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## Co-Generation Opportunities for Lower Grade Geothermal Resources in the Northeast—A Case Study of the Cornell Site in Ithaca, NY

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### ABSTRACT

For geothermal to have a national impact as a major energy supplier in the U.S., deployment must eventually utilize lower grade hydrothermal or Enhanced Geothermal Systems (EGS) resources. In these locations the costs of drilling as a function of depth will limit produced fluids to lower temperatures. This limitation favors applications for direct use and/or co-generation of electricity and heat. The Northeast region of the US where geothermal gradients are low and annual heating loads are substantial are of special interest. The paper provides the rationale for selecting Cornell University's Ithaca campus in upper New York State as a test site for commercial-scale geothermal development in the eastern U.S. At Cornell, geothermal heat would be used in an advanced co-generation system in conjunction with other renewable resources such as biomass and lake source cooling along with deployment of aggressive on-campus energy efficiency measures to substantially lower and eventually eliminate carbon emissions. A site development plan outlined in the paper characterizes the thermodynamic, environmental, and economic advantages that EGS could provide for direct heating and co-generation as a replacement to the coal and natural gas fired systems currently in use at Cornell.

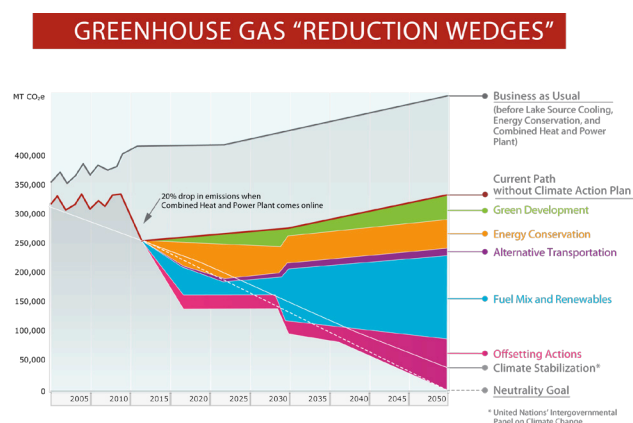
### Motivation and Scope

High electrical loads and high thermal energy demands for winter heating in the Northeast region may lead to future energy supply disruptions and may continue to impact population patterns and regional economic viability if there is a shortage of carbon free energy sources. With a limited availability of solar and wind resources in the Northeast, viable alternatives to coal are needed. Eastern geothermal resources are large in terms of their stored thermal energy but they are at greater depth to those available in the western U.S.

Cornell University provides an ideal setting for evaluating the viability of geothermal energy in the Northeast. The Ithaca campus has a large heating demand given its northern latitude in

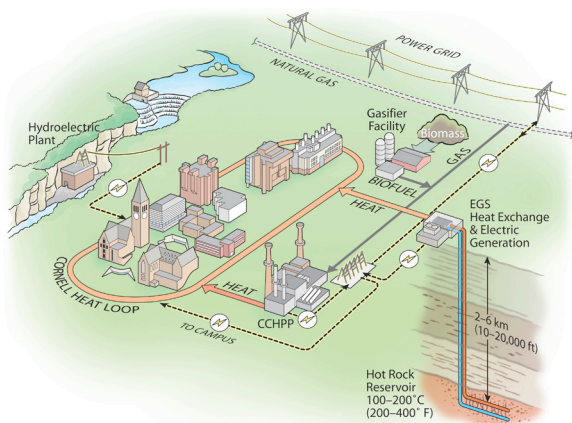
upstate New York State and Ithaca is located in a region that has higher than average heat flow.

In addition to Ithaca serving as a representative site for geothermal development in the Northeast, there is an additional motivation. In 2007, Cornell's President David Skorton signed the President's Climate Commitment, pledging the university to achieve climate neutrality of its total energy footprint by 2050. As a first step towards implementation, the Cornell Climate Action Plan (CAP) was created with financial support from the New York State Energy Research and Development Authority (NYSERDA). The plan not only provides a framework for elimination of net greenhouse gas (GHG) emissions required to heat, cool, and power Cornell's Ithaca campus that serve a community of 30,000 faculty, students, and staff it also would lead to substantial reduction of greenhouse gas emissions associated with University-sponsored transportation through incremental expansion of existing demand-side programs and cost-saving new initiatives. In addition, sustainable energy education, research, and outreach associated with the CAP are significant components and an integral part of the Cornell Center for a Sustainable Future (CCSF). Figure 1 illustrates the time lines for various options being considered in the CAP.



**Figure 1.** Projected carbon emission reduction as projected by Cornell's climate action plan. Contributions for fuel substitution, demand reductions, and energy conservation and efficiency illustrated by individual wedges.

A promising approach being considered by the CAP is to meet Cornell's thermal (heating and cooling) and electric loads by utilizing two of its most accessible renewable resources biomass and low-grade geothermal. Cornell already uses cold water from a deep section of nearby Cayuga Lake for cooling and air conditioning its buildings, laboratories and dormitories during the summer months. Adding geothermal would complement Cornell's lake-source cooling by providing hot water for winter heating. Produced fluids from an engineered geothermal reservoir extracted at temperatures ranging from 80 to 120 °C would be connected to the campus's district heating network. During warmer periods geothermal heat could be used for electric power generation. Figure 2 provides a schematic of the proposed plan



**Figure 2.** Schematic of Cornell's planned electric power and district heating co-generation system utilizing geothermal and biomass energy sources.

