Webinars

Welcome!

The program will begin soon.

You will not hear audio until we begin.

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On Repurposing Oil and Gas Wells to Geothermal Wells

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September 18, 2023

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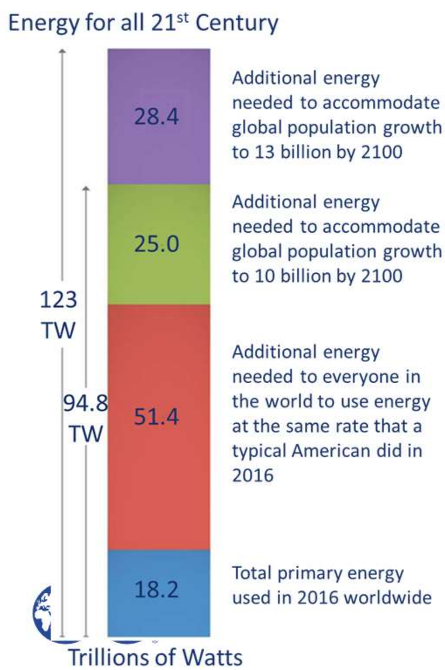

World Energy Outlook

- The world will need significantly increased energy supply in the future, especially cleanly-generated electricity.
- Electricity demand is increasing about twice as fast as overall energy use and is likely to rise by more than half to 2040.
- Energy use in currently low-income regions is catching up to that of the high-income nations.

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Abandoned Wells

- Approximate number of abandoned wells:
  - Pennsylvania - 0.4 Million
  - USA - 3 Million
  - World - 30 Million
- Future inventory of abandoned wells set to grow with active drilling

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Challenges with Abandoned Wells

- Health, Safety and Environmental
  - Potential methane emitters
  - Allow pollutants to reach freshwater
  - Need to be sealed in perpetuity
- Economics + Legal Liabilities
  - The cost to properly abandon an onshore well range from $50,000 to $150,000
  - Plugging and abandonment brings no financial returns/benefits to operators (no financial incentive)
  - Huge costs for many governments for P&A

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Alternatives to Abandonment

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- Decommissioning
  - Plugging & Abandonment → No more usage
- Repurposing for another application
  - Carbon capture and storage[1]
  - Production of biogas /upgrading into renewable natural gas (RNG) [2]
  - Exploration and extraction of other substances such as hydrogen, helium or lithium[3]
  - Geothermal power generation

1-IEA report, 2019
2- Haines (2018) EPA report
3-Faris (2021) H2 Bulletin

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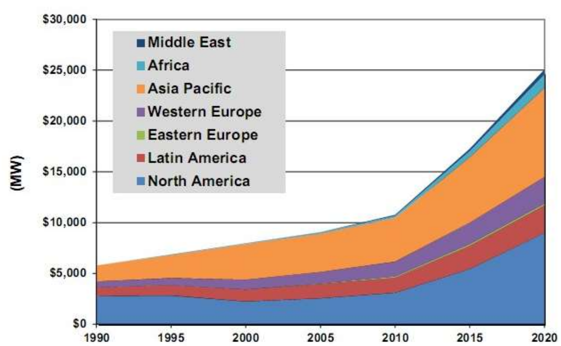
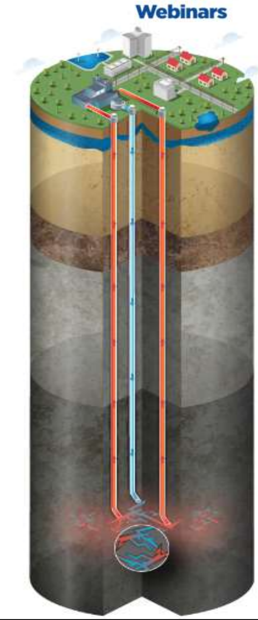
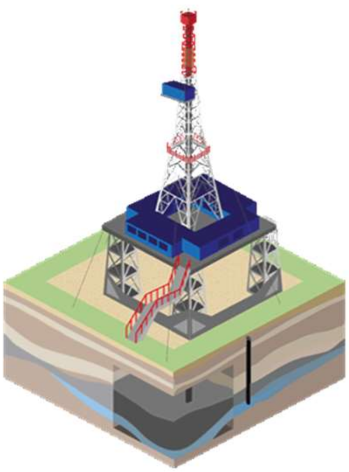
Why Geothermal?

