Geothermal Energy Potential in Tompkins County

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Executive Summary

The purpose of this report is to the give the reader a sense of the potential of geothermal energy in Tompkins county, and the role it can play in the county's 2020 energy strategy, putting the community on track to reduce greenhouse gas emissions by 80% by the year 2050. This report is part of the Tompkins's County Energy Road Map, which highlights the roles of multiple alternative energy solutions in achieving said goal. This report focuses on the potential of geothermal heat pumps to provide heating and cooling, rather than the use of deep wells for direct heating or large-scale geothermal electrical generation.

The potential of geothermal energy is unique to that of most other renewable and nonrenewable energies in that the limiting factor of geothermal is often not the resource itself, but the ability take advantage, extract, and utilize this wealth of thermal energy which is stored in the earth's crust into usable, cost effective energy. Another advantage of geothermal energy is that it can be supplied continuously, unlike wind or solar energy, which are inherently interruptible and can only support other energy sources, or rely on the devolving technologies of energy storage.

This report focuses on the potential of geothermal, ground source heat pumps (GSHP) and for a range of technical and economic assumptions calculates the total savings, in fossil fuel energy use and greenhouse gas emissions, possible if heating in the residential, commercial, and industrial sectors were switched to GSHP. The cooling demand for our region is much smaller compared to the heating demand, ~4%, so the report is focused on GSHPs used primarily as a heating source. Meeting the cooling demand in NY using GSHPs turns out to be very efficient and significant, improving the cost effectiveness of individual systems. It was found that in the extreme case of complete adoption of geothermal heat pumps for all of the county's heating and cooling needs, energy costs for heating from fossil fuels could be reduced by 30% and greenhouse gases from heating cut down by 73%. (Table 1 and Table 2)

% Reduction of fuel cost	Residential	Commercial	Industrial	Total
Fuel Oil	84%	84%	84%	84%
Natural Gas	13%	10%	27%	13%
Propane	86%	86%	86%	86%
Electric	73%	73%	73%	73%
Total Avg.	38%	18%	42%	30%

Table 1. Percent savings provided by a GSHP by sector when compared to current heating fuels or sources. Calculated using pricing information from (EIA 2013) and average efficiencies by source from (EPA 2013)

% GHG Reduction	All
Fuel Oil	93%
Natural Gas	70%
Propane	87%
Electric	73%
Total Avg.	73%

Table 2. GHG emission reductions available by switching to GSHP over conventional heating systems. Calculated using average fuel GHG intensities and electrical generation GHG intensity from the upstate NY region. (EPA 2013)

These figures show the possibilities of a substantial drop in fossil fuel heating demand and greenhouse gas emissions due to the high efficiency provided by geothermal heat pumps. In addition, the required electrical power needed to run GSHPs has a relatively low emission intensity in the upstate New York region versus other regions of the U.S.

These data in tables 1 and 2, which are based on average performance, illustrate the approximate potential of the effect of heat pump deployment. Due to the variability in efficiencies of currently installed systems and the variability of different models and forms of heat pumps available to the consumer. Projected averages were used in the calculation of these values. Differences will be looked into in a later section. The major setbacks in achieving the potentials shown are the high capital costs inherent to a heat pump system. A cost analysis was completed on the average case in the average Tompkins County household (~71 MMbtu/year heating demand) to determine in which cases it was cost effective to install a GSHP system, either to replace a current system or in a new building project. Results of the analysis are presented in table 3.

Current Heating Solution	Yearly Savings (per year)	Simple Payout (years)
Fuel Oil	$1,860	13
Natural Gas	$100	242
Propane	$1,960	12
Electricity	$1,900	13

Table 3. Yearly savings and simple payout for the average residential house replacing its current heating solution with a GSHP. Data from tables 1 and 2 and therefore data from (EPA 2013) and (EIA 2013) where used in the calculations. Current natural gas prices where used and assumed to stay constant.

Unfortunately, with an average useful lifetime of 25 years, it does not seem that heat pumps cost effectively replace the average natural gas systems due to the current cheap abundance of natural gas (with current prices around $11.20/MMbtu), and its relatively high efficiency and low emission intensity. But with the ever-changing unpredictable nature of natural gas costs, this result has the chance of changing in the future. A break even of price of natural gas for when the net present worth of the investment is zero and a the simple payout is 17 years would be $28.50/MMbtu, more than double the current price. These calculations take into account federal and state renewable energy incentives for the construction of the GSHP unit, but to do not take into account any future carbon tax or taxes based on greenhouse emissions. Another value to note is that while GSHPs do not provide much cost incentive over natural gas at today's gas prices , they do provide greenhouse gas emissions savings, with the unfavorable average cost of $2.27 per kg CO_2-e. Undoubtedly the price of natural gas will escalate significantly in the next decade or two, making the making using GSHPs more competitive with other greenhouse gas emission reduction methods.

When determining the potential of using shallow geothermal energy in Tompkins County, certain assumptions were made, including the fraction of buildings that could be served by GSHPs, which would be proportional to the fraction of heating and cooling demand that can be supplied by GSHP systems. These decisions primarily came from an economic evaluation and were affected by factors such as whether or not buildings had access to natural gas or if the building has higher cooling demand, increasing the cost effectiveness of the GSHP.

