Geothermal 101: Clean Energy from Air Conditioning to Space Heating to Electrical Power

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GRC
GEOTHERMAL RISING CONFERENCE
OCTOBER 26–29, 2025 | RENO, NV

Agenda

- What makes the Earth viable to help meet our clean energy needs?
- How are energy and power related and measured?
- How depth and T impact uses of geothermal energy?
  - Direct use-- thermal power for heating and cooling
  - Indirect use-- electrical power

Overture *(Background Fundamentals)*

- How can geothermal energy networks and direct use hugely help our energy needs?
  - Geothermal heat pumps and thermal energy networks
  - Deep direct use of hot geothermal fluids for space heating (Boise, ID; Paris, France; Peppermill Hotel)
  - How hot geothermal fluids can also cool (absorption chillers)

Part 1: Jay's look at using the Earth as a thermal bank (addressing the "elephant in the room").

Agenda (cont'd)

Source: *Yellowstone Naturalist*

- Using Hotter (>~120°C) Geothermal Systems
  - What criteria are needed to make a geothermal fluids viable for making electrical power?
  - What are some key attributes and challenges of producing electricity from geothermal energy?
  - Where are most currently developed geothermal systems found?
  - What makes Nevada prospective for geothermal energy?
  - What are some exciting new technologies for expanding use of geothermal energy?
- Recap summaries by Jay and Dave

Part 2: Dave's look at higher T geothermal fluids and power generation.

What makes the Earth a viable source of CLEAN energy?

- Earth is a giant heat engine-- ability to do work
- What might be examples of this work?
  - Erupting Volcanoes
  - Earthquakes
    - 2011 9.0 M Tohoku EQ heaved ~1500 km of ocean floor 50 m (*released enough energy in a few seconds to power Los Angeles for an entire year or could satisfy the energy consumption of the U. S. for about 2 months!*)
  - Plate Tectonics– continual movement of great chunks of Earth's crust and upper mantle over great distances for a long time (heat energy that drives plate tectonics)
- Thermal energy is vast!
  - Tapping <1/1000th of one percent of thermal energy of upper crust would equal the US energy consumption in a given year

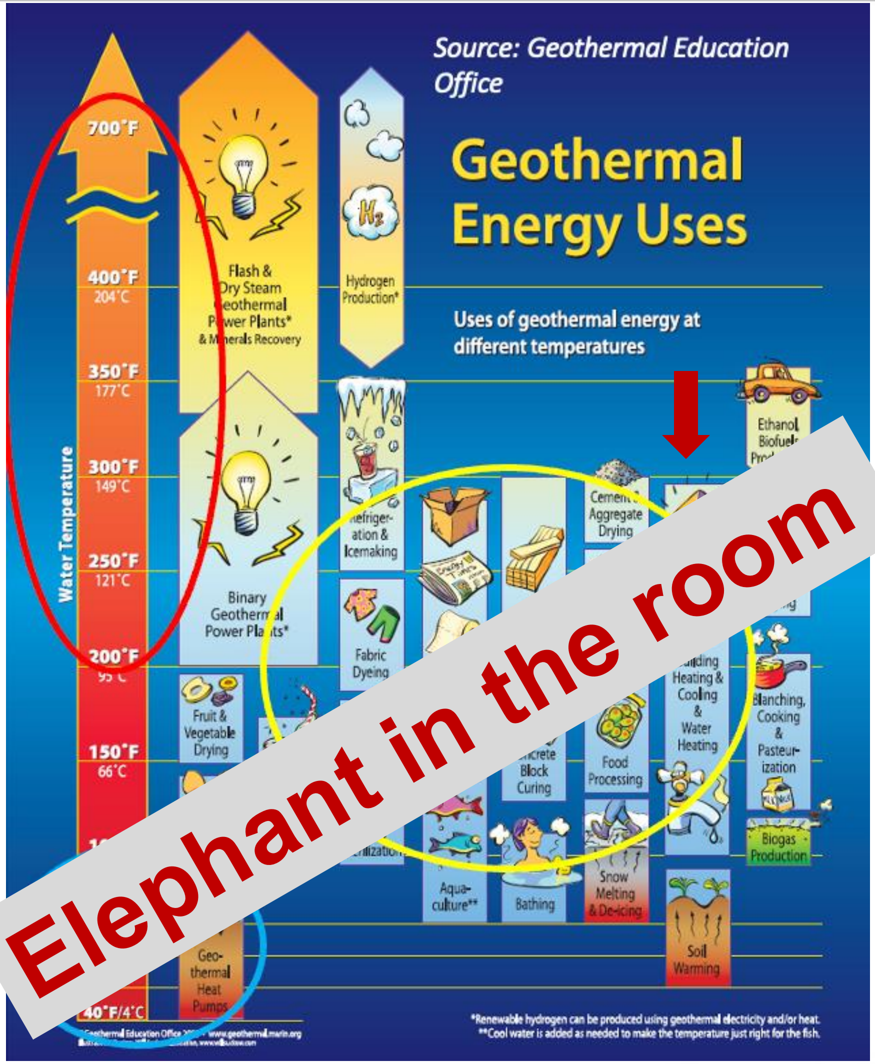
Free flowing well at Beowawe, NV

Distinguishing and Measuring Energy and Power

- Basic unit of **Energy is Joule**; basic unit of **Power is Watt**
- **Energy** is a quantity (ability to do work) and **Power** is a rate of energy delivery, both electrical (e) and thermal (t)
- **1 Watt of Power** = **1 Joule** per second (**P** = **E**/t)
  - One **k**ilo**W**att (1 kW) = 1000 Joules/second; one **M**ega**W**att (1 MW) = one million joules/s
  - MW is typically used in rating delivery of energy output of power plants or rate of energy output for geothermal wells
  - **1 MWe of power serves ~800 homes on average**
- **Energy = Power** x time→ kiloWatt x time (in power industry unit of time is hour)→ kWh
  - Energy generated from power plants measured in **MegaWatt-hour (MWh)** or **GigaWatt-hour (GWh)**
  - Palo Verde nuclear plant in Arizona (4.0 GW of power x 24 hrs/day = 98 GWh of energy per day)
    - Serves ~70% of AZ energy needs and no GHG emissions
- **For geothermal**:
  - Electrical power can be measured by mass flow rate (kg/s) x enthalpy (kJ/kg)→ kWe (Indirect Use)
  - Thermal power can be measured by mass flow rate (kg/s) x Cp(kJ/kg℃) x T℃→ kWt (Direct Use)

USES OF GEOTHERMAL ENERGY

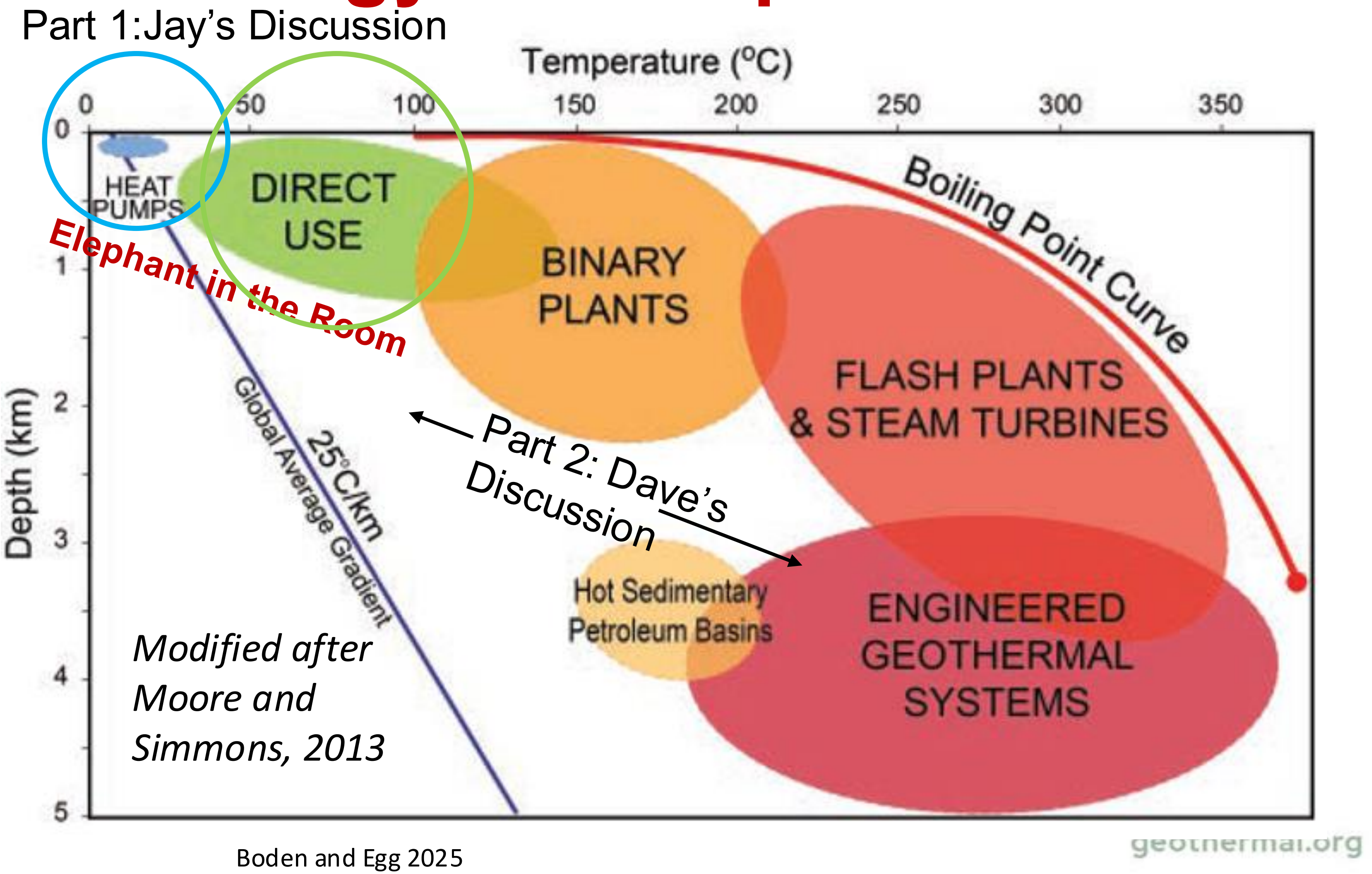
- Produce electrical power (T >~120℃)
- Deep direct use of geothermal fluid (T >~40℃)
  - More energy efficient than power production
  - Heat (cool) buildings and homes
  - Aquaculture (fish hatcheries)
  - Greenhouses and fruit/vegetable drying
- Shallow direct use--Geothermal Heat Pumps (T 10°– 15℃)
  - Can be used anywhere
  - Use Earth as a thermal bank
  - Reduce energy costs by as much 40%. Why?
    - More efficient to move energy than produce energy
  - Largest application of direct use (71%)



Uses of Geothermal Energy with Depth and Temperature

Heat Pumps and Thermal Energy Networks

Deep Direct Use of Geothermally Heated Fluids



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PART 1: Low Temperature Geothermal Exchange Utility Thermal Energy Networks and Direct Use

Jay Egg

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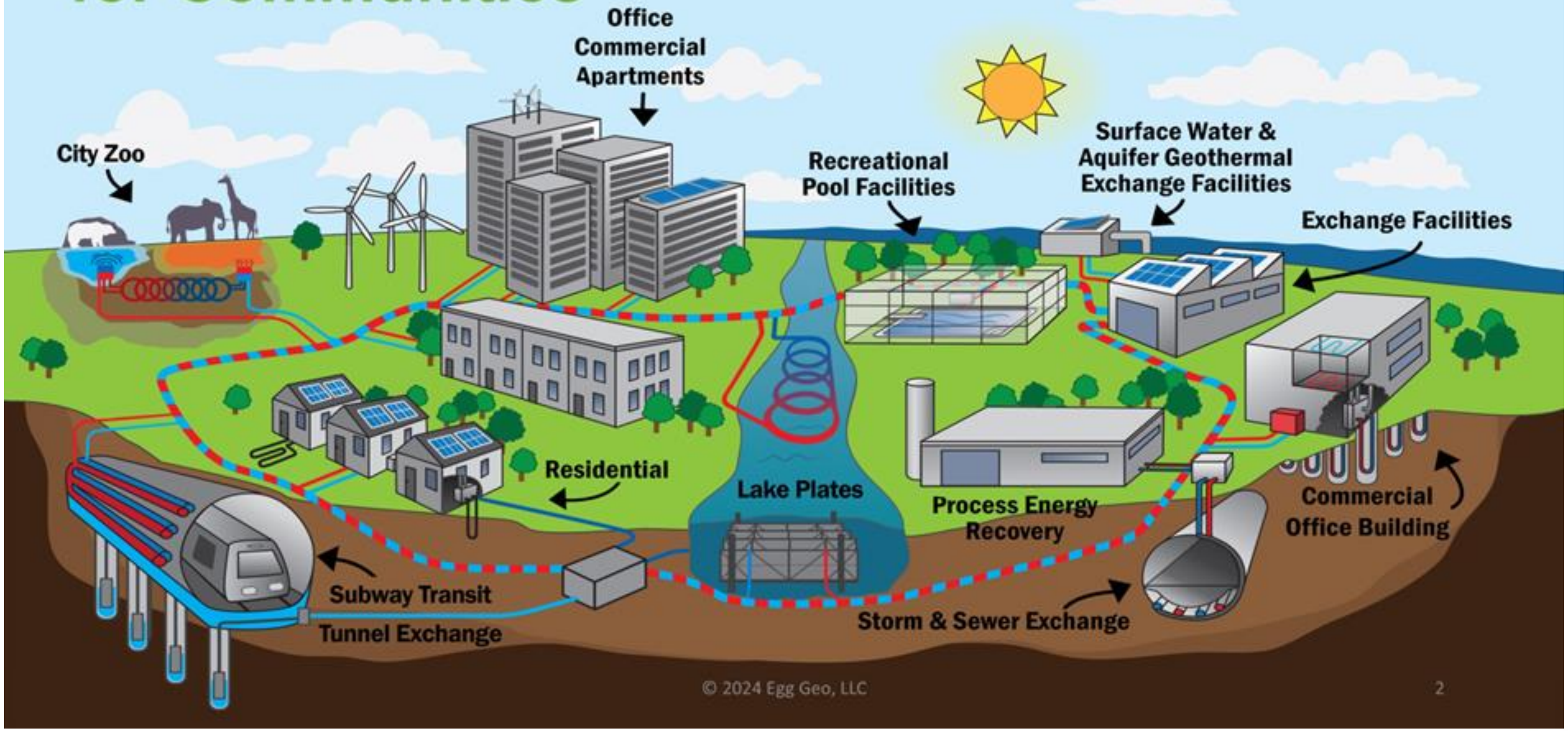
Geothermal 101; Thermal Energy Networks for Communities

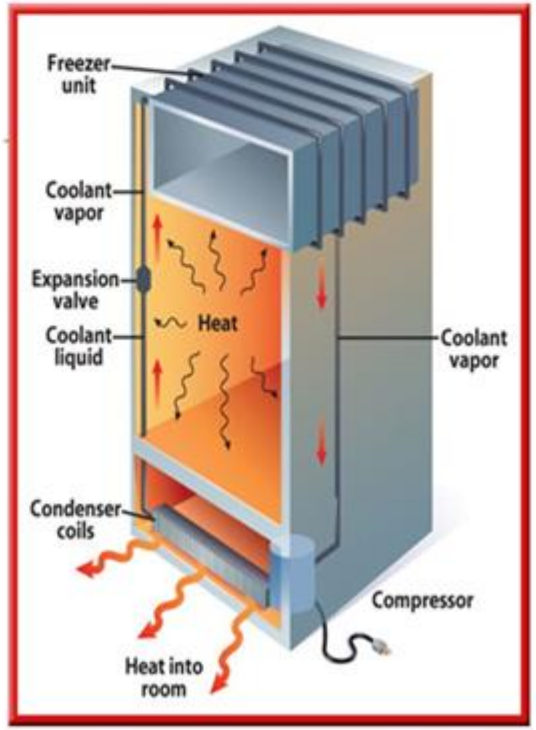


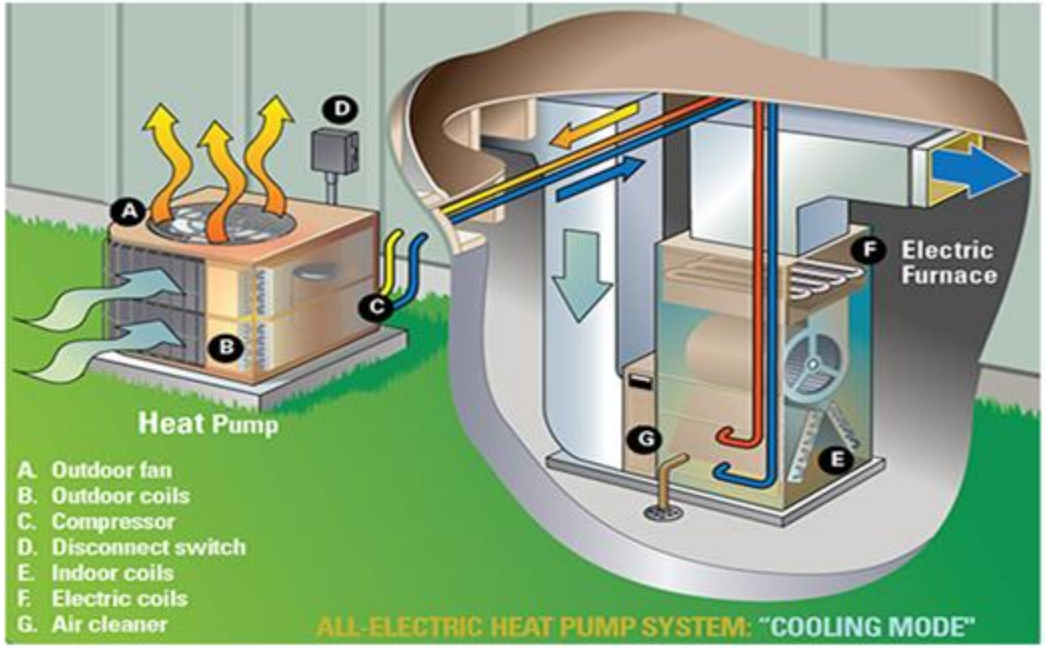
Learning Objectives: Thermal Energy Networks for Communities

Main topics of the presentation.

- *Objective 1:* Understand the context and verbiage of **heat pumps** in clean heating and cooling technology
- *Objective 2:* Identify the importance, adaptability, and benefits of the technology as vital to infrastructure and building construction
- *Objective 3:* Understand existing barriers to geothermal energy network adoption and how to manage them
- *Objective 4:* Understand how direct use of hot fluids may be used:
  - as a source of heating for municipalities or for individual properties
  - as a source to also cool using absorption chillers
- *Objective 5:* Internalize our collective capability and responsibility to make these changes

Heat Pumps: How to cool & heat spaces by "pumping heat"- exactly like a refrigerator





Heat Pump = about 3.0 to 5.0 + COP

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Efficiency Ratings: EER and COP

- Energy Efficiency Rating (EER) is often used for Cooling Efficiency
- EER is the is the Net Cooling Capacity/Applied Energy in watts

- Coefficient of Performance (COP) is often used for Heating Efficiency
- COP is the BTUs delivered/BTUs consumed

EER = COP x 3.412

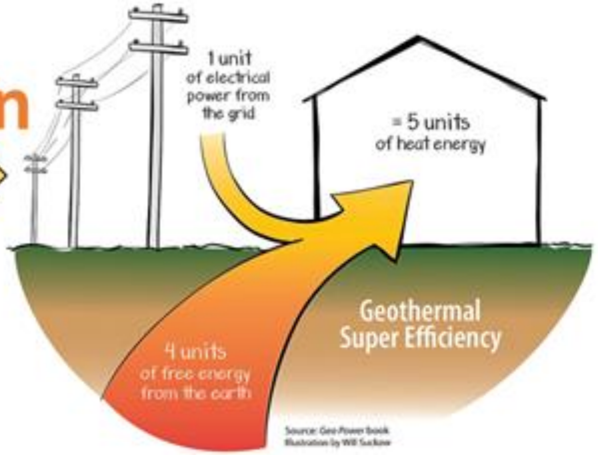
1 watt of electricity = 3.412 BTU/HR

1 kW of Electricity = 3412 BTUs/Hr

1 kW in

= 3,412 BTUs/Hr of heat
(Electric Space Heater)

1 kW in



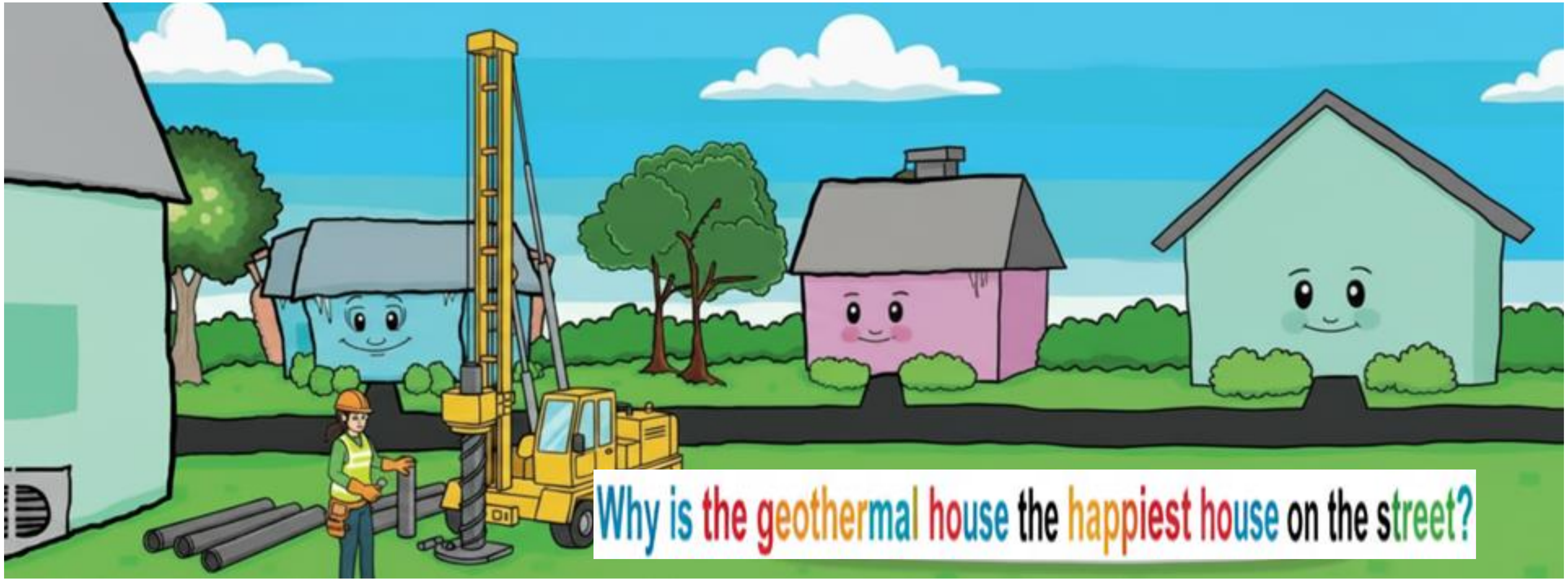
= 17,060 BTUs/Hr of heat*
(Geothermal Heat Pump)