- Available all year round versus intermittency of solar and wind
- Clean resource – very low emissions
- Safe and flexible
- Rapid growth of geothermal energy





Why is Geothermal Underdeveloped?



- Elevated cost to drill geothermal wells
  - Drilling corresponds to more than half of total costs of geothermal project
  - Drilling an average horizontal well can cost more than $10M
  - Completion corresponds to one third of the costs

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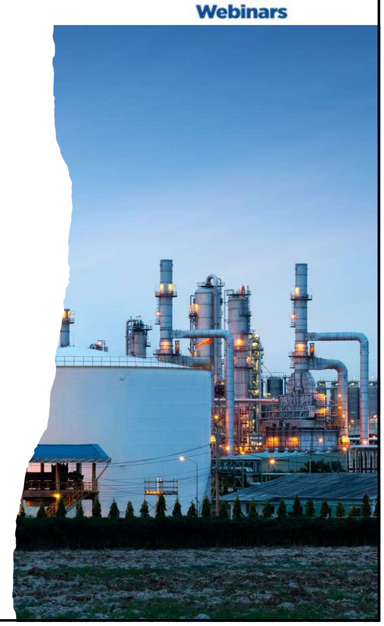
Repurposing Abandoned Wells

➢Bypass drilling costs

➢Infrastructures (roads, pipes, facilities, etc.) in the depleted oil and gas fields are already available in the project site.

➢Little additional footprint on the environment for the geothermal production

➢Geological information, drilling and completion data, reservoir rock and fluid properties, and production activities are already documented.



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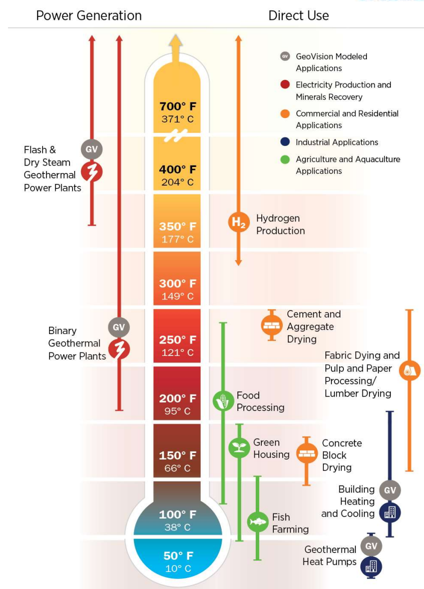
Geothermal Applications

(Limitations and Opportunities)

At higher temperatures, binary, flash, and dry steam power plants come into play.

At lower temperatures, direct use extends from agriculture and material production to home and commercial heating and cooling. Heat pump is relatively inexpensive.



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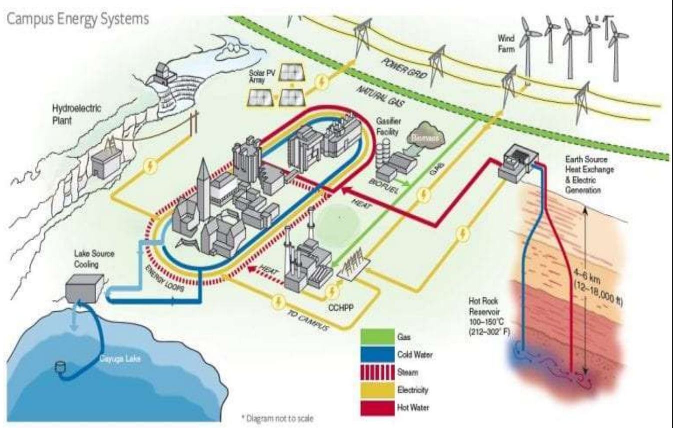
Direct Heating

