-Credit-Only Approach

The investment tax credit (30 percent for homeowners, 10 percent for businesses) lasts until 2016. Data from the ARRA demonstrations enhances confidence of architects, designers, and homebuyers in the expected benefits of GSHP systems. The adoption of a National Certification Standard by the GSHP industry improves consumer confidence in the installation and maintenance infrastructure. As we grow out of the recession, GSHP installations grow — but slowly.

4.2 BAU + Education, Outreach, Federal Purchasing

Authoritative guidance and GSHP design and installation web tools, and targeted (informed by ARRA results) regional mass buys by federal agencies, state governments, and educational institutions are an excellent way to leverage scarce federal resources in the near term. The large size (50-ton minimum) of the ARRA demonstrations make such buys easier to justify. Regional mass buys would be targeted to areas where electric utilities or other market actors offer financing programs that mitigate the first-cost premium by enabling consumers to pay from energy savings for access to the ground heat exchanger loop (rather than buy the loop outright as part of the purchase price). Loops are analogous to utility infrastructure (e.g., poles and wires), and the concept of financing them as infrastructure is beginning to emerge. Just like poles and wires, loops outlive the building and many generations of heat pumps. No other competitive HVAC/water heating system has a major portion of its initial cost locked up in a component that outlives the building. Even with building owners paying for loops up front, GSHP systems have been successful in retrofit markets since the 1990s. As we grow out of the recession, GSHP deployment grows steadily over the next decade.

4.3 BAU + R&D

Although the heat pump aspect of GSHP systems is well-known and has been optimized over the last few decades, the ground-source — where “ground” can include all manner of natural and anthropogenic heat sources and sinks — has not. Key cost-shared research to be supported by the federal government includes 1) consolidation of State and U.S. Geological Survey data to provide detailed characterization of groundwater depths and temperatures and detailed data on soil type and thermal conductivity from the surface down

to 200+ feet across the United States, 2) development of lower-cost thermal couplings to heat sources and sinks, 3) development of faster, cheaper, less disruptive drilling and installation technologies, and 4) enhanced design tools, including more accurate performance prediction, and cost estimating software that incorporates the latest results from 1), 2), and 3). Research success results in a 30% reduction in up-front system costs for GSHP systems, and GSHP deployment grows steadily for several decades, even after the expiration of tax credits in 2016.

4.4 Conclusion

All scenarios feature some level of steady growth in the GSHP market. In order to *accelerate* growth to the levels needed to meet Administration goals for emissions reduction and clean energy, a carefully tailored (informed by ARRA) combination of 4.2 and 4.3 appears to provide the balanced combination of near-, medium- and long-term success. Early market targets are new residential and commercial construction. Retrofit must also be addressed early on, but with a later ramp-up than new construction.

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