GeoExchange Systems (Ground Source Heat Pumps)

GeoExchange Ground Source Heating and Cooling:
A geoexchange ground source system is an electrically powered heating and cooling system for interior spaces. This system utilizes the earth or a pond or lake for both a heat source and a heat sink. A geoexchange system consists of three main parts: pipes buried in the ground, a heat exchanger and ductwork to distribute heat into the structure. The series of pipes, called a loop, is buried in the ground, either vertically or horizontally, near or beneath the structure. The loop circulates a fluid (water, or a mixture of water and antifreeze) that absorbs heat from, or relinquishes heat to, the surrounding soil, depending on whether the building requires heating or cooling. Components of this system include a heat pump, a hydronic pump, a ground heat exchanger, and a distribution subsystem. Most geoexchange systems utilize air ducting for the distribution system and polyethylene piping in the earth for the heat exchanger.

How GeoExchange Works:
The ambient temperatures above ground change from day to day and season to season. However, depending on latitude, the temperature beneath the upper 6 meters (20 ft.) of the Earth's surface remains nearly constant between 10 and 16 °C (50 and 60 °F) if it is undisturbed by the presence of a heat pump. A Ground Source Heat Pump (GSHP) is a type of central heating and/or cooling system that transfers heat to or from the ground. It uses the earth as a heat source (in the winter) or a heat sink (in the summer). Like a refrigerator or air conditioner, these systems use a heat pump to force the transfer of heat from the ground. Heat pumps can transfer heat from a cool space to a warm space, against the natural direction of flow, or they can enhance the natural flow of heat from a warm area to a cool one. This is much more energy-efficient because underground temperatures are more stable than air temperatures through the year. Seasonal variations, drop off with depth and disappear below 7 meters (23 ft) to 12 meters (39 ft) due to thermal inertia. Geothermal pump systems reach fairly high Coefficient of Performance (CoP), 3 to 6, on the coldest of winter nights, compared to 1.75 - 2.5 for air-source heat pumps on cool days.[1] GSHPs are among the most energy efficient technologies for providing HVAC and water heating.

GSHP Cost and Deployment:
Initial installation costs for a GSHP are higher than for conventional HVAC systems, but the difference is usually returned in energy savings in 3 to 10 years, and even shorter lengths of time when federal, state and utility tax credits and incentives are applied. While equipment costs are competitive, installation costs vary significantly. The cost of the loop proves to be the most expensive component of the system. However, because the ground infrastructure is typically warrantied for 50 years, the assumption here is that the cost of installing a ground source heat pump is only slightly higher than the cost of conventional equipment. When the life cycle and replacement cost of conventional equipment are taken into consideration, compared to the warranted time frame the GSHP, the up-front added cost of the ground loop is offset over time. Cost is factored by including avoided boiler capital, operational, and maintenance costs.

In other applications, such as at campus locations, institutions, industrial parks and housing sub-divisions, geoexchange can be more cost effective because a single loop can be used to provide for multiple units, thereby lowering the installation cost of the loop. In the case of housing subdivisions a single loop can be used to accommodate multiple homes. In this way the cost of the loop can be split among the involved homeowners thereby lowering the cost. When it comes to residential heating and cooling loads, the trend is toward smaller loads (due to improved building envelopes with reduced air leakage, thicker insulation, and better windows), rather than larger loads. A new home with a good thermal envelope doesn't need much heating or cooling.

GeoExchange heat pump systems are reasonably warrantied by manufacturers, and their working life is estimated at 25 years for inside components and 50+ years for the ground loop. As of 2010, approximately 1.5 million GSHP units have

[1] Colorado Renewable Energy Society (2011). Geothermal Energy

been installed in the United States, accounting for approximately 337,000 tons of heating and cooling capacity.[2] Pennsylvania has installed approximately 21,350 tons of geothermal heating/cooling capacity.[2]

Summary:
This work plan strategy capitalizes on the energy-effectiveness of GSHPs in Pennsylvania's climate, and the accompanying reductions in carbon emissions and in demand for peak generation and transmission. The environmental impact of geoexchange energy depends on how it is used or on how it is converted to useful energy. GSHPs have almost no negative impact on the environment. GeoExchange heat pumps can actually have a positive effect because they may reduce or avoid the use of other types of energy that may have greater negative impacts on the environment.