Geothermal Resource Assessment

Geothermal resources are one of the few resources that do not directly, or indirectly, rely on the immense power of the sun. Solar photovoltaic cells and solar thermal panels focus solar radiation to capture usable energy, the energy obtained from all forms of wind energy are solar derived and from biomass, which depends on photosynthesis driven again by solar energy. On a geologic time scale of millions of years, the same thing can be said of fossil fuels. While the solar flux makes up 99.97% of all of earth's incoming energy, much of it is reflected while travelling through the atmosphere and the rest of it is absorbed by the land, water, and atmosphere, only to given off to space once again. A small, almost insignificant, amount of this solar energy is what is utilized by plants and finally consumed by animals and humans creating much of our total energy demand.

The majority of the remaining 0.03% of earth's energy flux is attributed to geothermal energy flowing from the Earth's core. And the remarkable fact is that this fraction of a percent of total energy could power the entire world twice over. Unfortunately, practically all of this energy is unrecoverable. Much like a nuclear reactor, this energy is created about 80% from the radioactive decay of minerals spurred on by the extremely high temperatures and pressures of the core, and 20% by residual heat from planetary rotation acceleration. The convective currents of the planet's mantle then distribute this heat to the earth's surface.

This heat is not evenly distributed, with a majority of the heat remaining nearer to the core of the earth and less near the surface. There is a heat gradient throughout the volume of the planet, simply called the geothermal gradient. This gradient is roughly 1° F in the earth's mantel. On the crust, this gradient is much different due to its insolation properties. This heat gradient ultimately acts as the driving force of the heat flow from near the core to the surface. From the heat flow equation, one can derive,

$$Q_i = \rho C_p V_i[\Delta T]$$

where Q is the heat flow outwards from the core and delta T is the heat gradient.

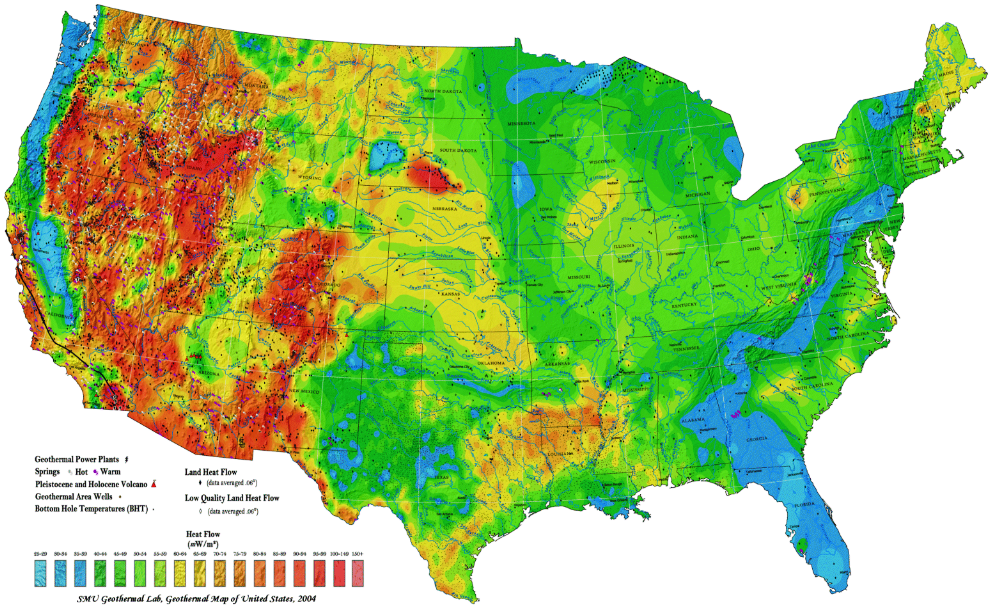

Figure 1. Heat gradients near the earth's surface where red is the highest temperature increase per unit depth, and blue is the lowest temperature increase per unit depth. (Blackwell and Richards 2011)

