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Research and Development Roadmap:

Geothermal (Ground-Source) Heat Pumps

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Prepared by:
Navigant Consulting, Inc.

Research and Development Roadmap: Geothermal (Ground-Source) Heat Pumps

Prepared for:
U. S. Department of Energy, Building Technologies Program

Prepared by:
William Goetzler
Matt Guernsey
Rahul Kar

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Navigant Consulting, Inc.
77 S. Bedford Street
Suite 400
Burlington, MA 01803

www.navigant.com

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List of Acronyms

ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BTP	Building Technologies Program (Department of Energy)
CO_2	Carbon Dioxide
DGX	Direct GeoExchange system
DOE	Department of Energy
DX	Direct Exchange system
EPA	Environmental Protection Agency
EERE	DOE's office of Energy Efficiency and Renewable Energy
GHG	Greenhouse Gas
GHX	Ground Heat Exchanger
GCHP	Ground Coupled Heat Pump
GHP	Geothermal Heat Pump
GSHP	Ground-Source Heat Pump
GWHP	Ground Water Heat Pump
GWP	Global Warming Potential
HVAC	Heating, Ventilation, and Air-Conditioning
LEED	Leadership in Energy and Environmental Design
LBNL	Lawrence Berkeley National Laboratory
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
SWHP	Surface Water Heat Pump
WBS	Work Breakdown Structure

1 Executive Summary

The Building Technologies Program (BTP) within DOE's Office of Energy Efficiency and Renewable Energy (EERE) is responsible for developing and deploying technologies that can substantially reduce energy consumption in residential and commercial buildings. BTP identified Geothermal Heat Pumps (GHP) as one such high-impact technology. GHP systems first gained popularity during the energy crisis in the 1970's, but despite having proven energy savings, the high cost of GHP systems has hindered penetration. In 2008, for the first time, contractors reached more than 100,000 installations per year in the U.S. However, the high installation costs still inhibit widespread industry growth.

In reviewing prior research, four key, consensus barriers emerged from multiple studies, including:

1. High first costs for ground loops (installation-specific design and cost of drilling/trenching) limit national energy savings versus ultra-high-efficiency Air-Source Heat Pumps, which generally provide shorter payback periods
2. Low market awareness and lack of knowledge/trust in GHP benefits by consumers, policymakers and regulators
3. GHP installation infrastructure limitations, including limited numbers of qualified installers
4. GHP design and business-planning-infrastructure limitations

Other key, non-consensus barriers include:

5. Lack of new technologies and techniques to improve GHP system cost/performance
6. Space constraints in many urban areas
7. High pumping parasitics if improperly designed/installed
8. Long-term temperature drift due to unbalanced heat transfer with the ground
9. GHPs can be difficult and costly to install in retrofit applications
10. Need codes to ensure proper design and installation of ground loop and pump selection

This R&D Roadmap identifies potential activities and technical innovations that may enable substantial improvements in residential and commercial GHP installed cost and/or efficiency. The identified initiatives address the major unfulfilled needs regarding the latest equipment, critical gaps in knowledge and tools, and market transformation activities related to these areas. The recommended schedule of activities occurs within a seven-year timeframe, beginning with Fiscal Year 2013, to accelerate advancements that might otherwise take much longer to realize.

To capture stakeholder inputs, Navigant held a GHP Roadmap Forum in October 2011 as part of the International Ground Source Heat Pump Association's Technical Conference in Tulsa, Oklahoma. In addition to this primary stakeholder information, we also conducted secondary research, ultimately identifying 27 potential initiatives for DOE to address. We calculated weighted scores for each initiative using three criteria:

1) Benefit
2) Fit with DOE mission
3) Criticality of DOE involvement

Navigant identified twelve high-priority initiatives, the selection of which we based primarily on the weighted scores, calculated from the above criteria. However, we also adjusted the rankings based on the GHP Roadmap Forum votes. The adjustments aid in preventing undervaluation of any initiative that may have received a lower score using the prioritization framework, but ranked high among stakeholders. Figure 1-1 shows all the initiatives, with the top twelve identified in green. The "Relevant Barriers" that the table references are included in the list above.

	Final Score	Initiative	Relevant Barriers
High Priority	4.5	Collect/Analyze Data From GHP Systems	1, 2
	4.4	Facilitate GHP-Specific Maps	1, 4
	4.3	Develop Regulatory Performance Standards for GHP	2, 7, 10
	4.2	Address Barriers to Greater Utility Participation in GHP Installations	1, 2
	4	Publish Best-Practice Reference Guides	2, 7, 10
	4	Develop Integrated Design and Simulation Tool	1, 8
	4	Evaluate and Characterize the GHP-Software Landscape	1, 4, 8
	3.9	Formalize Process for Third-Party Technology Validation	7, 10
	3.9	Develop a Comprehensive Lifecycle Cost & Estimation Tool	1, 2
	3.8	Innovative System Architectures	1, 5
	3.8	Innovative Heat Sources and Sinks	1, 5
	3.8	Advanced Ground-Loop Heat Exchangers	1, 5
Lower Priority	3.8	Research the Impacts of GHP Use on Ground Temperature	8
	3.7	Aggregate Region-Specific Perfromance Data for Marketing	2
	3.6	Introduce GHP System Design Modules into Engineering Curriculums	2, 3, 4
	3.5	Review Policies and Regulations and Guide Best Approach with Model Policies	3, 4
	3.4	Collect Information on other Countries' GHP Installations and Design Approaches	1, 5
	3.3	Update Key Design Books and Include Best Practices/Pitfalls	1, 2, 10
	3.2	Support Long Term Development of Software Tools to Drive Continuous Improvement	1, 5
	3	Train Contractors in Alternative Architectures Including Hybrid and Combination GHPs	1, 3, 4
	3	Develop Industry Case studies on Validation of Existing Software Tools	4
	2.7	Establish System to Evaluate and Monitor Software Maturity and Maintain Quality Control	2
	2.3	Augment Lifecycle Cost Estimation Tools for Educational Purposes	4
	2.1	GHP-Specific Compressors	1, 5
	2.1	GHP-Specific Indoor Heat Exchangers	1, 5
	2	Advanced Drilling Technologies	1, 5, 6
	1.7	Prepare Software Case Studies (See Software) and Use for Educational Purposes	4

Figure 1-1: GHP Roadmap Initiatives in Prioritized Order

2 Introduction

2.1 Overview

The Building Technologies Program (BTP) within DOE's Office of Energy Efficiency and Renewable Energy (EERE) is responsible for developing and deploying technologies that can substantially reduce energy consumption in residential and commercial buildings. Activities in recent years have included technical pathways to achieve net zero energy new buildings. Most recently, DOE has paid particular attention to energy savings potential in existing buildings because the impacts are immediate, due to the slow turnover of the building stock, and the overall savings potential is much greater.

HVAC systems are the single largest component of building energy consumption, accounting for 42% of residential primary energy use and 33% of commercial building primary energy use.[1] While many high efficiency options are available, Geothermal Heat Pumps (GHP), also known as Ground-Source Heat Pumps (GSHP) are among the most efficient, with annual energy consumption as little as half that of conventional unitary systems.[2] When compared to a typical air-source heat pump (ASHP) or typical furnace with an air conditioner, the primary energy savings is often in the range of 30 to 60 percent.[3] In many commercial and some residential applications, GHPs also provide water heating via a desuperheater.

While the primary energy savings technical potential of GHP technology is 3.7 quads, many barriers prevent realization of this potential.[4] Foremost among these barriers is the high installed cost of GHPs, due largely to the high costs of installing the ground loop. Other barriers include long, complex installations, site-specific engineering needs, creation of messes and disruptions during installation, space constraints, and exclusion of pumping power in current rating systems. While these barriers are formidable, overcoming them could produce dramatic benefits in terms of national energy savings.

By leveraging DOE resources, DOE/BTP can aid the GHP industry in developing and commercializing products and technologies that could make significant improvements feasible. Because development and commercialization of new approaches will require major investments and take several years, it is critical to target investments to those areas where the DOE can provide the greatest value. This Research and Development (R&D) Roadmap aims to guide such activities to ensure the best possible outcomes.

2.2 Objective

The HVAC industry has shown that GHP technology is a high-efficiency alternative to air-source heat pumps and other space cooling, space heating and water heating technologies. The key barrier that prevents greater penetration of GHP technology is its installed cost. The objective of this R&D Roadmap

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[1] U.S. Department of Energy, 2010 Buildings Energy Data Book, tables 2.1.6 and 3.1.5, available at: http://buildingsdatabook.eren.doe.gov

[2] Navigant Consulting, February 2009, "Ground-Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers," Final Report to U.S. DOE/EERE, Geothermal Technologies Program, Available at: http://www1.eere.energy.gov/geothermal/pdfs/gshp_overview.pdf

[3] Ibid., p. vii.

[4] Ibid., p. viii.

is to identify potential activities or technical innovations that may enable substantial improvements in residential and commercial GHP installed cost and/or efficiency. The three key steps to achieving this are to:

1. Obtain stakeholder feedback on technology options and savings opportunities
2. Recommend initiatives that DOE should undertake to increase market penetration
3. Create an R&D roadmap, including tasks and potential roles for various stakeholders

The objective of these R&D efforts will be to achieve a five-year simple payback period for ENERGY STAR-rated GHPs, relative to conventional ASHPs, in climate zones with substantial cooling and heating loads. GHPs represent a large fixed investment, and the only way to pay it back is through savings on heating and cooling. In regions with only high heating or high cooling loads, but not both, this target will be more difficult to achieve given that building owners will utilize their GHPs for a smaller portion of the year. GHPs have the potential to be an attractive alternative in certain regions based on specific local and regional factors. For example, high (and rising) heating-oil costs increase the attractiveness of GHPs in the northeast where heating-oil fueled water and space heating is common.

2.3 Technology

A GHP system, in its most basic elements, consists of a thermal source/sink (e.g., the earth, a pond, etc.), a heat pump (typically located inside the building), and a thermal output system to heat or cool the building space and/or heat water. In heating mode, the GHP pulls heat from the earth and transfers this heat to the indoor air or water; in cooling mode, the heat pump pulls heat from the indoor air and rejects the heat into the ground. Figure 2-1 shows these system elements.

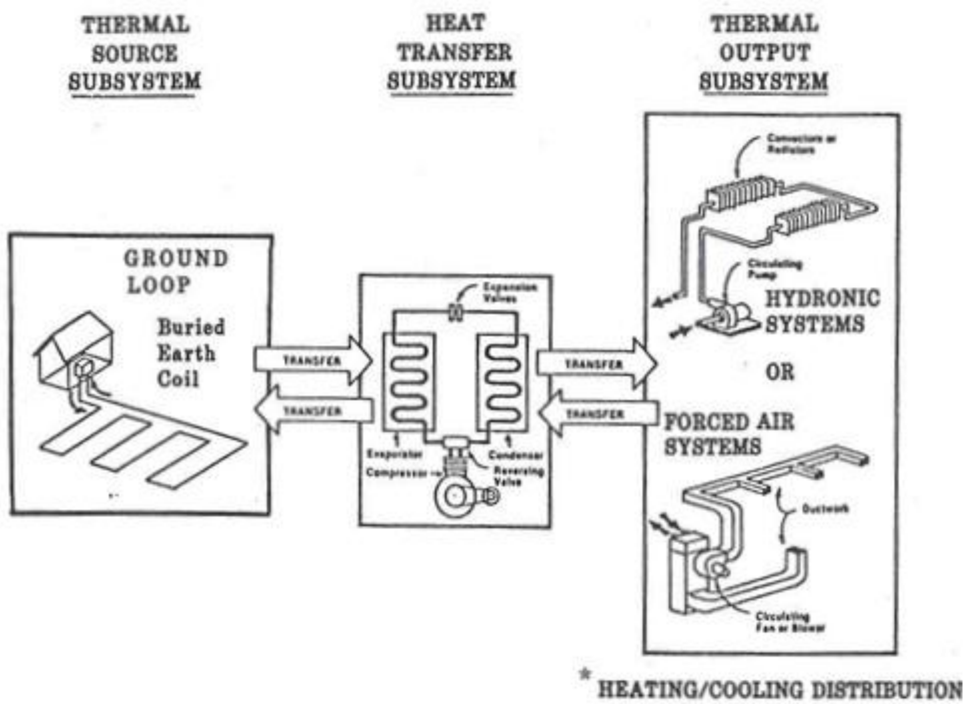

Figure 2-1: Basic Ground Source Heat Pump Components[5]

2.3.1 Indoor Components

The typical thermal output system in a residential application transfers heat to either a forced air heating/cooling system (a "water-to-air" system), or to a hydronic system for radiant floor heating, pool heating, or domestic water heating (a "water-to-water" system). A typical residential system has a 3-ton (36,000 Btu/hr) thermal capacity; however, manufacturers build product lines ranging from 1.5 to 6 tons to serve a variety of home sizes.