- *It takes 20% of the kW to do the same heating with a geothermal heat pump*

*@ 5.0 COP

egg geo Sharing Knowledge Engineering and Education

Securing Our Future: Why Early Education is a Critical Industry Investment



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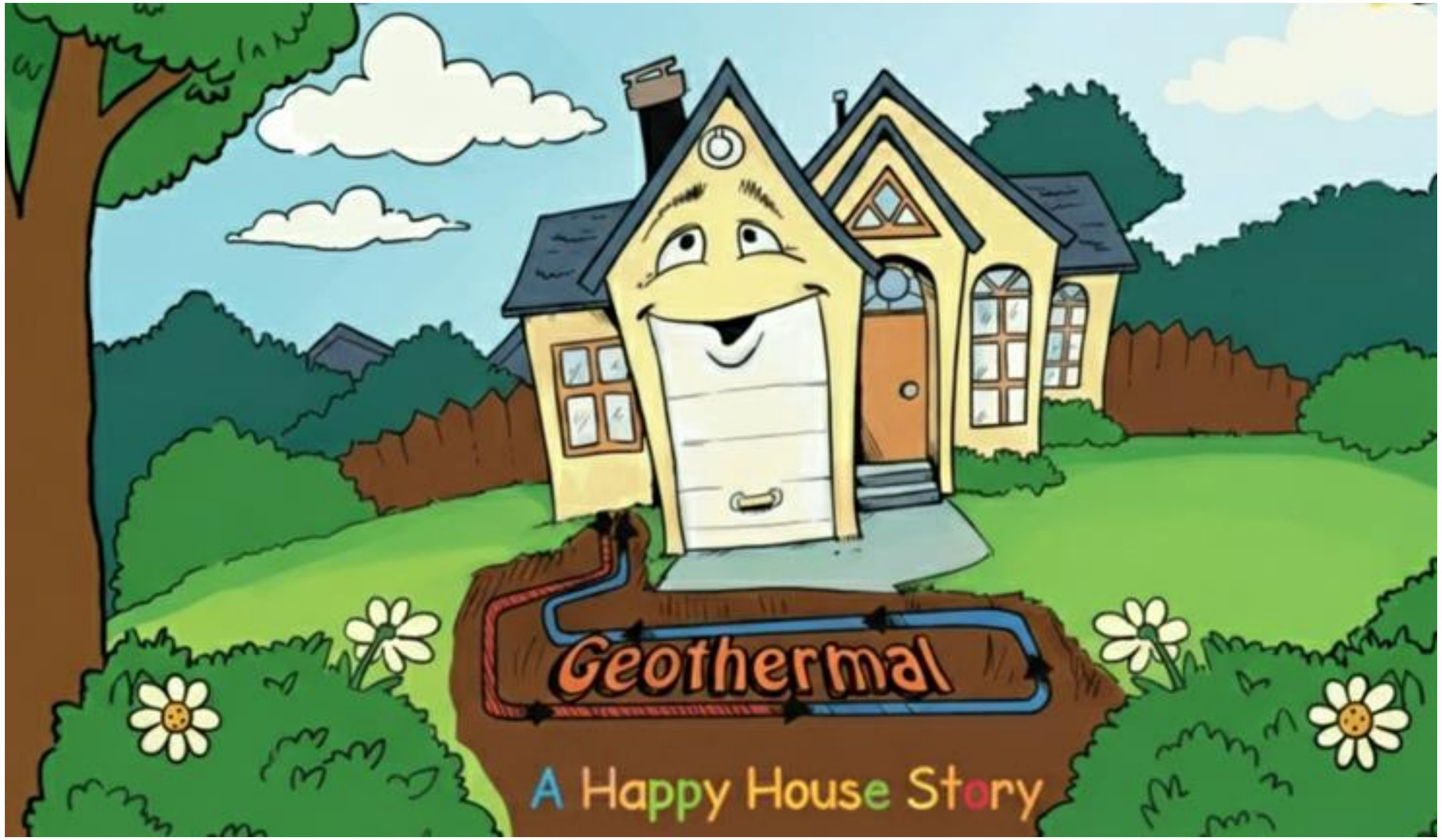
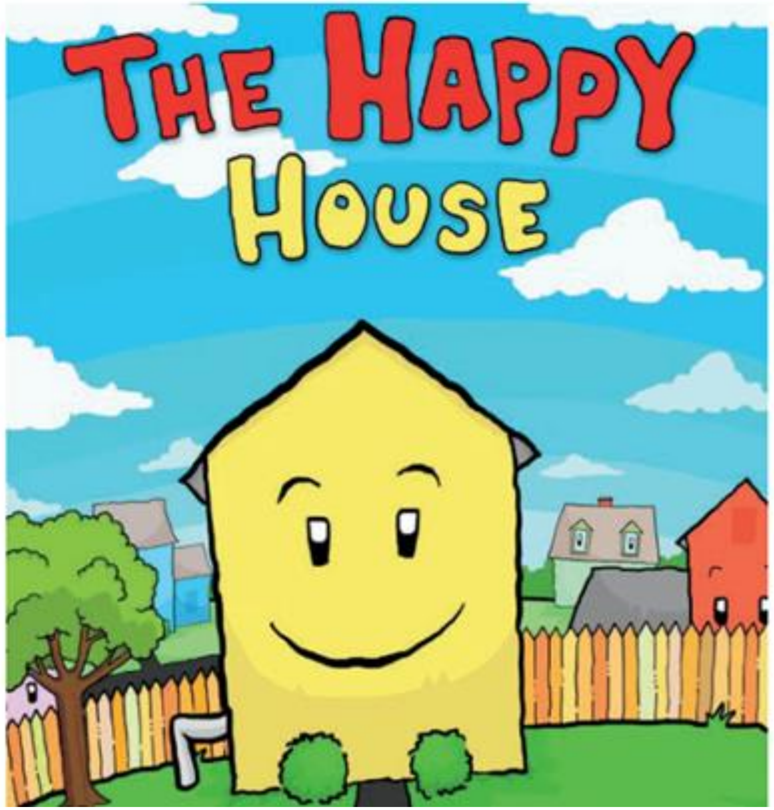
Engaging Our Youngest Learners: "A Happy House Story"





Building on the Basics
An Introduction to Geothermal Heating and Cooling

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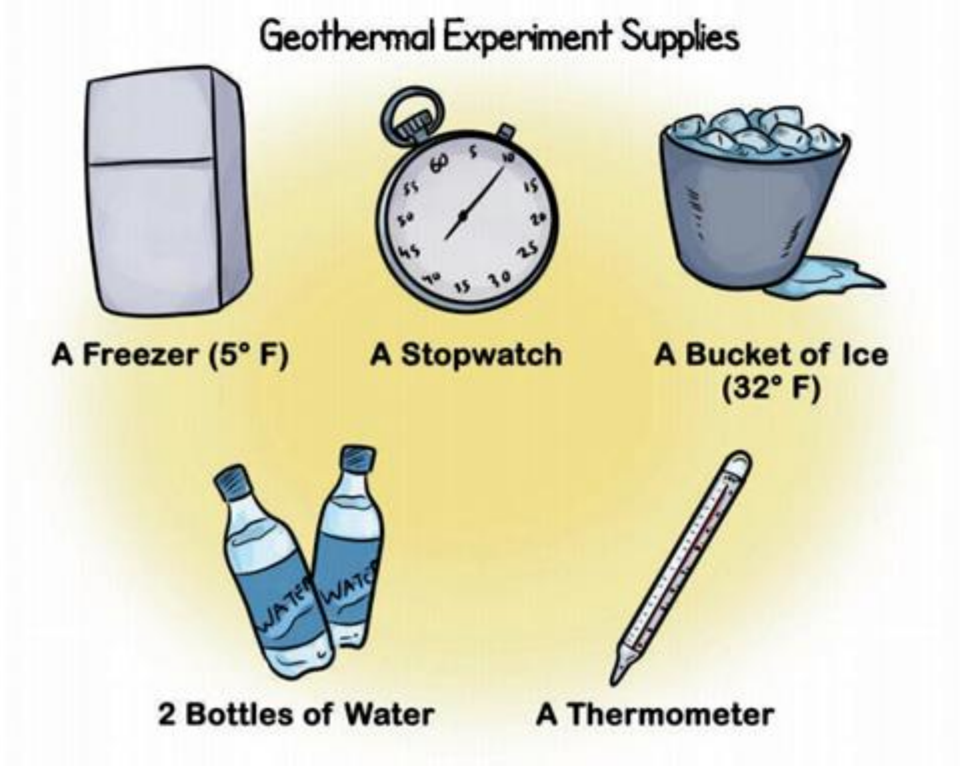
From Concept to Classroom: Making the Science Tangible



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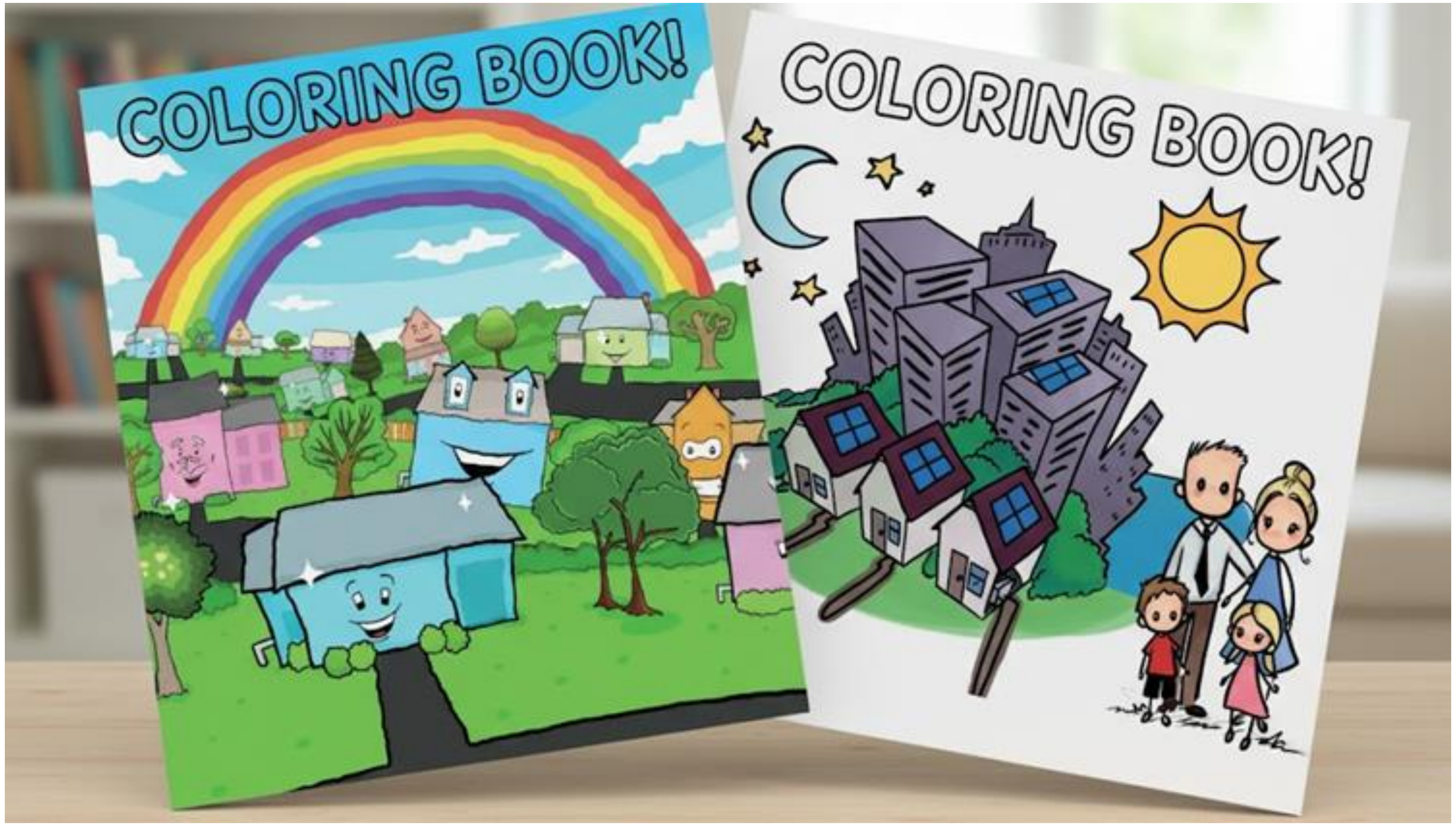
Your Role in Building the Future: A Call to Action



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District Geothermal Energy Networks

...make geothermal heat pumps a reality for all

- No more outdoor equipment to replace
- More hurricane and storm resilient (no HVAC equipment outside)
- HVAC system longevity (a benefit of having equipment inside)
- No combustion boilers, cooling towers or furnaces (Decarbonization)
- Noticeably superior comfort in heating and cooling modes
- Remarkable system efficiency at standard equipment pricing
- Geothermal Wells /Piping are permanent infrastructure

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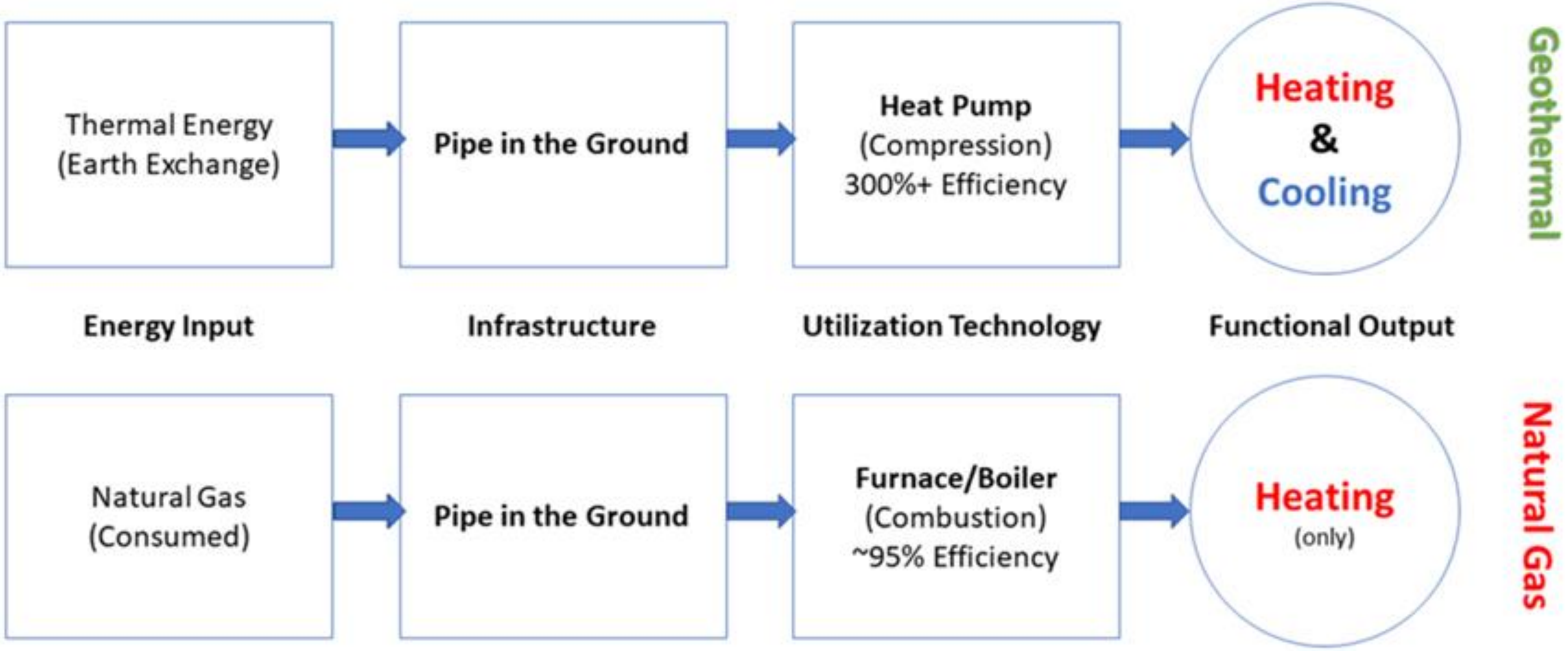
Convert Natural Gas to Geothermal Energy Networks



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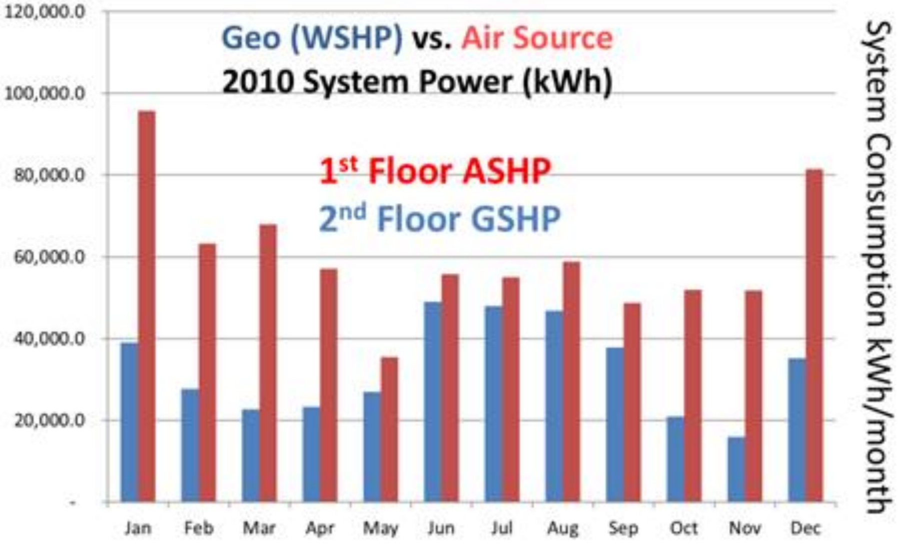
TENs share energy between structures using pipes between buildings and their Geothermal Heat Pumps

Geothermal Energy Networks will be installed by our Nation's piping trade unions https://youtu.be/SMdpHc_tl-o

Photo: piping installation in progress along Serra Mall.

Understanding efficiency; the ASHRAE Building in Atlanta

Ground-coupled HPs consume less energy than air-source HPs, but can be more expensive (Earth Coupling)



Power Consumption at ASHRAE Bldg, Atlanta

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Geothermal Energy Networks

…eliminate Outdoor Equipment and related hazards

Various Types of Geothermal Heat Pumps (GHPs)

Op Ed and Article in Standard & Poors

https://bit.ly/SandP_ThermalEnergyNetworks

Op-Ed

Op-Ed | We must work together to move towards an equitable transition away from fossil fuels

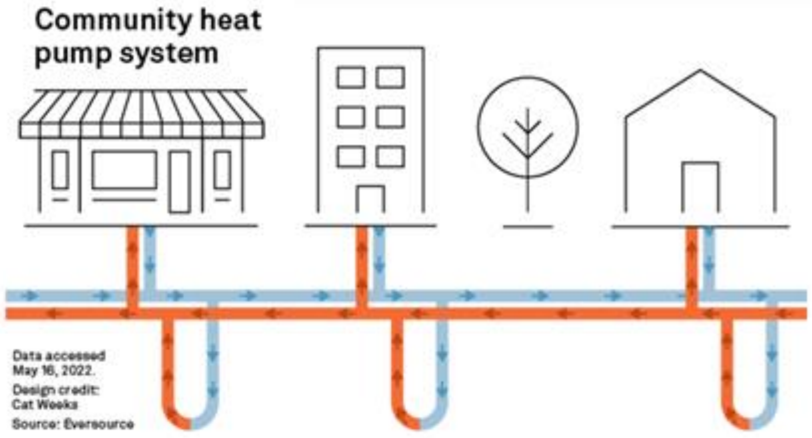
By John Murphy and Lisa Dix   8 comments   Posted on May 25, 2022

S&P Global
Market Intelligence

Efforts to develop centralized community geothermal heat pumps expand

The District of Columbia is soliciting design proposals for a community heat pump system, the latest pilot project to attempt to scale a decades-old geothermal heating and cooling technology to the neighborhood level.

The district's Public Service Commission asked developers May 17 to apply to construct a large community heat pump system, capable of serving multiple buildings.



