Capturing the Heat Beneath Our Feet: Cornell’s Deep Geothermal Heat Project and its Potential to Change the Energy System

Don Haas, PRI; Teresa Jordan, Cornell University

STANYS 2022
The changing energy picture
A few key ideas for climate change education

- Talking about climate change without talking about energy is like talking about lung cancer without talking about smoking.
- Fire is at the root of modern climate change.
  - We need to talk more explicitly about fire - everyone knows what it is, unlike GHG emissions.
  - There was no fire for 90% of Earth history, now humans burning stuff is causing dangerous changes in climate.
- The best way to reduce anxiety is to reduce the threat causing the anxiety.
  - In other words, work on the problem.
The largest sources of energy used in NYS (2020):

In alphabetical order:

- Biomass
- Distillate fuel oil (mostly for building heat)
- Gasoline
- Hydroelectric power
- Jet fuel
- Natural gas
- Nuclear electric power

In rank order:

- Natural gas
- Gasoline
- Nuclear electric power
- Hydroelectric power
- Distillate fuel oil
- Biomass
- Jet fuel

Rank order them from largest to smallest.
The largest sources of energy used in NYS (2020):

In rank order:
- Natural gas
- Gasoline
- Nuclear electric power
- Hydroelectric power
- Distillate fuel oil
- Biomass
- Jet fuel

Discuss:
- What’s most surprising?
- How do other states differ?
- How is New York different from the US on the whole?
- What’s likely different in NYS in 2022?
- How are different regions of the state different?
- How will it likely be different in 2035?

See current data [here](https://www.eia.gov), on EIA.gov.
The largest sources of energy used in NYS (2020):

In rank order for NYS (2020):
- Natural gas
- Gasoline
- Nuclear electric power
- Hydroelectric power
- Distillate fuel oil
- Biomass
- Jet fuel

In rank order for the US (2021):
- Petroleum (mostly gasoline)
- Natural gas
- Coal
- Nuclear electric power
- Biomass
- Wind
- Hydroelectric power

See current data [here](https://eia.gov), on EIA.gov.
New York State Energy Quick Facts (from eia.gov)

- New York revised its Clean Energy Standard in 2019 to require 100% carbon-free electricity from both renewable sources and nuclear energy by 2040. In 2020, renewable sources and nuclear power, together, supplied 60% of New York's in-state generation from utility-scale and small-scale facilities.
- Nuclear power accounted for 29% of New York's utility-scale net generation in 2020, down from 34% in 2019 because of the retirement of one reactor. A second reactor retired in 2021, completing the closure of Indian Point, one of the state's four nuclear power plants.
- In 2020, New York accounted for 11% of U.S. hydroelectricity net generation, and the state was the third-largest producer of hydroelectricity in the nation, after Washington and Oregon.
- In 2019, New York was the sixth-largest natural gas consumer among the states. New York's natural gas consumption per capita was less than in almost three-fourths of the states even though three in five households use natural gas for home heating.
- In 2019, New York was the fifth-largest consumer of petroleum among the states, but New Yorkers consume less petroleum per capita than residents of any other state in the nation.
Direct use (in buildings) is primarily for heating.

Explore & discuss the interactive graph, with an eye to the so far largely unchanged direct use data.

Note that total building square footage has increased substantially.
Zero-carbon generation includes nuclear, hydro, wind, and solar.

Wind is overtaking hydro as the 2nd largest zero-carbon source behind nuclear power.
How hot is it?

Methane burns at 3,560° Fahrenheit / 1,960° Celsius.

Gasoline, coal, and wood are more complicated as they are more varied in composition.
The thermal spectrum of low-temperature energy use in the United States

Is it wasteful to burn a fossil fuel at over 1000 °F if we then cool it down to under 300 °F to use it?

Fig. 4 Thermal energy use temperature distribution from 0 to 260 °C without Electrical System Energy Losses. The end-uses with the largest contribution are annotated. The total thermal energy demand from 0 to 260 °C in 2008 was 22.1 EJ (20.9 quads). Refer to the electronic supplemental information for the Cornell Energy Institute report for tabulated values of each temperature bin.