Commercial units are also available in both water-to-air and water-to-water configurations; capacities range from less than 10 tons to more than 500 tons. Depending on the layout of a given building and the nature of the heating/cooling loads, the building may use either a distributed architecture or a centralized architecture. A distributed architecture uses many small units, each one serving a specific zone or subset of the building space, while a centralized architecture uses fewer, but higher capacity units in combination with a traditional distribution system.

Figure 2-2 shows examples of the indoor equipment only for two residential water-to-air units and one commercial water-to-air unit.

[5] Photo Source: Modified from www.geothermal.org/Powerpoint07/Tuesday/Heat%20Pump/Garcia.ppt

Figure 2-2: Select example heat pump indoor units clockwise from upper left: residential water-to-water, residential split-system, commercial water-to-air, and residential water-to-air (various orientations/configurations)[6]

2.3.2 Outdoor Components

Closed-loop heat pumps, also known as ground-coupled heat pumps (GCHP), are the most common system type. In such a system, the refrigerant in the indoor heat pump transfer heat to and from a dilute water/glycol mix within an outdoor ground heat exchanger (GHX) via a liquid-to-liquid heat exchanger. The GHX loop is typically high-density polyethylene (HDPE). The heat pump controller operates one or more pumps to circulate the water/glycol solution throughout the GHX as necessary to meet the heating or cooling load. The glycol in the solution acts as an antifreeze to prevent the water from freezing.

Closed-loop ground heat exchangers come in a variety of configurations. Horizontal loops lie in trenches four to six feet deep and require 125 to 300 feet of trench per ton of cooling/heating capacity delivered. A vertical loop runs down the length of a vertical borehole and returns to the top. Each ton of capacity typically requires a single borehole approximately 150 to 300 feet deep.[7] The wide range in required depth (or length of trench) is due to varying geologic characteristics. For example, where the ground's thermal conductivity and heat capacity promote rapid heat transfer (e.g., dense and/or moist materials) the ground loop can be shorter and vice versa. Figure 2-3 shows the layout of a vertical (borehole) ground loop.

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[6] Photo sources: http://www.residential.carrier.com/products/, http://www.waterfurnace.com/geothermal-heat-pumps.aspx, http://www.climatemaster.com/commercial-tl-product, http://residential.climatemaster.com/products

[7] Kevin Rafferty, Heatspring Learning Institute, March 2008, "An Information Survival Kit: For the Prospective Geothermal Heat Pump Owner," Available at: http://town.newcastlenh.org/Pages/NewCastleNH_Bcomm/Energy/geo.pdf

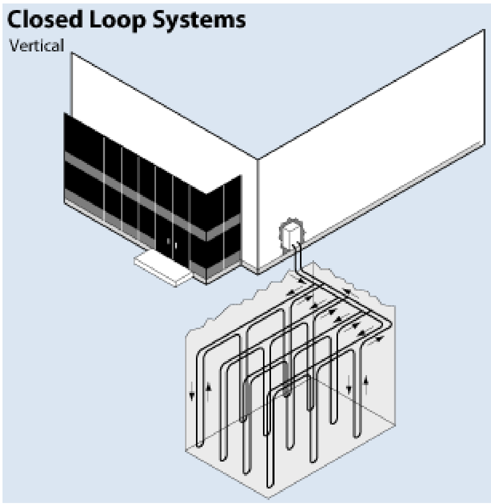

Figure 2-3: Example Horizontal Closed-Loop GHP Schematic

The particular horizontal loop in Figure 2-3 is in a "slinky" configuration, which is an alternative to using straight runs of pipe. Straight runs of pipe are more common due to the cost and complexity of correctly backfilling a vertically installed slinky configuration as Figure 2-3 shows. Alternatively, if the slinky sits horizontally at the bottom of a trench, it requires costly excavations because of the large volume of earth that installers must move in the process. Figure 2-4 shows two examples of horizontal trench cross sections, including the most common layout (right) which consists of six pipes per trench.

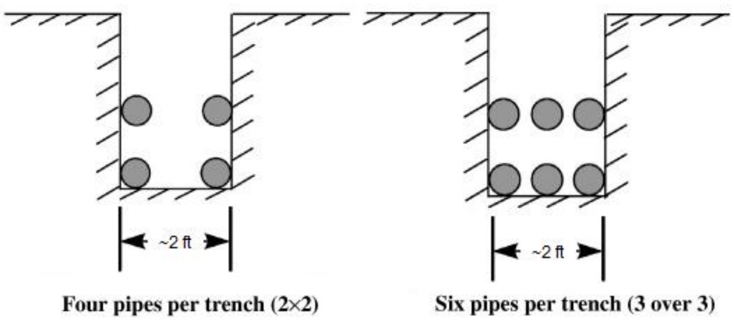

Figure 2-4: Example Piping Configuration in Horizontal, Closed-Loop Trenches

Open-loop systems, also known as ground-water heat pumps (GWHP), pump ground water from a well into the heat pump's heat exchanger and then re-inject the water back to the aquifer via a second well. In some applications, regulations allow the building owner to reject water into an existing body of surface water, thereby avoiding the need for an injection well. In regions where the local aquifer can provide sufficient water flow, open-loop GHP systems can provide a lower-cost solution.

Pond/lake configurations, also known as surface-water heat pumps (SWHP), can use either open-loop or closed-loop architectures. The latter often uses a submerged "slinky" configuration to exchange heat with the water at the bottom of a pond or lake. Figure 2-5 shows an example of such a system in addition to a traditional open-loop system.

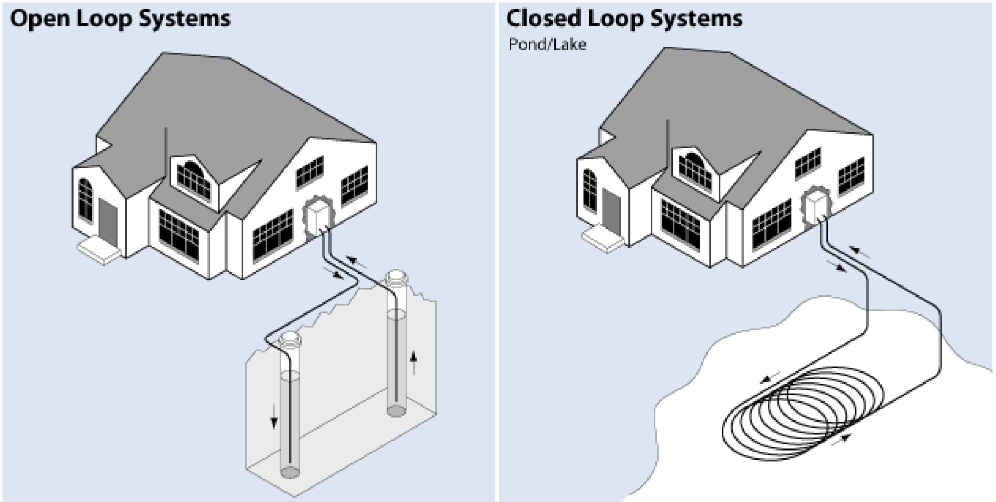

Figure 2-5: Schematics of Open-loop (Right) and Pond/Lake, Closed-Loop (Left) GHP Systems[8]

Direct Exchange (DX), also known as Direct GeoExchange (DGX) systems are a niche form of closed-loop system that circulate refrigerant from the heat pump directly through buried metal tubing instead of using a secondary glycol/water loop. Advanced DX systems are generally more efficient than advanced systems that use a conventional HDPE loop. This efficiency gain is due to the lack of a water-circulation pump, which directly reduces electricity consumption, and the lack of a water-to-refrigerant heat exchanger, which decreases the temperature lift.

DX loops are also appealing due to lower installation costs. The ground loop itself is smaller and requires less land area. Ongoing research into the use of CO2 as the working fluid in DX systems may further enable ground-loop cost reductions by using smaller diameter tubing, which allows for smaller and less expensive boreholes.

However, DX systems present many technical challenges for designers, installers and building owners. Underground leak of refrigerant (containing oil) pose serious performance and environmental concerns, in addition to the high cost and complexity of locating and repairing such leaks. As with conventional HDPE ground loops, appropriate sizing is vital to achieving expected performance. GHP Forum participants anecdotally mentioned installations where improper sizing led to excessive heat transfer rates that froze the surrounding ground, killing the lawn and trees in the near vicinity, as well as the efficiency of the system. While DX system have been sold for over 20 years, many technical challenges remain which have hindered market penetration to date.

Hybrid configurations, most frequently implemented in commercial applications, use a ground loop to meet the entirety of the smaller of the heating or cooling load (most all U.S. commercial applications are cooling-dominated). For cooling-dominated applications, the designer supplements the cooling capacity with a secondary thermal sink/source to meet peak loads. Designers typically call for a conventional fluid cooler (or less frequently, a cooling tower) as the secondary thermal sink. For heating-dominated applications, designers employ independent, resistance backup heat to meet peak loads. Hybrid systems provide two key benefits:

[8] Photo Source: http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650

- Balanced heat transfer to/from the ground – After years of use, unequal transfer of heat to and from the ground (i.e., unbalanced heat transfer) can cause significant changes in the equilibrium ground temperature, thereby reducing the efficiency of the system. Maintaining balanced heat transfer ensures that the system will always operate at the designed temperature set points with the intended efficiency.
- Reduced installation cost – Studies show that the reduced ground-loop cost (enabled by reducing the size of the ground loop to meet only the needs of the smaller of the heating or cooling load) outweighs the additional equipment costs of the secondary thermal sink/source.[9]

Some estimates indicate that for offices and other select building types, hybrid systems may provide benefit across the majority of climate regions in the contiguous 48 states; only a small portion of the colder, northern portion of the U.S. has equal heating and cooling loads that would undercut the need for a hybrid system.[10] In such locations, under-sizing the ground loop would require the addition of secondary sources for both heating and cooling.

Figure 2-6 shows an example schematic of a hybrid system that utilizes a fluid cooler or cooling tower to supplement the ground loop during cooling season.

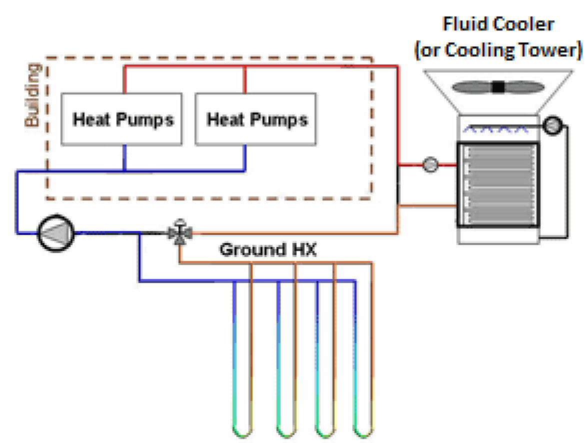

Figure 2-6: Example Schematic of Cooling-Dominated Hybrid GHP for a Large Commercial Building[11]

Some large buildings now have systems that use a variety of alternative ground-heat-exchanger architectures, including flooded-mine water, municipal wastewater systems, standing column wells, and combinations of various water sources. Despite the need for custom engineering design for each system, utilizing such alternative heat sinks/sources enables greater energy savings and reduced overall first costs.

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[9] Scott Hackel, Energy Center of Wisconsin, June 2011, "Hybrid Ground-Source Heat Pump Installations: Experiences, Improvements and Tools," Available at: http://www.ecw.org/ecwresults/262-1.pdf

[10] Information sourced from an Energy Center Wisconsin Webinar on September 29, 2011, by Scott Hackel, PE. This estimate is highly dependent on heating and cooling loads, which can vary significantly between building types.

[11] Photo Source (modified): http://www.ecw.org/project.php?workid=1&resultid=464

2.4 *Roadmap Development Process*

2.4.1 Overview

Navigant followed three steps to gather information, articulate needs, and develop the final roadmap. Navigant conducted literature reviews twice during the development of this roadmap: prior to contacting stakeholders and then again as follow up for additional research. Figure 2-7 shows the steps of the process, which are further detailed below.