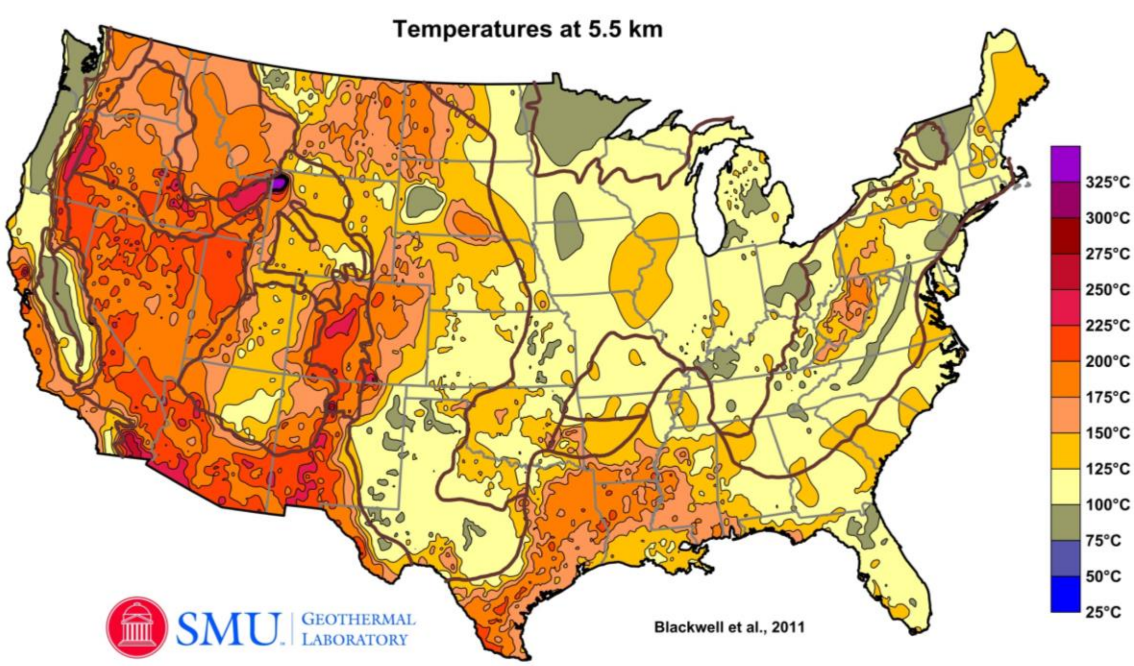

Figure 2. Temperature at a depth of 5.5 km (Blackwell and Richards 2011) Note the high temperature compared to the surrounding area were Tompkins County is located.

With this paper's focus on the potential of shallow ground source, geothermal heat pumps, all this information might seem irrelevant. This is far from the truth because in understanding the performance of GSHPs, it is important to know the source of the energy.

There is a common misconception (that is actually quite surprising considering the amount of material that references it as such) that heat pumps are powered by taking advantage of the soil absorbing solar energy as heat. It is actually quite the opposite, particularly for vertical well systems that penetrate into the ground to depth of 100 to 400 feet (30 to 120 m). These well depths are considerably greater than the maximum thermal penetration depth of 5 m or less for absorbed solar energy as shown in Figure 3. The shallower, trenched systems may appear to be affected by the solar flux penetration but over the course of the year, as much solar heat is lost as is gained. On average, GSHPs utilize thermal energy in the ground when there is a demand for heating by capturing a portion of the stored thermal energy that is conducted through the upper crust of the earth flowing to the surface. They also store energy in the ground during summer months, keeping the temperature a couple meters below the surface relatively stable, despite any fluctuations caused by solar heat absorption or losses or gains caused by differences between the ground temperature and that of the atmosphere. This allows the GSHP to use the subsurface of the earth as a reliable heat source or sink regardless of the outdoor conditions.

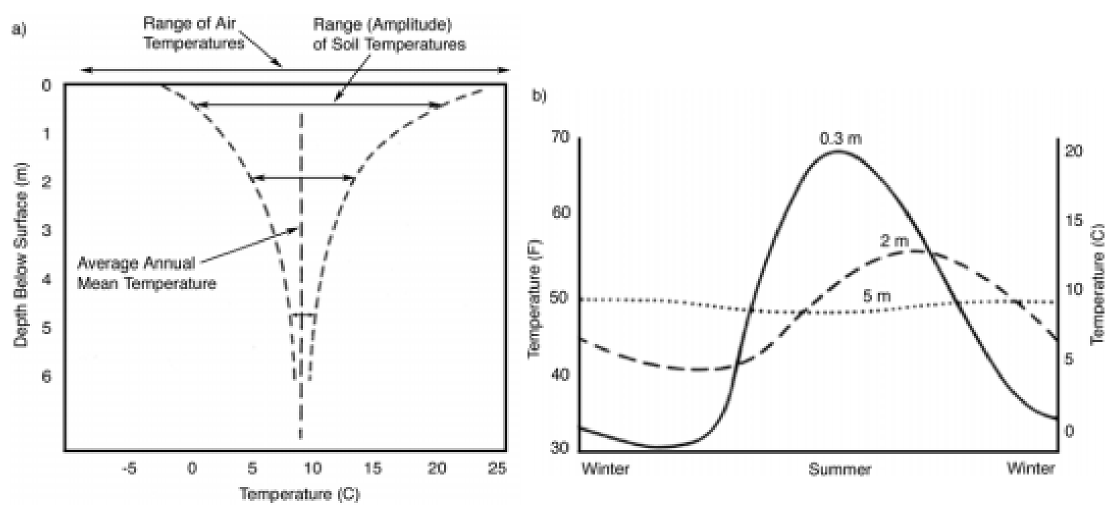

Figure 3. Depth dependence of ground temperature near Ottawa, Canada (Hanova and Dowlatabadi 2007)

Geothermal Heat Pump Basics

A heat pump is, as the name sounds, simply a device that transfers, or stores, heat from, or to, a hot reservoir to a cold reservoir. It is in many ways, similar to the function of a refrigerator but in reverse (among other differences). For a geothermal heat pump (GSHP) heating a residential house, the hot reservoir is in the subsurface of the earth, and the cold reservoir is the house being heated. If the heat pump is running in cooling mode the earth is used as a heat sink rather than a source. GSHPs do still require electrical energy to run the compressors and fans of the unit, but what makes them so attractive is their high efficiency. The amount of thermal energy that one can obtain from the electrical energy input is multiplied by the coefficient of performance (COP) of the heat pump. The COP is defined as the ratio of heat moved from the reservoir, to the electrical work consumed by the heat pump. This COP varies based on the type of heat pump system, and the quality of the hot and cold reservoirs. This value is always above 1, with a typical value around 3.5 to 4.0 for heating applications and for cooling during the summer in NY state will be much larger as the ambient ground temperatures are low.