- Cornell University is exploring geothermal heating as a sustainable method to warm its Ithaca campus
- Heating campus buildings by water that is hotter than about 80°C (176°F)
- Secondary uses for agriculture, food processing, and some manufacturing uses



https://deepgeothermalheat.engineering.cornell.edu

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	TBR	Basement
Installed Capacity (MW_{th})	10.5	13
Average Annual Heat Production (GWh/year)	92	115
Total Capital Costs (M$)	~~11.4~~ 4.2	~~16.9~~ 4.5
Well Drilling and Completion (2 wells)	~~7.4~~ 1.0	~~12.9~~ 1.3
Reservoir Stimulation	~~0.8~~ -	~~0.8~~ -
Surface Heat Exchanger and Pump Facility	2.2	2.2
Connect to Campus Heat District System	1	1
Total Operating and Maintenance Cost (k$/year)	918	865
Operating Labor	50	50
Pump Electricity	98	75
Heat Pump Electicity	541	429
Water	11	11
Maintenance	219	300
Levelized cost of Heat ($/MWh)	**21**	**20**

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Power Generation

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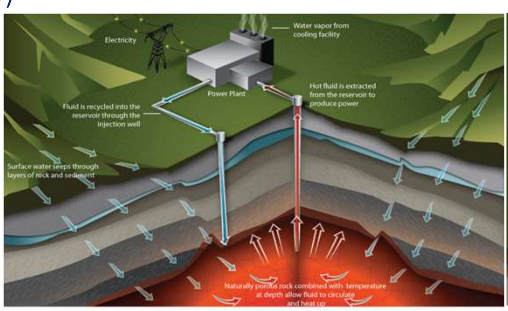
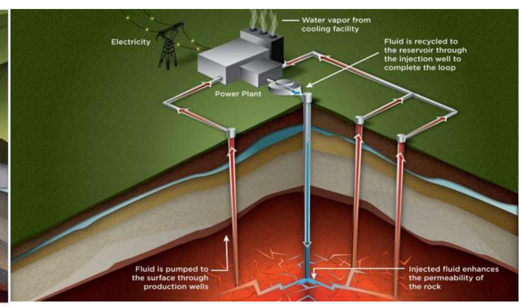
- Power plants use steam to generate electricity
- The connection between injection and production wells can be engineered by hydraulic fracturing/shearing -Enhanced Geothermal Systems (EGS)





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Source: U.S. DOE

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Pilot Project –Rocky Mountain Oilfield Testing Center (RMOTC) – Wyoming

- DOE tested for 3.5 years binary power generation starting 2008
- Demonstrated the commercial feasibility of generating power from low- temperature co-produced fluids
- Currently used as a testing facility
- Main challenges: lack of available clean water, extremely cold winters, and frequent maintenance works.

Depth (m)	1500
Water cut (%)	98
Temperature (°C)	90-98
Flow rate (bpd)	2880
Power output (kW)	180

Installation of the energy converter. The unit was installed and commissioned in four weeks

(Reinhardt et al., 2011, Nordquist and Johnson, 2012)

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Pilot Project – Denbury's Laurel Oilfield, Mississippi

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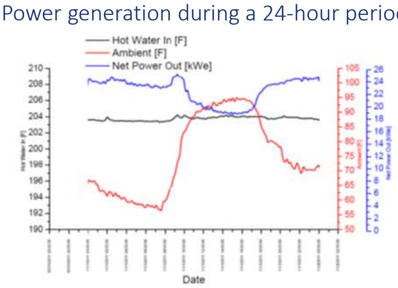
- ➢Low temperature co-production for power generation
- ➢The ORC unit worked with R245Fa fluid and produced a maximum of 22kW and average of 19kW of power.
- ➢Main challenge: high ambient temperature – reduced power output
- ➢A reference for future applications to reduce installation time, increase efficiency, generate additional power and minimize maintenance.