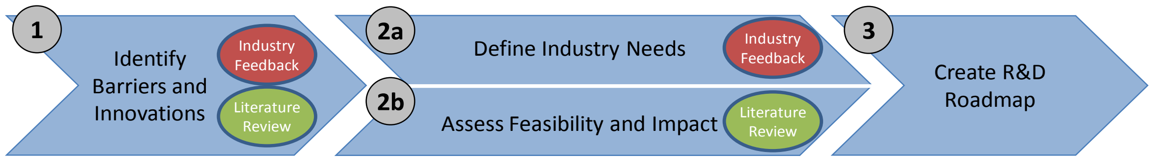

Figure 2-7: Flowchart of the Roadmap Development Process

Task 1: Identify and Evaluate Barriers and Innovations
Based on a review of published literature and discussions with industry experts and the research community, we identified possible innovations and activities to increase GHP market penetration. The literature review encompassed technical research documents, conference proceedings, industry publications, project websites, etc., to cover a broad sample of the industry. We focused on technical innovations at both the component and system levels, but also looked for financial and regulatory innovations that could address key GHP adoption barriers.

We obtained stakeholder input via a DOE R&D Roadmap Forum, held on October 5, 2011 at the International Ground Source Heat Pump Association's (IGSHPA) Annual Conference, as well as through follow-up phone conversations. The forum generated a high volume of input from stakeholders and provided the key drivers for task 2.

Appendix A provides a summary of the IGSHPA Roadmap Forum.

Task 2a: Define Market Needs
Based on the literature review and one-on-one follow-up conversations with industry experts, Navigant identified a preliminary list of initiatives to accelerate market adoption of GHP technology. The innovations from the literature review and the suggestions from the Roadmap Forum captured a substantial breadth of market needs. While the initiatives generally came directly from the forum, we refined them based on both discussions with industry leaders and internal HVAC market expertise. A key factor in refining industry-recommended initiatives was to ensure that the initiatives will ultimately serve the needs of the broad market (and the technology) and not just to serve the short-terms needs of any individual stakeholder. We identified twenty-seven initiatives to evaluate in the screening process in Task 2b.

Task 2b: Assess Feasibility and Impact
Navigant assessed the feasibility and impact of each initiative based on literature review of current research and published recommendations. We categorized and prioritized all relevant initiatives to identify a list of high priority initiatives. Section 2.4.2 describes in detail the prioritization framework.

Task 3: Finalize R&D Roadmap
We aggregated prioritized initiatives along with information from the literature reviews and stakeholders feedback to create the roadmap. The section also lists the remaining 15 lower-priority that are worthy of additional follow-up activity, but are either not as high impact or not as suitable for DOE to address at the current time.

2.4.2 Initiative Prioritization Framework

After identifying key initiatives for DOE, the initiatives were prioritized in a three-step process (see task 2b in Section 2.4.1, above. Figure 2-8 shows the steps of the process.

Figure 2-8: Activity Prioritization Process

Navigant selected three criteria with which to rate each initiative: 1) Benefit, 2) Fit with DOE mission, and 3) Criticality of DOE involvement. As Table 2-1 shows, we scored each initiative on a scale of 1 to 5 with predetermined definitions for each value of each criterion. Table 2-1 also shows the weighting for each prioritization criterion.

Table 2-1: Prioritization Criteria Definitions

Score*	Benefit	Fit for DOE BTP	Criticality of DOE Involvement
5	Addressing this critical gap leads to significant savings and/or market transformation	Core to mission/goals; Only entity responsible	Critical to success
3	Addressing this important gap leads to modest savings and/or market impact	Relevant to mission/goal; DOE could play key role	Beneficial
1	Addressing this gap leads to minimal savings or minimal impact on the market	Outside of DOE scope	Not needed for success
Weight:	**50%**	**30%**	**20%**

*Navigant additionally applied scores of 2 or 4 for those initiatives whose assessed score fell between two of the definitions in the table.

Criteria Definitions:

Benefit

The "benefit" of each initiative indicates the specific value that the initiative could provide in lowering GHP barriers. For technology-based initiatives, we evaluated "benefit" directly on the energy or cost savings of the technology, whichever could lead to a greater impact. For non-technology-based initiatives, we evaluated "benefit" on qualitative value, representing, for example, increased knowledge/skills for an education-based initiative.

Fit for DOE BTP

The "Fit for DOE BTP" criterion indicates the degree of alignment with DOE's mission or goals. Other entities may actually be better suited to address certain market needs. If DOE were to embark on an initiative with a low score in this category, it is likely that DOE would not be as effective as another organization with a better fit.

Criticality of DOE Involvement

The criticality of DOE involvement is a measure of the need for DOE to be involved. A score of 5, or "Critical to success," indicates that if DOE does not get involved, it is unlikely that other organizations will address the issue. This criterion helps separate initiatives that industry will likely address on its own from initiatives that likely need some level of DOE involvement to achieve their respective benefits.

After scoring each initiative with the above criteria and calculating weighted scores using the weights from Table 2-1, a set of twelve high priority initiatives were identified (for which we provide extensive details in Sections 4). To ensure proper accounting of stakeholder feedback from the Roadmap Forum (see section 2.4.1 above), the high-priority initiatives were identified based on both weighted scores and qualitative adjustments to account for forum participant feedback. Therefore, the final top twelve initiatives do not exactly match with the top twelve weighted scores.

3 State of the Industry

3.1 *GHP Challenges and Barriers*

In 2008, an ORNL study collected survey data and identified three tiers of barriers to greater market penetration.[12] A 2009 study by Navigant echoed many of the same barriers and separated barriers based on three categories: 1.) Technology, 2.) Market, 3.) Institutional and Regulatory.[13]

The consensus barriers that arise from these sources include high costs, limited knowledge, and limited infrastructure. Specific key consensus barriers include:

1. High first costs associated with the ground loop (installation-specific design and cost of drilling/trenching) limit national energy savings versus ultra-high-efficiency Air-Source Heat Pumps, which generally provide shorter payback periods
2. Low market awareness and lack of knowledge/trust in GHP benefits by consumers, policymakers and regulators
3. Limited GHP installation infrastructure– many regions have limited numbers of qualified/experienced installers
4. Limited GHP design and business-planning infrastructure

Other key, non-consensus barriers include:

5. Lack of new technologies and techniques to improve GHP system cost/performance
6. Space constraints in many urban areas
7. High pumping parasitics if improperly designed/installed
8. Long-term temperature drift due to unbalanced heat transfer with the ground
9. GHPs can be difficult and costly to install in retrofit applications
10. Need codes to ensure proper design and installation of ground loop and pump selection

Section 4 describes in detail the potential pathways to address these barriers.

3.2 *Status of Current Geothermal Heat Pump RD&D*

Current GHP R&D efforts focus on reducing installation costs through advanced design and installation configurations and approaches. Additionally, many organizations, including DOE/BTP, are focusing efforts on innovative financing approaches to defer or reduce upfront costs. Table 3-1 shows a representative selection of recent GHP R&D activities.

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[12]Hughes, Patrick; December 2008; Oak Ridge National Laboratories; "Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barrier;" Available: http://www.ornl.gov/sci/ees/etsd/btric/pdfs/geothermal_report_12-08.pdf

[13] William Goetzler, et. al, February, 2009, "Ground-Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers," Available: http://www1.eere.energy.gov/geothermal/pdfs/gshp_overview.pdf

Table 3-1: Representative Selection of Recent GHP Research Activities (Barriers reference Section 3.1)

Activity	Description	Relevant Barriers
Update to Design and Installation Standards	In 2010, IGSHPA completed the latest updates to their "Closed-Loop/Geothermal Heat Pump Systems: Design and Installation Standards"[14]	7, 10
Ground Loops Installed in Construction Excavations	ORNL and Oklahoma State University studied the installation of ground loops in the over-excavation area around the foundation of new homes. Full-scale field-testing modeling showed viability with significant cost reduction potential.[15]	1, 5, 6
Data Collection and Reporting	ORNL is developing a platform for "Co-Engagement through the Web," called CoNNECT for both consumers and utilities to monitor and benchmark performance.[16] Additionally, ORNL is managing the data collection process for 26 ARRA-funded demonstration projects (See below).	2, 8
Hybrid System Research	The Energy Center of Wisconsin is evaluating the performance of hybrid systems, focusing on configuration and pumping-strategy optimization.	1, 5, 8
Multifunction GHP Unit	ClimateMaster, through an R&D collaboration with ORNL, developed a single integrated GHP unit that provides all of the required heating, cooling, and water heating on-demand in a residential application, and reduces annual energy use by up to 65% compared with conventional systems.	5
Utility/Municipal Ground Loop Ownership Programs	The city of Wyandotte, MI, and the Delta Montrose Electric Association (DMEA) for example have both instituted centralized ownership of ground loop infrastructure so that the homeowner pays only a monthly usage fee.	1, 2, 3, 4
Optimal GHP Design Software	DOE has funded a crosscutting team to develop a least cost design tool to analyze system performance and cost.[17]	1
International Collaboration	ORNL is collaborating with the China Academy of Building Research on emerging GHP technologies in an effort to understand benefits of the alternative configurations and approaches that the Chinese are using.[18]	5

[14] IGSHPA; 2010; "Closed-Loop/Geothermal Heat-Pump Systems: Design and Installation Standards;" Available: http://www.igshpa.okstate.edu/pdf_files/publications/Standards2010s.pdf

[15] Hughes, P.J. and Piljae Im. January 2012. Oak Ridge National Laboratory, ORNL/TM-2012/27, "Foundation Heat Exchanger Final Report: Demonstration, Measured Performance, and Validated Model and Design Tool"

[16] Patrick Hughes, October 2011, "Potential Utility Scale Benefits from GHPs," presentation at IGSHPA 2011 Technical Conference.

[17] Metin Ozbek, May 19, 2010 presentation: "Optimal Ground-Source Heat Pump System Design," Available: http://www1.eere.energy.gov/geothermal/pdfs/peer_review_2010/gshp_ozbek_optimal_system_design.pdf

[18] Dr. Robert C. Marley, June 22, 2011 Presentation: "U.S.-China Clean Energy Research Center Overview," Available: http://www.us-china-cerc.org/pdfs/Marlay_CERC_Update_v14.pdf

Activity	Description	Relevant Barriers
Design Handbooks	ASHRAE Technical Committee 6.8 conducts periodic updates to the ASHRAE Handbooks. Additionally, IGSHPA conducts periodic updates to their design manuals.	10
Region Specific Data Analysis	The Heat Spring Learning Institute and the New England Geothermal Professional Association are together developing a regional study to: 1) Quantify performance of actual installations 2) Identify best practices for installations in the region 3) Compute local thermal conductivity and build geology-based database 4) Raise awareness	1, 2
Data Collection Platform Development	Ground Energy Support released a web-based monitoring system for residential and light-commercial GHP data collection and analysis.	1, 2, 8

Federal Government Activities[19]

Under the American Recovery and Reinvestment Act, DOE funded 36 cost-shared projects, of which the DOE's investment totaled $67 Million: 26 demonstration projects, nine analysis and data-collection projects, and one professional-certification project. This investment represents a massive increase in government GHP demonstration funding compared to funding-levels before ARRA[20]. DOE's objective with the technology demonstration projects was to demonstrate innovative financial and/or technical approaches. The technical approaches included making use of municipal grey water, water-filled abandoned mines, and improved ground-coupling technologies.

Figure 3-1 shows the 26 demonstration project sites with the capacity and number of heat pumps at each installation. These demonstration projects are currently at various stages of installation and construction. ORNL is overseeing the data monitoring and collection process for these demonstration projects.