Fox et al. 2011
Direct-use applications for geothermal resources

T (°C)

200
Digestion in paper pulp (Kraft); Evaporation of highly concentrated solutions; Refrigeration by ammonia absorption

180

170
Heavy water via hydrogen sulphide process; Drying of diatomaceous earth

160
Drying of fish meal and timber

150
Alumina via Bayers process

140
Drying farm products; Food canning

130
Evaporation in sugar refining; Extraction of salts by evaporation & crystallisation; Fresh water by distillation

120
Concentration of saline solution; Refrigeration (medium temperature)

110
Drying and curing of light aggregate cement slabs

100
Drying of organic materials eg: seaweed, grass, vegetables etc; Washing and drying of wool

90
Drying of stock fish; Intense de-icing operations

80
Space heating (buildings + greenhouses)

70
Refrigeration (lower temperature limit)

60
Animal husbandry; Greenhouses by combined space

50
Mushroom growing; Balneology/therapeutic hot springs

40
Soil warming; Swimming pools; Biodegradation; Fermentations

30
Warm water for year-round mining in cold climates; De-icing; Fish farming

Courtesy of Geoscience Australia - Bridget.Ayling@ga.gov.au (after Lindal, 1973)
The geology of geothermal
Capturing the Heat Beneath Our Feet: Cornell’s Deep Geothermal Heat Project and its Potential to Change the Energy System

STANSYS
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Teresa Jordan
Cornell University

Don Haas
Paleontological Research Institution
What is geothermal energy and how can we tap it?

Earth’s center is ~6000 °C (10,800 °F)
Heat Flow to Earth’s surface varies greatly across planet Earth
Powerplants that convert Geothermal Energy to electricity are located where the heat flow is most vigorous.
Across our continent, heat flow also varies

Geothermal power plants produce electricity only in areas with high heat flow.
Unfortunately, geothermal electric power is not available in the states that consume most of their energy to heat buildings.

Sources:
EIA 2018, 2019
McCabe et al. 2016
Yet there IS geothermal energy **everywhere**. Can we tap it without converting it to electricity? How about using the heat *directly*?

Earth’s center is \(~6000 \, ^\circ\text{C}\) \((10,800 \, ^\circ\text{F})\)
It can be more useful to think about the depth we need to drill if we want to tap into the hot rocks.

Temperature at 11,500 ft (3.5 km) below surface:
- 77 °F
- 212 °F
- 392 °F
Across New York, Pennsylvania and West Virginia some places require deeper drilling and some less deep drilling to reach rocks as hot as 80 °C (176 °F)
How do we know the gradient of temperature in New York state?  
*Data come from previously drilled wells, archived by NYS DEC/Museum*
Auburn Geothermal well
Auburn, NY
1983

A rare complete data set, but only to a depth half as deep as Cornell’s CUBO well.

The increase of temperature with increasing depth (geothermal gradient) is apparent in data from Auburn’s geothermal well.

The sedimentary rocks are INSULATORS relative to the metamorphic rocks, causing temperature gradient to change near bottom of borehole.
These data collected 1 day after drilling ceased. The rocks had not regained their natural temperature. It would take months before that would have fully occurred.

Auburn Geothermal well
Auburn, NY
1983

A rare complete data set, but only to a depth half as deep as Cornell’s CUBO well.
Why can’t we just “tell the temperature”? (Blame the “mud”)

See deepgeothermalheat.engineering.cornell.edu, under the heading What is the temperature in the borehole?

Inside the borehole some feature cause heating and others cause cooling (constantly):

The heating/cooling requires us to understand “mud” circulating in the borehole
Drilling Mud – the circulation system for the borehole

- traveling block
- swivel
- kelly
- mud hose
- standpipe
- vibratimg screen
- mud pump
- blowout preventer
- mud return
- mud pits
- drill pipe
- drill bit

bins of solids to add to water, to form “mud”

tanks of water

stirring tank
Drilling Mud – the circulation system for the borehole

mud pumped up into the drill pipe (continuously)
Drilling Mud – the circulation system for the borehole

Mud comes back up out of the well, to be cleaned and recirculated.
Why can’t we just “tell the temperature”?  

Drill bit – grinding rock creates heat at the well bottom

Drilling lubricant (“mud”) – carries “drill-generated heat” out of the hole
Why can’t we just “tell the temperature”?

Mud itself gains or losses heat while

1) going down the well in the middle of the drill stem (frictional heating)
2) coming up the well outside of the drill stream (frictional heating)
3) exchanging heat with the rock walls while coming up: rocks are colder than the mud at shallow depths, and hotter than the mud in deeper parts of the well
Why can’t we just “tell the temperature”?

See deepgeothermalheat.engineering.cornell.edu, under the heading

What is the temperature in the borehole?