Pennsylvania is already ranked as one of the top-tier states for experienced and competitive installation of GSHPs in its urban centers. This strategy would build on that strength, expanding the network of trained drillers and installers throughout the state. This strategy advocates GSHP installations for individual buildings and in district systems.

Additional benefits of GSHPs include:

- Levels seasonal electrical demand and 42 percent - 48 percent reduced demand for new capacity.[3]
- Widely applicable.
- Economical operating costs due to high coefficient of performance (metered Department of Defense installations in Pennsylvania achieve mean Coefficient of Performance of 4.0 [4] and energy efficiency ratio of 20.83) [5]
- Water heating integrated at low cost (waste heat can be scavenged whenever compressors are running).
- Excellent part-load performance.
- Maintenance simpler and less costly than conventional fossil fuel heating and cooling tower systems.
- Reduces the use of fossil fuels as heating fuel.
- Reduction in peak demand reduces the need for new power plants and carbon emissions are reduced.

The calculations here are based on GSHP installations for individual buildings. District systems can offer economies of scale in the exterior infrastructure, but data on this are limited. Table 1 shows the estimated GHG reductions and cost effectiveness projected for new installations in Pennsylvania.

Table 1. Estimated GHG Reductions and Cost-effectiveness

Annual Results (2030)			Cumulative Results (2015-2030)		
GHG Reductions ($MMtCO_2e$)	Costs (Million $)	Cost-Effectiveness ($/$tCO_2e$)	GHG Reductions ($MMtCO_2e$)	Costs (NPV, Million $)	Cost-Effectiveness ($/$tCO_2e$)
3.65	-$1283	-$367	35.1	-$7172	-$204.33

[2] Oak Ridge National Laboratory (US), Tianjin University (China), Chongqing University (China) (2010), A Comparative Study of the Status of GSHP Application in the US and China.
[3] Hughes, Patrick (2008). Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers. Oak Ridge National Laboratory. www1.eere.energy.gov/geothermal/pdfs/ornl_ghp_study.pdf
[4] The coefficient of performance (COP) of a heat pump is a ratio of heating or cooling provided to electrical energy consumed. Higher COPs equate to lower operating costs. COP is highly dependent on operating conditions, especially absolute temperature and relative temperature between sink and system.
[5] The Energy Efficiency Ratio (EER) of a particular cooling device is the ratio of *output* cooling energy (in BTU) to *input* electrical energy (in Wh) at a given operating point. EER is generally calculated using a 95 °F outside temp and an inside (actually return air) temp of 80 °F and 50% relative humidity.

Table 1- Residential emissions reductions and costs are calculated using 20 percent of new and 2 percent of existing dwelling GSHP installations for heating and cooling by 2030 scenario. Commercial reductions and costs are calculated using 12.5 percent of existing and 40 percent of new commercial building GSHP installations for heating and cooling by 2030 scenario.

Key Assumptions:

Key Data and Assumptions	2015	2030	Units
First Year Results Accrue		**2015**	
Electricity			
Incremental Cost of a GeoExchange GSHP system			
Residential, household with/without central cooling		**$3,000**	$/housing unit
Cost of Geothermal system[6]			
Commercial, existing buildings		**$14.4**	$/sq ft
Commercial, new buildings		**$12.5**	$/sq ft
Cost of NG+AC VAV system (base case system)[7]			
Commercial, existing buildings		**$14.4**	$/sq ft
Commercial, new buildings		**$12.5**	$/sq ft
Avoided Electricity Cost		**$134**	$/MWh
Avoided Natural Gas Cost		**$6.7**	$ / million Btu
Avoided Fuel Oil Cost	**$24.8**	**$29.7**	$ / million Btu
Emissions from additional Electricity Use		**0.85**	tCO_2/MWh

Results Summary	2015	2030	Units
Incremental GHG Emission Savings	**0.87**	**3.65**	MMtCO2e
Net Present Value		**-$7,172**	$ million
Cumulative Emissions Reductions		**35.1**	MMtCO2e
Cost-Effectiveness		**-$204.33**	$/tCO2e
Cost 2030		**-$1283**	$ million
Cost-Effectiveness 2030		**-$367**	$/tCO2e