Cornell currently consumes about 65,000 tons of coal per year in its co-gen plant. A major upgrade to a natural gas fired system will be operational in early 2010 that will dramatically lower carbon emissions by 25% for heating and power generation on campus (corresponding to the large drop in CO<sub>2</sub> emissions as shown on Figure 1 in 2010). To achieve further declines will require switching to renewable sources.

To investigate the feasibility of EGS technology, Cornell University has initiated an assessment project that would utilize geothermal heat extracted from deep reservoir rocks under its campus in Ithaca, New York. Thermal energy from EGS and from biomass produced on Cornell agricultural land are key components of Cornell's Climate Action Plan, which seeks to completely eliminate greenhouse gas (GHG) emissions attributed to campus operations by no later than 2050.

Accordingly Cornell's plan would result in an institutional-scale, publicly-accessible demonstration of enhanced geothermal energy use suitable for replication by any large institution or industry. Final complete EGS system would include multiple production and injection wells reaching up to 14,000 feet (about 4,300 meters) below ground surface into pre-Cambrian crystalline "basement". Heated geothermal fluids would feed a combined heat and power co-generation facility utilizing organic Rankine-cycle engines, direct plate-and-frame heat exchangers, and heat pumps (as needed). Acquired thermal and electrical energy would be directly interconnected to Cornell's existing district energy

system which supplies 30MWe of electricity and 1.8 trillion Btu per year of thermal energy for heating buildings in a community of 30,000 faculty, staff, and students

## Assessment of the Geothermal Potential of the Ithaca Region

In order to access the suitability of the Ithaca Site for a low temperature geothermal demonstration, a comprehensive evaluation of regional and local geologic and geophysical data is underway. Key elements include: 1. geology 2. the state of stress, 3. heat flow and geothermal gradients, 4. regional seismicity and seismic risk. The composition and structure of the overlying sedimentary cover to basement rock is known as are regional stresses and are described in the next section. In terms of the geothermal heat resource itself, our immediate focus has been to update existing legacy heat flow and gradient information with new bottomhole temperature data from recent extensive gas drilling activities associated with the Marcellus shale deposits. In addition, geologic information from the extensive outcrop of basement in the nearby Adirondack Mountains, and seismic reflection data from gas exploration surveys (2D and 3D) are being evaluated. New measurements of thermal properties of basement samples (e.g. from the Adirondacks) and *in situ* fluids (e.g. magnetotelluric) will be acquired as necessary. Background seismicity, a critical element for assessing of any future induced seismicity, will be calibrated by deployment of a dense surface seismograph network in the target area, to be operated for the two year duration of this proposed study.

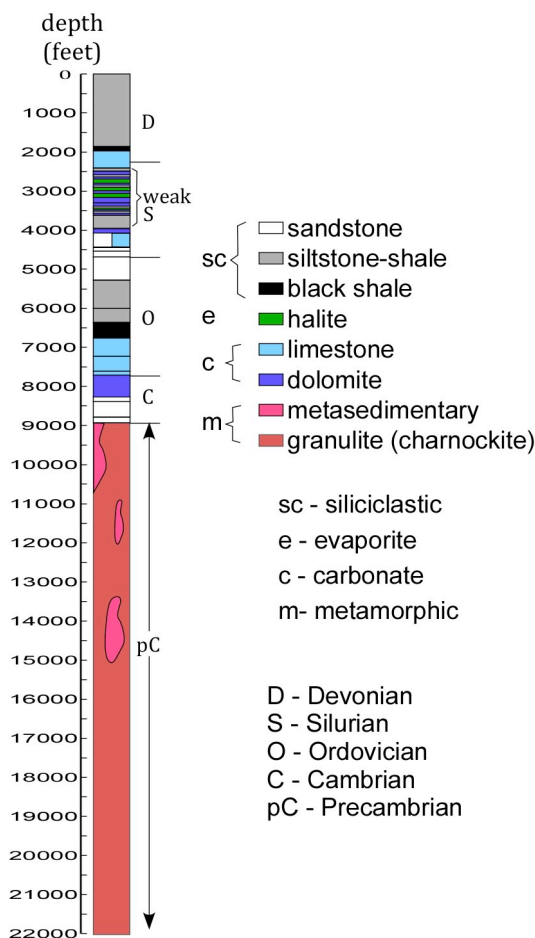
## Geology of the Cornell EGS Site

The spatial variation in the geology of central New York is simple: on a transect from north to south, the thickness of Paleozoic sedimentary rocks increases and the depth to crystalline basement increases. The subsurface geology of the Ithaca region is comprised of a tens to hundreds of feet of unconsolidated Quaternary deposits topping ~9000 ft of Paleozoic sedimentary rocks of the Appalachian basin, which overlie crystalline basement rocks of Precambrian age (Figure 3). Indirect and sparse data indicate that the basement lithologies are igneous and metamorphic rocks that are similar to those that crop out in northern New York State (Kay et al., 1983).