Inside the borehole some features cause heating and others cause cooling (constantly):

Drill bit – grinding rock creates heat at the well bottom

Drilling lubricant (“mud”) – it brings “air temperature” down to the bottom of the hole, and carries “drill-generated heat” out of the hole

Mud itself gains or losses heat while
1) going down the well in the middle of the drill stem (frictional heating)
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It’s complicated!
These data collected 1 day after drilling ceased. The rocks had not regained their natural temperature. It would take months before that would have fully occurred.

→The Equilibrium Temperature is not accurately known.
Cornell University’s Problem starts with a common situation in northern tier of U.S. states.

Located in a cold climate, large buildings need to be heated for ~ 8 months per year.
 Cornell’s Vision to reach Net Zero Energy Campus starts from *current campus annual consumptions of* Electric: 250 GWhₚₑ Heat: 380 GWhₚₜh
What is Earth Source Heat?
Earth Source Heat is Cornell’s vision for a campus-wide geothermal heating system that replaces fossil fuels with renewable heat.

How Does it Work?

• Uses existing **district energy system** with hot water
• Two (or more) deep wells are drilled to where rocks are hot (>160°F)
• **Hot water is pumped from one**, and cooled water is returned to the rocks through the other
• **Heat is extracted** from the geothermal water and transferred to surface water via a heat exchanger
• **The heated surface water circulates** through the pipes of the campus heating system
Earth Source Heat

Nice concept. Will it work?

**Biggest Challenges:**
1) plumbing in the rocks? – will water flow throw the rocks to harvest the heat?

2) money (costly to access the heat)
Earth Source Heat: A Phased Approach

- Preparatory Phase (2009-2021)
- Phase I: Exploration/Test Well Phase
  - Ia: Drill borehole, measure rock + fluid properties
  - Ib: Design demonstration wells, evaluate benefits & risks
- Phase II: Demonstration project
  - Ila: Drill first well, stimulate fracture set, test & analyze
  - IIb: Drill second well, build surface infrastructure, supply heat to east campus
- Phase III: Drill other well pairs and complete surface infrastructure

Today (Nov. 2022)
Earth Source Heat: A Phased Approach

- **Preparatory Phase**

- **Phase I: Exploration/Test Well Phase**
  - Ia: Drill borehole, measure rock + fluid properties
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- **Phase II: Demonstration project**
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- **Phase III: Drill other well pairs and complete surface infrastructure**
Phase I: Exploration/Test Well Phase

- **Ia: Drill borehole, measure rock + fluid properties**
- **Ib: Design demonstration wells, evaluate benefits & risks**

8 August 2022, Ithaca NY
2022 -- CUBO

Designed to gather data in order to analyze design and risks. Planned to monitor subsurface conditions later, if ESH moves forward to demonstration.

Drilling Phase

• Geophysical rock properties
• Temperature
• Fracture characteristics
• Rock samples
• Fluid samples
• Hydrogeologic tests
• Stress tests

Observatory Phase

• Fiber optic temperature profiler
• Borehole seismometer
Ready for Geological Analysis: Data sets are not as simples as an outcrop, yet reveal compositional change and the organization within the rocks.
What will be the Equilibrium Temperature after more time passes?

CUBO Borehole Temperature Data Immediately After Drilling

Geological Formations:
- Tribes Hill
- Little Falls
- Galway
- Potsdam
- Basement

Depth (ft):
- 8000
- 8500
- 9000
- 9500

Temperature (°C):
- 66
- 68
- 70
- 72
- 74
- 76
- 78
- 80

Thermal Zones:
1. Thermal Zone 1
2. Zone 2
3. Zone 3
4. Zone 4
5. Zone 5
6. Zone 6

Time:
- Time 2
- Time 3
- Time 4
- Time 5
- Time 6
- Time 7
Cornell Mission alignment (Education, Research, Extension) achieved in part through **student participation in the 2022 CUBO operations team**

*Environmental monitoring*

*Sample catching/management*

Students
- Roberto
- Daniela
- Madeline
- Sean
- Ivan
- Juliette

-Zachary

Eric (and George)
Phase I: Exploration/Test Well Phase

- **Ia**: Drill borehole, measure rock + fluid properties
- **Ib**: Design demonstration wells, evaluate benefits & risks

*coming soon...*
Careers
Geothermal career possibilities

- ~50 contractors with a wide range of kinds of educational preparation
  a. From completing formal education at 9th grade to PhDs
  b. (I'll be adding more here!)
- The example of drillers
  a. See clip P1000604 for the voice of one driller
- The broader context