[6]Hughes, Patrick (2008). Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers. Oak Ridge National Laboratory. www1.eere.energy.gov/geothermal/pdfs/ornl_ghp_study.pdf
[7]Meline Engineering (2009), Installed Costs (US Estimated Range 2009)

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Other Data, Assumptions, Calculations	2015	2030/all	Units
Inputs to/Intermediate Results of Calculation of Electricity and Gas Savings			
Total Commercial Floorspace in Pennsylvania	**5,336**	**6,139**	million sq ft
Annual demolition of commercial floorspace		**0.58%**	
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Est. area of new commercial space per year in PA	**85.2**	**89.8**	million sq ft
Total Residential Housing Units in Pennsylvania	**5,666,055**	**5,577,335**	units
Implied persons per housing units in Pennsylvania (for reference only)	**2.26**	**2.26**	persons
Annual demolition of residential floorspace		**1.43%**	
Estimated number of new residential units per year *Calculated based on estimates above.*	**88,286**	**90,020**	units
Average Electricity Consumption per Square Foot Commercial Space (2003)		**12.50**	kWh/sq.ft.
Average Natural Gas Consumption per Square Foot Commercial Space (2003)		**43.80**	thousand Btu / sq.ft.
Average Fuel Oil Consumption per Square Foot Commercial Space (2003)		**23.97**	thousand Btu / sq.ft.
Average Electricity Consumption per Housing Unit (2005)		**8.50**	MWh
Average Natural Gas Consumption per Housing Unit		**82**	million Btu / household
Average Fuel Oil Consumption per Housing Unit		**106**	million Btu / household
Cofficient of Performance (COP) - Residential and Commercial		**3.7**	
Energy savings due to ground source heatpumps			
Residential		**45%**	
Commercial[8]		**30%**	

<u>Implementation Steps</u>:

[8] Calculations and assumptions provided in this table can be found in the RCI Quantifications Work Book. Data was contributed by multiple sources including: *G. Mattern, P.E., Adjunct Professor & geothermal specialist, Carnegie Mellon Univ., Input from V. Loftness & N. Baird, CBECS Tables. RECS Table US14 EIA calculated estimate for AC assumes electricity*.

1. Encourage the Department of General Services (DGS) to do comprehensive life-cycle cost analysis for new buildings and building upgrades and advocate/support use of life-cycle cost analysis for all new and retrofit projects in the public and private sectors.
2. Outreach Training. Educate designers/contractors/consumers about geothermal heat pump efficiency ratings, COP/EER, and highlight currently achievable efficiencies in PA climate. Provide information on current Federal and State policies and programs that can provide grants and loans for geothermal installation. Establish a mechanism for verifying the competence of drillers and external loop/well installers, and require that only state-approved drillers/installers are used (Oregon has such a policy).
3. Establish or encourage policies that will give Electric Distribution Companies (EDC) an incentive to install the external loop infrastructure and lease them on per-ton basis such as allowing aggregated savings from GSHPs to be a proxy for carbon trading credits. With this strategy, utilities will lose energy sales revenue, but will recoup some of it on loop leases and rate-based infrastructure. They'll also lose money on demand charges, but can earn credit under the Alternative Energy Portfolio Standard. Consumers get some efficiency benefits.
4. Encourage Congress to extend the Federal Energy Efficiency Tax Credits beyond 2016.
5. Establish State-funded programs that offer tax breaks to companies who install geothermal heating at new construction and renovated commercial buildings.
6. Encourage State Agencies such as DEP and the Commonwealth Financing Authority to continue offering energy efficiency grants and loans.
7. Research the current geothermal resource availability and identify possible stakeholders. This will provide insight into the amount of geothermal opportunity in a particular area allowing for the design of policy that is feasible and will also address any strengths and weaknesses for geothermal deployment.
8. Provide incentives to land developers to install community loops and provide geoexchange heating and cooling options to potential home buyers in subdivisions.

Assumptions:

Related to implementation step #3 above and to the extent that it is allowed, EDCs can and/or should be eligible to receive Tier II AEPS credits from the energy savings associated with the operation of GSHPs. The same should also be true for compliance with Act 129.