Near Ithaca, Paleozoic sedimentary rocks to a depth of ~6800 ft are dominated by siliciclastic lithologies (siltstone, shale, and sandstone). Between ~6800 and ~8400 ft, carbonate rocks (limestone, dolomite) predominate. The interval between ~2500 and 3500 ft poses challenges to drilling because interbedded salt and thin shales deform the boreholes, while also offering advantages as they effectively impede upward migration of fluids (Smith et al., 2007). For 8 boreholes drilled in Tompkins County to more than 5000 ft depth, the units have been characterized from electric logs (gamma, neutron porosity, and density logs primarily) and infrequent well cutting samples, all of which are archived in the New York State ESOGIS database. A single well drilled to >10,400 ft penetrated the top of the crystalline basement (Shepard-1). Common among all the Paleozoic strata is low porosity, with infrequent sandstone and rare dolomite (Figure. 3) achieving 10-25% porosity

(e.g., Tamulonis, 2010; Smith, 2006a). In the sedimentary rocks below a depth of a few hundred feet, the pore waters are brines; those below the salt horizons have a salinity of ~30 wt% NaCl (Smith, 2006b; Smith *et al.*, 2007).

The nature of the basement rocks is known directly from xenoliths entrained in kimberlite dikes found at over a dozen locations in Tompkins County (Kay *et al.*, 1983), as well as indirectly from proprietary seismic reflection profiles (Jordan and Tamulonis, unpublished) and by comparison to outcrops in the Adirondack Mountains, >150 km to the NE.



**Figure 3.** Anticipated borehole geology for Tompkins County near Ithaca to a depth of 22,000 ft (7 km). For upper 9000 ft, direct data from exploration boreholes. At greater depths, direct data from xenoliths and inference from extrapolation from rocks exposed in the Adirondack Mountains.

Through reliance on the gravity and magnetic data to define regional trends, it is projected that the basement of Ithaca should be like the Central Granulite Belt of the Adirondacks (Reed, 1993). The xenolith rock fragments include syenite; granulite facies carbonate rocks, and a single fragment of a greenschist facies metamorphic rock (Kay *et al.*, 1983). The fragments are chemically and mineralogically similar to rocks exposed in the Adirondack Mountains. The abundance of the calc-silicate granulites among the xenoliths suggests that these rocks are likely voluminous and may occur just below the Paleozoic strata (Kay *et al.*, 1983). However, a single actinolite-bearing xenolith suggests that low-

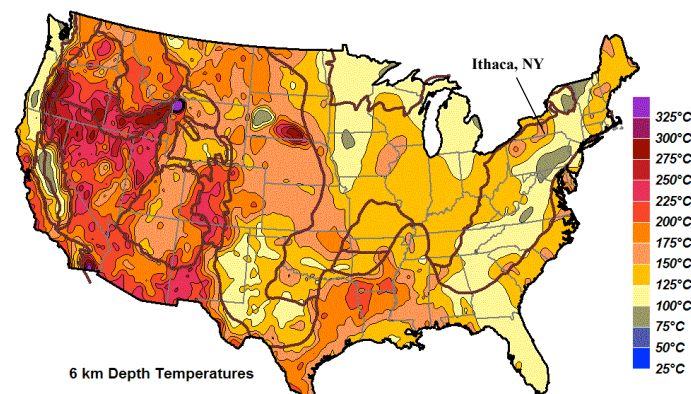
grade (greenschist facies) metamorphic rocks may also be present, which is consistent with the recognition of discontinuous patches of well-layered reflectors in the upper crust in seismic data from the northern border of Tompkins County which may be metasediments (Jordan and Tamulonis, unpublished). To maximize the utilization of well-mapped basement rocks in the Adirondack Mountains as an analogue for Ithaca subsurface geology, we use the COCORP seismic interpretation for the Adirondacks to project into the subsurface (Klemperer *et al.*, 1985). The projected borehole geology (Fig. 3) reflects the properly scaled Adirondack subsurface extrapolated to exist below the Paleozoic strata of Tompkins County.

Regionally, New York State has a fairly homogeneous stress field with an east-northeast trending maximum horizontal compression direction (World Stress Map database; Heidbach *et al.* 2007). These data come from borehole breakouts, hydraulic fracturing experiments, and the occasional earthquake. Locally near Ithaca, however, overcoring in the Tully Limestone documents elastic strain relaxation with an azimuth of 004° (Engelder and Geiser, 1984), suggesting the presence of a residual NS horizontal compression with a magnitude of about 14 MPa. Whereas the regional horizontal compression parallels late Paleozoic fold axes, this local residual stress is nearly perpendicular to the axis of the Fir Tree Anticline and parallel to the strike of cross-fold joints in the region.

## Heat Flow and Geothermal Gradients

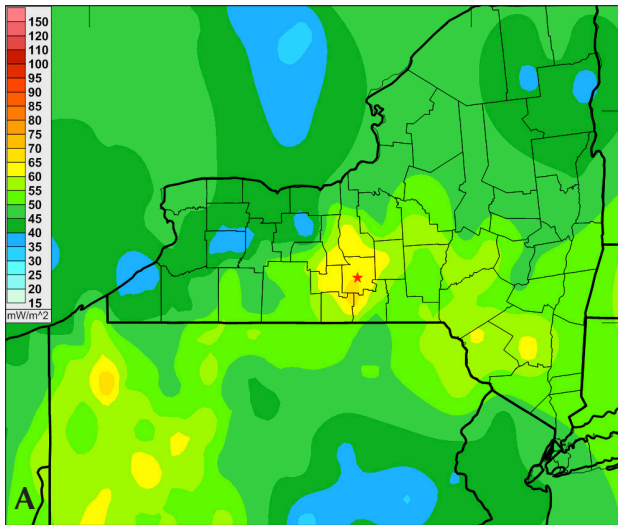
New York State's geothermal resource differs from that found in the western states in terms of rock types, heat flow, and resulting temperature gradients. Heat flow measurements for the Adirondack Mountains have typical values of 38 mW/m<sup>2</sup>, somewhat lower than the typical heat flow values for the adjacent Canadian Shield (45 mW/m<sup>2</sup>) (Mareschal *et al.*, 2000). If the basement rocks in the Ithaca area are analogous to those exposed in the Adirondacks, they are likely to have similar heat producing capacity.