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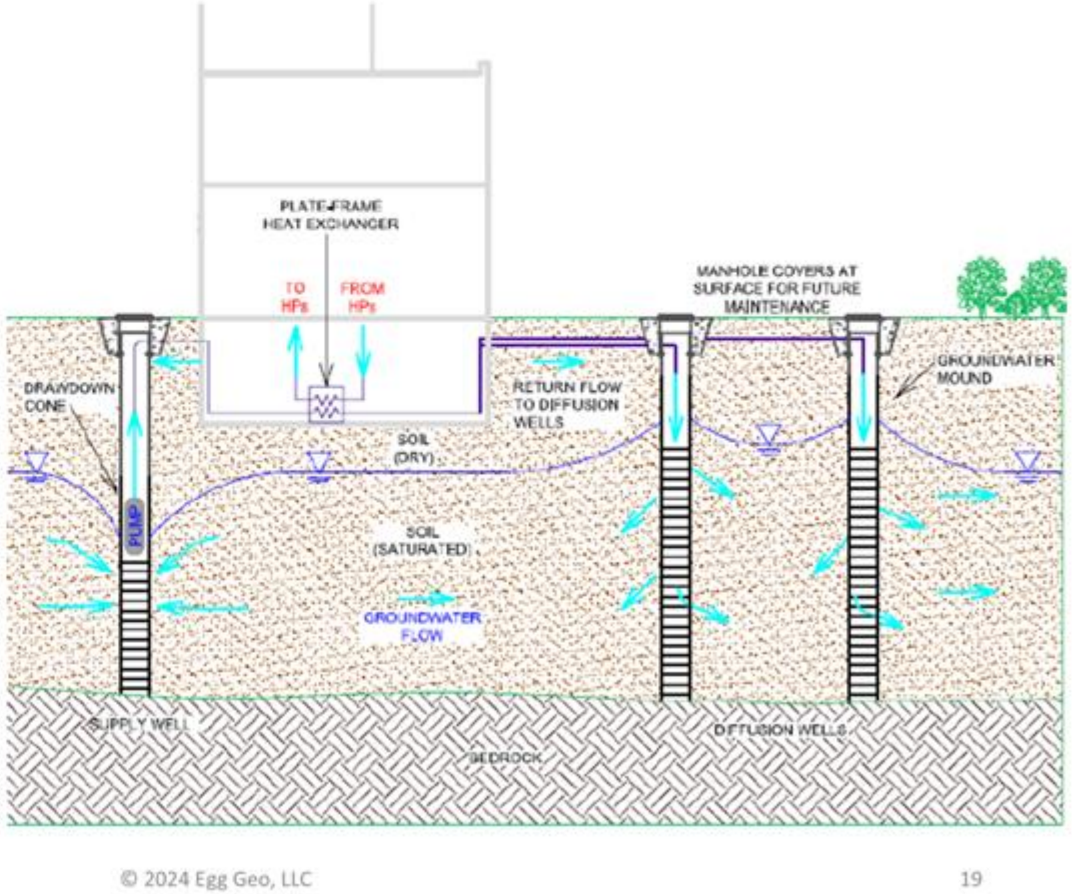
Energy Exhausted from Commercial Buildings is piped to Residential Structures



Aquifer Thermal Energy Doublets



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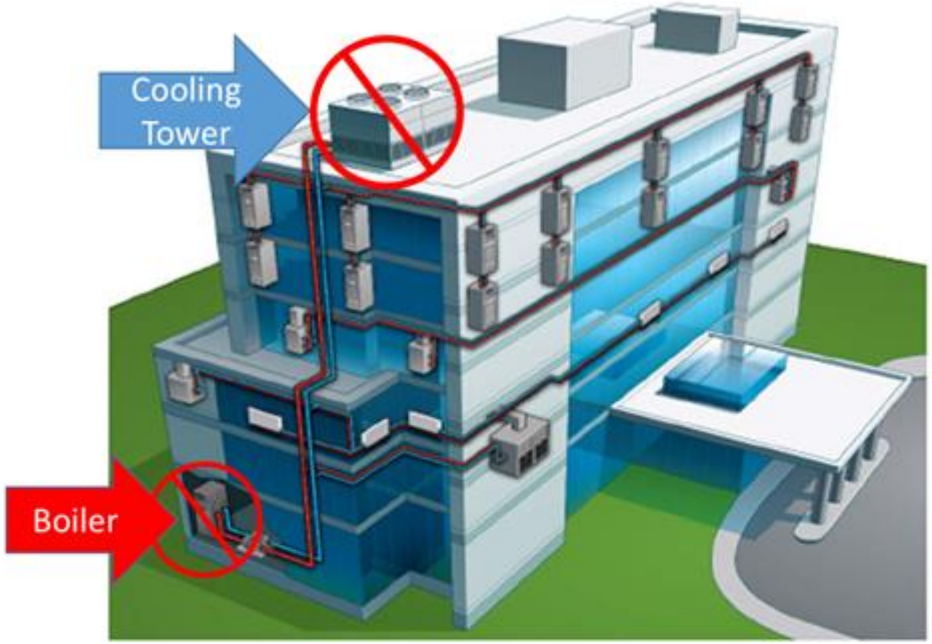
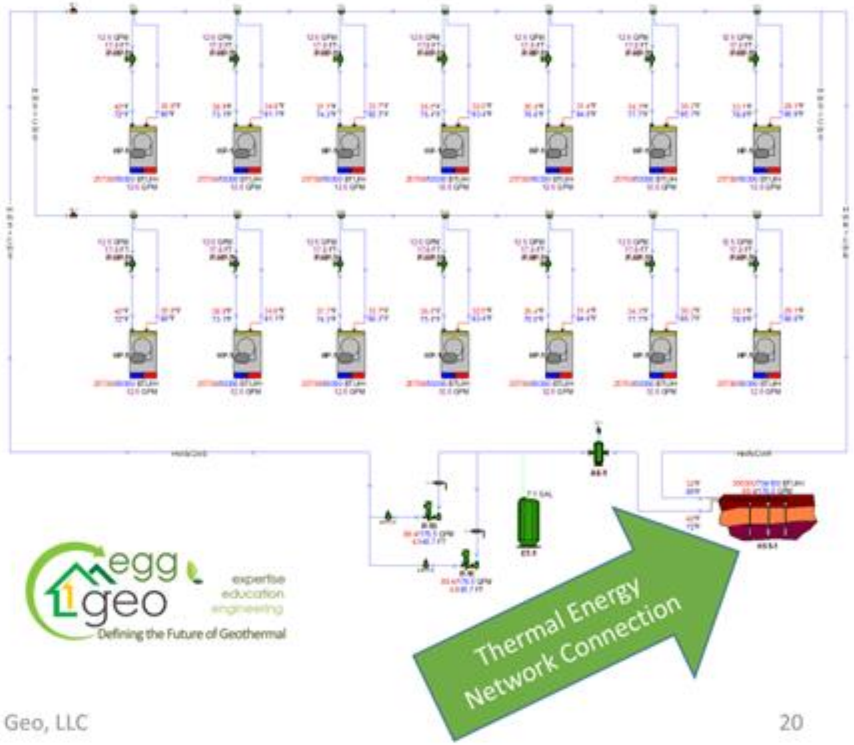
Thermal Energy Networks
Eliminate Cooling Towers and Boilers





Heat Pumps, Networks, and Water Energy

COLORADO MESA UNIVERSITY

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COLORADO MESA UNIVERSITY

Vision for Expansion

SGT proposed a modular “Central Loop” approach that could grow with the campus.

Backbone is an 18” HDPE single pipe system

Distributed mechanical rooms provide redundant pumping.

HDPE pipeline connects buildings and borefields

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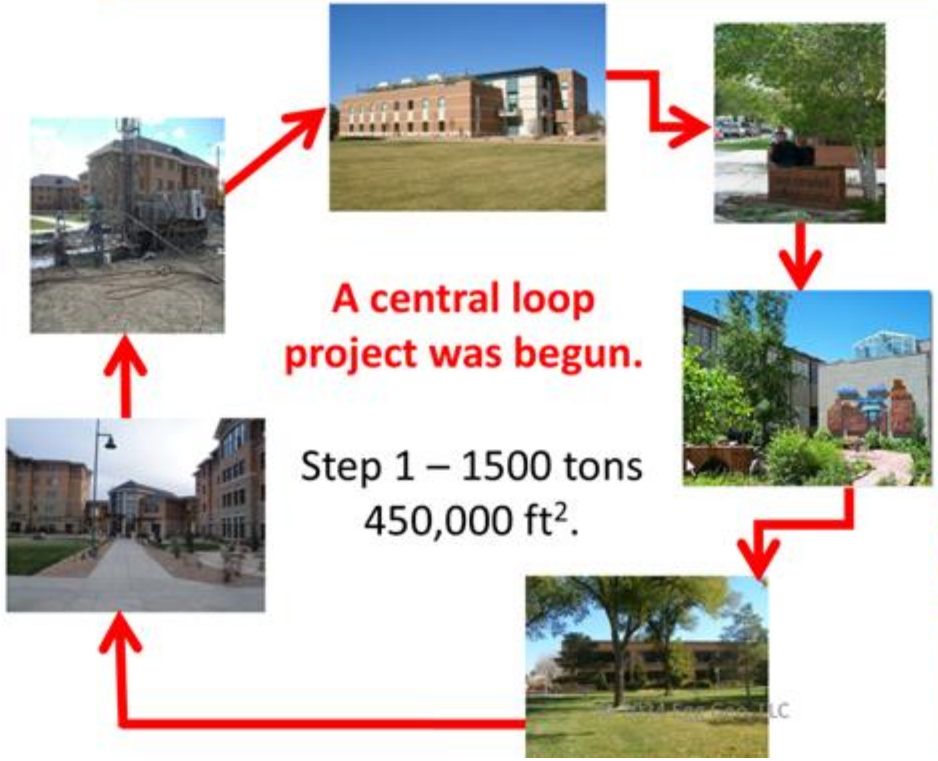
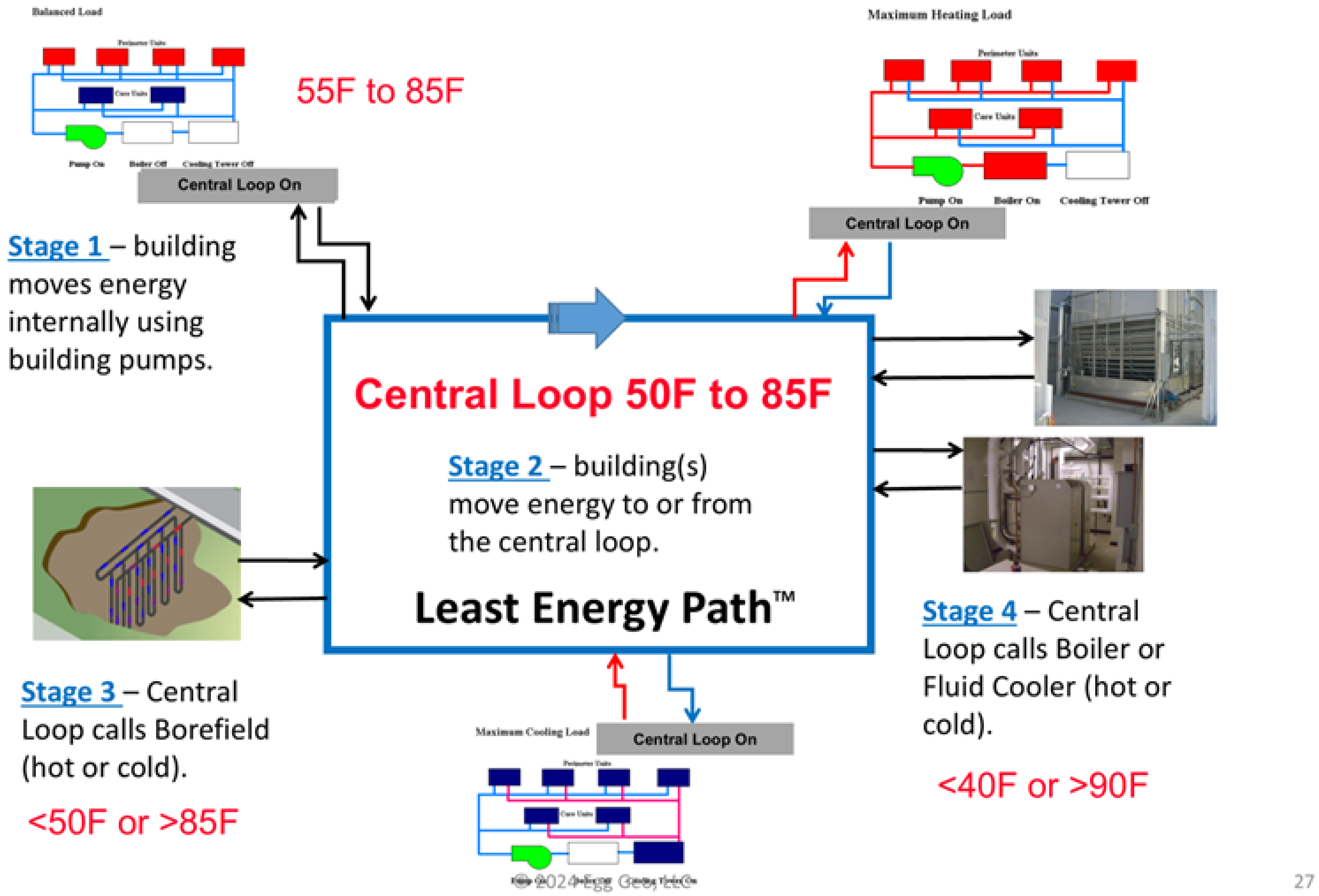
MESA STATE COLLEGE to Colorado Mesa University:

A Community loop evolves…2006




Balanced Load
Perimeter Units
Core Units
Pump On
Boiler Off
Cooling Tower Off
Central Loop On
55F to 85F
Maximum Heating Load
Perimeter Units
Core Units
Pump On
Boiler On
Cooling Tower Off
Central Loop On
Stage 1 – building moves energy internally using building pumps.
Central Loop 50F to 85F
Stage 2 – building(s) move energy to or from the central loop.
Least Energy Path™
Stage 3 – Central Loop calls Borefield (hot or cold).
<50F or >85F
Stage 4 – Central Loop calls Boiler or Fluid Cooler (hot or cold).
<40F or >90F
Maximum Cooling Load
Central Loop On
Perimeter Units
Core Units
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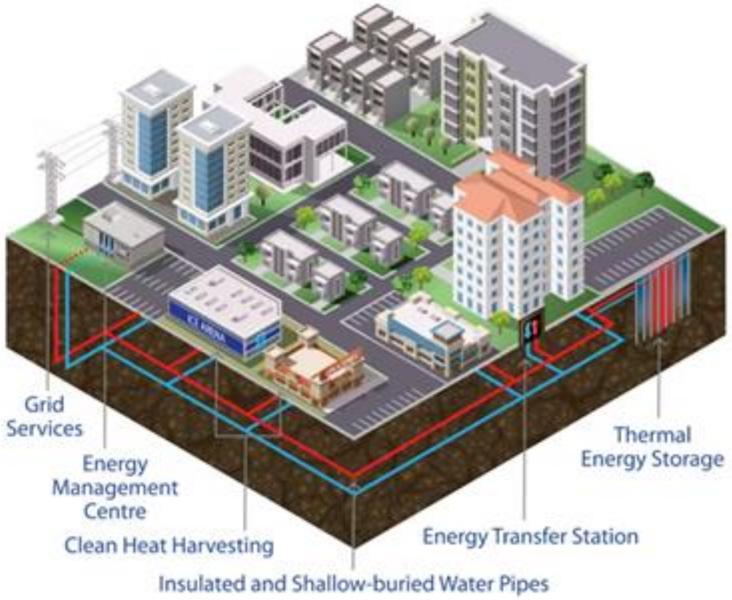
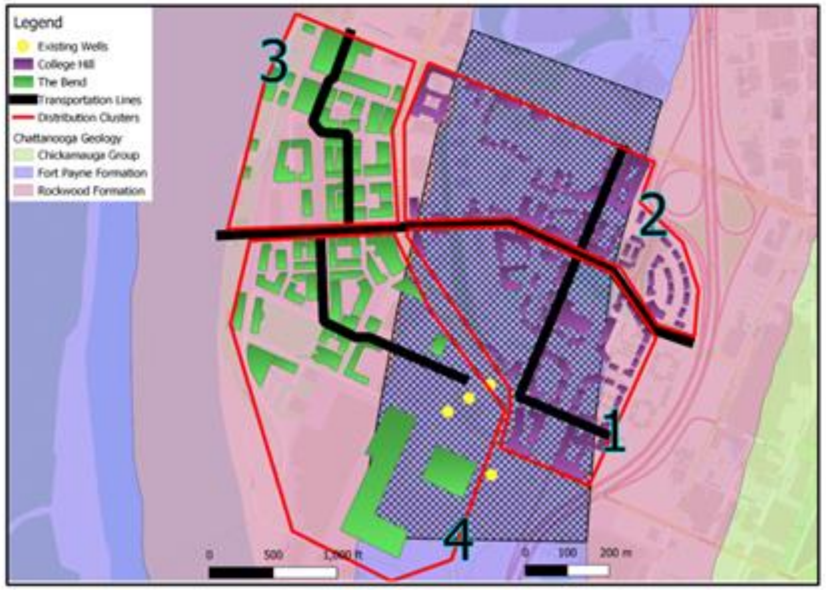
Thermal Network Integration for City Centers





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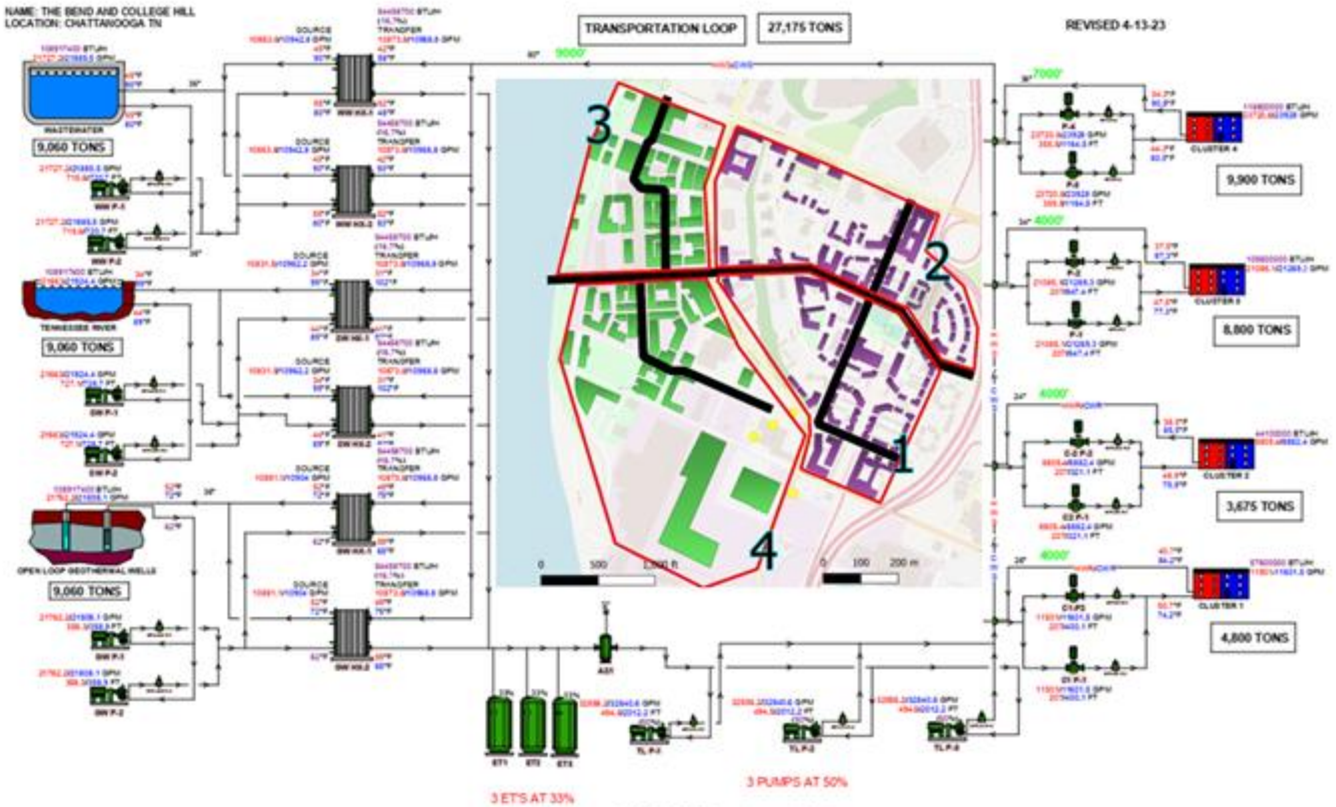
Thermal Network Integration for City Centers



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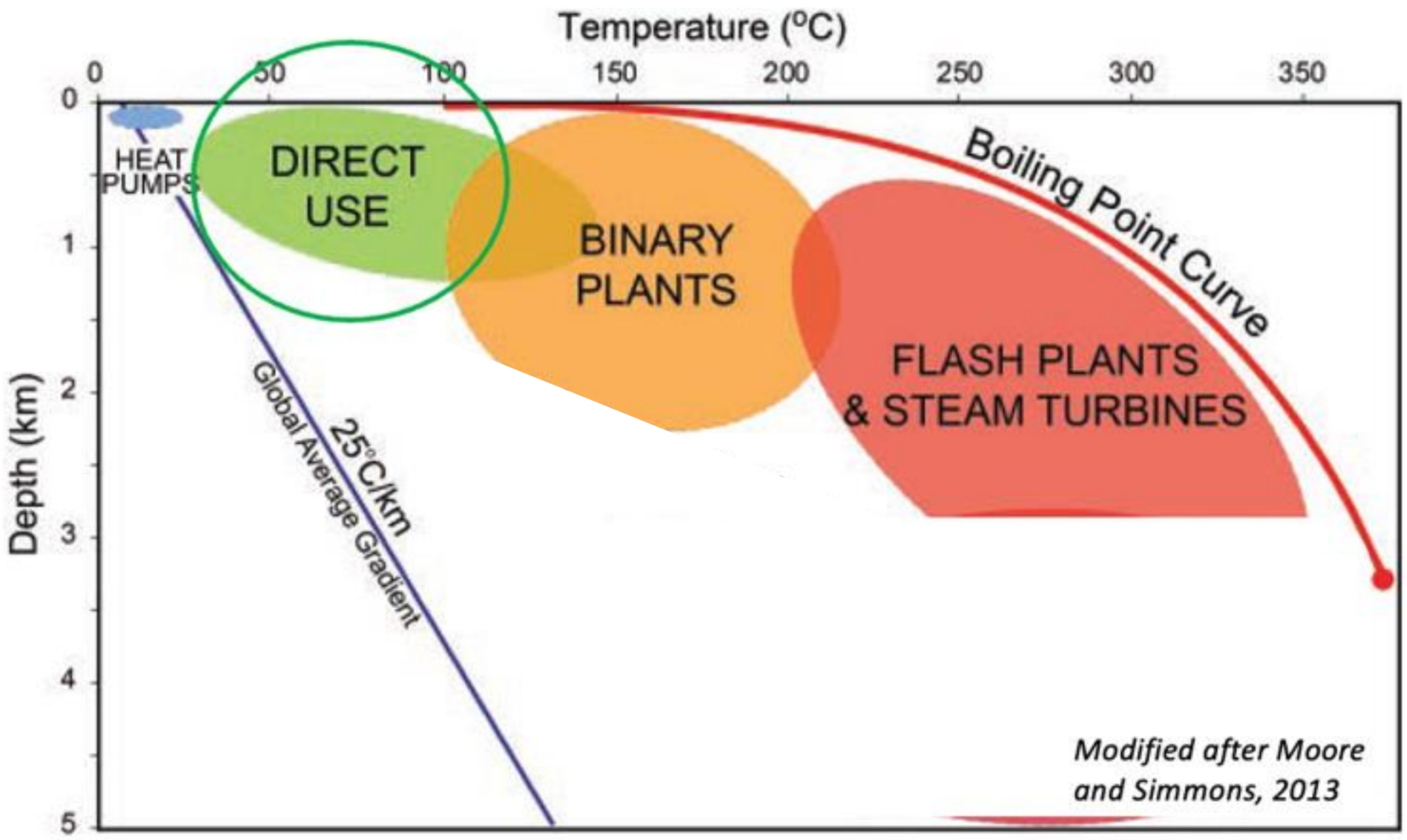
Uses of Geothermal Energy with Depth and Temperature

Deep Direct Use of Geothermally Heated Fluid



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Deep Geothermal Direct Use—Community Scale

- Boise, ID district geothermal heating system
  - Largest in U. S.
  - Began in 1890 (not a typo!)
  - System now heats about 7.5M ft^2 in about 100 buildings
  - Fluid T: 72-75℃
- Paris, France district geothermal system
  - Established in 1969
  - Exploits the Dogger aquifer at 1.5–2 km depth with geothermal fluids at 60℃
  - Serves 2M people in about 250,000 homes using 50 heating networks, each consisting of a doublet production / injection well system