[19] Xiaobing Liu, Presentation for GovEnergy: "Discover Opportunities with Ground Source Heat Pump (GSHP)," Available: http://www.whitehouse.govenergy.gov/Files/1Presentations/Renewables/Session8_XLiu.pdf

[20] Tina Kaarsberg, October 2011, "Geothermal or Ground Source Heat Pumps at DOE, ACORE Webinar," Available: http://www.acore.org/wp-content/uploads/2011/11/Presentation_Tina_Kaarsberg.pdf

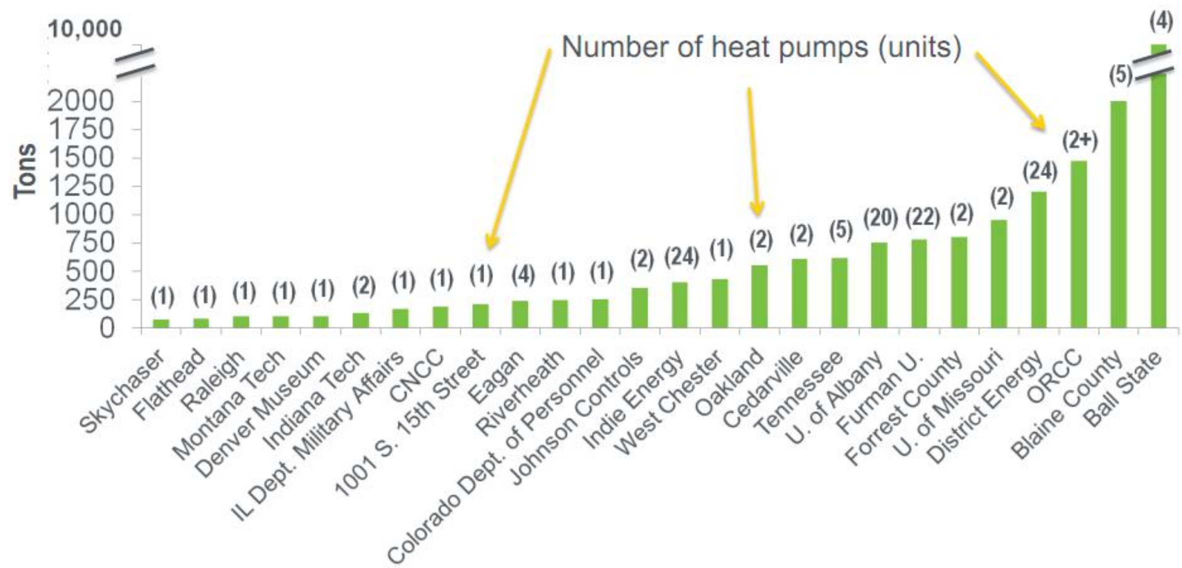

Figure 3-1: ARRA Demonstration Projects[21] [22]

DOE awarded ARRA funds to nine different organizations who are improving models and gathering and analyzing various data subsets (e.g., for hot-humid or hot-dry climates), including many universities, manufacturers, and independent non-profits. The recipients of the funds included: ClimateMaster, Inc., Colorado School of Mines, Energy Center of Wisconsin, Environ Holdings, Florida International University, Hartford College for Women, Oklahoma State University, University of Texas at Austin, and Wright State University.

DOE awarded the final ARRA grant to GEO, who is managing the Geothermal Heat Pump National Certification Standard (GHPNCS) project. Key partners in the project include IGSHPA and ORNL. The goal of the project is to develop a national certification standard for all "primary personnel involved in the installation" of GHPs, with the intent of increasing consumer confidence and providing quality assurance.[23]

With $3.2 billion in ARRA funding, DOE also funded more than 2,200 Energy Efficiency and Conservation Block Grant Program (EECBG) projects—30 of which involve GHPs.[24, 25] The EECBG, authorized in Title V, Subtitle E of the Energy Independence and Security Act (EISA) of 2007, assists U.S.

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[21] Kaarsberg, Tina; October 2011; "Geothermal or Ground Source Heat Pumps at DOE, ACORE Webinar;" Available at: http://www.acore.org/wp-content/uploads/2011/11/Presentation_Tina_Kaarsberg.pdf

[22] Outlier note: The Ball State University GHP is unique in that it utilizes large 2,500-ton chillers that will circulate water for district heating/cooling. Additional information is available from "BSU GHP District Heating and Cooling System (PHASE 1) Geothermal Project," at: http://en.openei.org/wiki/BSU_GHP_District_Heating_and_Cooling_System_(PHASE_I)_Geothermal_Project

[23] Geothermal Heat Pump National Certification Standard Website: http://www.ghpncs.org/

[24] EECBG information available at http://www.recovery.gov/Transparency/Pages/DataExplorerLanding.aspx, including total number of EECBG projects.

[25] Tina Kaarsberg, October 2011, "Geothermal or Ground Source Heat Pumps at DOE, ACORE Webinar," Available: www.acore.org/wp-content/uploads/2011/11/Presentation_Tina_Kaarsberg.pdf. This source states the number of EECBG projects, which include GHPs.

states, cities, and counties in developing, promoting, and implementing energy efficiency and conservation projects. EECBG projects have been and will continue to be a valuable tool for the Department in promoting energy-efficient technologies such as GHPs. [26]

Apart from ARRA projects, DOE is also supporting technology RD&D by leveraging the Department's expertise, resources and programs. This includes allocating funding to focus on the most promising technologies through programs such as the Energy Innovation Hub, ARPA-E and the national laboratories. Recently BTP, the Oak Ridge National Laboratory, and ClimateMaster, Inc., collaborated to develop a ground source integrated heat pump (GS-IHP). The GS-IHP is a single unit capable of heating, cooling, water heating, and dehumidification.[27] Field tests and analysis show that the unit is capable of saving 30-35 percent of annual energy usage compared to current state-of-the-art GHPs.[28]

To support future work, in addition to this roadmap, DOE's Building America Program also provides guidance on residential GHP R&D through strategic plans in focused technology areas. Currently, Building America includes GHP in two different strategic plans: Analysis Methods and Tools, and Space Conditioning.[29] The draft of the space conditioning strategic plan includes many of the same topics detailed in section 4 of this roadmap.

3.3 Equipment Shipments

Annual GHP shipments in the US reached more than 100,000 units in 2008 and 2009, equaling more than 400,000 tons of capacity per year.[30] Figure 3-2, from the U.S. Energy Information Administration's Renewable Energy Annual Report, shows the most recent data from 2009.

[26] DOE, Office of Energy Efficiency and Renewable Energy Website: "Energy Efficiency and Conservation Block Grant Program," provides additional information. Available: www1.eere.energy.gov/wip/eecbg.html

[27] More information available at http://residential.climatemaster.com/climatemaster_breaks_the_40_eer_barrier

[28] More information available on the Integrated Heat Pump at: http://residential.climatemaster.com/climatemaster_breaks_the_40_eer_barrier

[29] DOE Building America program strategic plans available at: http://www1.eere.energy.gov/buildings/residential/ba_strategic_plan.html

[30] U.S. Energy Information Administration, December 2009, "Renewable and Alternate Fuels data: Geothermal Heat Pumps," Available: http://www.eia.gov/cneaf/solar.renewables/page/heatpumps/heatpumps.html. Updates to this report have since been discontinued.

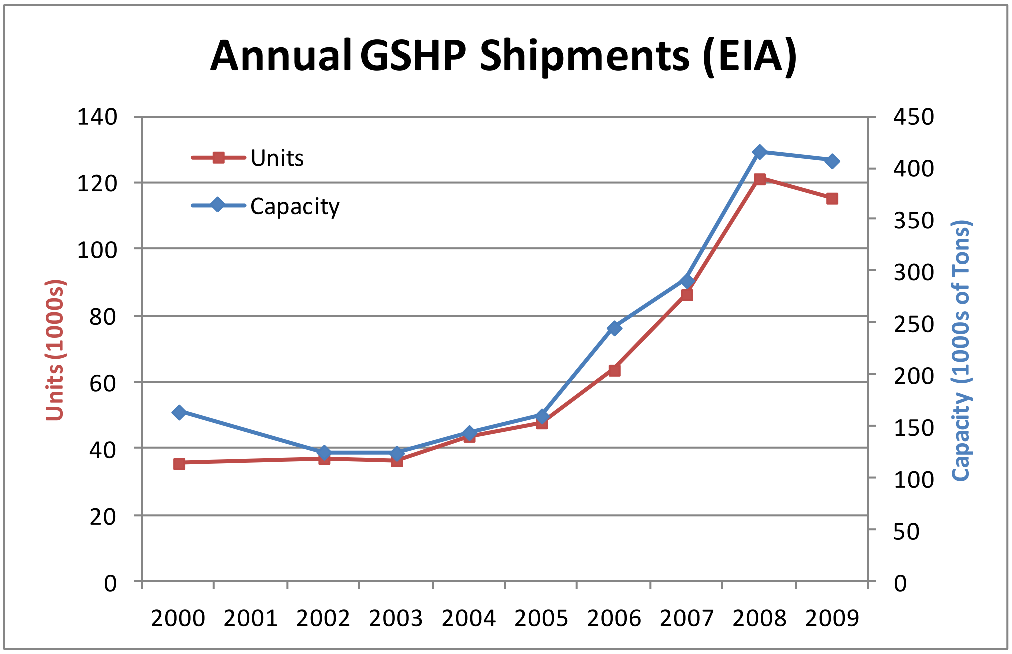

Figure 3-2: Annual U.S. GHP Shipments[31]

3.4 Industry Standards

Approximately 3600 GHP models are ENERGY STAR certified.[32] Table 3-2 shows the ENERGY STAR performance specifications for various configurations of GHP systems and the approximate number of certified models for each configuration. Because of the commonality of major components, manufacturers typically have a closed-loop and an open-loop version of each model.

Table 3-2: ENERGY STAR Specifications for GHP Units

ENERGY STAR Specifications (Effective January 1, 2012)[33]				Approximate Number of Certified Models
Product Type		Cooling EER	Heating COP	
Water-to-Air	Closed-loop	17.1	3.6	1500
	Open-loop	21.1	4.1	1700
Water-to-Water	Closed-loop	16.1	3.1	150
	Open-loop	20.1	3.5	150
DGX		16.0	3.6	60

[31] Ibid.
[32] ENERGY STAR certified GSHPs – List available at: http://www.energystar.gov/ia/products/prod_lists/geothermal_heatpumps_prod_list.pdf
[33] ENERGY STAR specifications available at: http://www.energystar.gov/index.cfm?c=geo_heat.pr_crit_geo_heat_pumps

The low number of ENERGY STAR-certified DX systems is indicative of the lower penetration rate of DX systems. DX systems are not new to the industry, but their market has grown slowly due to the many technical challenges. Section 2.3.2, above describes many of the challenges associated with this technology.

ENERGY STAR specifications are the only currently defined performance specifications within the industry; DOE does not have minimum standards that cover GHPs of any configuration.

Manufacturers and vendors rate performance based upon ISO Standard 13256, which AHRI and ASHRAE adopted in 2003.[34] Given the variability of each individual ground loop and the ground in which it lies, GHP field performance can vary dramatically among seemingly similar systems installed in different locations.

Design Standards

IGSHPA developed and updated (in 2010), the "Closed-Loop/Geothermal Heat-Pump Systems: Design and Installation Standards."[35]

Professional Certification Standards

GeoExchange, with support from IGSHPA and ORNL, is under contract with the U.S. DOE to initiate the development of a professional certification standard.[36] The project website states the potential impact of the project as follows:

> "The national standard will enable the development of a comprehensive new commercialization strategy to increase the deployment of geothermal heat pumps. By increasing customer confidence in the technology, the standard will facilitate growth of the industry, which will create and maintain green jobs and simultaneously stimulate the economy by lowering facility heating and cooling costs, lowering consumer utility bills, making U.S. businesses more competitive and promoting economic growth."

[34] http://www.appliancedesign.com/Articles/Breaking_News/0e9b2e31f3a38010VgnVCM100000f932a8c0____)

[35] IGSHPA, 2010, "Closed-Loop/Geothermal Heat-Pump Systems: Design and Installation Standards," Available: http://www.igshpa.okstate.edu/pdf_files/publications/Standards2010s.pdf

[36] GeoExchange, GHP National Certification Standard Project, Information available: http://www.ghpncs.org/.

3.5 Software

GHP design requires three key inputs: 1) Building loads and characteristics, 2) Geological data, and 3) GHP equipment characteristics; currently available software packages address each of these needs differently. Frequently used design software packages include (but are not limited to) GSHPCalc, OptGSHP, GLEPRO, HYGCHP, Gaia, GS2000, Right-Loop, and eQuest. For general HVAC and building load analysis, stakeholders also mention the use of EnergyPlus, DOE-2, Trace 700, and any other front-end packages, such as BEopt that use the simulation engines from one of these packages. According to stakeholders, the two most comprehensive software packages are eQuest and TRNSYS; however, TRNSYS is an academic research tool, not a commercial design package.

During the GHP Roadmap Forum, Stakeholders identified seven priority capabilities that currently available GHP software does not adequately provide:

- Building load determination (i.e., within the GHP package)
- Long-term ground temperature impact
- Pumping and piping configuration
- GHP optimization
- Hybrid design
- Ground water flow
- Life-cycle cost analysis

Note that many of the available software packages accommodate a variety of these individual capabilities; the challenge, according to stakeholders, is in piecing together all the necessary capabilities into a smooth workflow to be able to efficiently design a GHP system. GHP Roadmap Forum attendees indicated that use of two or even three different tools is common to complete a single GHP design. Further, while many software packages claim to provide comprehensive design needs, the software does not always contain fully developed features for all types of installations, and stakeholders question whether third parties have thoroughly validated some such features using actual field data.