Based on earlier assessment data reported by the SMU laboratory, we expect the average geothermal gradients in the immediate Ithaca area to be considerably higher than other regions in the New York as illustrated in Figure 4. As early as 1975, this anomaly had been noted in heat flow and gradient maps of the region. A more extensive database of bottom hole temperatures has become available in the last few years from the drilling of

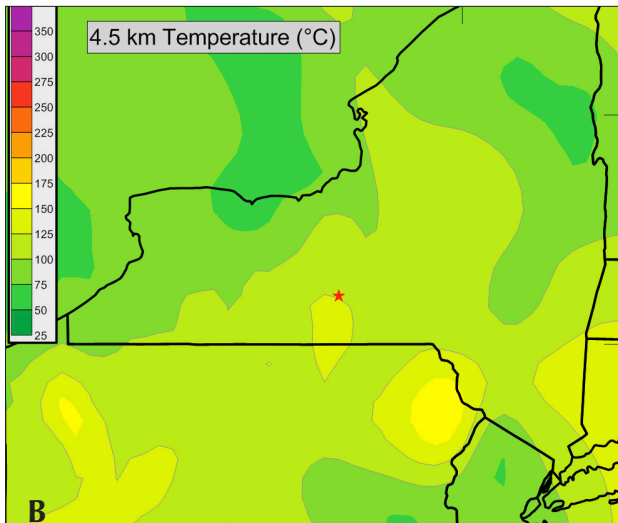


**Figure 4.** Predicted temperature at a depth of 6 km for the continental U.S.

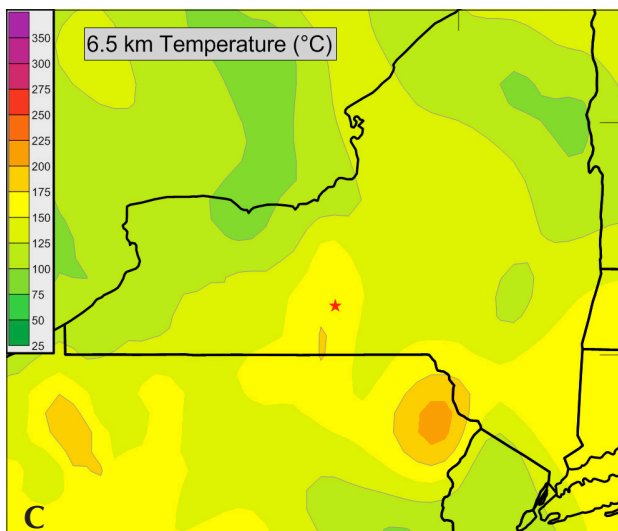




**Figure 5a.** Heat flow map of New York and Pennsylvania. The red star corresponds to Ithaca, NY.



**Figure 5b.** Predicted rock temperature at a depth of 4.5 km.



**Figure 5c.** Predicted rock temperature at a depth of 6.5 km

over 1000 holes into the Marcellus and other tight gas shales in Central New York and Western Pennsylvania to depths ranging from about 4000 to 13,000 feet. Preliminary analyses incorporating these additional data have been performed to develop the regional heat flow map and the maps of temperatures at depths of 4.5 and 6.5 km shown in Figures 5a, 5b, and 5c. These new data confirm that the geothermal resource under Ithaca is likely to have measurably higher temperature gradients than the surrounding region.

## Regional Seismic Assessment

### Seismicity

The area of Central New York under consideration for an EGS demonstration is an intraplate area which is relatively aseismic from both the regional and local perspective (e.g. Figure 6, 7). Correspondingly, it is typically characterized as a region of minor, if any, risk of damage from natural events (e.g. Figures 8, 9). However the Ithaca, NY, area is bordered by regions of diffuse and poorly understood seismicity, including the nearby Clarendon-Linden fault zone to the west and the Adirondack Mountains to the northeast (Figure 10), and the regionally significant NW-SE trending Boston-Ottawa seismic belt and the SW-NE trending seismicity loosely related to Appalachian structures (e.g. Figure 7). While no intraplate region can be considered completely risk free, the lack of historical and instrumentally located events in the region under consideration indicates a relatively high degree of tectonic stability within the current stress regime, especially given the density of pre-existing geological weaknesses suggested by both surface and basement lineaments (Figure 11; Jacobi, 2002).

### Seismic Risk

Seismic risk is a function not just of seismicity (as represented by source magnitude, mechanism and distance) but of the physical properties of the medium through which seismic waves propagate and upon which structures are built, and the structural standards used in building construction, particularly their consistency with appropriate seismic codes. Since seismic propagation in the crust of the eastern U.S. is considerably more efficient than in the western U.S., smaller magnitude events can be expected to result in damage to greater distance than equivalent sized events in the west. While seismic design parameters are part of the New York State Building Code, the adequacy of such parameter is debatable for an area with such low levels of seismicity, and certainly of limited value in the context of induced seismicity which may lie outside the statistical limits of natural seismicity. Readers should refer to the following web site for details (<http://www.fraengineering.com/Downloads/1.pdf>).