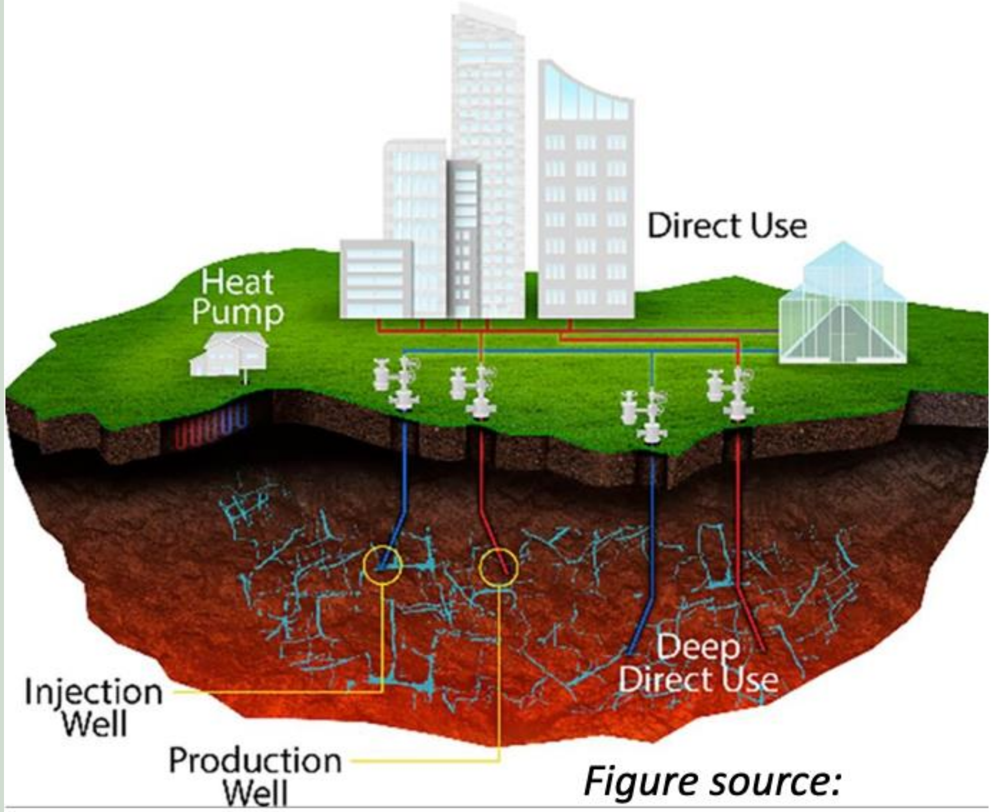

Figure source: Beckers et al., 2021

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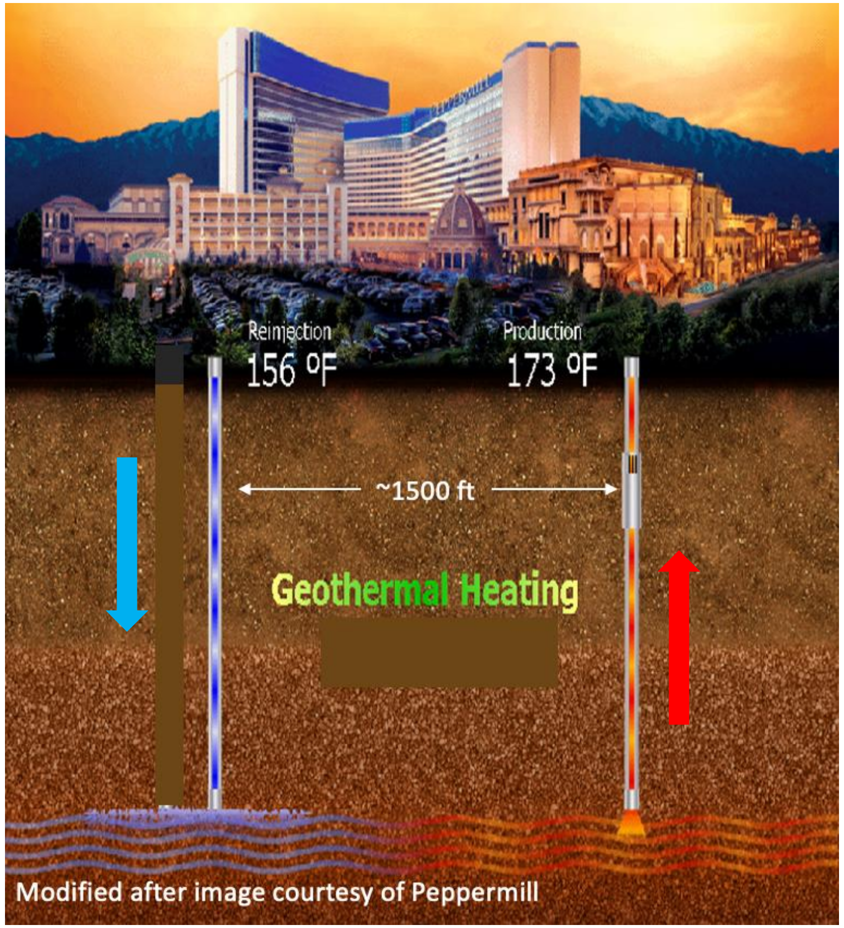
Peppermill Hotel Geothermal Direct Use

- Major conversion to direct use in 2007-2009
- Drilled two new wells, one for production and one for injection
  - Production well ~4400 ft deep produces ~1500 gpm at a T of 170°–174℉ (77°-79℃)
  - Injection well ~3900 ft deep accepts 2000 gpm (pump assisted) located
- Heats entire campus
- Reduced NG consumption by ~85% saving ~$2.25M/yr in 2010
- ROI ~3.5 years!



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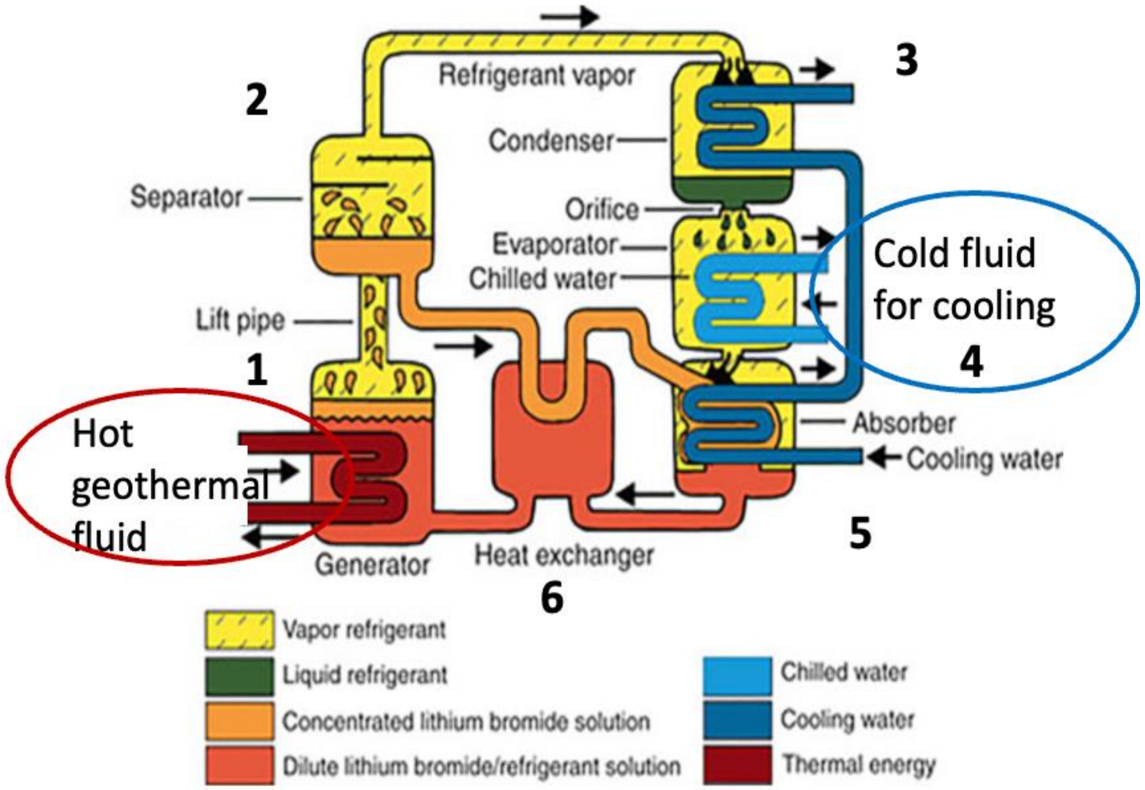
Hot geothermal fluids can cool too—Absorption Chillers

- Use heat energy (from geothermal fluid) instead of electrical/mechanical energy (compression chillers) to transfer heat from building to outside;
- Hot geothermal fluid used to boil (separate) refrigerant from absorbent (1 and 2), refrigerant vapor then condensed (3) and evaporated at low pressure (4) which absorbs heat to cool environment;
- Refrigerant vapor recondenses when mixed with a concentrated absorbent residual from the boiling done previously (5);
- Absorbent-refrigerant mixture then pumped (**only electrical energy used**) through heat exchanger to be reheated and boiled from hot geothermal fluid to repeat the cycle (6).
- Minimum geothermal fluid T to drive cycle is about 160°F (70℃)



Modified After Hoffschmidt et al., 2022

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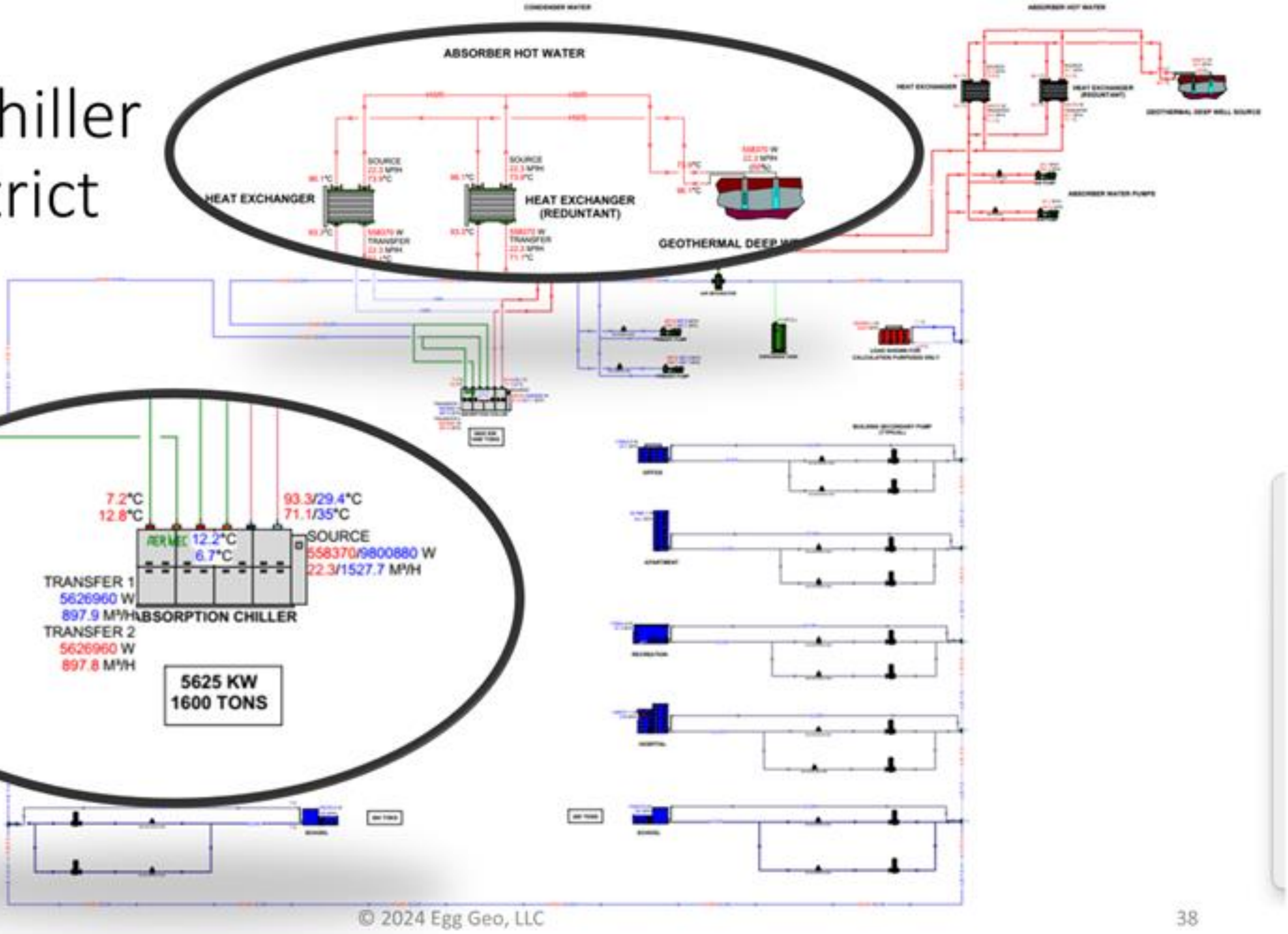
Potential Absorption Chiller Hydronic District Layout for a District



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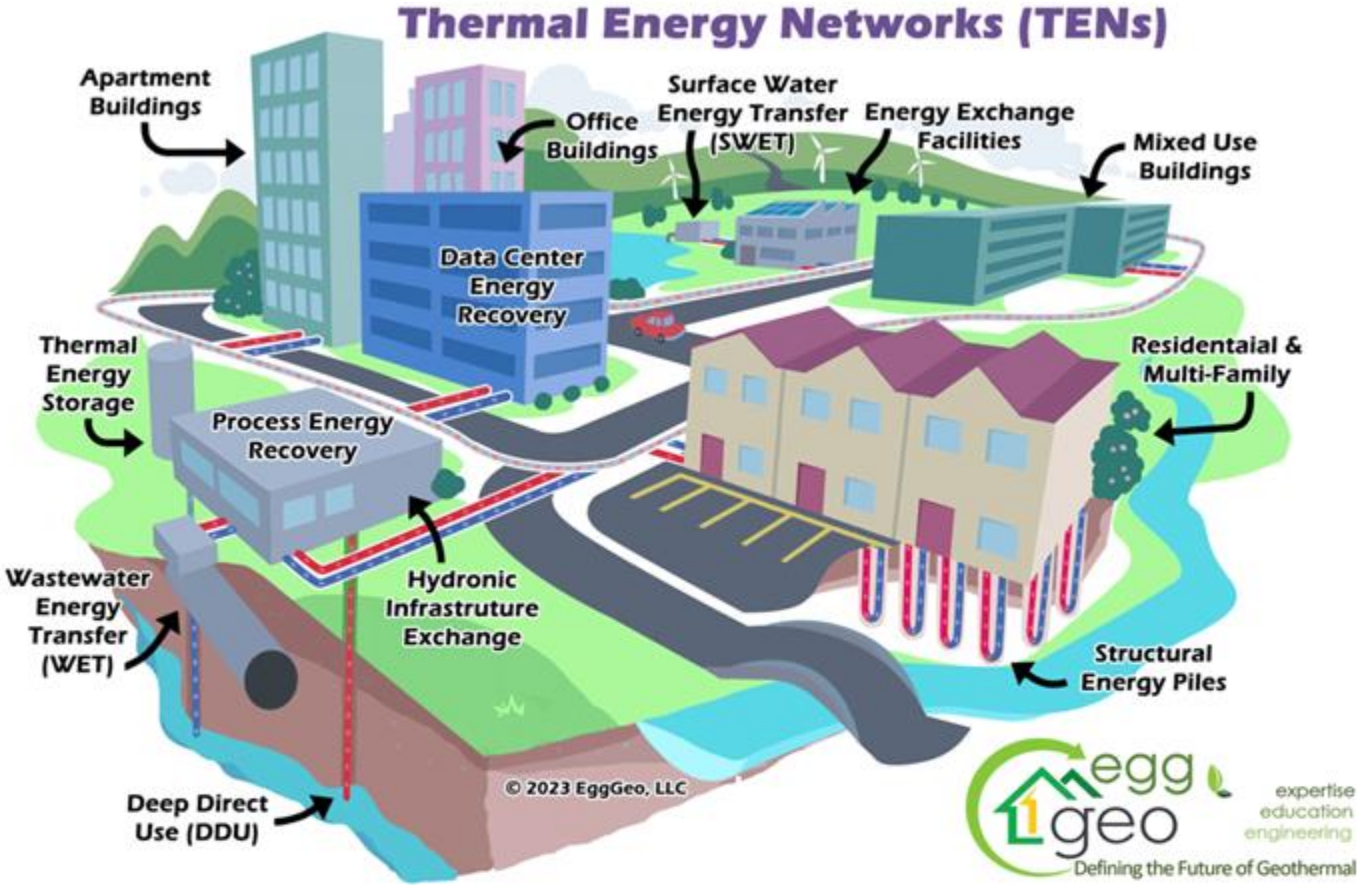
Engineering Master-Planned Thermal Energy Networks (TENs) to Cut Pollution from Buildings and Create Jobs



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Geothermal 101 2025

PART 2: Geothermal Systems for Power Generation

Dave R. Boden

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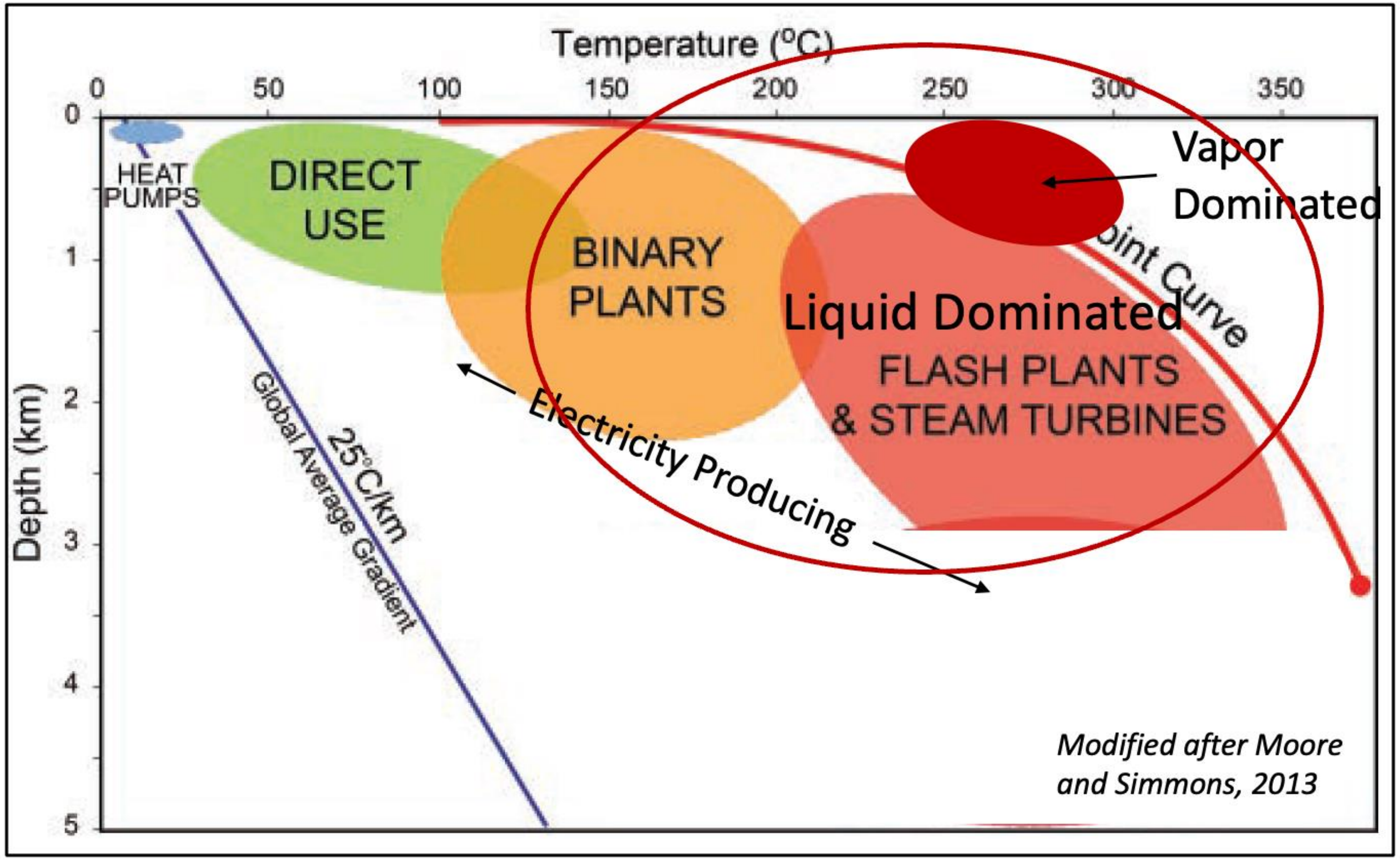
Uses of Geothermal Energy with Depth and Temperature

Higher T Electricity Producing Systems



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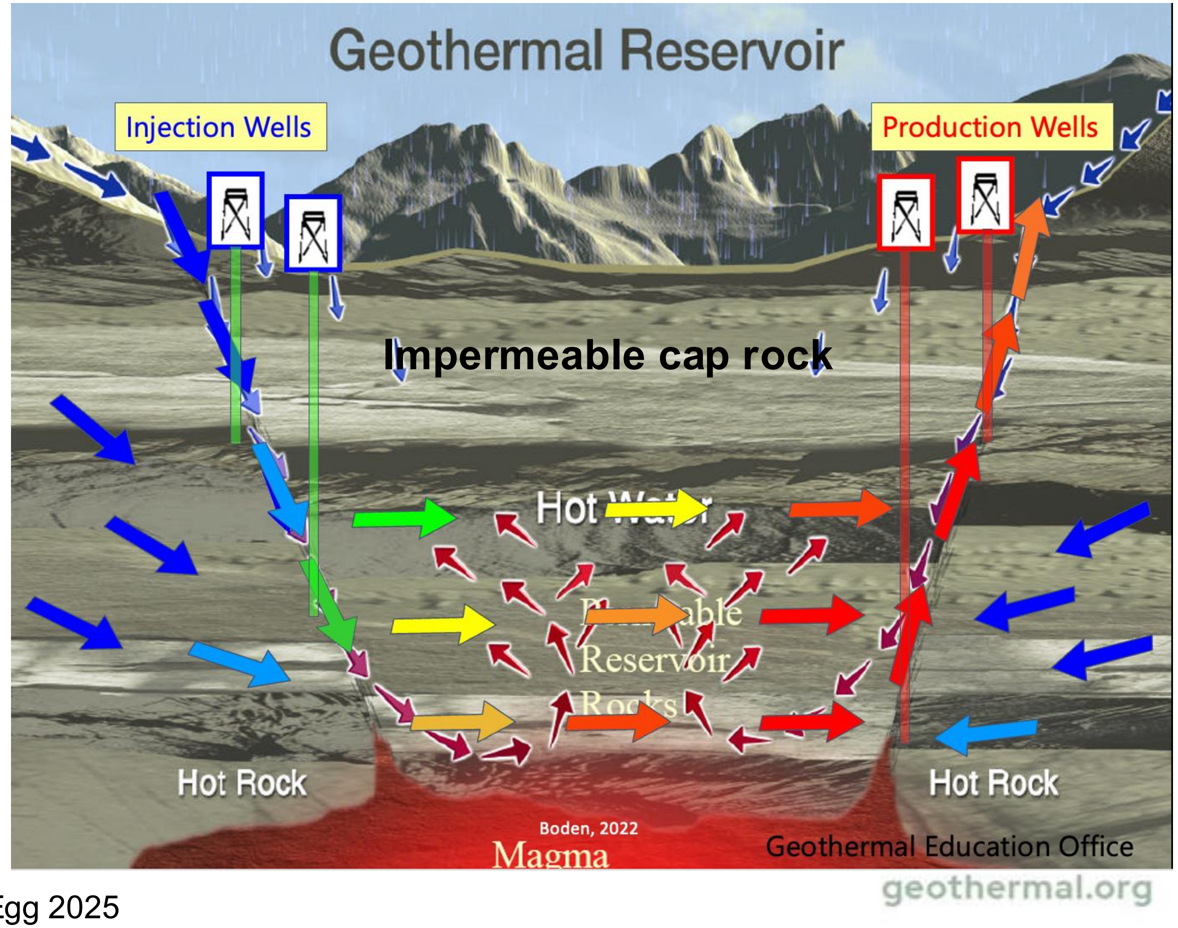
What is needed to make a conventional geothermal system viable for power development?