The calculated efficiency of the system, using the electrical energy input required to run the system as a basis, would equal around 350%! Anyone who has taken a physics or thermodynamics course knows that an efficiency above 100% seemingly violates the laws of physics. But the way in which the COP is defined is valid. Analogously, if we were to operate the system as a heat engine, the efficiency would be defined as the ratio of electricity produced per unit of thermal energy transferred which is proportional to the reciprocal of the COP. Because of the huge magnitudes of scale explained prior, the amount of heat extracted by a GSHP is completely negligible to the resources of heat in the earth. Therefore, it is appropriate to solely use electrical energy input as a calculation basis and a 350% pseudo-efficiency is reasonable.

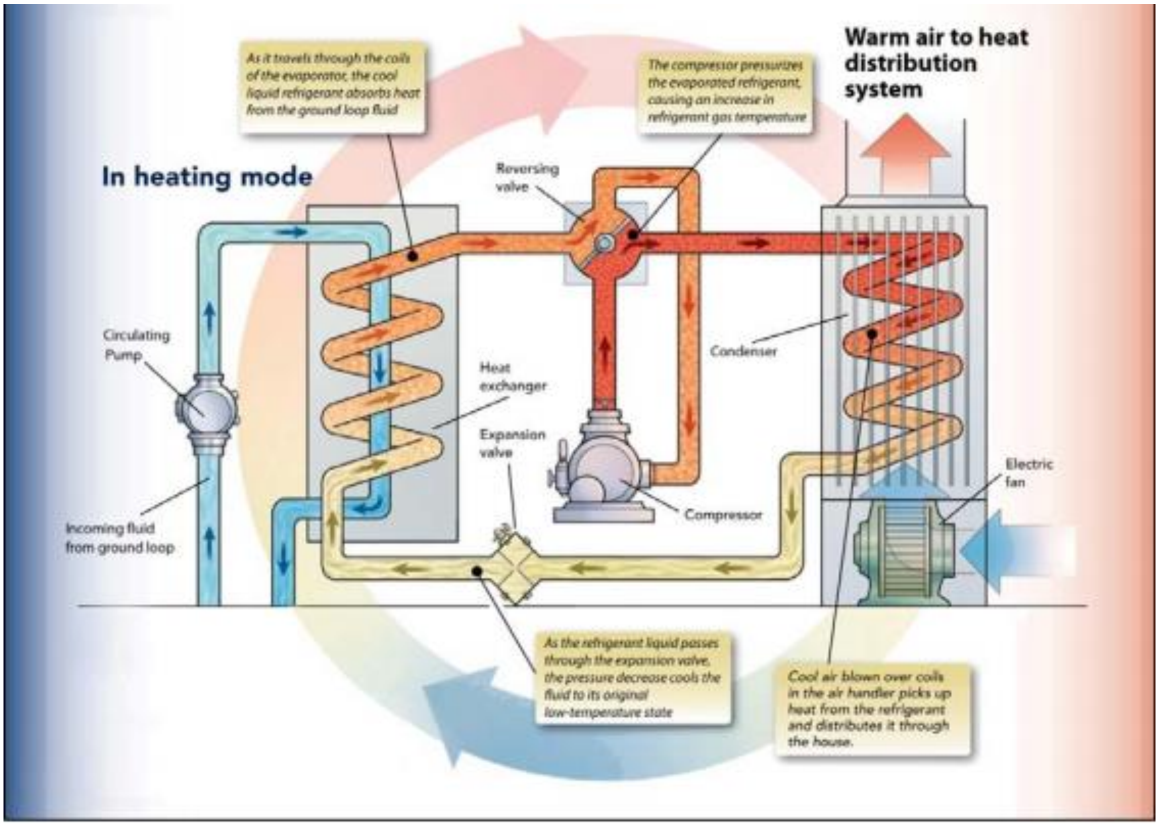

Figure 4. Detailed diagram of a heat pump running in heating mode. (Alaska Center for Energy and Power 2011)

Figure 4 displays an easy to follow diagram on the workings of an average heat pump running in heating mode. The blue flow on the left is fluid that has been flowed through ground loop tubing to exchange heat with the subsurface, our hot reservoir. The circling yellow to orange flow signifies the working fluid drawing heat from the ground loop fluid and vaporizing. The working fluid is refrigerant fluid with low boiling point specifically chosen to work effectively with the unique parameters of the system. This vapor is then adiabatically compressed to the liquid state that increases its temperature even further. This fluid subsequently exchanges its heat with incoming cool air (our cold reservoir) that is warmed and sent to heat the house or unit. Our working fluid passes through an expansion valve decreasing the temperature original low-temperature state thus enhancing its heat exchange with the ground loop fluid and the process is repeated.