The impact of local geology on potential seismic risk in the central N.Y. area has received little attention, largely due the aseismic nature of the region. However, with highly variable thicknesses of the glacial till that overlies bedrock in the region, one can expect some degree of small scale variability in site response to seismic shaking (e.g. local amplification). However, the length scales of glacial depocenters (e.g. buried stream valleys etc) would suggest seismic wave focusing effects would be minimal.

## Induced Seismicity

Evidence of induced seismicity in similar, nearby geological environments is limited. Seeber and Armbruster (1993) cite examples related salt brine recovery in western NY, oil/gas recovery in southern Ontario and, perhaps most relevant, from waste disposal in northeastern Ohio. This latter case, reported by Armbruster *et al.* (1987), convincingly links a mb 3.8 event and its aftershocks to fluid injection into a deep disposal well. Although the disposal reservoir was the basal Mt. Simon sandstone, the trend of aftershocks and focal mechanisms of the induced seismicity are interpreted to indicate reactivation of an underlying- and previously unknown- basement fault (e.g. Seeber and Armbruster, 1993). Notably, seismicity along this proposed fault has continued even after injection ceased. Concern over induced seismicity in New York and Pennsylvania has been revived by hydrofracturing activity associated with current and planned exploitation of the Marcellus. Although there has been no definitive evidence that hydrofracturing for gas production has triggered tectonically driven earthquakes in this region, public sensitivity to the issue has certainly been greatly increased.

## Implications for Geothermal Energy in Central N.Y.

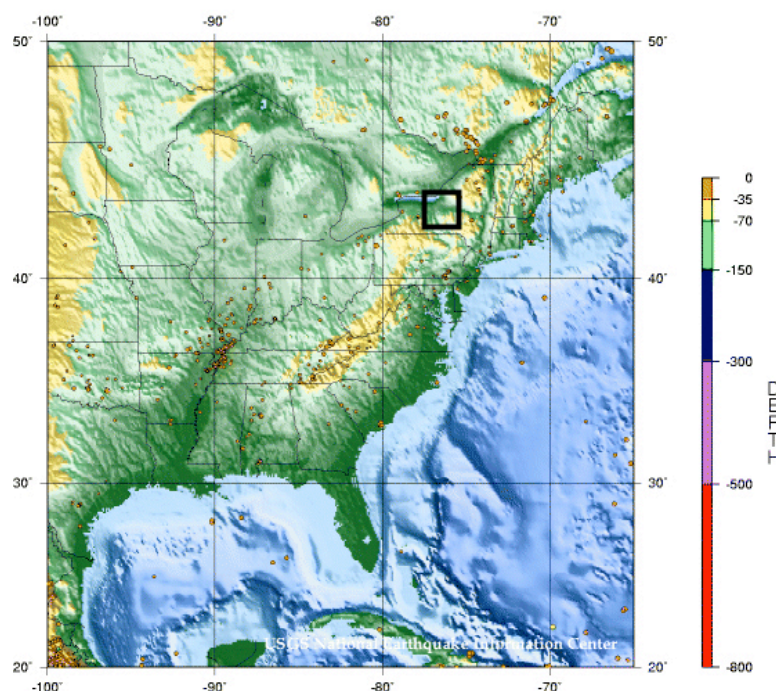
The aseismic nature of the proposed EGS site in central New York would suggest that the potential for induced seismicity is much less than at sites in tectonically unstable regions. However the same lack of experience with natural events raises public sensitivity to any events that might occur, either naturally or triggered, in the region during EGS operations. Lack of historical experience with seismic shaking also raises concerns regarding the vulnerability of infrastructure (e.g. power plant, synchrotron, bridges, high rise campus building) to events which lie outside the statistical norms for expected seismic risk that were in place when they were built. Such concerns place a priority on carrying out the following investigations in preparation for EGS development:

- microzonation of the region, especially in the immediate proximity to any proposed EGS site, with particularly attention to building standards and local geological conditions (esp. foundations in glacial deposits vs. bedrock).
- monitoring of background seismicity to smaller magnitudes than current permanent networks provide. Typically local networks “fill in” evidence of smaller magnitude events in previously “aseismic regions” (e.g. see Mereu *et al.*, 2002, for an excellent example from the nearby Lake Ontario region). It is essential to know the level of natural seismicity down to magnitudes that are likely to be relevant to even small triggered events associated with geothermal hydrofracturing and subsequent production. A long term, local seismic network is needed to provide this level of monitoring, and installation of such a network should be done as soon as possible to provide a sufficient record against which to compare activity during EGS operations. The surface network should be augmented by borehole monitoring capabilities to track details of hydraulic stimulation and fluid flow during EGS operations.

c) geophysical mapping of bedrock structure. As implied by the NE Ohio case, basement faults may play a critical role in both providing pre-existing weaknesses to host failure and pathways for fluids to trigger such failure. Any EGS site in central New York will operate through a substantial cover of Paleozoic sedimentary rocks which mask basement (i.e. Grenville age) structure. Identification of such structures by extrapolation of surface trends and exposed basement geology in the Adirondack Mountains and Canadian shield (e.g. Jacobi, 2002), guided by geophysical data such as magnetic anomalies, is helpful but ultimately of limited value for predicting properties at a specific locale. 3D reflection seismic imaging of potential EGS sites is critical to defining structural details with sufficient resolution to constrain models for fluid migration as well as identifying pre-existing faults that are candidates for reactivation. Such data, collected for gas exploration, already exists and provides piecemeal coverage within this region. However, additional surveys will be probably be needed to document all candidate sites.