3.6 Policy and Regulations

The Federal Government provides tax credits for GHP systems installed between December 1, 2009 and December 31, 2016.[37] Table 3-3 summarizes the benefits of the tax credit. While significant growth in the industry began prior to the credit implementation (see Section 3.1), GHP Roadmap Forum attendees voiced strong support for the tax credit's ability to mitigate the near-term impact of the economic downturn and significantly strengthen the industry in the long term.

[37] ENERGY STAR website (EPA) details on Federal Tax Credits; Available: http://www.energystar.gov/index.cfm?c=tax_credits.tx_index

Table 3-3: GHP Federal Income Tax Credit Details

Income Tax Credit Benefits	
Residential	*Commercial*
30% of total GHP system cost (no max)	10% of total GHP system cost (no max)
Can be used to offset regular income taxes or AMT[A]	Can be used to offset regular income taxes or AMT[A]
Can be combined with other tax credits	Can be used in with subsidized financing
Can be used in more than one year	Can be used in more than one year
	5-Year MACR depreciation for system

[A] Alternative Minimum Tax

Our survey of the GHP regulatory environment noted several policy and regulatory inconsistencies including:

- Inclusion in Renewable Portfolio Standards (RPS)
- Permitting costs and processes
- Drilling-fluid disposal regulations and costs

Of the 33 states with RPS's in place, only ten states count GHPs in reaching their targets.[38] Table 3-4 lists the states that currently count GHP systems towards their RPS targets.

Table 3-4: States with Renewable Portfolio Standards That Include GHPs[39]

	Percentage of Renewable Sources	Goal Year
Arizona	15%	2025
Hawaii	20%	2020
Maryland	20%	2022
Michigan	10%	2015
New Hampshire	15%	2025
Nevada	25%	2025
North Carolina	13%	2021
Pennsylvania	8%	2020
Texas	5,880 MW[A]	2015
Wisconsin	10%	2015

[A] Texas does not stipulate a percentage, but rather a specific capacity target.

[38] From DOE/EERE website on RPS and DSIRE; note that eight additional states have voluntary renewable portfolio standards that do not have binding targets. Available: http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm and http://www.dsireusa.org

[39] Emily Roberson, EnLink GeoEnergyServices, Inc., "A Case for Geothermal Heat Pumps' Contribution to Renewable Portfolio Standards," Available: http://enlinkgeoenergy.blogspot.com/2011/08/case-for-geothermal-heat-pumps.html

4 Roadmap Initiatives

Section 4.1 presents the selected high priority initiatives. Section 4.2 discusses Navigant's categorization of initiatives. Sections 4.3 through 4.8 detail the barriers associated with each of six areas relates to GHP development. These sections present all the identified initiatives (not just high priority) to address these key barriers.

4.1 High-Priority Inititiaves

Using three criteria, Benefit, Fit with DOE Mission and Goals, and Criticality for DOE Involvement, we calculated weighted scores for each for the 27 initiative according to the prioritization framework outlined in Figure 2-8, above. We arrived at the list of twelve high-priority initiatives primarily from the weighted scores. However, we adjusted the rankings based on the GHP Roadmap Forum votes and internal knowledge of HVAC markets. The adjustments aid in preventing undervaluation of any initiative that may have received a lower score using the prioritization framework, but ranked high among stakeholders. Because of the dual approach for determining priorities, note that the weighted scores that follow in Sections 4.3 through 4.8 do not necessarily match the final scores used to determine the high-priority category. Initiatives with weighted scores above 3.75 tend to be in the high-priority tier. Figure 4-1 shows the final scores of each of the initiatives. The "Relevant Barriers" in Figure 4-1 reference the barriers from Section 3.1, above.

	Final Score	Initiative	Relevant Barriers
High Priority	4.5	Collect/Analyze Data From GHP Systems	1, 2
	4.4	Facilitate GHP-Specific Maps	1, 4
	4.3	Develop Regulatory Performance Standards for GHP	2, 7, 10
	4.2	Address Barriers to Greater Utility Participation in GHP Installations	1, 2
	4	Publish Best-Practice Reference Guides	2, 7, 10
	4	Develop Integrated Design and Simulation Tool	1, 8
	4	Evaluate and Characterize the GHP-Software Landscape	1, 4, 8
	3.9	Formalize Process for Third-Party Technology Validation	7, 10
	3.9	Develop a Comprehensive Lifecycle Cost & Estimation Tool	1, 2
	3.8	Innovative System Architectures	1, 5
	3.8	Innovative Heat Sources and Sinks	1, 5
	3.8	Advanced Ground-Loop Heat Exchangers	1, 5
Lower Priority	3.8	Research the Impacts of GHP Use on Ground Temperature	8
	3.7	Aggregate Region-Specific Perfromance Data for Marketing	2
	3.6	Introduce GHP System Design Modules into Engineering Curriculums	2, 3, 4
	3.5	Review Policies and Regulations and Guide Best Approach with Model Policies	3, 4
	3.4	Collect Information on other Countries' GHP Installations and Design Approaches	1, 5
	3.3	Update Key Design Books and Include Best Practices/Pitfalls	1, 2, 10
	3.2	Support Long Term Development of Software Tools to Drive Continuous Improvement	1, 5
	3	Train Contractors in Alternative Architectures Including Hybrid and Combination GHPs	1, 3, 4
	3	Develop Industry Case studies on Validation of Existing Software Tools	4
	2.7	Establish System to Evaluate and Monitor Software Maturity and Maintain Quality Control	2
	2.3	Augment Lifecycle Cost Estimation Tools for Educational Purposes	4
	2.1	GHP-Specific Compressors	1, 5
	2.1	GHP-Specific Indoor Heat Exchangers	1, 5
	2	Advanced Drilling Technologies	1, 5, 6
	1.7	Prepare Software Case Studies (See Software) and Use for Educational Purposes	4

Figure 4-1: Weighted Scores for All Identified Initiatives

4.2 *Initiative Categories*

We separated the initiatives into six categories for ease of understanding and comparison: Software, Data Collection, Best Practices, Education and Training, Policy and Regulation, Enabling Technology. While soliciting industry feedback, stakeholders consistently placed greater emphasis on system design and education (for consumers, policymakers, installers, etc.) than on traditional component R&D activities, which they feel individual manufacturers can sufficiently address.

Figure 4-2 shows the minimum, maximum, and average weighted scores for all the initiatives within each category (not just first and second priority initiatives). Policy and Regulations, Data Collection, and Best Practices categories had the highest average weighted scores, all between 3.5 and 4.

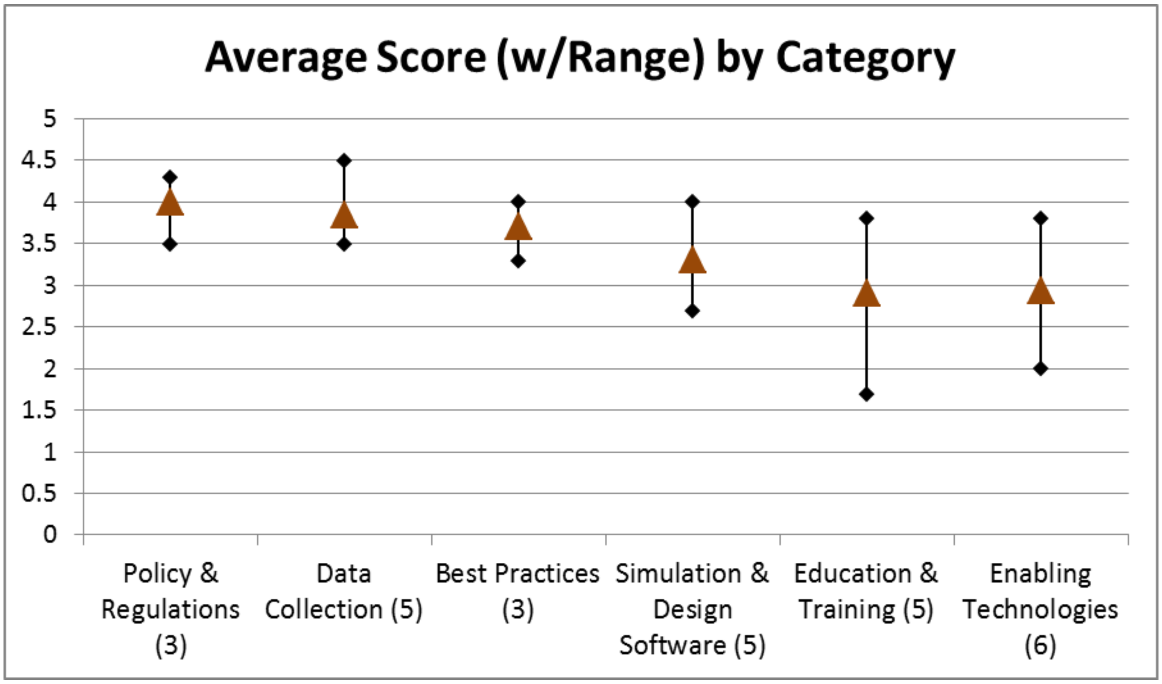

Figure 4-2: Weighted Scores of all Identified Initiatives (27)

4.3 *Software*

4.3.1 Barriers

The simulation and design software landscape for GHP applications is a patchwork of industry and academic tools without comprehensive integration of features. As a result, designers frequently report using multiple software tools simultaneously to compile a complete set of software capabilities. The design workflow includes up to as many as three separate tools, each addressing various needs, to complete a ground-heat-exchanger design. Such software limitations may limit the penetration of technological advances.

The GHP software industry lacks strong design and quality standardization. This is likely due to the industry's small size and limited software market. Overall, the industry's size supports few development firms, and inhibits investment in software R&D.

Academic software, which may flourish in a niche market, also lacks features. Often designed with only thermal modeling in mind, some designers feel that academic software is disconnected from engineer's needs. Furthermore, academic software may lack the necessary customer support resources to maintain a strong user-base.

For emerging technological methodologies and architectures, academic software can sometimes be quite useful because research engineers use the software to aid in technology development. For instance, the GHP industry in general still does not completely understand GHP heat-transfer science, but academic software is advancing in this area.

The suboptimal characteristics of the GHP software landscape leave open opportunity for errors in design. While additional software training could certainly help designers to avoid common pitfalls, a more direct approach to improve the comprehensiveness and performance of software help bridge existing gaps.

4.3.2 Initiatives

Figure 4-3 shows the plotted scores of each initiative.

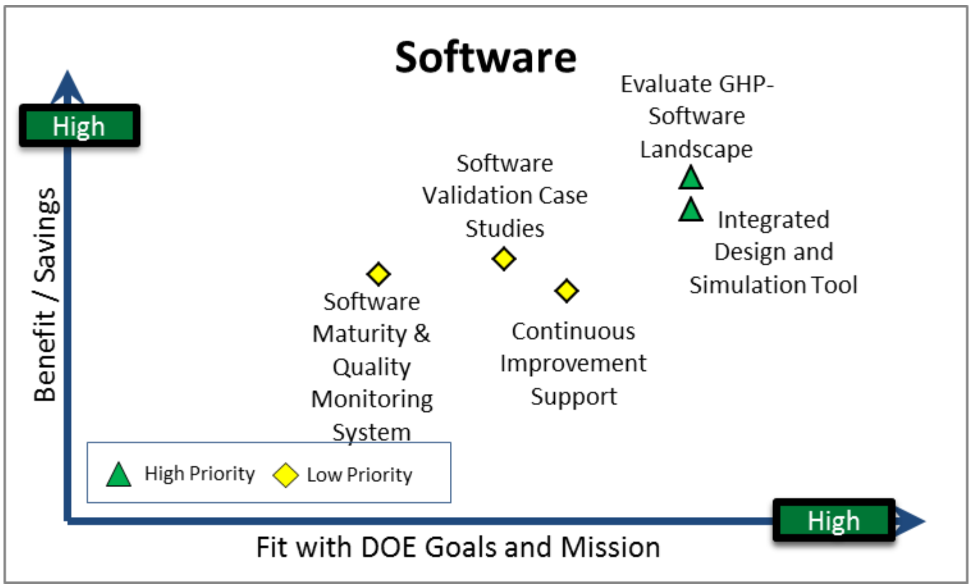

Figure 4-3: Plotted Scores for all Software Initiatives

Table 4-1 lists each individual software initiative and their respective scores.