- Five main criteria to make a hydrothermal resource economically viable:
  1. Large heat source (T of fluid >~120℃)
  2. A permeable reservoir (>~100mD or >~10^{-14} m^2)
  3. A supply of water
  4. A impermeable cap rock
  5. A steady recharge mechanism



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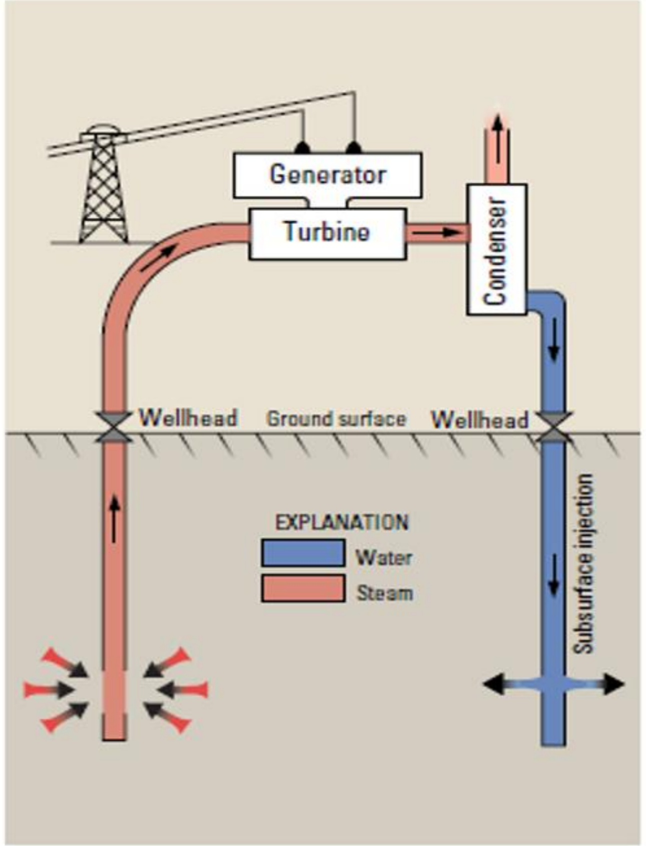
Types of Geothermal Systems and Related Power Plants—Vapor (Steam) Dominated

- Provide greatest amount of power per mass of fluid
- Because reservoir is already steam, all fluid mass goes to turbine
- In order for fluid to occur as steam, reservoir is underpressured compared to surrounding rock—**geologically rare conditions**
- World class examples are The Geysers, CA and Larderello, Italy (the first commercially produced geothermal reservoir for power generation in 1913).



After Duffield and Sass, 2003

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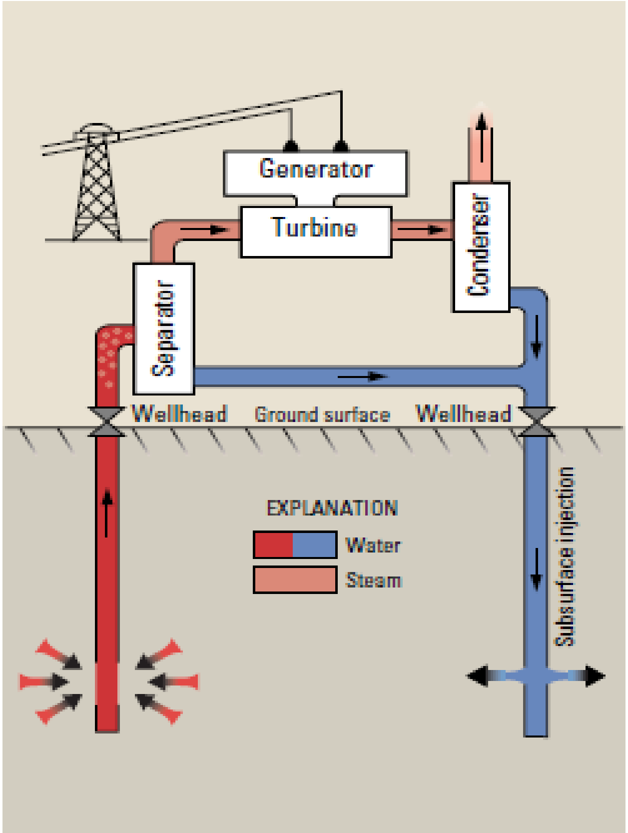
Types of Geothermal Systems and Related Power Plants—High T, Liquid Dominated

- T ≥ ~180°C
- Original mainstay of the industry (flash)
- Fluid exists as a liquid in reservoir
- Fluid starts to boil as pressure falls when fluid rises up well (mixture of steam and liquid—2 phase fluid)
- From wellhead, 2-phase fluid goes to separator where steam rises to top and liquid (brine) goes to bottom
- Only steam goes to turbine, and brine is re-injected
- Energy is partitioned between steam and brine unlike vapor-dominated reservoirs



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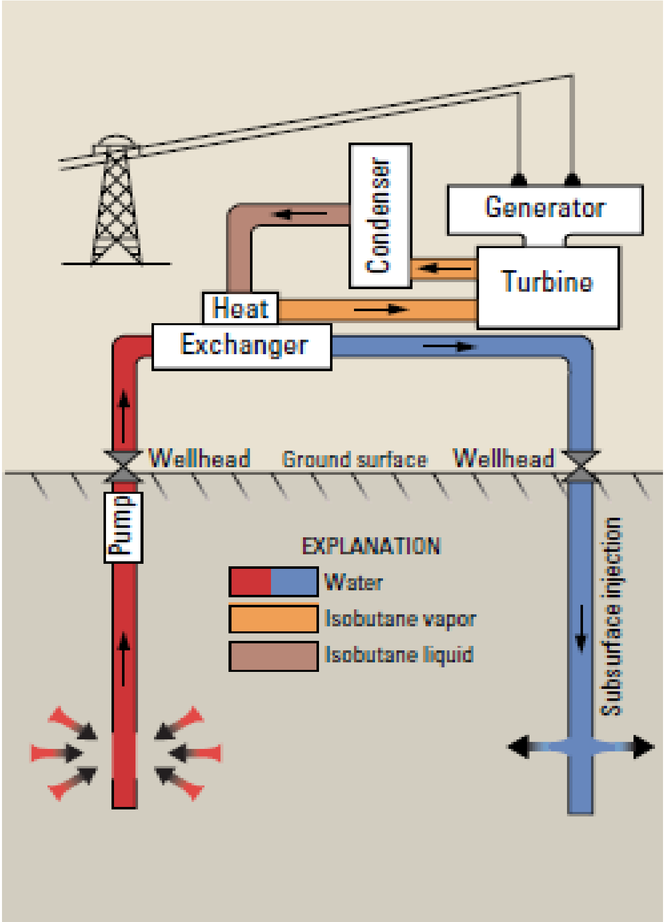
Types of Geothermal Systems and Related Power Plants—Moderate T, liquid dominated

- T > ~120º - 180°C
- Provide an increasing proportion of power for 2 reasons:
  - Lower T systems are more common than high T systems
  - Reservoir stability over time
- Binary systems:
  - Two fluids—the geothermal fluid provides the heat, and a working fluid that serves the turbo-generator
  - Geothermal fluid passes through heat exchanger to flash working fluid having a low boiling point to generate more steam pressure than water
  - Both geothermal and working fluids form closed loops
    - No GHG emissions
    - Water conservative when combined with air cooled condensers



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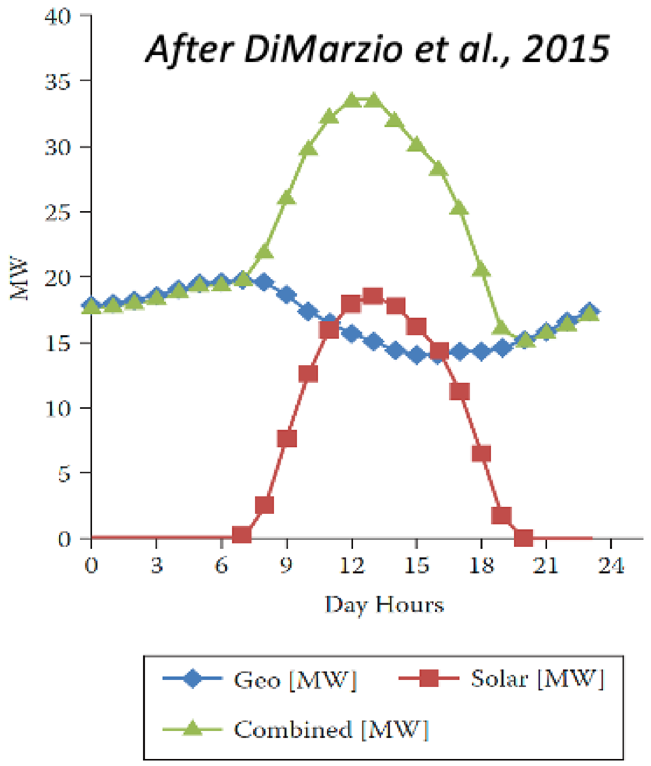
Other Types of Geothermal Power Plants– Synergistic Configurations

- Integrated Flash-Binary
  - Brine goes to a bottoming binary plant to produce power prior to reinjecting to increase power output
- Hybrid Binary Geothermal and Solar Facilities
  - Stillwater Triple Hybrid Facility
    - 33 MW capacity geothermal
    - 53 MW solar PV (boosts power output during summer)
    - 17 MWt from concentrated solar provides about a 2 MWe boost to plant
- Combined Heat and Power Facilities
  - Hellisheidi, Iceland has installed capacity of 303 MWe and 400 MWt
  - Fresh water heated, via steam condensation and heat exchangers, to 83-93℃ and sent to Reykjavik via a 20-km long pipeline at ~2000 kg/s (30,000 gpm).



Geothermal Energy Attributes

1. Base load power (available 24-7 unlike wind and solar);
    - 90%+ capacity factors (ratio of energy produced over a given time; only nuclear is comparable)
        - Solar and wind capacity factors typically 25-35%; coal- and natural-gas-fired power plants about 50-70%
2. Sits on top of energy source;
    - No fuel price exposure; price certainty; insulated from price volatility;
3. Proven resource, mature technology (dating back to 1913 in Italy and 1958 in NZ);
4. Can provide dispatchable power (load following);
    - E.g., Puna geothermal power plant, HI can ramp up or down from 22 MW to 38 MW at 1-2 MW/min
    - During off peak periods when intermittent renewable sources are abundant, geothermal can use its base load electricity to make green H, for pump hydrostorage, or charge batteries

Geothermal Energy Attributes

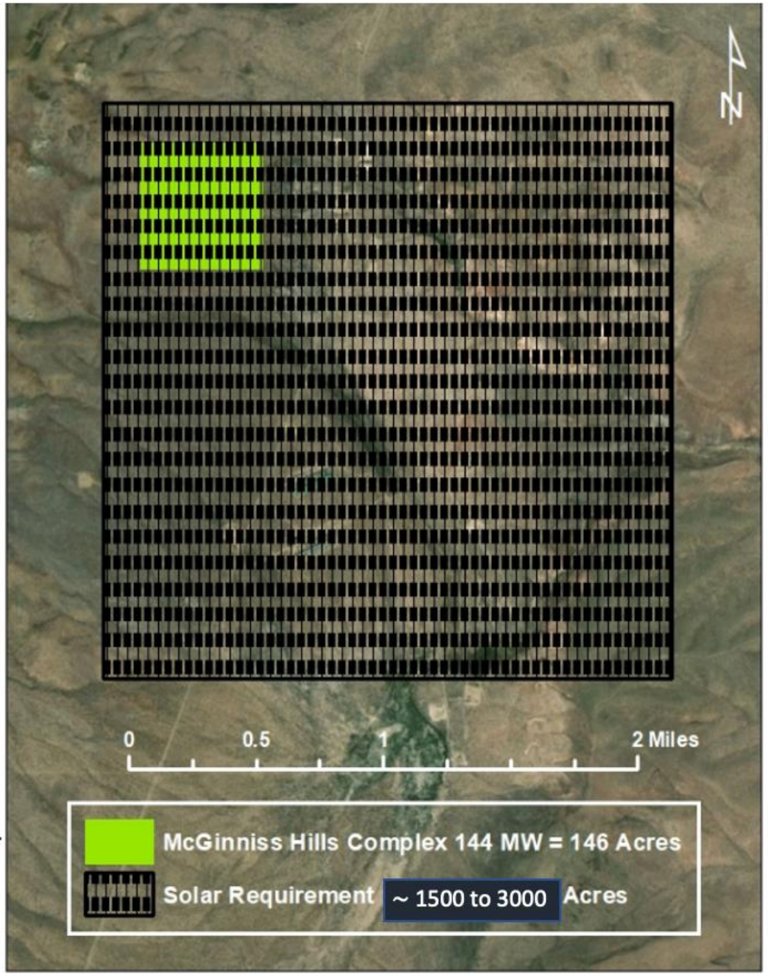
5. Economic impact on construction/operation: number of jobs per MW;
    - CalEnergy Salton Sea: ~390 MW; ~240 employees (about 1 employee for every ~1.6 MW produced)
    - Comparably sized natural gas plant: 15 employees; commercial solar/wind plant: 10-15 employees (1 employee for every 25-34 MW produced)
6. Minimal environmental impacts:
    - Minor or no greenhouse gas emissions
        - Conventional geothermal flash plant releases only 2% GHG emitted by NG-fired power plant
        - Binary plants have **ZERO** greenhouse gas emissions
    - Small footprint for power produced
    - Land available for multiple use

Small Footprint

- At McGinness Hills, NV about 1 acre is required for every MW
- Solar PV requires about 10 acres/MW* (varies depending on latitude, efficiency of installed panels, time of year, and setbacks and zoning restrictions)

*Does not include storage facilities for round-the-clock power availability as with geothermal. If so, then then solar footprint increases to about 15-20 acres/MW

Modified after image courtesy of P. Thomsen, Ormat Technologies

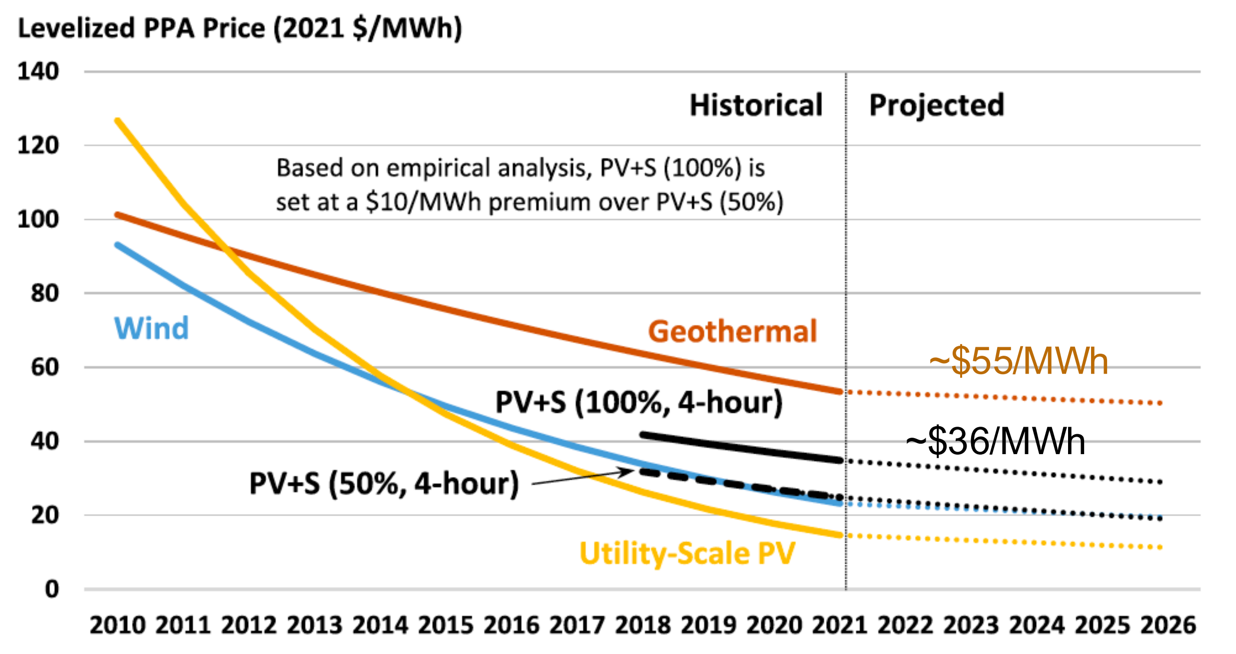


Challenges for Geothermal Power Development

- **1. Currently developed geothermal systems are location restricted**
  - Presently biggest problem for more widespread geothermal application
  - Require a special orchestration of geologic processes not widely met:
    - Conditions most commonly satisfied near boundaries of tectonic plates or widely scattered geologic hot spots, like Hawaii or Yellowstone
  - Potential solutions include:
    - Develop more widespread hot dry rock by creating artificial reservoirs (EGS)
      - Enhanced drilling technologies, artificially generated fracture permeability via improved hydroshearing and hydrofracking techniques
    - Use of downhole heat exchangers and closed loop technologies

Challenges for Geothermal Power Development

- **2. Higher cost compared to solar PV and wind**
  - Reflects higher risk and expense to develop geothermal resources



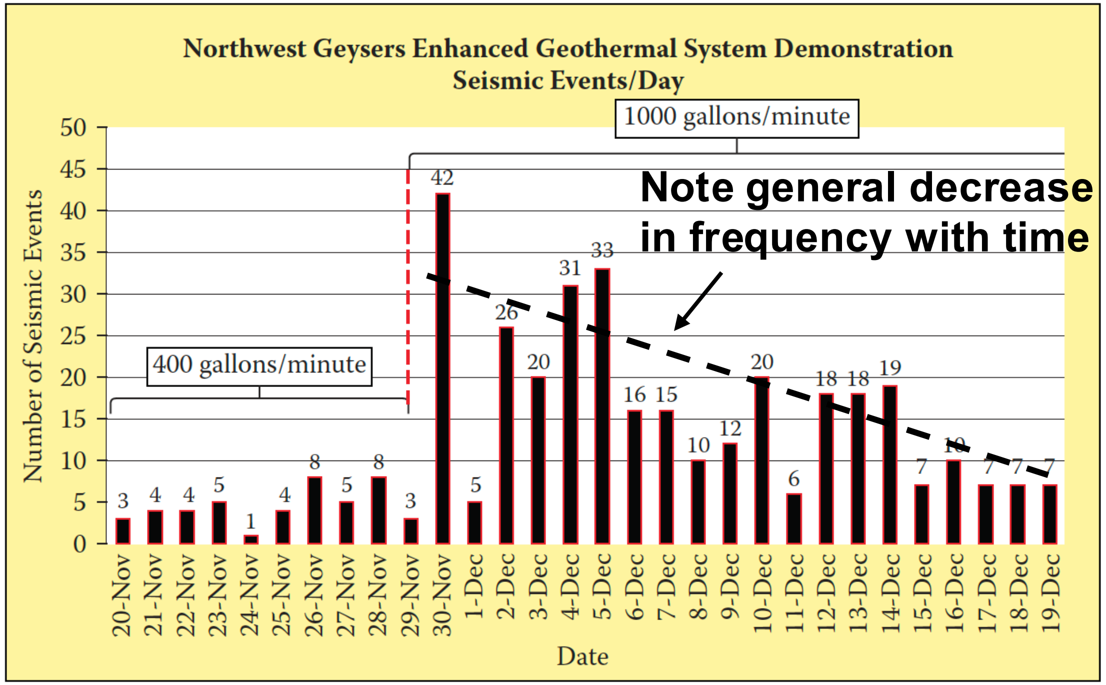
Modified after Bolinger et al., 2023

- Potential solutions:
  - Policy intervention to promote non-intermittent renewable energy sources
    - e. g., 2021 CPUC Energy Procurement Order requires an additional 2000 MW of geothermal by 2035
    - Expand oil and gas exploration efficiencies that currently do not require EA or EIS under NEPA to also include geothermal (CXs being considered)
  - Advances in drilling technology to lower costs via faster drilling times

Challenges for Geothermal Power Development

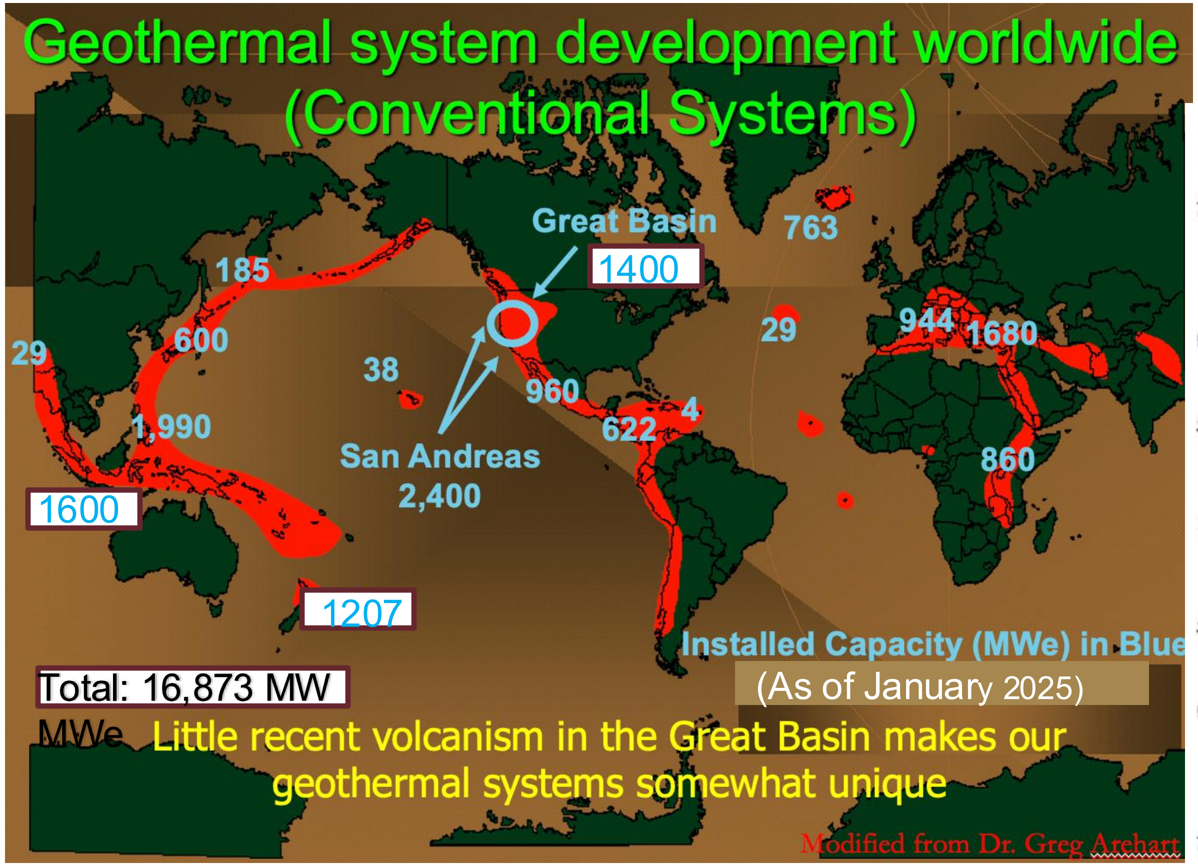
3. Possible Induced Seismicity

- Can occur from both production and injection of fluids (rock contraction from withdrawal of fluids and cooling during injection)
- Generally small magnitude events, mainly <0 to about 2 (most can't be felt)
- Largest at The Geysers about 4.5M; largest on record is Pohang event in South Korea at 5.5M
- Basel EGS project cancelled due to a swarm of EQs (largest being 3.4M related to injection during reservoir stimulation in 2009
- Solution:
    - Inject at lower rates
    - Spread injectate (via drill legs) over a larger volume of rock limiting pore water pressure that can cause rock to break