## Summary

The aseismic nature of central N.Y. suggests that the risk of induced seismicity is also relatively low compared to more tectonically active regions. However, the lack of experience with seismic activity also could lead to heightened (and potentially exaggerated) public concern over the potential for such seismicity to occur during EGS development and operation. Therefore a thorough program of geological site assessment and seismic monitoring is essential to both success of geothermal development and public acceptance of the risks involved.



**Figure 6.** Seismicity of the Eastern U.S. 1990-2000. National Earthquake Information Center, USGS. Box indicates area of interest.



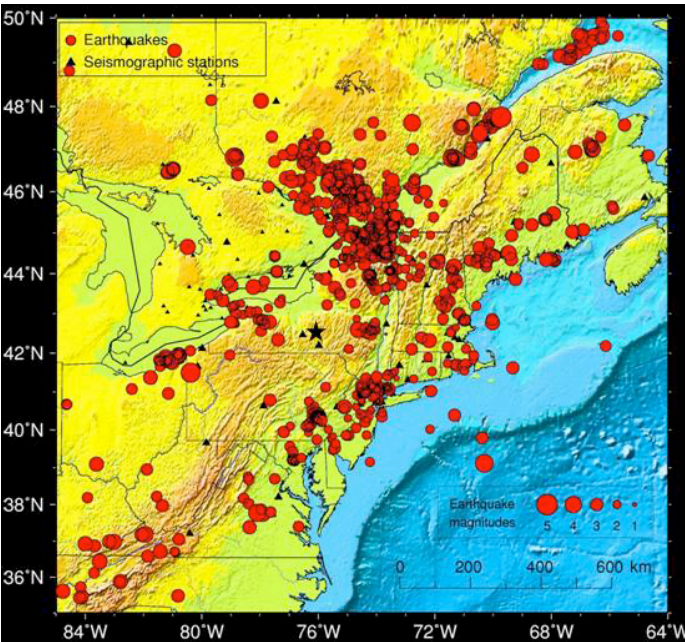


Figure 7. Seismicity of the Northeastern U.S. 990-996. Star indicates Ithaca, N.Y., center of the area of interest. <http://www.ldgeo.columbia.edu/LSCN>.

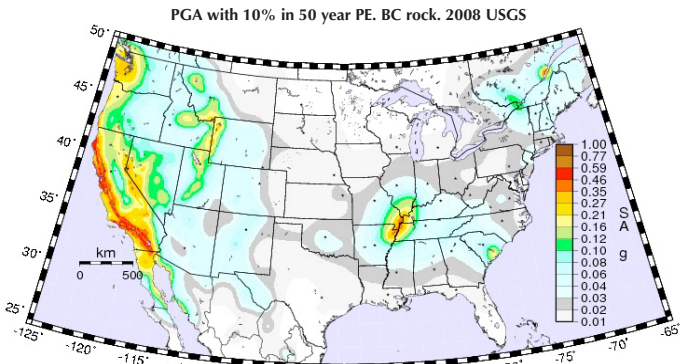


Figure 8. Estimate of the likelihood of ground acceleration attributable to earthquakes in the U.S. <http://earthquake.usgs.gov/hazards/products/conterminous/2008/maps/>.

Opportunities for Direct Use of Lower Grade Resources at Cornell

The opportunities for utilizing lower grade geothermal resources are greatly expanded when direct use and co-generation options are considered. For example, in the U.S over 30% (about 30 out of 110 EJ) of the primary energy consumed per year is actually used at temperatures below 250°C.

Nonetheless, there are big economic challenges for generating electricity given the low second law efficiencies of converting thermal energy into electric power at lower geofluid temperatures. Direct use as thermal energy would be a more attractive alternative. Thus proximity to both thermal and electric demands would be more attractive for increasing the utilization of lower grade geothermal energy.

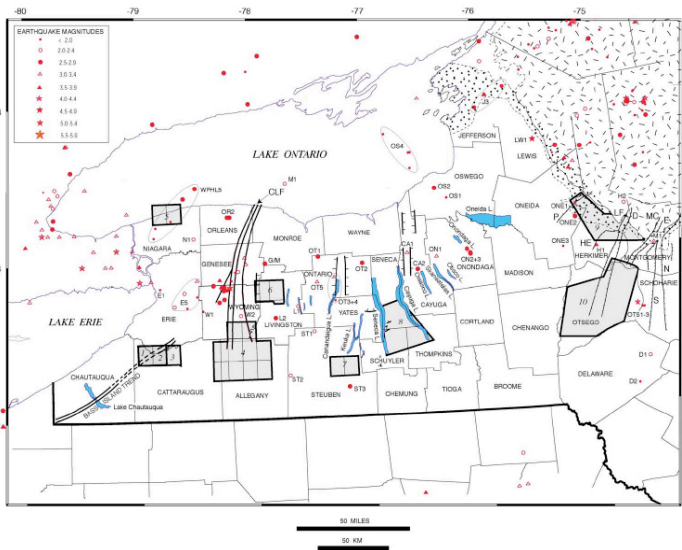


Figure 9. Seismicity and major structural features of New York State. CLF- Clarendon-Linden Fault Zone. Stippled pattern represents basement outcrop of the Adirondack Mountains. (Jacobi et al, 2000).