The maximum efficiency of this system is thus defined as the COP with a theoretical Carnot efficiency limit of

$$COP_{carnot,heating} = \frac{T_h}{T_h - T_c}, \quad COP_{carnot,cooling} = \frac{T_c}{T_h - T_c}$$

with T_h defined as the temperature of the hot reservoir in absolute temperature units, and T_c as the temperature of the cold reservoir. The first equation is for when the GSHP is running in heating mode and the second for when it is cooling. Limits of the physical system lower the actual efficiency below the ideal Carnot efficiency. The ideal Carnot COP equation can still be used to illustrate what the efficiency of a practical unit will depend on. When comparing these two equations, the most important factor affecting the COP is the denominator, the difference in temperature between the cold reservoir and the hot reservoir. When this difference is the smallest, the COP becomes the largest. Therefore, GSHPs become more effective at moderate times of the year, but unfortunately have dips in performance at the coldest and hottest times of the year.

The other important factor in the operation of a GSHP is the type of ground loop. A ground loop is the series of tubes that actually extracts the heat from the soil. There are four basic types of loops that are normally chosen. They are horizontal loops, vertical loops, lake loops, and open loops that use the water from a lake or ground itself as the heat exchange fluid. Due to the location requirements of the former two options, the analysis in the report will primarily deal with horizontal and vertical loops.

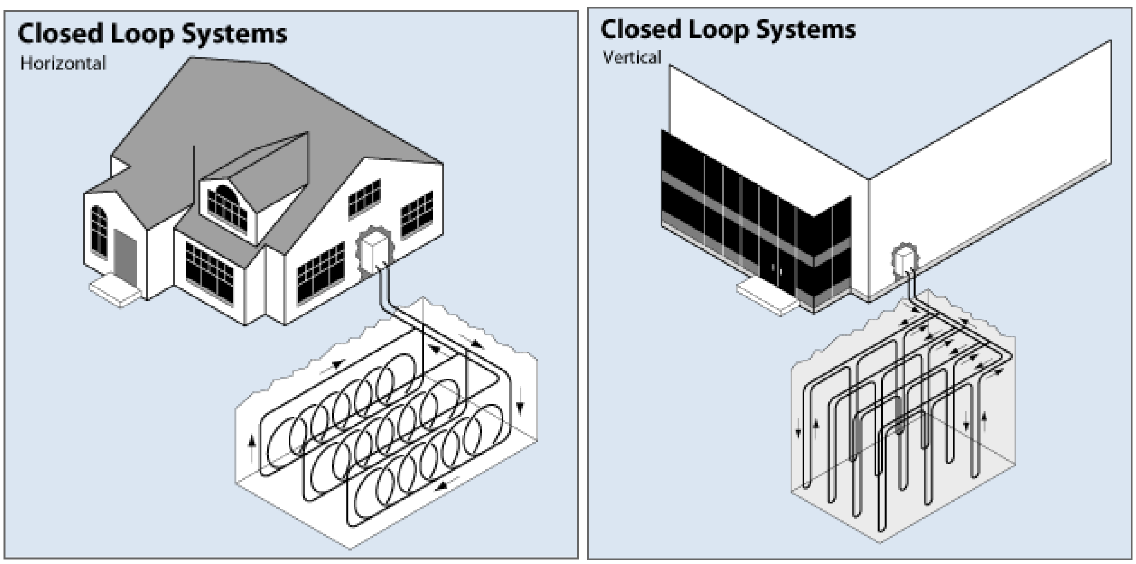

Figure 5. Visual diagrams of horizontal and vertical closed loop GSHP systems (Evans 2011)

Horizontal loops consist of coils of tubing laid in a flat depth in the soil. They are normally less deep than vertical loops and require more land. This makes them cheap, but more susceptible to soil temperature fluctuations. They are normally the most cost effective option if the land is available. Vertical loop systems consist of series of deep vertical wells. They are more expensive, but make more efficient use of land and are chosen in circumstances when land is limited or a high heating demand building requires a high amount of fluid heat exchange with the soil. As is indicated in the diagrams of figure 5, horizontal loop systems are used more often in residential applications while vertical loop systems find more use in commercial or industrial applications; although, it is not uncommon for a residential house to use a vertical loop due to space constraints or a commercial location taking advantage of a large flat parking lot and placing a horizontal loop underneath.

Current Heating Demand

The first step in calculating the total potential savings of GSHPs is to determine the current heating demands of the county by type of heating fuel used and sector of the demand (residential, commercial, or industrial). The following data in table 4 were obtained from the 2008 Tompkins County Greenhouse Gas Emissions Inventory, with adjustments made to the MMBTU/year for electric heat, as described below.