Depth (m)	2900
BWPD	4000
Water cut (%)	98
Temperature (°C)	75
Flow rate (m^3/h)	27
Avg power output (kW)	50

Power generation during a 24-hour period



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(ElectraTherm, 2011)

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Pilot Project – Huabei Oilfield, China

- First low-temperature plant in China using fluids co-produced from an oil field
- 8 production wells to confirm feasibility and test production rates, lifting ability of ESP, and water reinjection
- When fully operated, generates 2,700,000 kWh per year electricity.
- Upon conclusion, the project was expanded with power generators with a greater capacity

Depth (m)	3000
Water cut (%)	97.5
Temperature (°C)	110
Flow rate (m^3/d)	2880
Power output (kW)	360

Heat exchanger and geothermal power generation plant

(Xin et al., 2012)

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Pilot Project - Caldwell Ranch Exploration – Geysers Field, California

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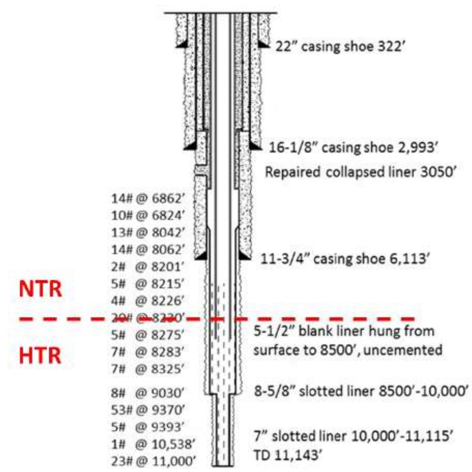
- Wells originally drilled in the 1980s but were never produced due to elevated concentrations of non-condensable gases
- Two wells were deepened, recompleted, and used as injector and producer
- Natural fracture reactivation by water injection
- Confirmed 11.4 MW potential of power generation



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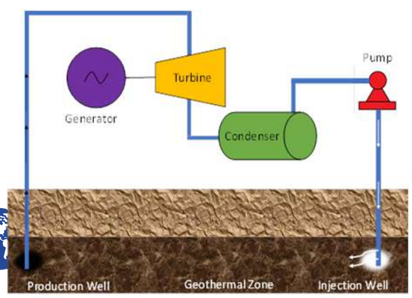
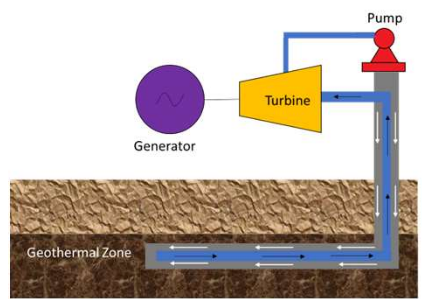
Open Loop Systems

- Two or more wells are employed, at least one well for production and another one for reinjection
- Requires high permeability
- Clogging and corrosion problems due to brine and mineral deposits, natural organic particles, and acidity.



Closed Loop Systems

- A single well is used with the wellbore acting as a heat exchanger
- Tubing is replaced by borehole exchanger (BHE)
- Presents absolutely no environmental impact to the earth or our aquifers



Closed Loop System

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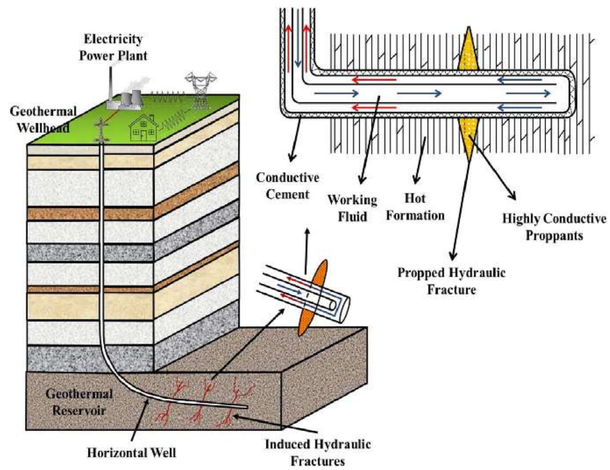
- ➢Thermal conductivity of the system can be increased with hydraulic fractures
- ➢Proppant with a high thermal conductivity
- ➢Thermally conductive coating: Carbon-steel, aluminum, and graphite
- ➢Conductive blades act as a heat sink to transfer heat to the wellbore