Table 4-1: GHP Initiatives – Software

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Evaluate and Characterize the GHP Software Landscape	4	4	4	4
Description: Comprehensive evaluation of the software landscape provides a fundamental starting point for any other software initiative. The GHP industry needs to understand better the fragmentation of the software industry and patchwork of existing tools in order to focus R&D efforts and identify core needs. Further, many software R&D initiatives are best addressed by industry and by existing software developers; understanding how and where DOE can make important contributions is fundamental to successful initiatives.				
Develop Integrated Design & Simulation Tool *(High Priority)*	4	4	3	3.8
Description: Simplify the workflow of system designers to enhance design consistency and reduce design time. No currently available tool provides end-to-end design capabilities for a comprehensive and consistent approach. Such a tool could optimize system design and reduce design costs, thereby reducing overall ownership cost				
Support Long-Term Development of Software Tools to Drive Continuous Improvement	3	3	3	3
Description: Software tools require regular updates to stay relevant to the industry. Long-term support of software packages, with regular releases, could enhance accommodation for emerging technologies, thereby enabling accelerated market penetration of best practices and efficient technologies.				
Develop Industry Case Studies on Validation of Existing Software Tools	3	3	3	3
Description: Rigorously vet all GHP software packages prior to commercial use due to the inherent complexity of GHP systems. Validation through case studies and peer review will increase industry confidence and ensure quality for consumers for the life of the ground loop.				
Establish System to Evaluate and Monitor Software Maturity and Maintain Quality Control	3	2	3	2.7
Description: Light competition in GHP software may enable the sale and use of immature or low quality software packages. A system for monitoring maturing and quality in the GHP software industry will minimize changes for poorly designed systems, and enhance industry and consumer confidence.				

4.4 Data Collection

4.4.1 Barriers

Greater data availability could help the GHP industry to improve future designs. With over 100,000 new installations every year, the industry has many opportunities to collect data, but few organizations take advantage of the opportunities.[40] Because GHP technologies have existed for decades, some installations have been functional for many years and could provide useful data for R&D purposes on operating and maintenance costs, energy savings, and long-term ground temperature and environmental impacts (still only loosely understood).

[40] U.S. Energy Information Administration, December 2009, "Renewable and Alternate Fuels data: Geothermal Heat Pumps," Available: http://www.eia.gov/cneaf/solar.renewables/page/heatpumps/heatpumps.html

Despite the large installed base of GHP systems, no organization has undertaken a concerted effort to collect operational characteristics of GHPs over their lifetime to help future designs. Few organizations are independently motivated to do so; designers/installers do not collect data from installed systems because of the cost. The only performance feedback that contractors receive is in the form of customer complaints.

Currently available data are not easily accessible in a centralized fashion for stakeholders like policymakers and sales and marketing groups. Accordingly, the industry has little insight into existing system performance and operating costs. As the industry grows, this lack of monitoring allows inadequately proven products to enter the market, contributing to negative consumer experiences.

Current geological data used for GHP design are outdated and inadequate in many cases. Ground–water-flow characteristics and earth conductivity are vital to the design on GHP systems. Without such data, designers must build in an additional factor of safety into each ground-loop design to ensure proper performance. For large systems, contractors can justify drilling a borehole to perform a conductivity test, but this is not cost effective for small systems. Insufficient geological data therefore adds difficulty to feasibility studies and adds cost to small systems.

Until 2009, the U.S. Energy Information Administration published annual manufacturing data that covered GHP systems. This data helped to monitor the health of the industry at a high level. Stakeholders expressed concern that without such data, it could be difficult for DOE to monitor the impact of GHP R&D initiatives.[41]

4.4.2 Initiatives

Figure 4-4 shows the plotted scores of each initiative.

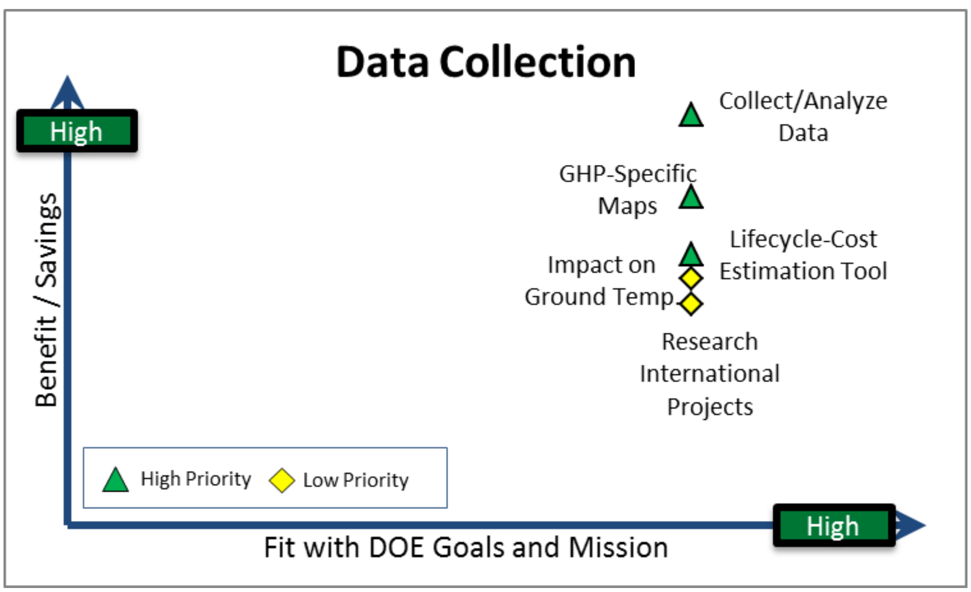

Figure 4-4: Plotted Scores for Data Collection Initiatives

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[41] EIA manufacturing data (through 2009) available at: http://www.eia.gov/renewable/annual/#geohp

Table 4-2 lists each individual Data Collection initiative and their respective scores.

Table 4-2: GHP Initiatives – Data Collection

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Collect and Analyze Data from GHP Systems ***(High Priority)***	5	4	4	4.5
Description: Existing GHP systems are a valuable resource for the GHP industry. Comprehensive performance and cost data collection and analysis of the best and worst practices of existing systems and their historic performance could accelerate design cycles and drive significant gains in efficiency. Further, a central reporting mechanism, much like current, state-organized reporting mechanisms for water-well drillers, could provide a valuable data source for analyses. The first step will be to define clearly the needs of the industry (the 'what' and 'how' of data collection), and how each data set will be used. If planned carefully, this data collection effort can support a variety of analysis activities.				
Evaluate the Feasibility of GHP-Specific Map Development (Collaborate with USGS/GWRP) ***(High Priority)***	4	4	5	4.2
Description: Updated and more detailed geological data may reduce system cost by reducing initial cost estimate variability. Such data also enables analyses of regional differences, and development of regionally optimized architectures. However, map development may not be economically feasible because ground characteristics may vary significantly over small distances, necessitating production of many maps.				
Develop Lifecycle-Cost Estimation Tool ***(High Priority)***	3	4	4	3.5
Description: Contractors and other stakeholders lack a comprehensive GHP lifecycle cost-estimation tool. Such a tool could help explain the ownership costs of GHPs to potential buyers and could provide them with accurate analyses of future cash flows.				
Research the Impacts of GHP Use on Ground Temperature	3	4	4	3.5
Description: The GHP industry has little knowledge of the impacts on local ground temperature because of very limited ground monitoring. Understanding impacts and learning how to minimize large fluctuations are important for maintaining system efficiency and comfort of building occupants and homeowners. Existing research shows that seasonal and even shorter temperature fluctuations may have a greater impact than designers/installers realize.[42]				
Collect Information on other Countries' GHP Installations and Design Approaches	3	4	4	3.5
Description: Western European and select Asian countries are pursuing GHP technology aggressively. This provides a key opportunity for information sharing and learning from what are currently varying approaches to GHP advancement.				

[42] Example research includes CDH Energy research, available at: http://www.cdhenergy.com/ghp/ghp.php

4.5 Best Practices

4.5.1 Barriers

Many stakeholders are concerned about the GHP industry's lack of updated comprehensive design literature. Best-practices resources are fragmented and not easily accessible. Many key design guides and handbooks accordingly lack guidance and best practices on new or emerging methodologies, including, for example, hybrid or alternative architectures for commercial systems. Frequent updates to design guides and handbooks would help accelerate the diffusion of new technologies and methodologies into the field.

The design and certification standard development process that is currently underway (see Section 3.2, above) will improve communication and sharing of best practices, but will not be solely responsible for update of design and best-practices handbooks. Further, without any system in place to capture new, emerging best practices, publications are in danger of becoming rapidly out of date.

4.5.2 Initiatives

Figure 4-5 shows the plotted scores of each initiative.

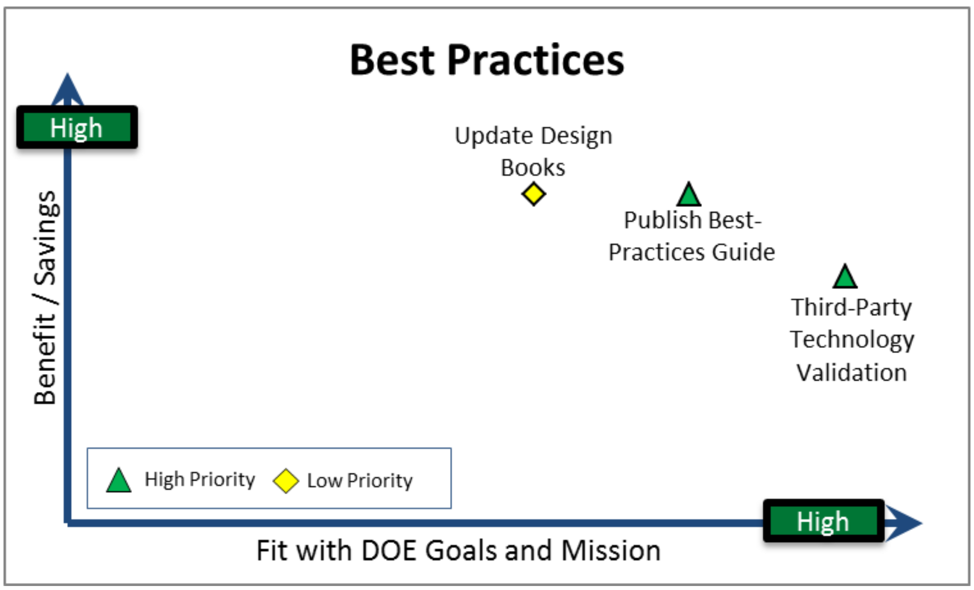

Figure 4-5: Plotted Scores for Best Practices Initiatives

Table 4-3 lists each individual Best Practices initiative and their respective scores.

Table 4-3: GHP Initiatives – Best Practices

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Formalize Process for Third-Party Technology Validation ***(High Priority)***	3	5	5	4
Description: The GHP industry has room for a variety of technological advances. A third-party validation process for new technologies and methodologies may increase customer confidence by helping deter spurious claims and encouraging adoption of proven technologies and best practices.				
Publish Best-Practice Reference Guides ***(High Priority)***	4	4	3	3.8
Description: Shared knowledge of best practices enables industry growth through efficient, optimized installation of GHP systems. Broad sharing of best practices may enable faster penetration of efficient methodologies and technologies, and provide greater confidence in system performance for consumers.				
Update Key Design Books and Include Best Practices/Pitfalls	4	3	2	3.3
Description: Regular updates to key industry design books enables accommodation of emerging ideas and best practices. In a rapidly advancing industry, stagnant information sharing can hinder progress in efficiency and cost reduction.				

4.6 *Education & Training*

4.6.1 Barriers

Industry Professionals

The industry has an unmet need for educating and training GHP professionals. Many HVAC industry professionals never received formal training in GHP design and often lack the skills to optimize system design (beyond basic, functional layouts). Even experienced professionals frequently use software as a 'black box' to guide key decisions and approaches without understanding the pitfalls. Consequences of poor design and installation can snowball in aggregate to produce a negative image among consumers, diminishing the industry's growth potential.

For example, GHP Roadmap Forum attendees voiced concerns over the dangers associated with high heat-transfer rates resulting from poorly designed DX systems. Elevated rapid heat-transfer rates can freeze the ground, potentially killing trees and lawns and even damaging foundations if the ground loop is in close proximity to the building. Such property damage is avoidable through proper design and installation. While DX is a niche product, this exemplifies the need for proper design training.

Multiple organizations have stepped up to provide much needed certification-level courses, but still, few courses exist in academia to help broaden the base of skills and knowledge in the industry. Engaging with student early in their careers not only helps to develop skilled industry leaders for the future, but also serves as a marketing tool for the industry. With early awareness of GHP capabilities and knowledge of design fundamentals, all HVAC professionals will be well versed in GHP and will be more likely to promote it as a viable option.