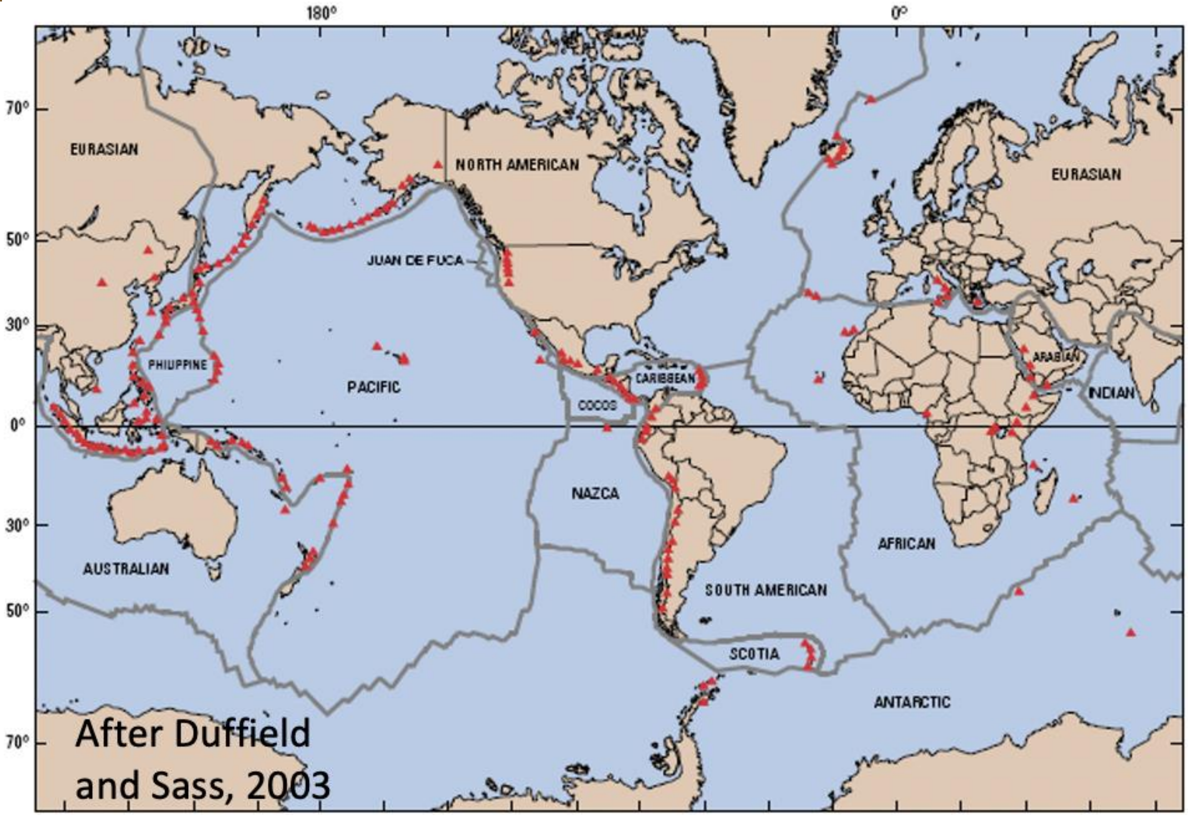


After: J. Garcia et al., 2012

Worldwide Distribution of Power-Producing Geothermal Systems



Note correspondence between distribution of current geothermal systems and boundaries to tectonic plates

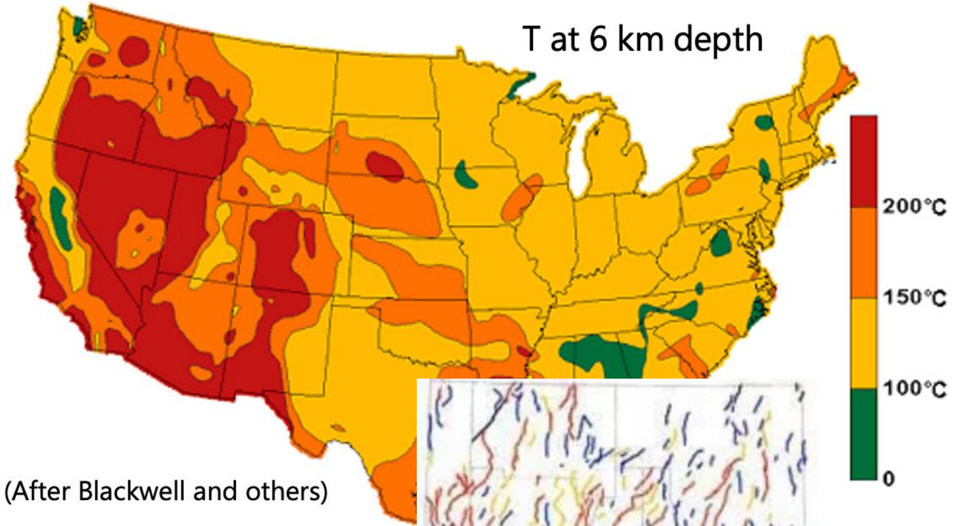


Tectonic Plates

Boden and Egg 2025

What Makes the Great Basin (Nevada) So Prospective for Geothermal Energy?

- Crust is being stretched and thinned
  - Results in high heat flow (>~90 mW/m^2)
  - Hot rocks of mantle are closer to surface
- As crust is stretched, rocks break to make fractures (faults)
  - Allows for deep circulation of fluids and conduits of good permeability



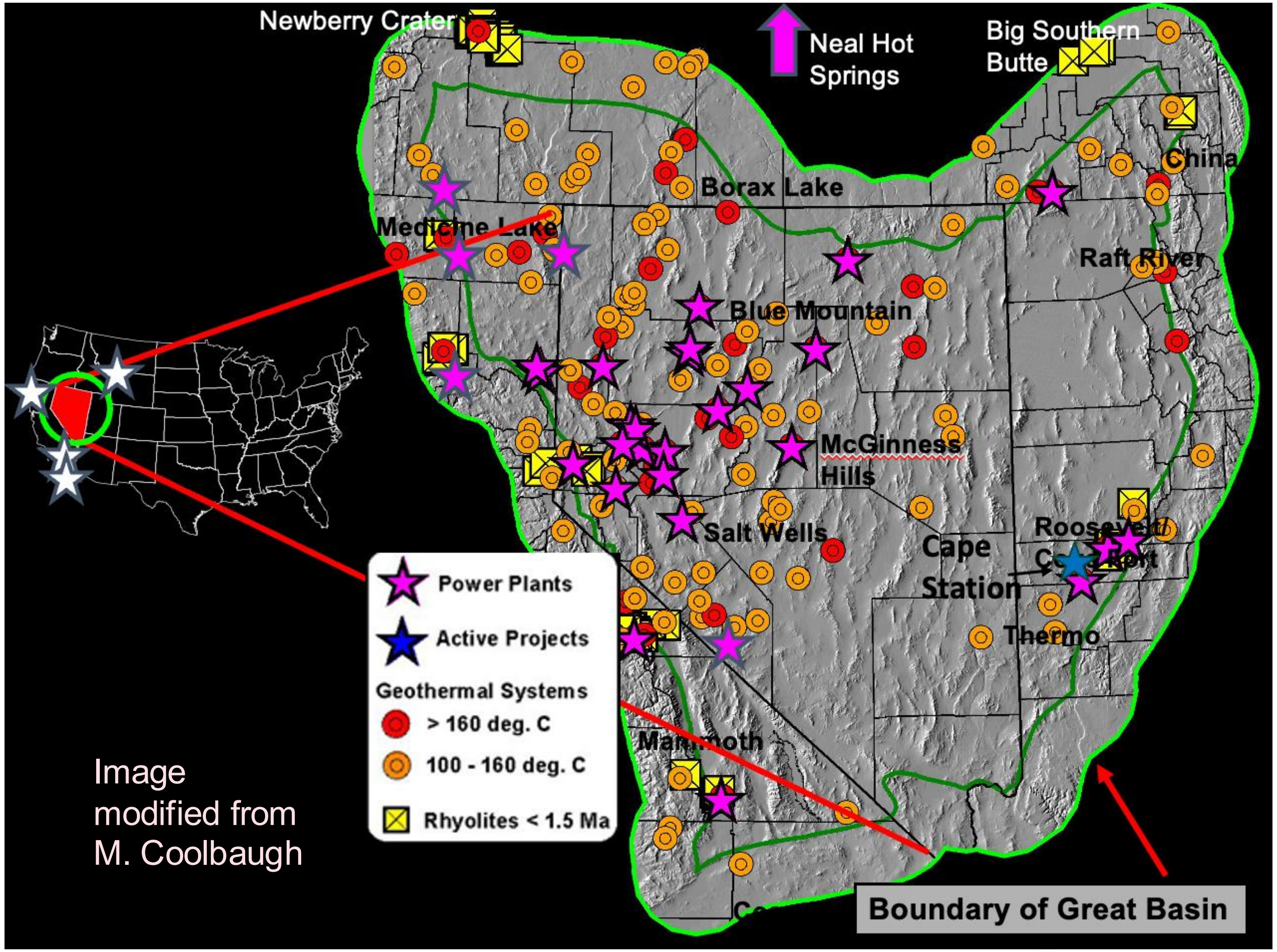
(After Blackwell and others)


Source: USNPS

Geothermal Systems in Nevada & Great Basin, USA

2025 Great Basin Geothermal Power Plant Capacity is ~1400 MWe.

NV = ~950 MWe for 31 power plants at 19 power plant sites.



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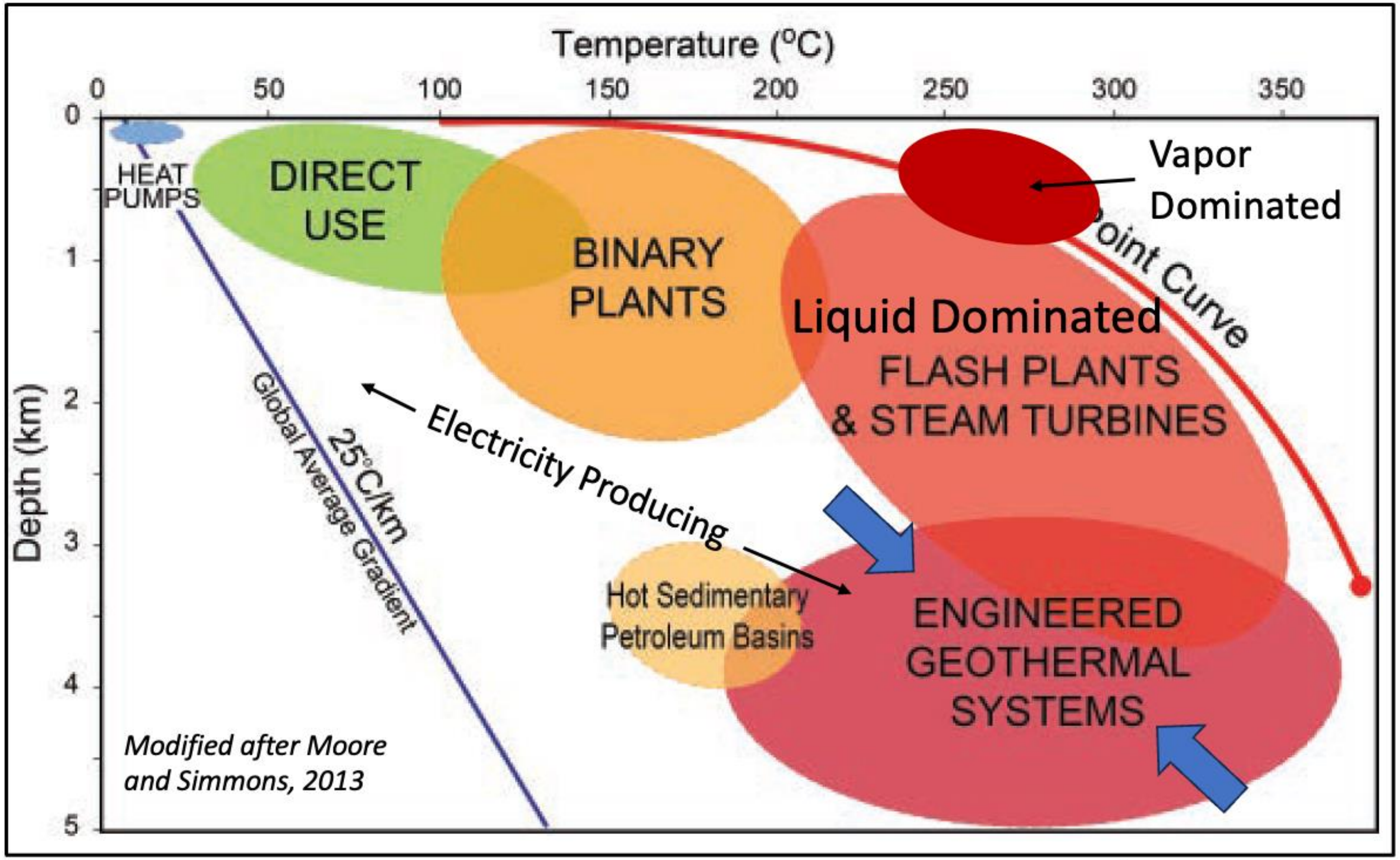
Exciting Emerging Pursuits

- Generating Artificial Geothermal Reservoirs (Engineered Geothermal Systems or EGS)
  - DOE's FORGE program
  - Fervo Energy's Project Cape, UT
- Developing Hot Sedimentary Aquifers
- Repurposing oil/gas wells for coproduction or depleted wells for geothermal
- Reinvigorating waning conventional geothermal systems
- Harnessing Superhot/Supercritical Geothermal Reservoirs
- Advanced Geothermal Technologies

Exciting Emerging Pursuits (EGS)



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Engineered Geothermal Systems (EGS)

- Artificially generated convecting hydrothermal system.
  - Inject water deep underground (3-5 km) into hot, previously impermeable rock
  - Improve permeability via thermal shocking → hydroshearing and pumping water under hi-P (2000 to >8000 psi) → hydraulic fracturing.
  - Fracture permeability achieved in stages via zonal isolation (using bridges and plugs) to maximize size of engineered reservoir of newly formed permeable fractures
- Upside:
  - Have the potential to increase current geothermal power output by 1 to 2 orders of magnitude (Tester et al., 2006). How so?
    - Hot rock is much more widely distributed than hot rock with circulating water (currently developed conventional systems)
    - Much less restricted to specific geological favorable regions, such as along and near plate tectonic boundaries
  - Significant reduction in CO_2 emissions by displacing fossil-fuel-fired power plants by making geothermal power more widespread than currently developed

EGS (DOE-Supported FORGE Venture)

- Located in southwest Utah
- Nearby operating geothermal power plants are:
  - Thermo (14.5 MW-binary)
  - Roosevelt or Blundell (34 MW–integrated flash-binary)
  - Cove Fort (25 MW-hybrid binary-hydroelectric)
- Goal to develop a productive geothermal reservoir in largely impermeable granitic rock

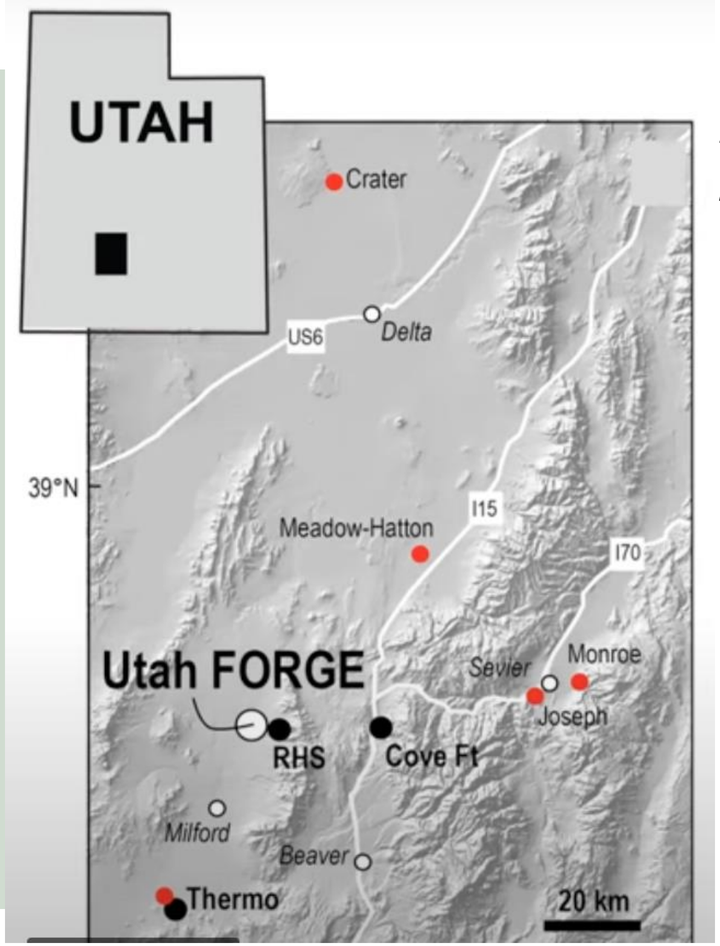


Image from: https://utahforge.com/laboratory/geoscience/

EGS (DOE-Supported FORGE Project)

- Injection well shown in blue; production well shown in red. Physical separation of two wells in reservoir ~150 m.
- Each well drilled over a period of 2.5-3 months with TD in each well of about 11k feet (~8000 ft deep with about 3000 feet lateral legs
- Bottom hole T about 230℃, reservoir T 175° to 225℃
- Injection well stimulated in 3 stages in 2023 and connection to production well demonstrated, but required hi injection pressure
- Both wells further stimulated in spring 2024; a nearly month-long circulation test yielded improved results:
  - 8+ bpm vs. <<1 bpm in 2023
  - 90% of injected fluid returned at 188℃
  - Induced seismicity minimal (<1.9 M)

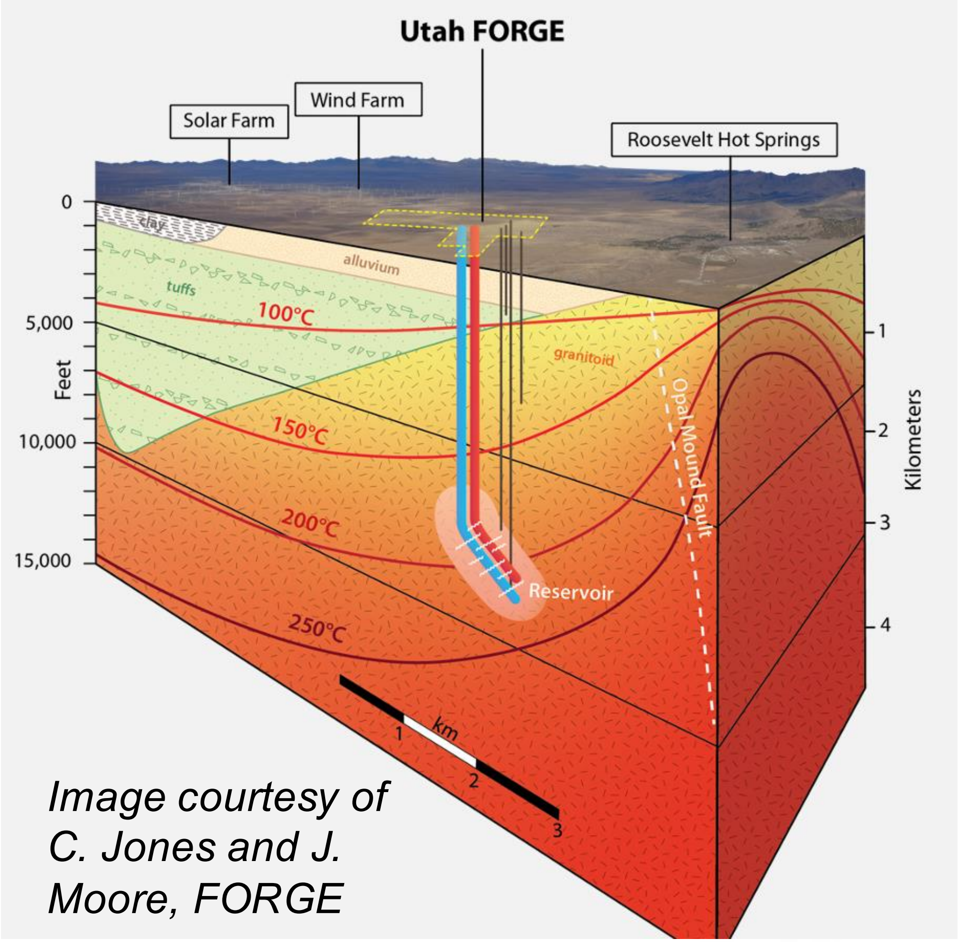
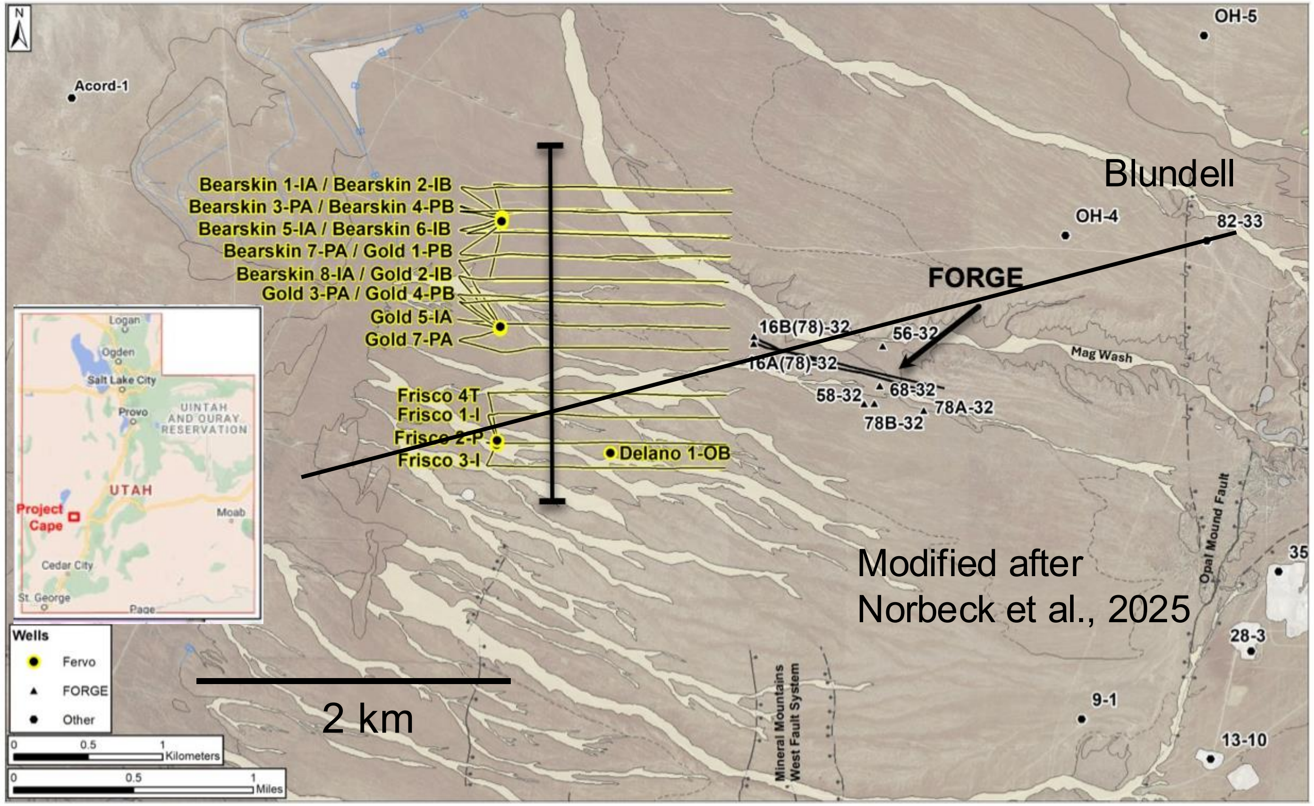