(Dahi Taleghani and Ahmadi, 2017)

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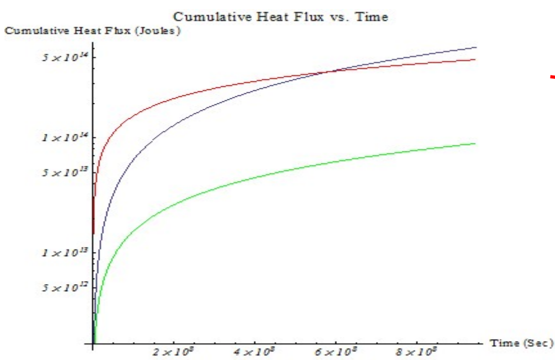
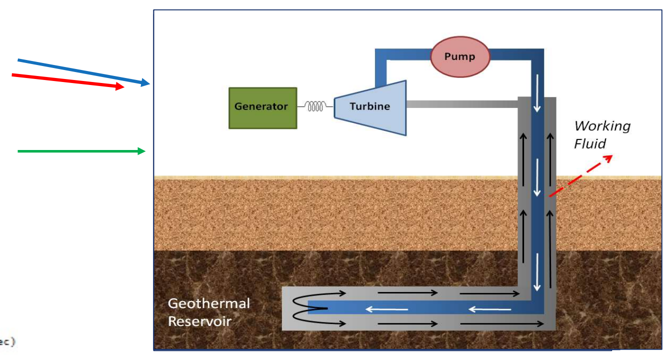
Impact of Heat Exchanging Mechanisms

➢Coupled thermo-poroelastic simulations to predict the well performance

➢Selecting thicknesses of insulation tubing and flow rate of the circulating fluid.





(Dahi Taleghani, 2013)

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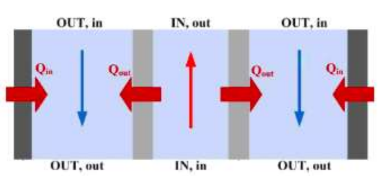
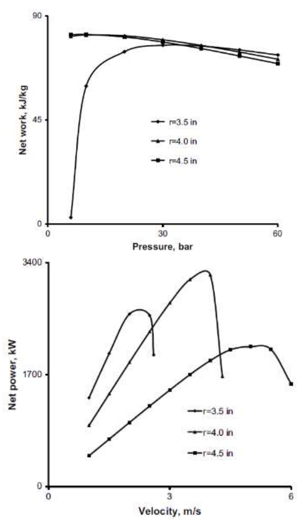
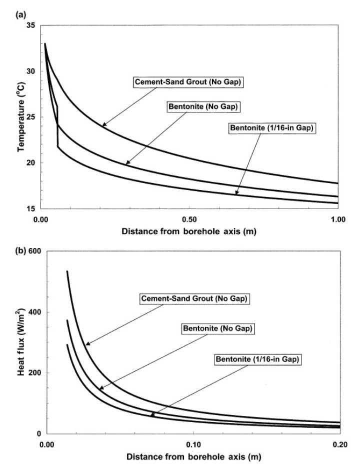
Closed Loop Systems

- Tubing design
  - Insulating tubing materials: Polyethylene, High Density Polyethylene (HDPE), PVC, and CPVC.
  - Diameter
  - Thickness
- Microannulus kills heat transfer through the casing







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Pilot Project - Coso Geothermal Field, California

- Converted abandoned open loop geothermal well into a closed loop system in 2020
- Well originally abandoned due to production of non-condensable gases (NCG)
- Addressed by a closed-loop water system at 170°C
- Although the well is 1000m deep, only 330m BHE was installed due to budget constraints .