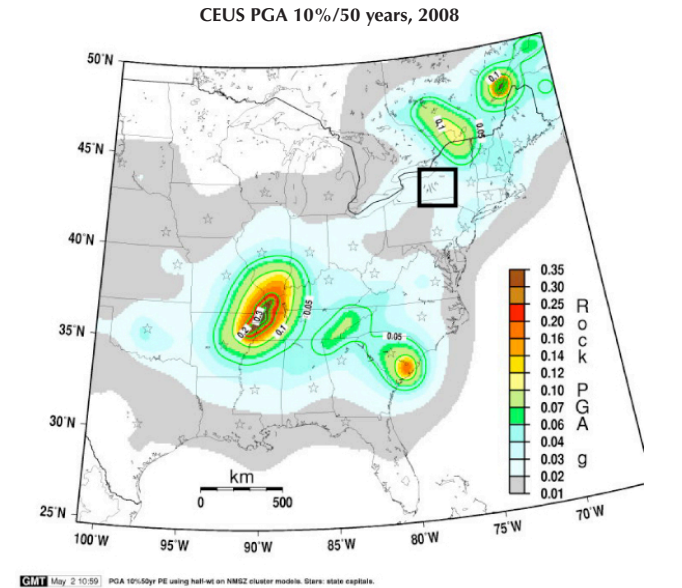
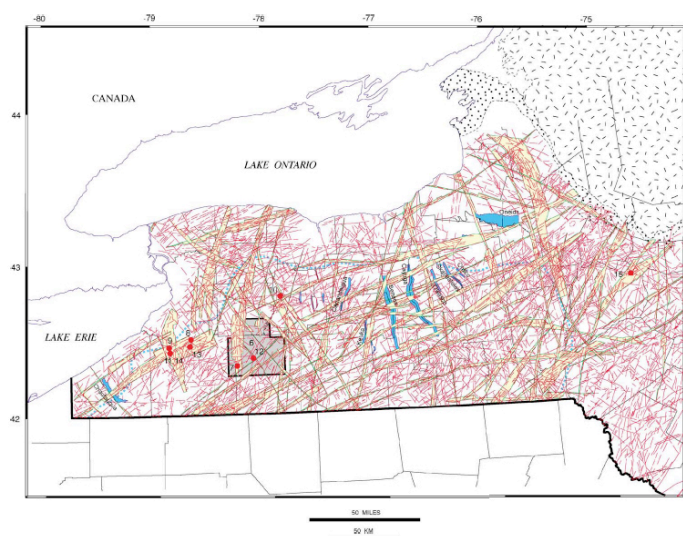


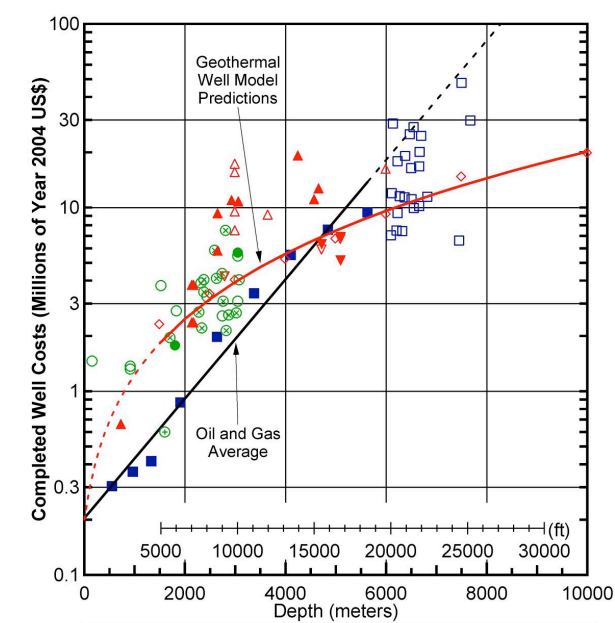
Figure 10. Estimate of likelihood ground acceleration attributable to earthquakes in the east central U.S. Area of interest indicated by box. <http://earthquake.usgs.gov/hazards/products/conterminous/2008/maps/>.

Cornell University heating and electric loads provide an ideal setting for such a co-generation application of geothermal. Averaging over the last few years , Cornell’s demand for electric power is a about 30MWe with about 65,000 tons of coal (1.8 trillion Btu) consumed per year for heating its buildings .

Based on anticipated performance metrics for existing geothermal resource developments, we conducted a preliminary parametric analysis of the levelized energy costs for both electricity and heat for a range of resource grades, reservoir performance, and financial factors expected for the proposed Cornell application. These are summarized below:



**Figure 11.** Lineaments systems of New York (Jacobi et al., 2000). The relative lack of seismicity in Central New York in spite of such a large pool of candidates for reactivation, indicates local stress levels are relatively low.