In MMBTU/year	Res	Commercial	Industrial	Total
Fuel Oil	247,000	59,000	4,100	310,000
Nat Gas	1,700,000	2,130,000	423,000	4,260,000
Propane	445,000	0	96,000	540,000
Electric	266,000	240,000	58,000	567,000
Total	2,660,000	2,430,000	580,000	5,670,000

Table 4. Heating demand of Tompkins County by sector and heating method, heating by electricity estimated to account for 10% of total heating (Tompkins County Planning Department 2010)

The shortcoming of the data obtained was that it did not discern between energy used for heating, and energy used for lighting and other uses. This was an issue for determining what portion of electricity was devoted to heating.

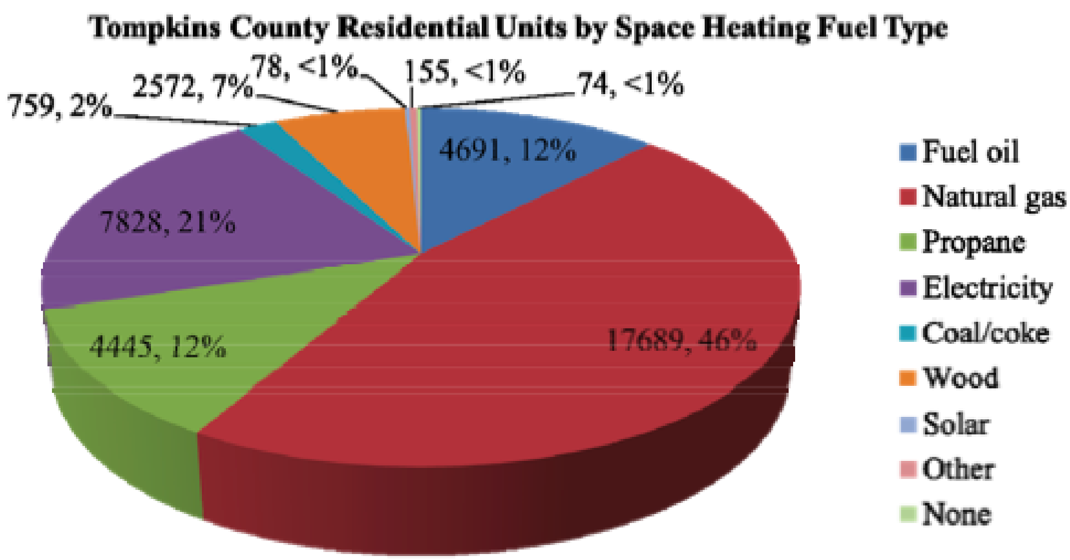

Figure 6. Energy profile breakdown of heating generation in Tompkins County (NYSERDA 2012)

Using the heating generation break down provided by NYSERDA in figure 6, and considering the fact that most electircal heating systems are, on average, smaller than other heating systems, it was estimated that 10% of Tompkins County's heating demand was provided by electrical systems. Thus the total heating demand found in the GHG emissions inventory was simply multiplied by 10% to determine electric heating demand.

Current Cost of Heating Fuels

The most recent average fuel and electricity prices were compiled from the EIA reports for calculation of energy savings. Pricing for the Residential sector is generally higher than the other sectors due to the tendency of the commercial and industrial sectors to “buy in bulk” and obtain savings. They generally sign contracts with the energy suppliers and pay months or even years in advance for the energy rather than after the bill has come. While the cost of natural gas remains low, rapidly increasing demand from the residential sector, along with remaining reserves getting progressively more costly to produce natural gas from, indicates that price is set to rise in the near future. Reports are generally in consensus that natural gas can more than double in price within the next 20 years (EIA 2013). This report will use both the current price of natural gas and a future outlook price of twice the current price a cases in calculations. Table 5 contains the data of energy costs used in further calculations.

$/MMbtu	Residential	Commercial	Industrial
Fuel Oil	31.00	31.00	31.00
Nat Gas	11.16	8.19	7.63
Future Nat Gas	22.32	16.38	15.26
Propane	32.20	32.20	32.20
Electric	36.20	27.34	20.81

Table 5. Fuel and electricity prices by sector in the New York State region. Provided by the EIA report. Prices are from most recent reported period, ranging from Jan 2013 to March 2013 (EIA 2013) Future Natural gas prices are double current prices based on estimates on price growth over the next 20 years.

Current Efficiencies of Heating Fuels

For the sake of the calculation of the overall potential of GSHP, conservative average efficiencies were chosen for each fuel source as shown in table 6, although in reality the efficiency has as much to do with the model and upkeep of the boiler or heater than it does the fuel source. A COP of 3.5 was chosen as the efficiency for calculation, because it is currently industry standard of new GSHPs, and to obtain certain tax rebates or incentives, the system must meet this standard. This COP is a yearly average and does not take into account the normal seasonal variance of a GSHPs COP.

	Thermal Efficiency
Fuel Oil	80 -85%
Nat Gas	85- 95%
Propane	80- 95%
Electric (not including generation or transmission losses**)**	98%
Geothermal (includes an average COP or 3.5**)**	350%*

Table 6. Average efficiencies for heat generation for varying fuels. Electrical efficiency is end source efficiency or the electrical heater. *Geothermal efficiency is displayed as COP (EIA 2013)

Potential Cost Savings from Switching to Geothermal for Heating

The following equation was used to determine the amount of savings in dollars per MMbtu that would be obtained if one made the switch from one of the traditional heating fuel sources to geothermal via GSHP with the same heating demand

$$\frac{Energy\ Saving}{Heating\ Load} = \frac{Fuel\ Price}{thermal\ Eff.} - \frac{Electricity\ Price}{COP}$$

These saving are due to the high effective "efficiency" of heat pumps. Although they still require outside energy input, and when one is replacing an electric heating system with a GSHP they are even still using the same fuel source, the heat pumps simply require less power to run.