Equipment Pad and Partial Installation

Installation of Insulated Tubing

(Higgins et al., 2018)

Kiskunhalas, Hungary

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- A 2000m deep vertical well, dry hole, drilled in 1960 was converted to closed-loop geothermal system in 2021
- Heat plant generates 0.5 MW of power output – enough to heat up a condominium consisting of 600 apartments.
- The cost of the implementation of this project was about 10 percent of that of other types of geothermal systems, with practically negligible risks.

https://www.en.weheat.systems/technology

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Challenges

- Regulations
  - Vary in accordance with the location
  - Projects can take 7-10 years due to regulatory barriers
  - Most geothermal wells are regulated by mining authorities
  - The code of practice for deep geothermal wells NZS 2403:2015 is the norm usually adopted for designing geothermal wells
- Wellbore Integrity Issues
  - Decrease of the overall heat transfer rate
  - Increase of the total resistance of the system

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Project Design

Step	Needs
Identify potential targets	Location screening
	Local regulations
Verify data availability	Reservoir data (pressure, temperature, fluid composition, formation)
	Well construction (age, drilling and completion data, well trajectory)
	Well historic operation data (operational pressures, temperature)
	Well maintenance data
	Additional reports (LOT, annular pressure, cementing reports, well logs)
Feasibility Study	Well integrity (well barriers, casing, cement)
	Heat generation (temperature, fluid flow rate, tubing selection)
	Risk analysis (technical, environmental, financial)

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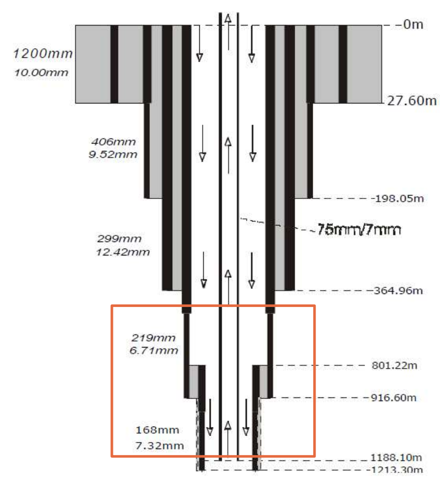
Wellbore Integrity Concerns

- Geothermal wells have a longer expected life span
- **Presence of microannuli can severely reduce heat conductivity**
- Mature wells may present corrosion and various well integrity issues
- Failure in well integrity is a very common issue, with around 35% of the wells worldwide
- Frequent exposure to thermal stress and high CO_2 and H_2S concentrations and hypersaline brines



BHE Plant in Weissbad, Switzerland

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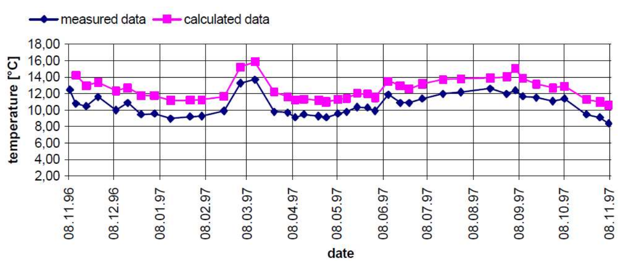
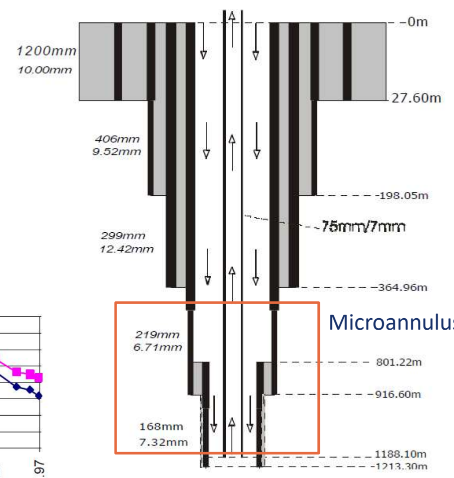
BHE Plant in Weissbad, Switzerland

- A 1214m deep closed loop geothermal well was drilled in 1993
- The circulation flow rate was 10.5m^3/h and expected delivery temperature of about 15°C in the long term
- Output temperatures were significantly lower than expected due to microannulus between cement and casing