**Figure 12.** Predicted and actual drilling costs from Tester et al, 2006.

- Direct-use geothermal is able to capitalize on low-T resource
  - $T = 110, 130, 150^{\circ}\text{C}$  at
    - 2.5, 3.0, 3.5 km ( $40^{\circ}\text{C}/\text{km}$ ),
    - 4.0, 4.5, 4.75 km ( $30^{\circ}\text{C}/\text{km}$ ),
    - 5.0, 6.0, 7.0 km ( $20^{\circ}\text{C}/\text{km}$ )
- Assumed \$150/kWth for heat exchangers and piping for the direct heating system
- Capacity factor – 95%
- Doublets (1 injector, 1 producer)
  - 2004 US\$ and 2x(2004 US\$)

- 500 m separation
- 7-inch diameter
- Debt/equity rates
  - 5%, 10%, 15%
  - 30-year project life
- Assumed 80 kg/s in producer

The MITEGS and GETEM economic models were used for the calculations ( see Tester, et al. 2006). In addition, we examined the effect of drilling cost by using two drilling costs versus depth models – based on 2004 estimates (given in Figure 12) and 2 times the 2004 costs. The results are tabulated in Tables 1 and 2 where we immediately see the economic

**Table 1.** Estimated levelized energy prices for geothermal electricity and district heat. Ithaca NY conditions assumed at  $30^{\circ}\text{C}/\text{km}$  and 80 kg/s per producer.

Projected LECs for electricity in cents/kWh				
2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	14.54	24.33	33.66
	130	27.05	45.05	62.21
2X2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	20.85	35.85	49.94
	130	38.88	66.65	92.73
	110	146.78	250.02	346.97

Projected LECs for District Heating in \$/MMBtu

2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	2.1269	3.0642	4.1203
	130	2.4403	3.3343	4.4448
2X2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	3.2389	4.8776	6.7237
	130	3.5303	5.2613	7.2115
	110	3.9824	5.8553	7.9652

**Table 2.** Estimated levelized energy prices for geothermal electricity and district heat. Ithaca NY conditions assumed at  $40^{\circ}\text{C}/\text{km}$  and 80 kg/s per producer.

Projected LECs for electricity in cents/kWh				
2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	13.58	21.54	29.08
	130	24.4	39.81	54.53
2X2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	18.03	30.5	42.26
	130	33.93	57.21	79.13
	110	135.04	228.48	315.07

Projected LECs for District Heating in \$/MMBtu

2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	1.9043	2.6766	3.5467
	130	2.1211	2.9331	3.8479
2X2004 Drilling Costs	T ( $^{\circ}\text{C}$ )	5%	10%	15%
	150	2.7546	4.0632	5.5375
	130	3.0274	4.4110	5.9697
	110	3.4514	4.9504	6.6392



attractiveness of using lower grade geothermal resources for direct heat over electric power generation given anticipated commercial electricity prices ranging from about 5 to 12 ¢/kWhr and heating costs based on purchased natural gas ranging from \$2 to 10 per MMBtu. For example, using Cornell's project debt/equity financing rates of 5%, geothermal would be competitive for district heating for average gradients ranging from 30 to 40°C/km over the range of depths/temperatures examined as shown in Tables 1 and 2.

## Conclusions

The rationale behind the selection of Cornell University in Ithaca, NY as a demonstration site for low temperature geothermal energy utilization is based both on the favorable geologic conditions present in the region and the existence of a fully operational co-generation system for the campus. Cornell's energy use level is representative of many rural communities and cities with populations ranging from 10,000 to 50,000 in the eastern region of the U.S. at latitudes where a significant heating demand exists. Given that the geothermal resource grade is uniformly lower in the Eastern U.S. than in the West, deeper, more costly well drilling will be involved to reach comparable useful rock temperatures. Inevitably, this leads to having to utilize lower rock temperatures to achieve acceptable economic performance with lower gradients and the high costs of drilling deep. To maximize the utilization of the extracted heat it makes sense to make use of co-generation of heat and electricity to offset the thermodynamic losses incurred by just generating electricity.

On-going advances in drilling and reservoir stimulation and completion technology coupled to rising energy prices for electricity, heating oil and natural gas suggest that lower grade geothermal resources are now within reach. Cornell's commitment to a zero-carbon future with its Climate Action Plan provides substantial motivation for transitioning to renewables that utilize Cornell's indigenous geothermal and renewable biomass resources to generate both electric power and heat to meet its significant on-campus demand. Cornell's existing assets – including a new gas-fired, cogeneration power plant, lake source cooling and operational district heating infrastructure -- greatly reduce the capital investment needed to demonstrate low temperature geothermal utilization at scale. Significant financial advantages also result from the University's commitment to deploy a lower carbon energy supply system. This leads to lower discount rates for capital investments and should be representative of future public investments in municipal geothermal energy supply systems.

## Overall Path Forward

### *Continuation of Site Assessment and Engineering*

Improved understanding of water and land use issues along with seismic risks associated with hydraulic stimulation and production will allow for utilization of underground geothermal resources with reduced environmental impacts.

## *Drilling and Reservoir Stimulation*

Occurring in parallel to the site characterization and assessment studies, a detailed drilling plan and reservoir stimulation design will be developed in collaboration with ThermaSource.

### *Cogeneration Plant Modifications and Utilization Plans for Geothermal Heat*

In collaboration with Ormat, we plan to develop a range of power plant concepts that could efficiently generate electricity during warmer months when heating demand is much lower. These would involve organic Rankine cycles with specially selected working fluids to optimize power generation with lower geofluid temperatures and low heat rejection temperatures.

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