Beyond the fundamentals required by certification courses, contractors could benefit from specific knowledge about hybrid GHP architectures and other technological advances. For example, few contractors (other than those concentrated around major metropolitan areas) are very experienced with hybrid systems. Such low awareness of any GHP advances means slow market penetration; select firms push the technology within their own markets, but do not benefit from more concerted efforts to share knowledge of the benefits and increase the market penetration.

Consumers

Consumers lack knowledge about GHP applications and overall lifecycle costs/benefits. Unfortunately, the GHP industry has insufficient real-world data available on two of the most vital pieces of information for potential customers: cost and performance (as discussed in section 4.4.1 above).

4.6.2 Initiatives

Figure 4-6 shows the plotted scores of each initiative.

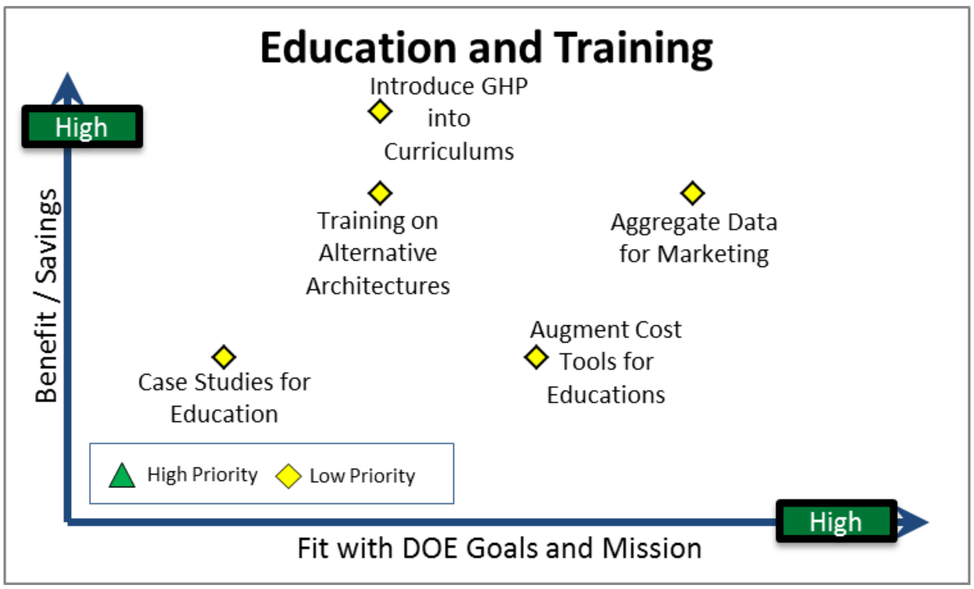

Figure 4-6: Plotted Scores for Education and Training Initiatives

Table 4-4 lists each individual Education and Training initiative and their respective scores.

Table 4-4: GHP Initiatives – Education and Training

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Aggregate Region-Specific Performance Data for Marketing	4	4	3	3.8
Description: Armed with comparable data on GHP performance, installers, contractors and other stakeholders can better market GHP systems. Additionally, such data also facilitate implementation of favorable policies and regulations when shared with policymakers.				

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Introduce GHP System Design Modules into Engineering Curriculums	5	2	3	3.7
Description: Knowledgeable engineering graduates, who have studied approaches and design methodologies for GHP systems, are better prepared for successful careers in the industry and will provide greater visibility to the GHP industry even if they choose alternate careers.				
Train Contractors in Alternative Architectures Including Hybrid & Combination GHPs	4	2	2	3
Description: Expanded training with high-efficiency hybrid and combination GHPs will enable accelerated penetration of the technologies. It is vital that designers/installers learn about such options to identify specific installations that may benefit and offer such lower-cost solutions to customers.				
Augment Lifecycle Cost Estimation Tools for Educational Purposes	2	3	2	2.3
Description: Lifecycle cost-estimation tools help to educate potential consumers about the benefits of GHP systems. Without such tools to inform customers directly about resulting cash flows, customers often view the savings as abstract and highly variable – a major hurdle in selling GHP systems.				
Prepare Software Case Studies (see Software) and Use for Educational Purposes	2	1	2	1.7
Description: *A* software case study is a teaching tool for HVAC engineers that carefully documents the how and why of GHP design through study of a specific "case" or application. Such teaching tools help students to understand the fundamental principles of GHP design. Engineers that do not understand the fundamentals may unknowingly take shortcuts that introduce potential performance problems.				

4.7 Policy & Regulation

4.7.1 Barriers

Our survey of stakeholders identified several policy and regulatory gaps that either add to upfront costs of GHP systems or hinder faster adoption. The key policy issues include exclusion from Renewable Portfolio Standards (RPS), non-uniform permitting, and fragmented drilling-waste disposal regulations.

Increased consistency in permitting and in regulations for drilling-waste disposal will reduce uncertainty around project costs and quotes. Overall, a coordinated approach to policy and regulation that addresses policy gaps and leverages existing state and federal policy will enhance new policy effectiveness.

Stakeholders also voiced concern about the lack of value placed on the durability of ground loops that may function for 50 years or more. A ground-loop investment will provide a steady return for the owner until he or she sells the property. Ownership may change several times during the life of the ground loop and, while some capital investments stimulate appreciation in property values, this is generally not the case for investments in GHP ground loops.

Utility on-bill-financing (OBF) can provide first-cost relief to home or building owners by providing low- or no-interest loans. The loan payment is included on the customers' monthly bill and is no higher than the energy savings that result from the upgrade, so the utility bill is no higher than before the upgrade. When the customer pays off the loan, the customer's bill is permanently lower. Utilities commonly provide OBF for expensive energy efficiency measures such as solar photovoltaics. Most frequently, utilities focus OBF on small-business markets, but the same financial instruments are also appropriate for homeowners. For larger projects, such as community-scale or large commercial projects, utilities are also uniquely positioned to help with financing, but perhaps through alternative mechanisms.

4.7.2 Initiatives

Figure 4-7 shows the plotted scores of each initiative.

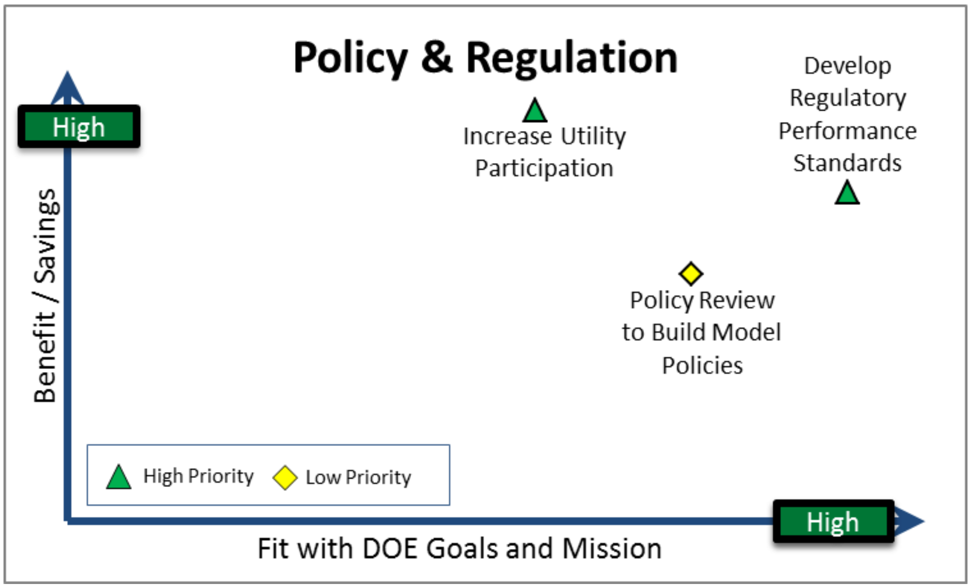

Figure 4-7: Plotted Scores for Policy and Regulation Initiatives

Table 4-5 lists each individual Policy and Regulation initiative and their respective scores.

Table 4-5: GHP Initiatives – Policy and Regulation

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Develop Regulatory Performance Standards (System-Level Performance) ***(High Priority)***	4	5	4	4.3
Description: Performance standards help to uniformly improve overall efficiency, and reduce the frequency with which low-performing technologies enter the market and damage the industry's reputation. For GHP systems, it is particularly important to evaluate options for addressing system performance since current ratings do not properly account for pump energy consumption.[43]				

[43] DOE's decision regarding initiation of performance standards depends on both their regulatory authority as well as the priority of GHP standards relative to other product classes.

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Address Barriers to Greater Utility Participation in GHP Installations ***(High Priority)***	5	3	4	4.2
Description: There was interest by the stakeholders to explore utility and municipal supported GHP solutions. Utilities and municipalities may have the ability to provide substantial support to the GHP industry by lessening the upfront cost burdens on consumers. Working with industry and with public utility commissions to address barriers may provide key opportunities for industry growth outside of traditional market options. Particular areas to evaluate and address could include on-bill financing or other financing mechanisms (such as PACE models), rate structures that recognize the benefits of GHP (and the variable price of a BTU), energy efficiency incentives (both financial and behavioral), and utility or municipal ownership of ground loops.				
Review Policies and Regulations and Guide Best Approach with Model Policies	3	4	4	3.5
Description: A consistent approach to policy and regulation throughout the country may facilitate industry expansion. Inconsistency of federal, state, and local policies related to permitting, incentives, and state/local/utility support, inhibits expansion in many regions. Support for sharing policy best practices through example, model policies, can help enable optimal implementation of consistent policies and regulation.				

4.8 Enabling Technology

4.8.1 Barriers

Advances in GHP technologies can help address high upfront costs and simplify system design. While stakeholders seem to expect that standard market forces will naturally take care of most technology R&D needs, DOE could still help accelerate the time to commercialization.

In particular, advances in the use of innovative architectures have recently received publicity; however, they are not widely known or utilized. For example, the "one-pipe" configuration for large buildings, which utilizes a single pipe for distribution instead of two, provides energy savings when operating at part load, and saves on piping costs.[44] Additionally, advances in innovative heat sinks/sources, such as the use of municipal wastewater infrastructure, can provide cost savings by eliminating a traditional bore-field altogether.

Energy savings could also come in the form of component advances. Many compressors and heat exchangers used in today's GHP systems are not purpose-built for GHP. To-date, the rate of GHP sales has not been sufficient for compressor manufacturers to build specific units that they optimize for GHP operating conditions. Use of optimized components could provide additional energy savings without any impact on other parts of the industry and no need for educating customers or GHP professionals.

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[44] Kirk Mescher, P.E., "One-Pipe Geothermal Design: Simplified GCHP System," October 2009, ASHRAE Journal pp24-40. Available at: http://www.dist228.org/parent_student/geothermal.pdf

While many of the barriers expressed by stakeholders focused on low-risk R&D activities, DOE has historically pursued long-term, higher-risk technology R&D. Two key areas where DOE may be able to contribute include: 1. radically new and different approaches for transferring heat from the ground to indoor space using different heat transfer mechanisms and configurations, and 2. similarly new approaches for drilling and installation of ground loops.

Component-level R&D can be very valuable for conventional air conditioners and ASHP technology as well as GHPs. If multiple system types can leverage GHP R&D initiatives, the impacted market share, and therefore the total energy savings, will be much greater. Specific areas of such component R&D in which DOE may investigate include:

- Advanced control systems
- New compressor architectures
- Advanced heat exchangers to improve air-side and refrigerant-side heat transfer
- Low-loss thermal distribution systems
- Integrated hot water heating
- Low-GWP working fluids such as CO_2, or other natural refrigerants

4.8.2 Initiatives

Figure 4-8 shows the plotted scores of each initiative.

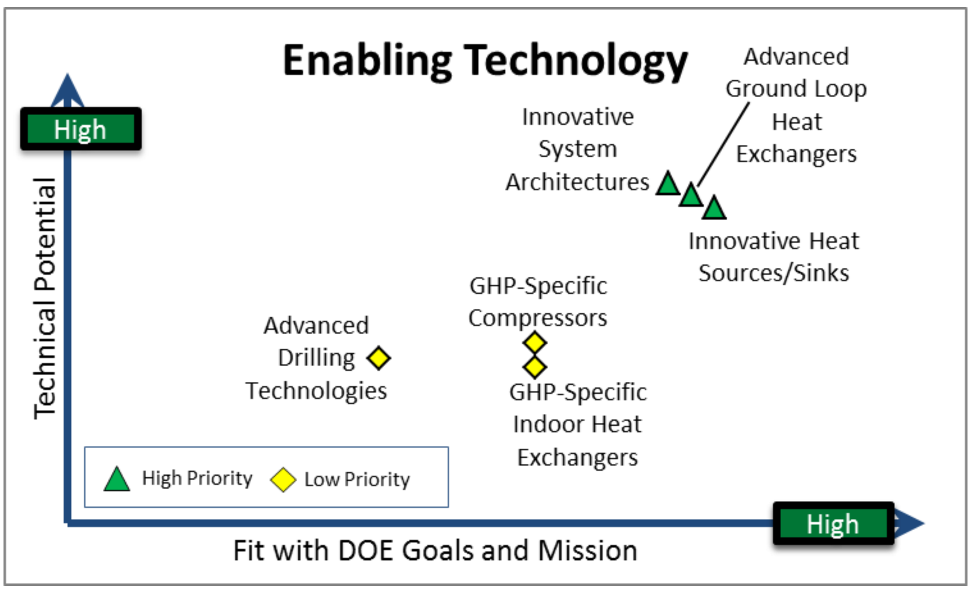

Figure 4-8: Plotted Scores for Enabling Technology Initiatives

Table 4-6 lists each individual Technology initiative and their respective scores.