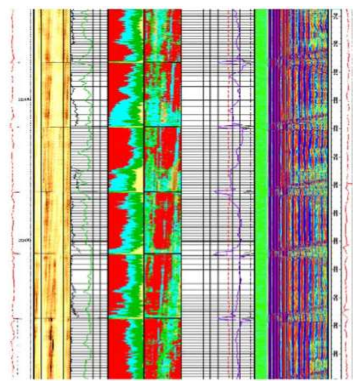




(Kohl and Rybach, 1993)

Wellbore Integrity Concerns

- Cement systems may show sufficient bond strength at the early stages of setting but will lose their strength in the long term
- Microannuli lead to:
  - Temperature drop along the cement interface
  - Decrease of the overall heat transfer rate
  - Increase of the total resistance of the system



Microannulus detected by ultrasonic log. Red represent gas

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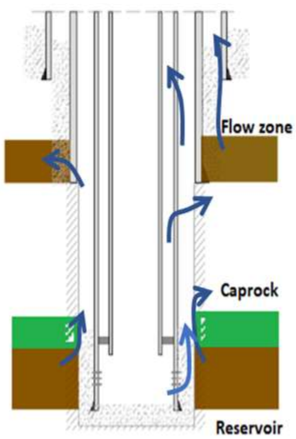
Wellbore Integrity Concerns



Verify indications of sustained casing pressure	Verify cement quality	Assess casing integrity
Verify pressure in all annulus	Analyze cement logs, if available	Verify integrity of the connections
Verify if reservoir fluids are found when bleeding the pressure	Assess cement quality and cement bond quality	Verify thickness of casing wall
Check if pressure rebuilds	Locate signs of integrity issues	Check for signs of corrosion and scaling
Check if pressure reached comply with local standards	Recommend cement remediation based on the previous assessment	Recommend assessment of casing integrity

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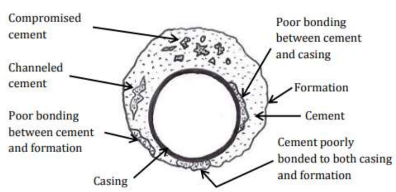
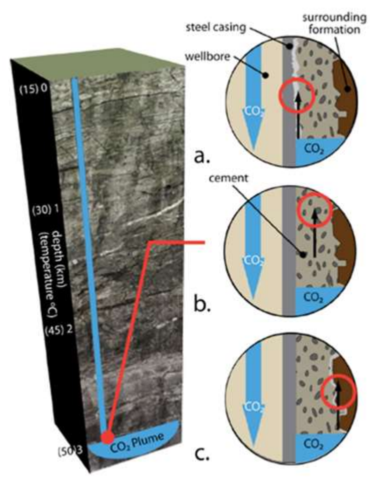
Remedial Cementing

- Squeeze job may be needed:
  - to repair some casing damage
  - to repair a damage cement sheath



  - to remove annuli that hinder heat transfer



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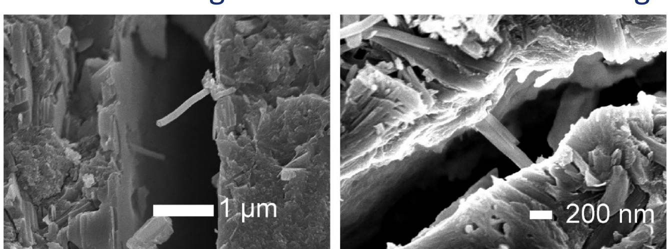
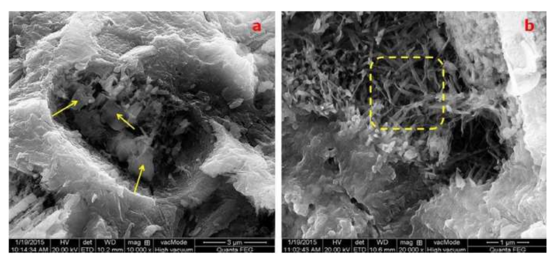
Remedial Cementing