$/MMbtu Savings	Residential	Commercial	Industrial
Fuel Oil	26.13	26.13	26.13
Nat Gas	1.41	0.81	2.09
Future Nat Gas	13.16	9.43	10.13
Propane	27.54	27.54	27.54
Electric	26.59	20.09	15.29

Table 7. Savings provided by a GSHP when compared to current heating sources. Calculated using electricity and fuel prices found in table 5.

% Savings	Residential	Commercial	Industrial	Total
Fuel Oil	84%	84%	84%	84%
Nat Gas	13%	10%	27%	13%
Future Nat Gas	59%	58%	66%	59%
Propane	86%	86%	86%	86%
Electric	73%	73%	73%	73%
Total Avg.*	38%	18%	42%	30%

Table 8. Percent savings provided by a GSHP by sector when compared to current heating fuels. Total average excludes the future natural gas outlook case.

As shown in table 7 and 8, because of the current low prices of natural gas that make it less than one third of the cost per BTU, there really are not any tangible savings to be had when choosing a heat pump over the more conventional and common natural gas. In fact, when including capital costs, a GSHP is likely never to payback over natural gas at current natural gas prices. But when looking at future outlook of increasing natural gas prices, if prices increase as expected, the savings can be significant on par with the savings GSHPs provide over the other heating fuels.

Potential GHG Emissions Savings from Switching to Geothermal for Heating

While GSHPs currently provide little benefits over natural gas in terms of cost savings, an advantage might become apparent when analyzing greenhouse gas savings.

kg CO2e/MMbtu	Energy Intensity
Fuel Oil	85.0
Nat Gas	59.2
Propane	69.2
Electric	73.3

Table 9. Energy Intensities for of different fuel sources (EIA 2013) (EPA 2013)

Because natural and propane gas are such clean burning gases, and they have a much higher ratio of carbon atoms to hydrogen atoms, their energy intensities are quite low as shown in table 9. While the energy intensity of electricity generation is higher than both natural and propane gas, Tompkins County is lucky to be part of one of the cleanest electrical grids in the US. Because electrical energy is what powers GSHPs at their high efficiencies, this clean electricity is a boon for geothermal heat pumps in the area. GHG emission savings were calculated in a similar fashion to cost savings before and are shown in table 10 and 11.

$$\frac{GHG\ Saving}{Heating\ Load} = \frac{Fuel\ Intensity}{Eff.} - \frac{Electricity\ Intensity}{COP}$$

(kg CO2e/MMbtu)	All
Fuel Oil	79.1
Nat Gas	41.4
Propane	60.4
Electric	53.8

Table 10. GHG emission reduction provided by a GSHP when compared to current heating fuels. Calculated using energy intensities found in table 9.

% GHG reduction	All
Fuel Oil	93%
Nat Gas	70%
Propane	87%
Electric	73%
Total Avg.	73%

Table 11. Percent GHG emission reduction provided by a GSHP when compared to current heating fuels

Thanks to low electrical generation intensity in our region the reductions in greenhouse gas emissions are very profound and can give geothermal heat pumps a chance even if the monetary savings can be poor in certain cases.

Cost Analysis

The fate of geothermal then hangs on the outcome of a cost benefit analysis. This calculation is extremely difficult to do for the average case because there really are no "average cases" for the installation in an average residential house. The costs can vary wildly based on the installers, location, type of soil, type of ground loops, and size of the home. A rough estimation was made of $42,000 dollars for the installation in the average Tompkins County home (a demand of ~71 MMbtu/year) before any incentives are deducted. Tax credits and incentives available in New York state are taken in table 12 and the net cost of the average system comes out to ~$24,000.

Typical Cost	**$42,000.00**
Federal Tax Credit	30%
Green Certification	$5,125.00
Property Tax Exemption	N/A
Loan Program	N/A
Net Cost	$24,275.00

Table 12. Sample tax credits and incentives for geothermal heat pump in the state of New York (DSIRE 2013)

Using this net capital cost, a conservative discount rate of 3% and a time period of 25 years, which corresponds to the average lifetime of GSHP units, were chosen. A cost analysis was done with the results shown in table 13.

	Yearly Savings	Simple Payout	NPV	Annual Cost/Worth
Fuel Oil	$1,860	13 years	$8,100	$460
Natural Gas	$100	240 years	$(22,500)	$(1,290)
Future Natural Gas	$940	26 years	$(7,990)	$(460)
Propane	$1,960	12 years	$9,800	$560
Electricity	$1,900	13 years	$8,600	$495

Table 13. Cost analysis of savings provided by a GSHP when compared to current heating fuels. Calculated with a discount rate of 3% over a life of 25 years.