Image courtesy of C. Jones and J. Moore, FORGE

Fervo Energy: Project Cape EGS project, UT

- Located about a mile west of the FORGE project
- As of February 2025, 1 vertical monitoring well and 18 wells drilled from 3 drill pads (8k-9k vertical feet with 4.5k to 5k foot-long horizontal laterals).
- 3 wells stimulated (2 injection, one production) involving 80 stages of plug-and-perforate
  - 30-day long production test had a peak output of 12 MW and sustained 8-10 MW at a T of 195℃ and mass flow rates of 90-100 kg/s (~1500 gpm)
  - Very high power density calculated of 8-9 MW/km^3; (Norbeck et al., 2024)



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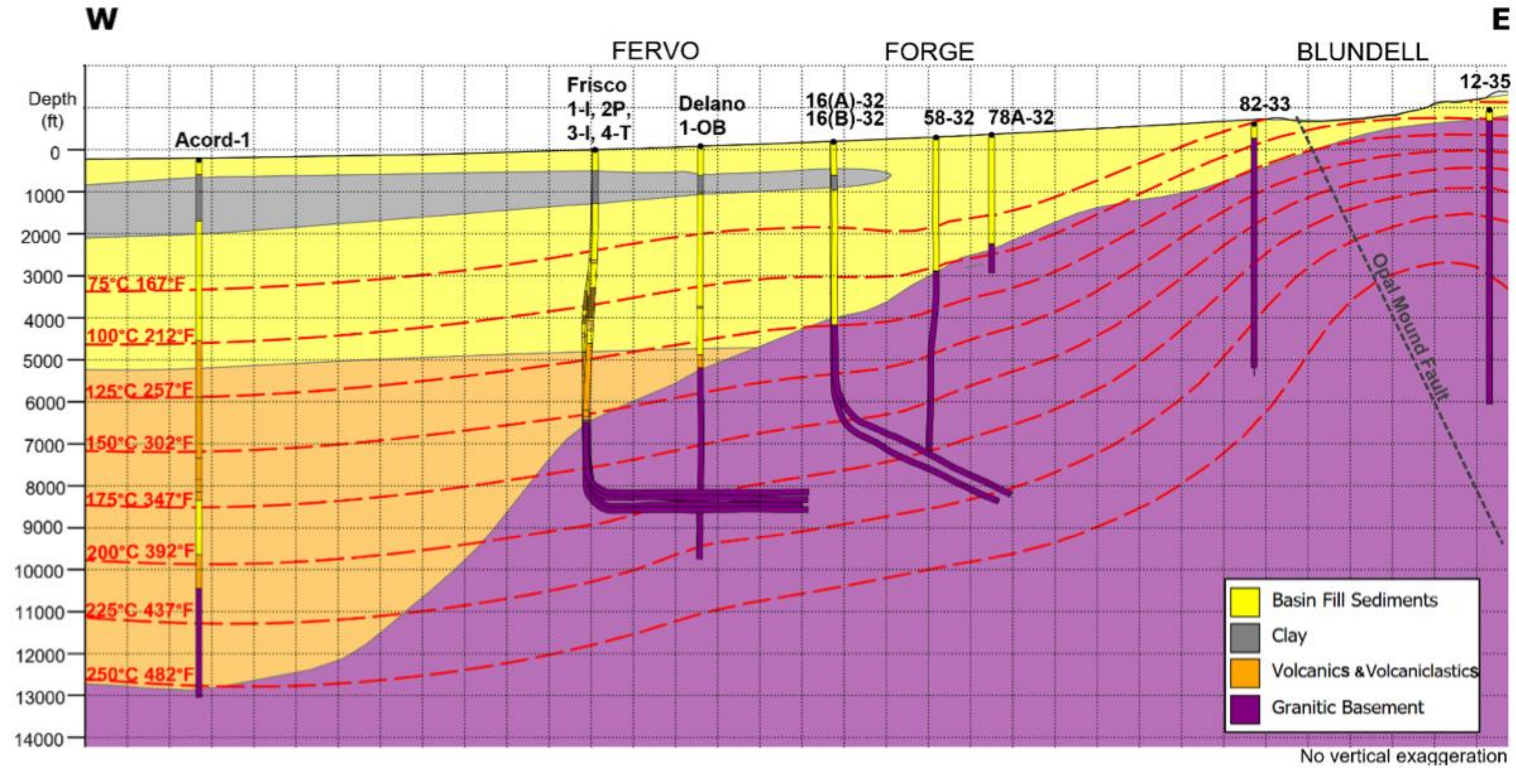
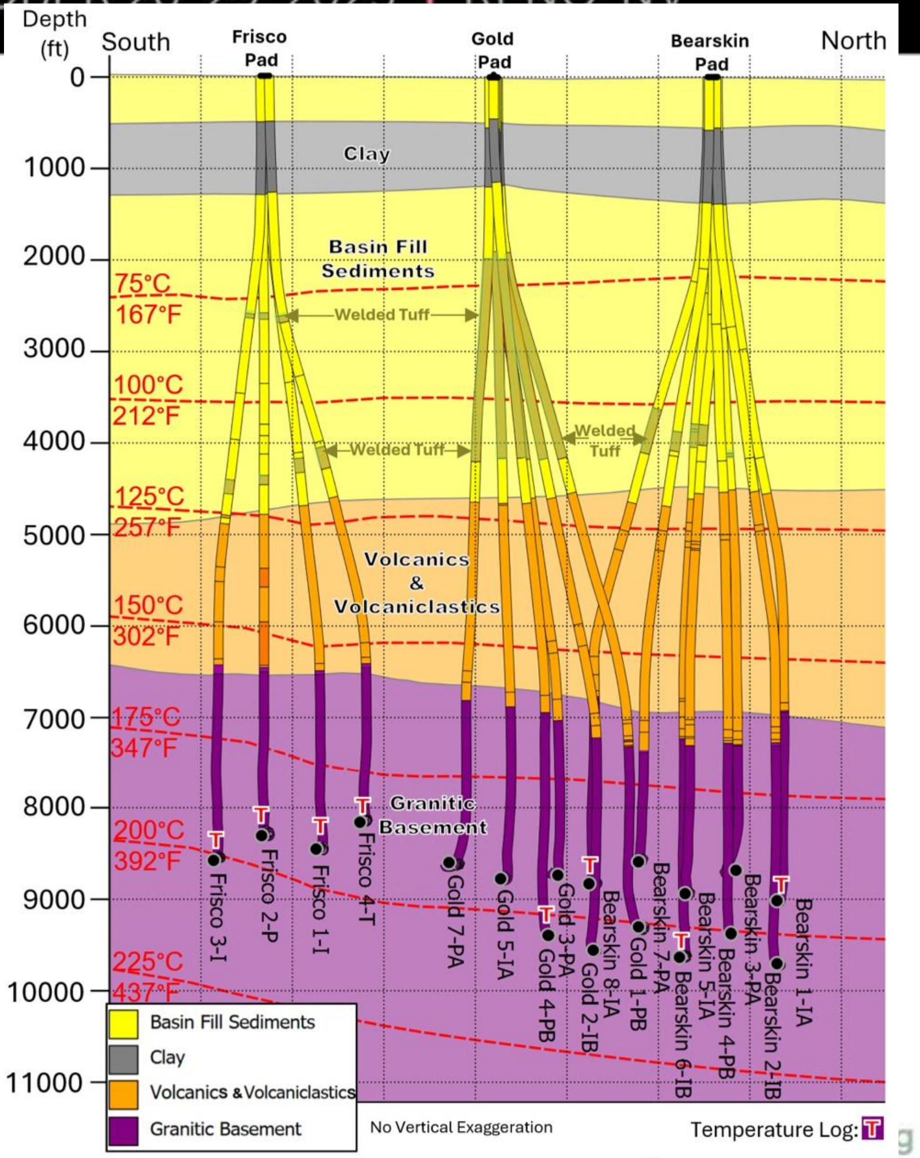
Fervo's Project Cape, UT



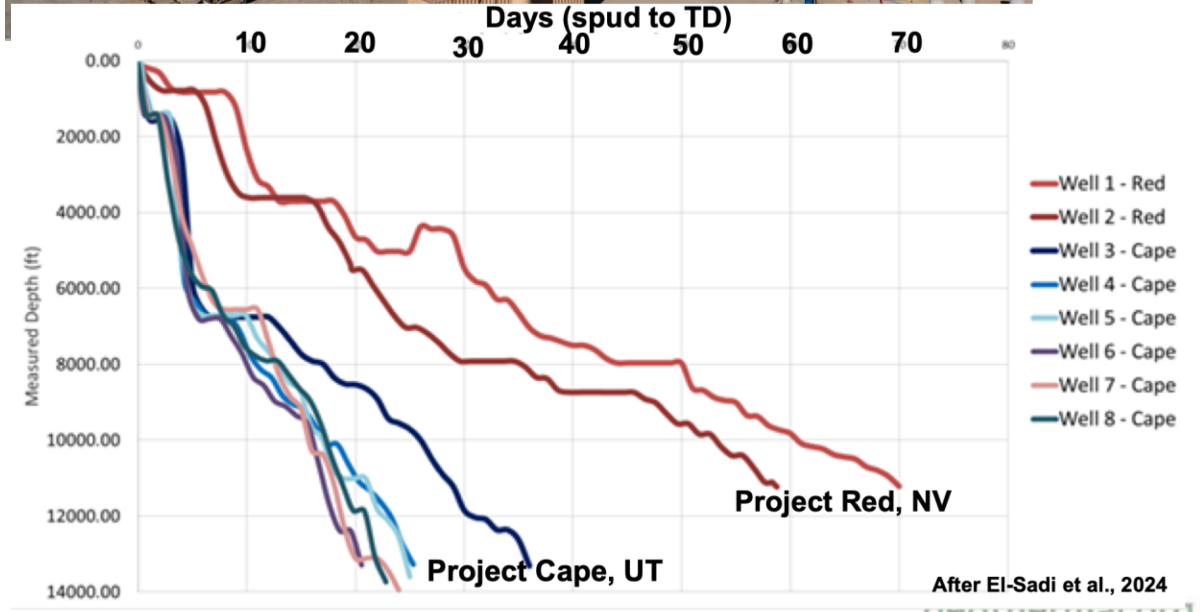


As at FORGE, Fervo's wells targeted the granitic basement.

Figures after Norbeck et al., 2025

Project Cape, UT

- Fervo's plans to have 100 MW available by 2026, and 400 MW by 2028
- Ambitious timeline due to significant advances in drilling rates, with 14k ft wells drilled in ~20 days
  - PDC bits
  - Mud coolers
  - Applying lessons learned from previous drilling results
- Google signed a 115 MW PPA with Fervo to deliver power for its data centers



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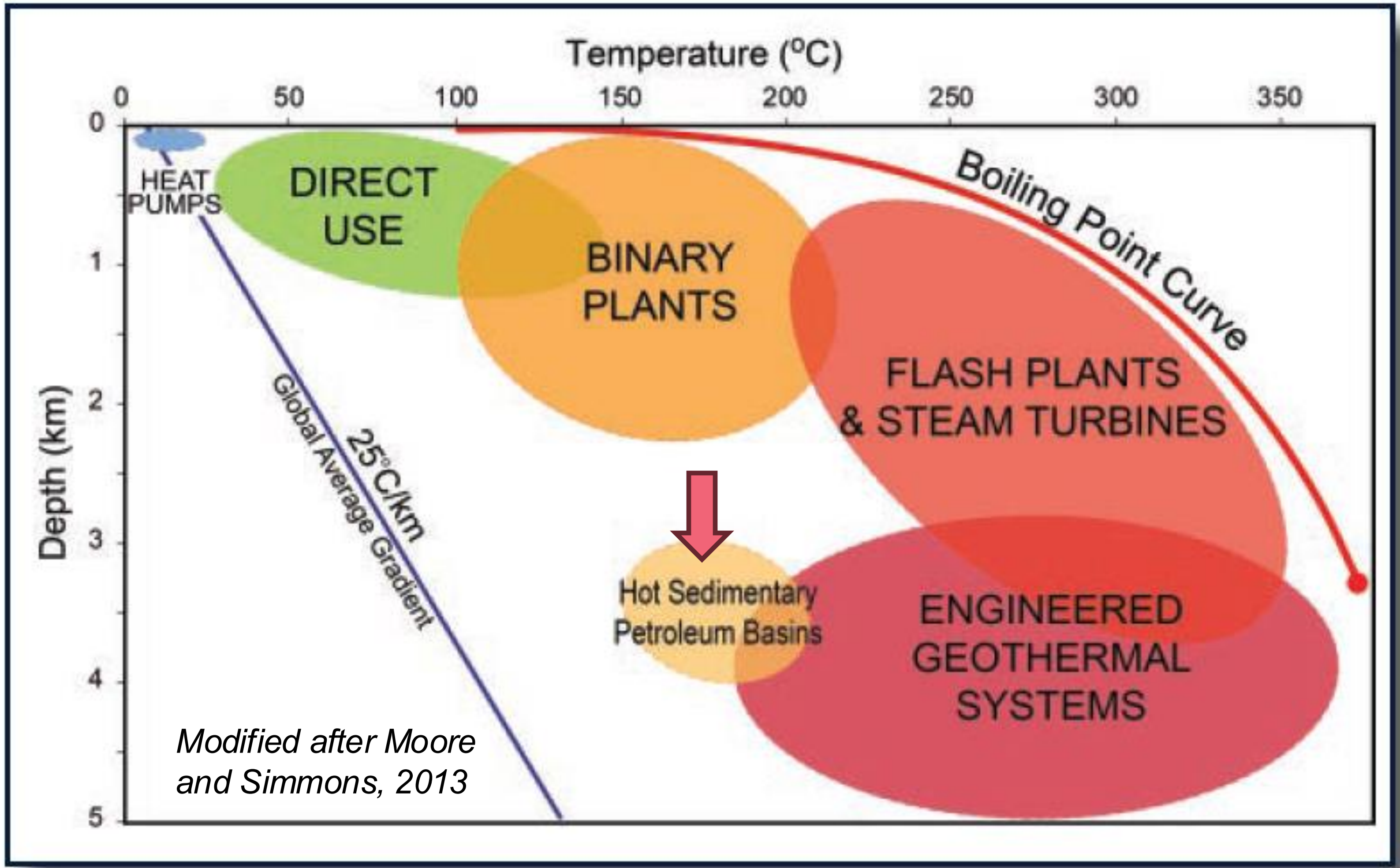
Hot Sedimentary Aquifers



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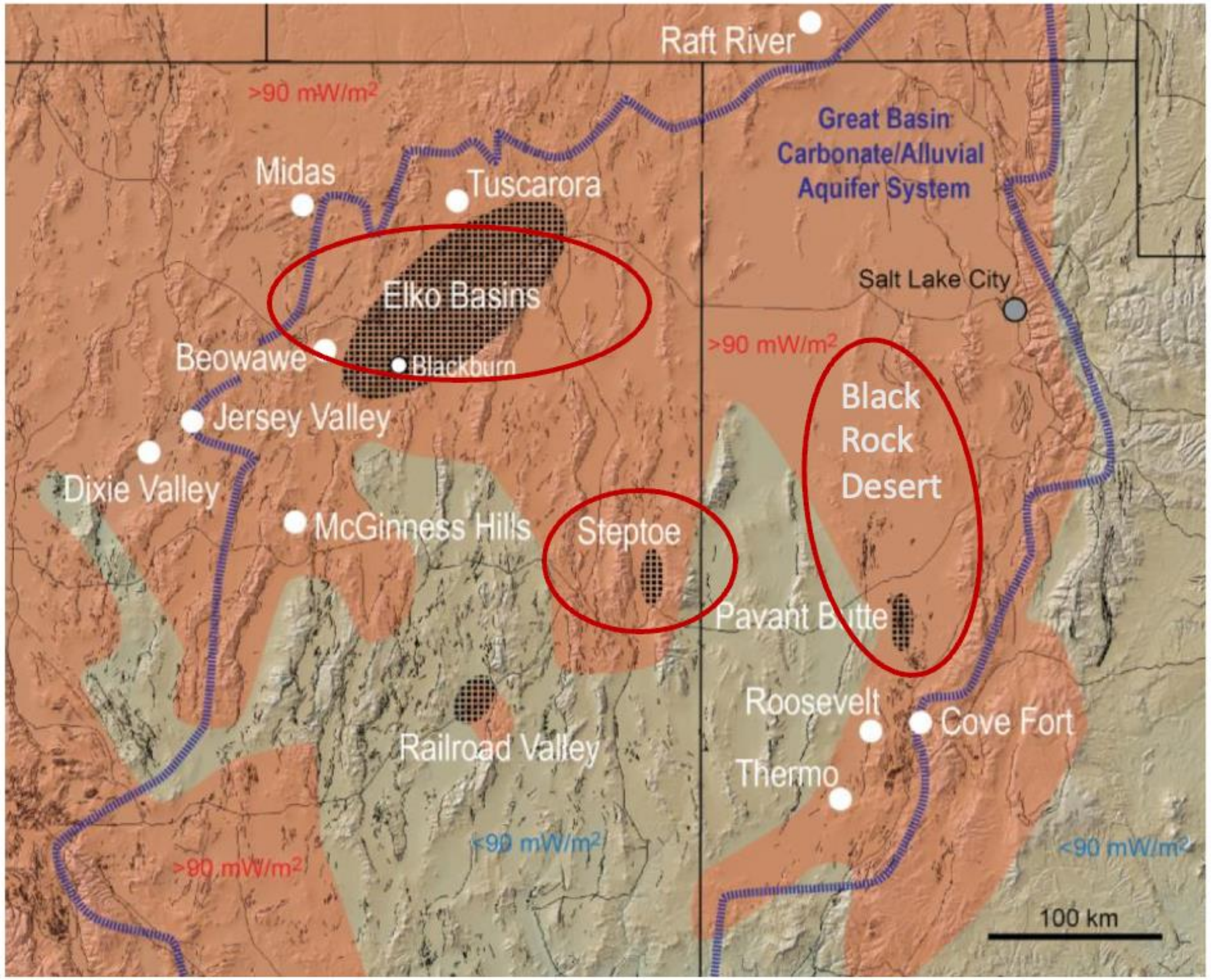
Hot Sedimentary Aquifers

- Require permeable sedimentary layers at depths of 3-5 km in regions of elevated heat flow (orange areas >90 mW/m^2) to achieve power generation temperatures of >~150°C.
- Potential aquifer basins include:
  - Elko and Steptoe, NV
  - Black Rock Desert and Pavant Butte, UT
- Because of large surface areas and rock volumes involved, potential exists to produce 100s of MWs



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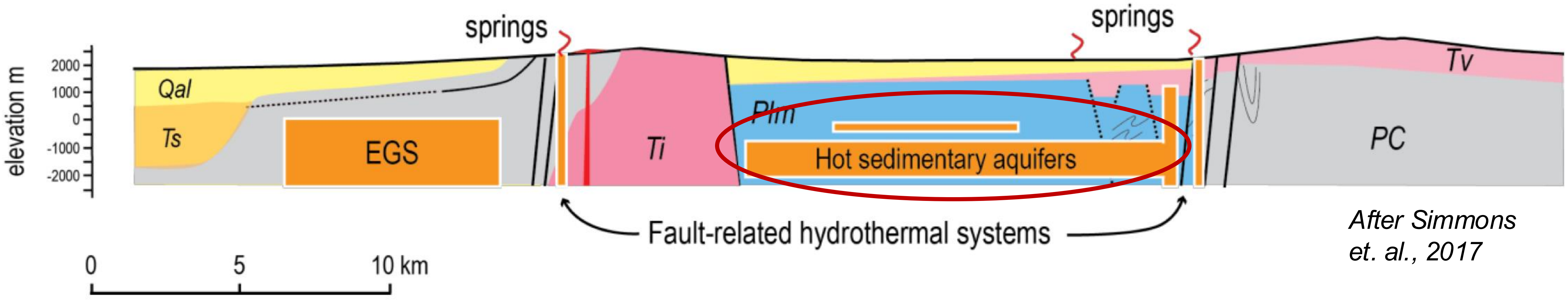
Hot Sedimentary Aquifers

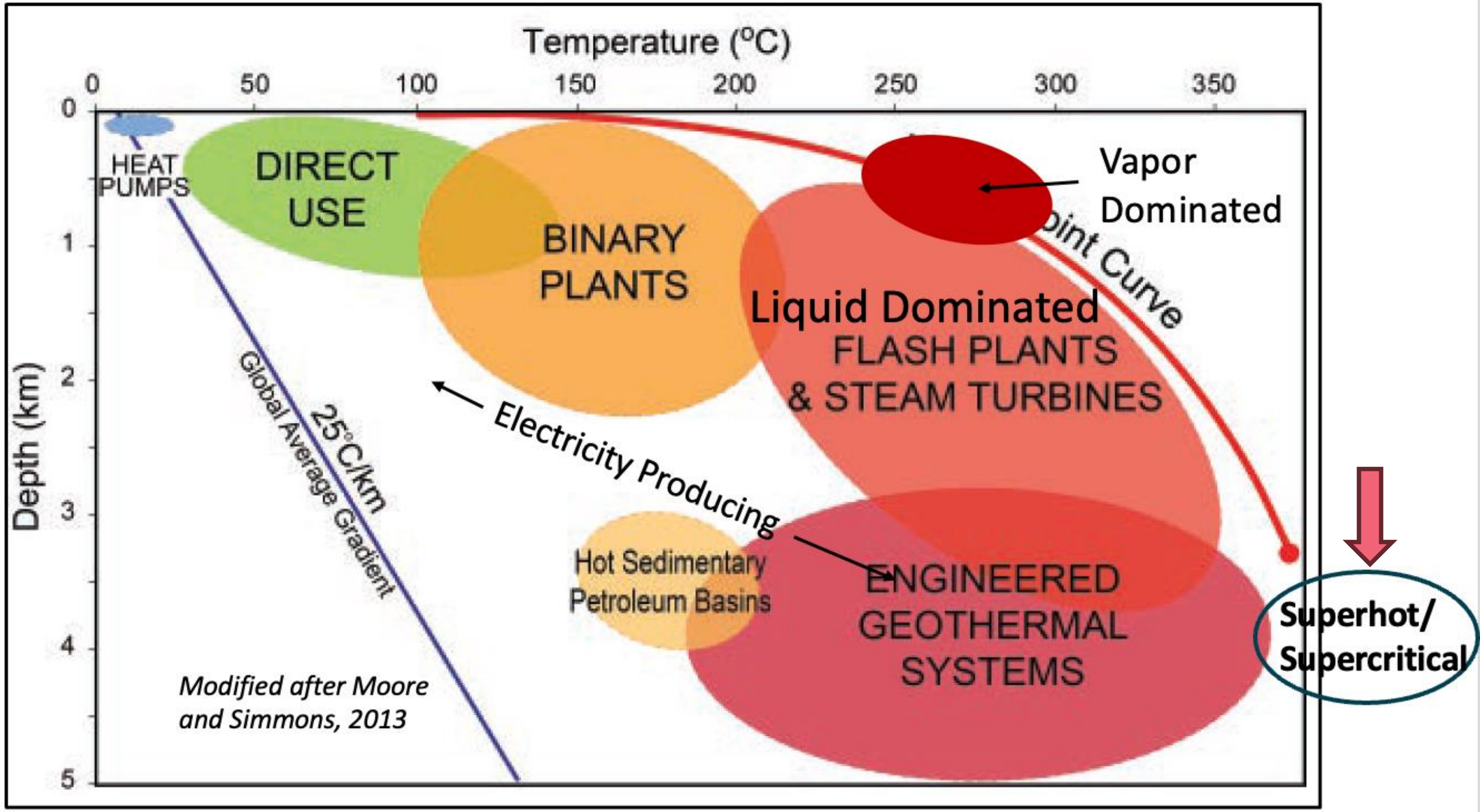
- Schematic Cross Section



After Simmons et. al., 2017

Note the large surface area of hot sedimentary aquifers compared to fault-related geothermal systems developed by current geothermal power facilities in Nevada