Table 4-6: GHP Initiatives – Enabling Technologies

Activity	Benefit	DOE Fit	Criticality of DOE Involvement	Weighted Score
Innovative System Architectures ***(High Priority)***	4	4	3	3.8
Description: Innovative system architectures, particularly for commercial and institutional installations may provide significant energy and cost savings. It is important to understand the trade-offs in specific applications of various architectures. Sharing the results of performance evaluations on such innovations will drive down costs and improve efficiency. Specific focus areas include distributed versus centralized systems, central systems with a single distribution pipe instead of supply and return pipes, district- or community-scale systems, and seasonal energy storage in the ground.				
Innovative Heat Sources and Sinks ***(High Priority)***	4	4	3	3.8
Description: Creative use of heat sinks and sources, such as wastewater, ponds, standing column wells, etc., may dramatically reduce installation costs. Several companies have recently made significant progress in using municipal sewage systems as heat sources or sinks. Developing detailed understanding of the benefits and costs of such systems is important in order to enable assessment and replication of these approaches.				
Advanced Ground-Loop Heat Exchangers and Configurations ***(High Priority)***	4	4	3	3.8
Description: Advanced ground-loop configurations may provide first-cost relief to consumers and enable greater penetrations of GHPs. Key features include reduced installation time and complexity, and increased repeatability in performance among similar size installations to reduce individual engineering costs.				
GHP-Specific Indoor Heat Exchangers	2	3	1	2.1
Description: Heat-exchanger optimization will boost system efficiency. Typical GHP heat exchangers that transfer heat between the ground loop and the vapor-compression loop are not purpose built. Design research could help balance cost and performance to produce an optimized product.				
GHP-Specific Compressors	2	3	1	2.1
Description: Manufacturers can improve system efficiencies by using purpose-built compressors that operate in GHP-specific operating conditions. Current low-cost compressor options are all best-fit options, selected from compressors designed for other HVAC applications.				
Advanced Drilling Technologies	2	2	2	2
Description: Drilling costs typically exceed all other component or installation costs; research and evaluation of emerging and/or optimized drilling technologies will likely reduce first costs to consumers.				

5 Conclusions

Through stakeholder discussions and literature review, 27 initiatives were identified. Throughout the roadmap process, stakeholders consistently placed greater emphasis on system design, policy, and awareness topics than on traditional component R&D activities. Accordingly, only six of the 27 initiatives are technology-based. However, we identified many valuable, non-technology-based initiatives with which DOE can assist that industry stakeholders may not address themselves.

Using a prioritization process, we identified twelve high-priority initiatives across five different categories (the sixth category, Education, did not produce any high priority initiatives). The following list summarizes the themes in each category and lists the high-priority initiatives:

Software – Broad evaluation is necessary – though many solutions are currently available, most only address individual issues, and few are sufficiently comprehensive

High Priority Initiatives:

- Develop Integrated Design and Simulation Tool
- Evaluate and Characterize the GHP-Software Landscape

Best Practices – Insufficient knowledge sharing exists among industry members, inhibiting penetration of best practices

High Priority Initiatives:

- Publish Best-Practices Reference Guides
- Formalize Process for Third-Party Technology Validation

Technologies – Focus on system-level technologies and approaches instead of components is most valuable for DOE R&D

High Priority Initiatives:

- Innovative System Architectures
- Innovative Heat Sources and Sinks
- Advanced Ground-Loop Heat Exchangers and Configurations

Data Collection – Broad data collection and analysis can serve as a base for many initiatives

High Priority Initiatives:

- Collect and Analyze Data from GHP Systems
- Evaluate the Feasibility of GHP-Specific Map Development
- Develop a Comprehensive Lifecycle Cost and Estimation Tool

Policy and Regulations – Policies vary regionally and broad utility support is lacking

High Priority Initiatives:

- Develop Regulatory Performance Standards (System-Level Performance)
- Address Barriers to Greater Utility Participation in GHP Installations

Selection of individual initiatives within this roadmap will depend primarily on availability of DOE funding and quality of proposals received. Pursuit of these initiatives may help drive industry expansion and help achieve DOE goals of developing and deploying energy efficient building technologies.

Appendix A Roadmap Stakeholder Forum Summary Report

October 12, 2011

United States Department of Energy (DOE) Research and Development Roadmap
Forum Summary – IGSHPA Conference

A.1 Summary

On October 5, 2011, Navigant Consulting, Inc., (Navigant) on behalf of the U.S. Department of Energy (DOE) Building Technologies Program, hosted a stakeholder forum to identify research, development, and demonstration (RD&D) priorities as part of the development of DOE's Geothermal Heat Pump (GHP) R&D Roadmap. DOE's Building Technologies Program, under which DOE manages GHP activities, aims to "develop technologies, techniques, and tools for making buildings more energy efficient, productive, and affordable."[45] By supporting R&D activities for GHP technology, DOE hopes to reduce barriers to market penetration of GHP technology.

Navigant held the forum in Tulsa, Oklahoma, in conjunction with the International Ground Source Heat Pump Association (IGSHPA) Technical Conference. Twenty-nine participants attended the workshop, including equipment manufacturers, engineering firms, installers, DOE laboratories, and other research institutions. A list of attendees and their affiliations is included in the Addendum after section A.5.

A.2 Objective

The objective of this forum was to engage participants in a discussion of the key R&D priorities that will reduce barriers to greater market penetration of GHP systems. The output was a prioritized list of R&D activities that may be appropriate for DOE to support, and which industry stakeholders believe will aid the industry in reducing barriers to greater adoption of this highly efficient technology.

A.3 Market Context

Since 2005, GHP annual shipments more than doubled to almost 100k units/yr.[46] However, this is only 2% of the unitary air conditioner and air-source heat pump market (5.1MM/yr), indicating huge potential for growth and consequent energy savings if market barriers can be reduced. [47]

The greatest barrier to greater penetration is the high installed cost of the ground loop, a component that is unnecessary for competing technologies such as air-source heat pumps (ASHPs). For high-efficiency GHP systems, the total lifetime costs can often be lower than for ASHPs. However, especially in the current market environment, many consumers are not willing or able to surmount the high GHP first costs to achieve the long term financial and comfort benefits.

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[45] Building Technologies Program homepage at http://www1.eere.energy.gov/buildings/
[46] Shipment data from WaterFurnace: http://www.waterfurnace.com/downloads/Shareholders2010.pps
[47] 2010 Building Energy Data Book, Section 5.3.1: buildingsdatabook.eren.doe.gov/TableView.aspx?table=5.3.1

A.4 Results

Navigant organized the discussion at the forum around four RD&D categories:

- Ground loops
- Component and other technologies
- System design and analysis tools
- Hybrid/combination systems

The discussion generated 20 topics for DOE to focus on in future R&D. A majority of the discussion focused on the first two categories, and correspondingly, 70% of the topics stem from these categories. However, this may not be a realistic indicator of the relative importance of the categories, since time was slightly constrained at the end of the session.

In order to understand how forum participants prioritized the topics, Navigant asked each individual to vote on their top three recommended topics to pursue (i.e., three votes per person) across all four categories. Tables A-1 through A-4 list the topics and corresponding votes.

Table A-1: Ground Loop Discussion Topics by Priority Votes

Category	Topic	Votes
Ground Loop	Ground loop designs*	11
	Measured data on long-term ground temperature rise especially for large commercial	9
	Geological data for ground loop design, including central reporting systems and integration of data	7
	Research and monitoring of advanced horizontal HX designs	5
	Enhanced surfaces on ground loop HX High Density Polyethylene	1
	Loop Materials	1
	Reduced borehole resistance HX	0

*Topic is combined with "Piping Shape/Structure" – Deemed to be sufficiently identical – did not add additional votes

Table A-2: Component Technologies and Processes Discussion Topics by Priority Votes

Category	Topic	Votes
Component Technologies and Processes	Total cost evaluation to guide R&D, including all lifecycle cost elements	17
	Comprehensive data collection on installation best practices and performances (e.g., Department of Defense)	8
	Compressors optimized for GHP systems	5
	Working Fluids (i.e., refrigerant)	0
	Drilling Fluids management, i.e., environmental impact and variability of regulations and knowledge	0
	Advanced drilling techniques for reducing costs*	0

*Topic is combined with "Drilling Processes" – Deemed to be sufficiently identical.

Table A-3: Systems Design and Analysis Tools Discussion Topics by Priority Votes

Category	Topic	Votes
Systems Design and Analysis Tools	Improved tools for complete system design (including all indoor and outdoor components)	8
	Hybrid GHP control algorithm improvements	1
	Optimized trenching analysis tools	1
	Optimized bore field analysis tools	0

Table A-4: Hybrid and Combination GHP Discussion Topics by Priority Votes

Category	Topic	Votes
Hybrid and Combination GHP	General R&D	1
	Best Practice guidelines	2

A.5 Next Steps

This summary report is the first step in developing the DOE R&D Roadmap. In consultation with DOE's Building Technologies Program, Navigant Consulting will next undertake a process of researching and prioritizing the ideas generated during the forum, as well as considering additional topics, through follow up with individual stakeholders and industry experts. The prioritization will consider:

- Preferences, determined by votes, of the forum participants;
- Appropriateness of DOE participation;
- DOE resources;
- Potential impact of DOE involvement; and
- Follow up research with industry stakeholders.

It should be noted that the final vote tallies noted in Tables 2-5 are one element that DOE will consider in making decisions regarding which topics to support, but they are not the sole criteria. Issues related to appropriateness of government support, fit with overall DOE BT priorities, and likelihood of technical and market success must be considered.

Review by stakeholders will be solicited prior to finalizing the Roadmap. The roadmap will serve as a guide for DOE and its partners in advancing the goal of reducing building energy consumption, while maintaining the competitiveness of American industry.

Finally, Navigant and DOE wish to thank all the participants in this workshop. The suggestions, insights, and feedback provided during the forum are critically important for developing a useful GHP Roadmap.

Addendum: Forum Attendees

The R&D roadmap forum brought together 29 individuals representing 26 different organizations across the industry. Table A-5 lists all the attendees and their affiliations.

Table A-5: Attendee List

First Name	Last Name	Affiliation
Manufacturers		
Shawn	Hern	ClimateMaster
Ellisa	Lim	ClimateMaster
Wes	Wostal	ClimateMaster
Mike	Kapps	WaterFurnace International, Inc.
Tom	Huntington	WaterFurnace International, Inc.
Brian	Key	McQuay International
Kelvin	Self	The Charles Machine Works, Inc.
Al	Fullerton	Trane
Remo	Eyal	TEVA Energy
Utilities		
David	Dinse	TVA
Agatha	Vaaler	Avant Energy/ Minnesota Municipal Power Agency
Design Consultants and Contractors		
Lisa	Meline	Meline Engineering
Jim	Cusack	UMR Geothermal
Eric	Baller	Energy Wise
Kevin	Bouchey	Strategic Energy Solutions
Richard	Soyka	Strategic Energy Solutions
Mike	Keeven	Keeven Heating and Cooling
John	Henrich	Bergerson Caswell
David	Dixon	Hill Country Ecopower
Adam	Hawks	Energy 1
Selene	Bienvenido	Blue Energy Intelligent Services
Israel	Gonzalez	Blue Energy Intelligent Services
Abram	Glas	Green Sleeves LLC
Jimmy	Gaffney	Earth Tech
Research Institutions and Other		
Robert	Young	Autry Tech Center
Patrick	Hughes	ORNL
Chris	Welton	UCLA
Jeff	Spitler	OSU
Steve	Yadon	Mid-America Technology Center
Liz	Battocletti	Bob Lawrence & Associates

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