Due to the poor yearly savings of geothermal heat pumps over conventional natural boilers, the decision to choose the heat pump can be a costly one because of the annual cost of ~$1,300 over the entire 25 year lifespan of the system. This disparity can make it hard to switch to a geothermal heat pump even from one of the other heating fuels because of the savings one can be afforded currently with natural gas. Even if the price of natural gas rises to double the current prices, GSHPs do not payback in their useful lifetime for the average Tompkins County residence when looking at the heating demands. For a GSHP to break even over its lifetime (the NPV will equal to $0), the cost of natural gas must rise to $28.50/MMbtu. This is about 2.5 times the current price of natural gas.

Potential in Tompkins County

To interpret the data and the results of our analysis and assess the potential for the use of GSHPs in Tompkins County, the first task is estimating the appropriate demand to be supplied by GSHPs. Because of the financial and environmental benefits that GSHPs have over fuel oil, propane, and electricity as well as natural gas at prices higher than $28.50/MMbtu , the potential is estimated assuming all heating is supplied by these fuels is instead provided by GSHPs. Therefore the power necessary to run these GSHPs yields a modified demand for electricity.

Another factor that has been overlooked is the availability of GSHPs to provide cooling during the summer months, using the near constant temperature sub surface as a heat sink instead of a heat source. This combination of heating and cooling is what makes heat pumps so effective and more prevalent in more temperate climates such as the south. This type of climate demands moderate heating and cooling, rather than high heating and low cooling, thus taking more equal advantage of the system capacity in heating and cooling modes.

Cooling demand in Ithaca is on average a small fraction, ~5%, of heating demand when looking at the ratio of heating degree days to cooling degree days. (NOAA 2013) Heating and cooling degree days are simple metrics which quantify heating or cooling demand in particular geographic locations as a function of outdoor temperature. But the inclusion of supplied cooling by GSHPs can increase its benefit and have favorable effects on the cost benefit analysis. Unfortunately, information on actual cooling demand, percentage of residences with central cooling, amount of window units, and the demands of large commercial buildings are hard to come by and more assumptions must be made.

On consultation with contractors with experience in the installation of GSHPs in the Tompkins County area, GSHPs can become more economically feasible when compared to natural gas furnaces when the buildings demand a higher fraction of cooling. This comes into play in most commercial buildings and in large multi-room houses that take advantage of large amounts or air conditioning. Initial estimates on the percentage of demand that can potentially meet this criteria, and therefore may make economic sense to adopt GSHPs over natural gas in the near future, are 60% for residential buildings, and 80% for commercial buildings. Therefore, the potential makes the assumptions that it is possible for all fuel oil, propane, and electric heating to be replaced by GSHPs while 60% of residential natural gas supplied heating and 80% commercial natural gas heating can be replaced with GSHPs. Heating demand reductions possible from meeting this full potential were calculated and are shown in tables 14 and 15.

The heating demands in figure 14 are the reduced demands made possible by adoption of GSHPs. They were calculated as follows,

$$\frac{Conventional\ Heating\ eff.}{GSHP\ COP} \times Current\ Heating\ Demand = Potential\ Heating\ Demand$$

for each of the current conventional heating fuels, and summed for each sector for total demand by sector. For the case of natural gas, where there is only partial adoption, the calculation is as follows,

$$\%\ adoption \times \frac{Conventional\ Heating\ eff.}{GSHP\ COP} \times Current\ Demand + (1 - \%\ adoption) \times\ Current\ Demand = Potential\ Heating\ Demand$$

	Heating Demand in MMBTU
Residential	1,130,000
Commercial	724,000
Industrial	447,000
Total	2,298,000

Table 14. Heating demand by sector after full potential (as described by full GSHP adoption over fuel oil, propane, and electrical systems, and 60% adoption over residential natural gas systems and 80% of commercial natural gas systems) is met.

	Percent Decrease in Conventional Heating Demand
Residential	58%
Commercial	70%
Industrial	23%
Total	60%

Table 15. Percent decrease in demand after full potential of GSHPs is met. This decrease of demand is in decreased conventional energy input required due to the COP of GSHPs

Conclusion

At current natural gas prices, it is not advisable to install a geothermal heat pump to replace a natural gas furnace when looking solely at heating requirements. But they will often be cost effective in buildings with high cooling demands, new constructions, or when natural gas is not available at all. Also, the price of natural gas can vary and it has been known to vary wildly in the past. When priced above $28.50/MMbtu our study showed that GSHP can begin to provide both economic and environmental benefits over conventional natural gas heating systems.

Natural Gas has both been a blessing and curse to the energy landscape in the United States. On one hand, its current low cost, abundance, and cleanliness relative to coal and oil have made a huge impact on reducing the greenhouse gas emissions in US. Nonetheless, low cost natural gas is stifling the options of other, even lower emission renewable alternatives from gaining much of a foothold.

Another point to note is that this average calculation is by no means conclusive. Many houses might get a price quote on a heat pump much lower than the values used in this study and with higher priced natural gas and electricity, heat pumps could provide tremendous monetary and greenhouse gas savings. In any case, it makes sense to get an estimate for installing a GSHP in a new house or when retrofitting a house with an out-of-date heating system and to include any tax or other incentives that are available.

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