Superhot/ Supercritical Geothermal Systems



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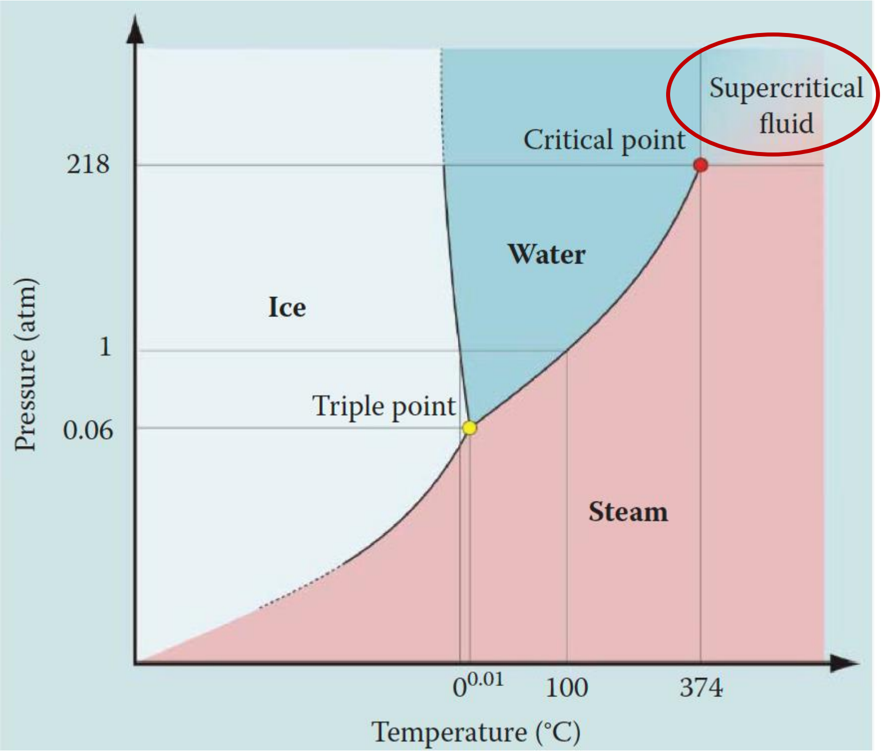
Superhot/Supercritical Geothermal Systems (SGS)

- Being explored by Iceland Deep Drilling Project (IDDP); Supercritical Geothermal Project in Japan; Geothermal: The Next Generation in New Zealand, and NREL's DEEPEN Initiative in the U.S.
- What is supercritical water?
  - Fluid with properties intermediate between liquid and gas (density of liquid but mobility of gas)
  - No surface tension at these conditions resulting in high buoyancy to viscous forces and high mass transfer→less permeability needed compared to subcritical conditions
  - Well tapping supercritical reservoir would have 5x –10x power output of a conventional well
    - **5 to 10 times fewer wells needed, saving ~$25M–$50M**
- H.R. Bill 8665—Supercritical geothermal research and development act (Passed out of committee in Dec. 2024; yet to be voted on)
  - (a) DOE to establish a program to research, develop, and demonstrate SGS; (b) USGS to regularly assess geothermal resources; and (c) DOE to collaborate with other agencies on geothermal activities



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Superhot Geothermal Systems

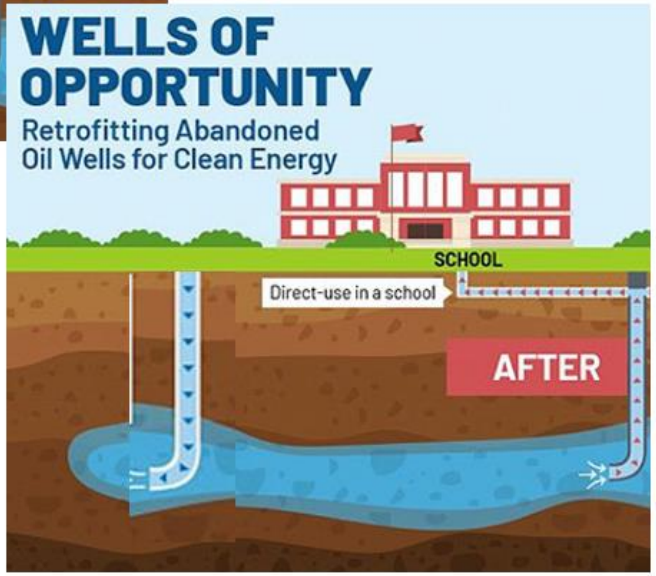
- IDDP-1 Well, Iceland
  - Drilled into rhyolitic magma at a depth of about 2 km before reaching supercritical pressure conditions
  - Flow tested well for about 2 years before eventual wellhead valve failure and shut in:
    - Produced 450℃ superheated steam at 50 kg/s and wellhead P of 40 bars
    - Hottest geothermal well on planet while active
    - Steam enthalpy ~3300 kJ/kg capable of 36 MW
    - Superheated steam inert in wellbore but became acidic and corrosive as steam began to condense at wellhead (100 mg/kg of HCl)
    - Heat flow across conductive boundary layer above rhyolitic magma measured at 23,000 mW/m^2

IDDP-1: Magma enhanced geothermal well at Krafla, Iceland (Aug. 2012). Photo credit: K. Einarsson in Fridleifsson et al. 2015

Other emerging pursuits– Repurposing oil/gas wells

- Coproduction
  - Reconfigure wells to coproduce hydrocarbons and geothermally heated water
  - Heated water applied for direct use to heat and cool buildings
- Depleted (Abandoned) oil/gas wells
  - Depending on T, residual water in reservoir can be used for:
    - Direct use, if hot enough (>~40℃)
    - A geothermal heat pump (geoexchange system)

Graphic modified from NREL publication Full Steam Ahead: https://www.nrel.gov/news/features/2023/full-steam-ahead-unearthing-the-power-of-geothermal.html



geothermal.org

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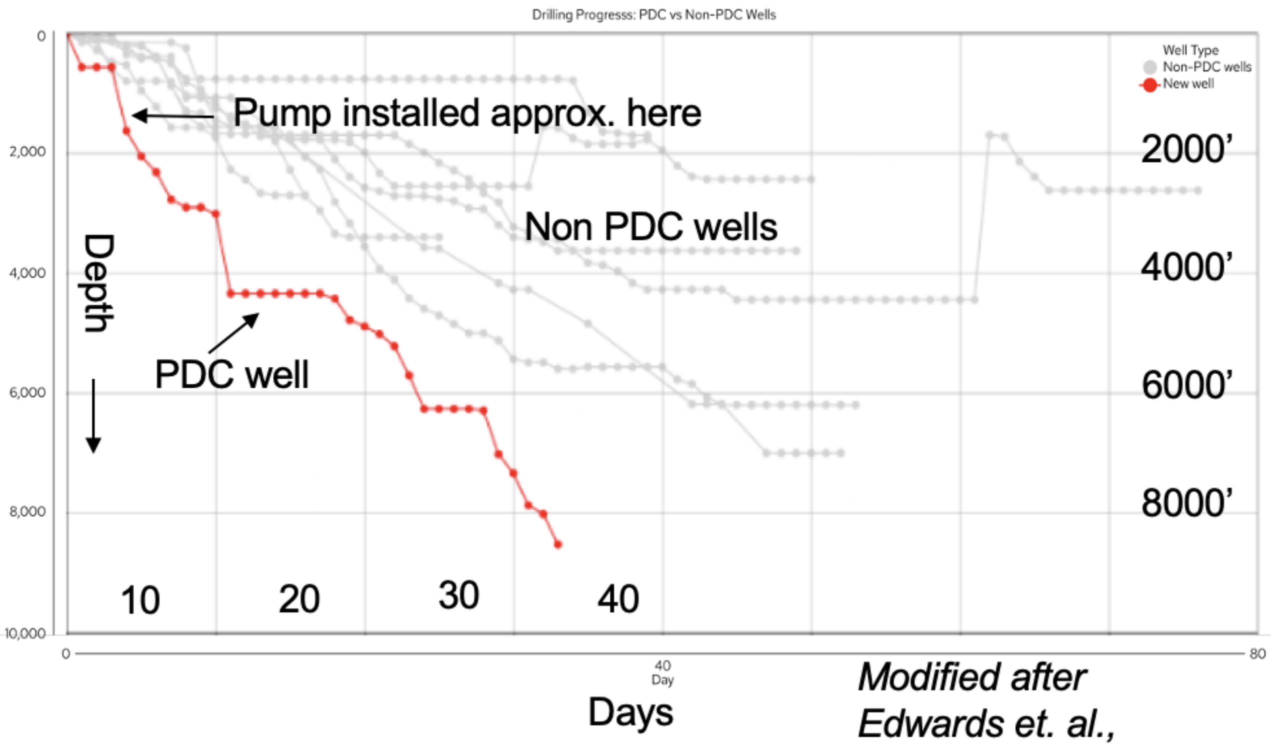
Other Emerging Pursuits-- Resuscitating Anemic Conventional Geothermal Systems

- Zanskar's Lightning Dock Power Plant
  - Made use of AI-supported stochastic resource modelling to simulate drilling scenarios incorporating existing data
  - Using PDC drilling bits, drilled an 8600 ft deep well in 32 days to tap hotter region of a fault-controlled reservoir
  - Steered upper portion of well within 1° of vertical using mud motors and directional drilling equipment
  - Allowed installing a 14-inch diameter line-shaft pump at greater depth resulting in the most productive pumped geothermal well in U. S.
  - This one well restored power output from 5 MW to plant's nameplate capacity of 15 MW



Modified after Edwards et. al., 2025

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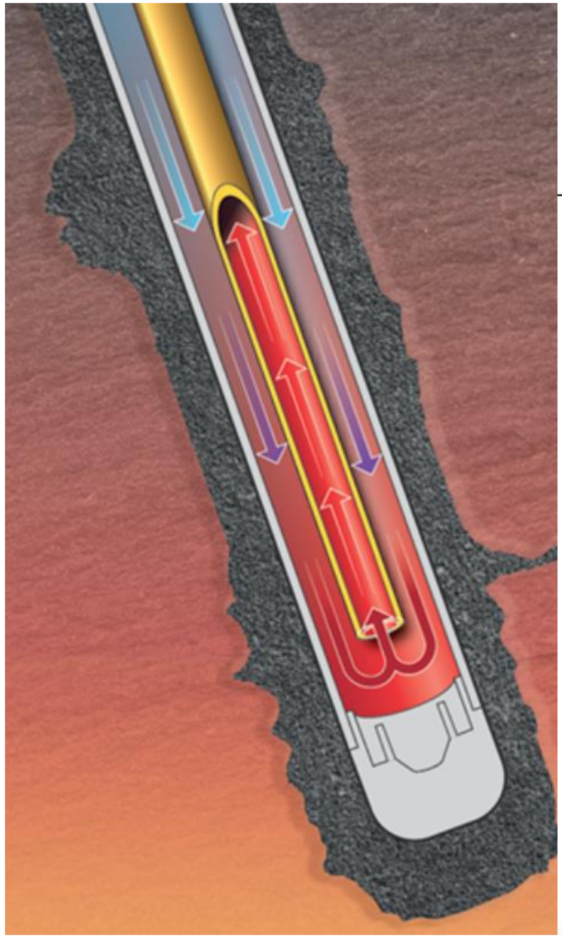
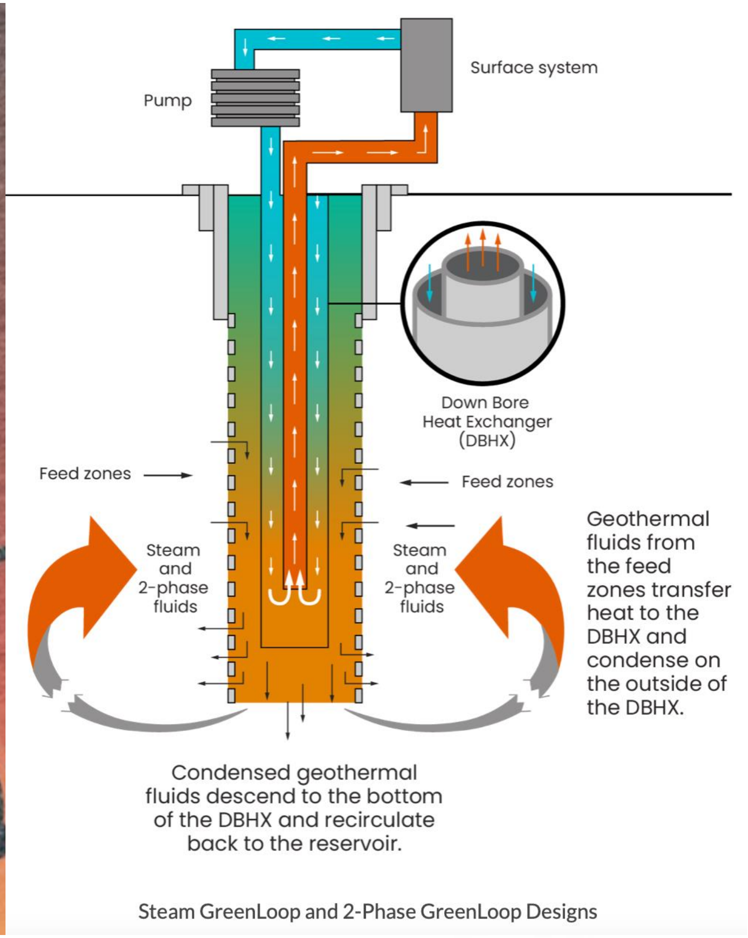
Advanced Geothermal Systems

- Two different configurations being explored:
  - 1. Modify existing nonproductive wells (Downhole heat exchanger—GreenFire and XGS Energy)
  - 2. Drill deep well with multiple laterals at depth to extract heat (Eavor closed-loop configuration)
- Downhole Heat Exchangers
  - Well pipe surrounded by Thermal Enhancement Material to facilitate conduction in liquid-dominated reservoirs (XGS Energy)
  - GreenFire's technology mainly used in steam- and 2-phase geothermal reservoirs
    - Steam condenses on outside of borehole transferring additional latent heat to injected fluid from that provided by conduction alone

XGS Energy



GreenFire Resources



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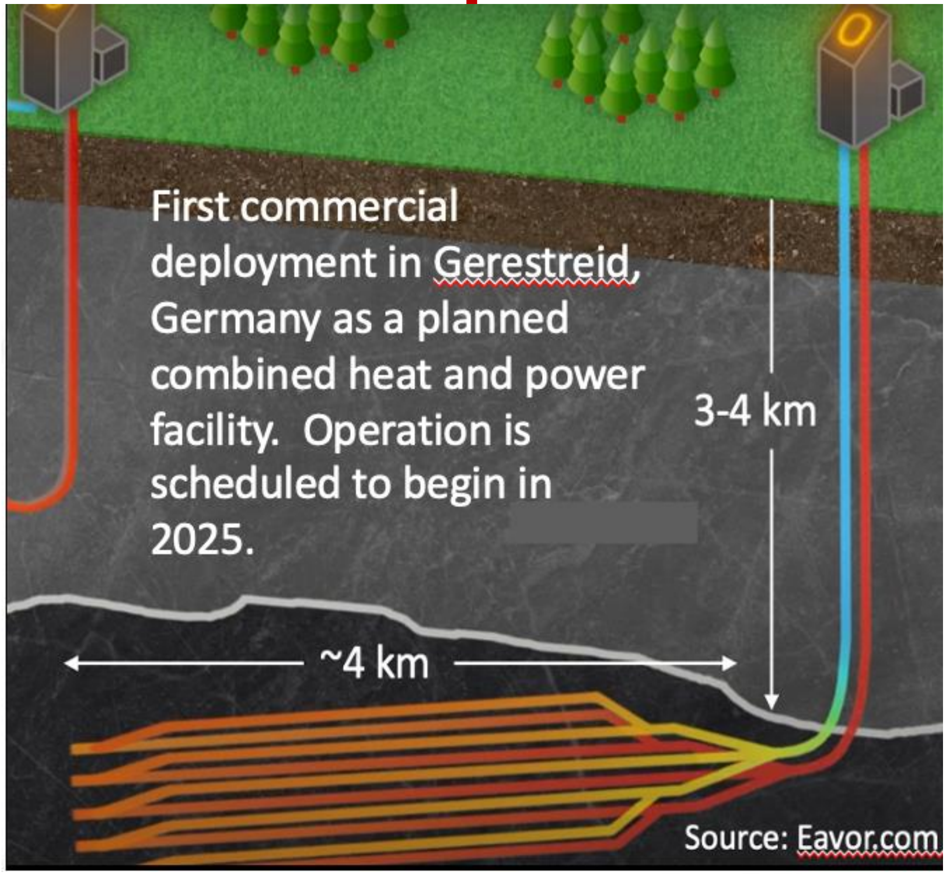
Advanced Geothermal—Closed Loop

- Deep Lateral Wells Configuration (Eavor Technology)
  - A fluid with a low boiling point is injected into a series of piping laterals at depth where it picks up heat to return to the surface to fuel a power plant and then reinjected
- Potential Advantages:
  - Can be applied anywhere (scalable)
  - No need to find zones of natural permeability
  - No need to artificially induce permeability via rock fracturing (EGS)—reduced induced seismicity
  - Avoids potential problems of producing from geothermal fluids (scaling and corrosion of equipment)
  - No added or make-up water needed
- Potential Challenges:
  - Potential cooling of working fluid with time (working fluid heated by conduction (slow heat transfer) compared to convection)
  - Initial high cost due to technologically advanced drilling technology (deep lateral well configuration and casing)



Learning Objectives: Thermal Energy Networks for Communities

Main topics of the presentation.

- *Objective 1:* Understand the context and verbiage of **heat pumps** in clean heating and cooling technology
- *Objective 2:* Identify the importance, adaptability, and benefits of the technology as vital to infrastructure and building construction
- *Objective 3:* Understand existing barriers to geothermal energy network adoption and how to manage them
- *Objective 4:* Understand how direct use of hot fluids may be used:
  - as a source of heating for municipalities or for individual properties
  - as a source to also cool using absorption chillers
- *Objective 5:* Internalize our collective capability and responsibility to make these changes

Dave's RECAP

- What makes the Earth viable to help meet our clean energy needs?
- How are energy and power related and measured?
- How does depth and T impact uses of geothermal energy?
  - Indirect Use → electrical power
  - Sometimes both direct and indirect for combined heat and power plants
- What criteria are needed to make a geothermal fluids viable for power development?
- What are some key attributes and challenges of geothermal power development?
- Where are most developed geothermal systems found (conventional systems)?
- Why is Nevada prospective for developing geothermal energy?
- What are some exciting new technologies for expanding geothermal energy?

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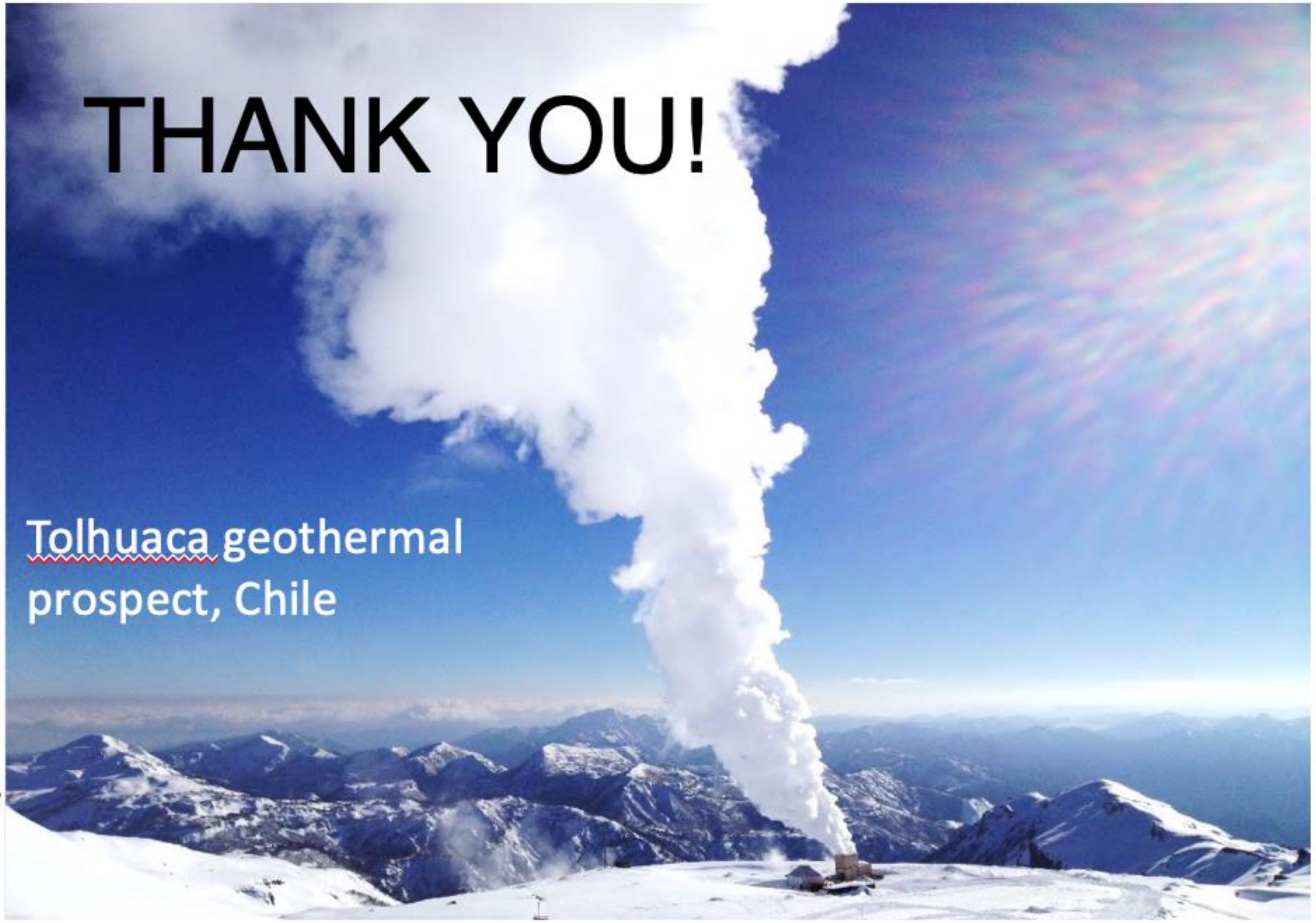

Image credit: GeoGlobal Energy Corp.