- Cement reinforced with carbon nanoparticles or thermal cements
  - Graphite-based materials improve thermal conductivity near the wellbore
  - Sealing cement microfractures
  - Reducing cement permeability
  - Increasing fracture cement fracture toughness



SEM image of a microcrack bridged by a carbon nanoparticles

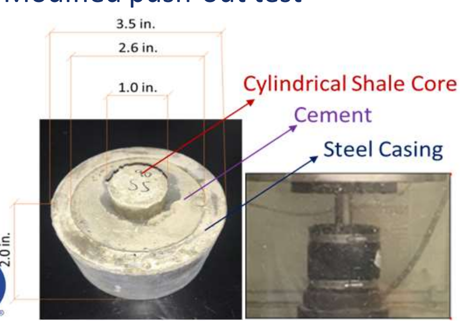


Graphene platelets

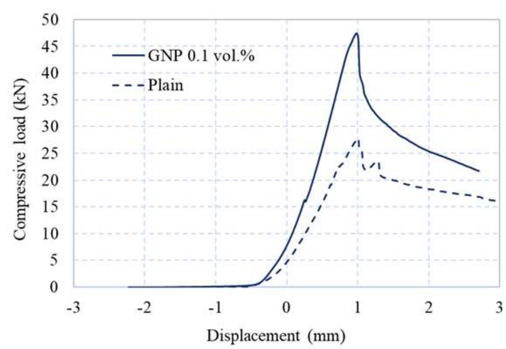
(Tabatabaei and Dahi Taleghani, 2020)

Assessment/Improvement of Cement Bonding

- Longitudinal thermal loading on casing
- Tensile bond strength measurement
  - Brazilian test
- Shear bond strength measurement
  - Modified push-out test



Experimental setup



71% improvement by adding 0.1 *vol.*% graphite additive

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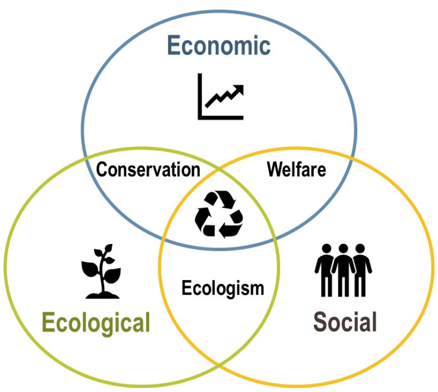
Conclusion

Toward Building Paths to Sustainability



- Inventory of abandoned wells keeps growing and increasing environmental and financial challenges
- Repurposing abandoned wells can help increase clean energy supply and meet future electricity demands.
- This solution eliminates geothermal drilling, considered the costliest step of geothermal projects
- Closed-loop geothermal systems are more reliable and requires less maintenance in the long term.
- Wellbore integrity should be thoroughly evaluated to ensure success of the project.

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Any Questions?

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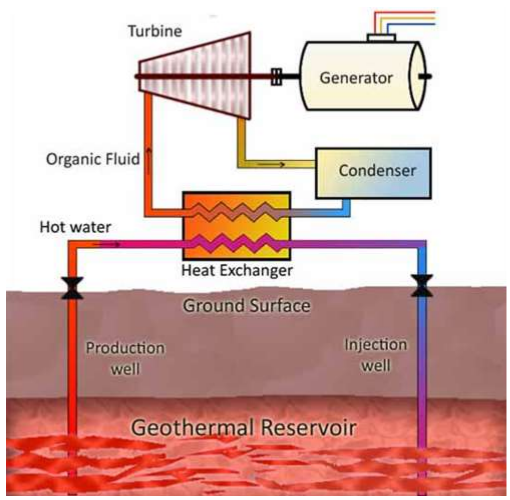
Economical Aspects

- Low temperature geothermal project in Clarke Lake, Canada
- 15 wells (10 productions and 5 injections) to achieve 100 kg/s of flow rate
- 15 MW production ($7466/kWh)

Item	Cost ($ 1M)
Drilling	21.75
Plant Site Development	5.89
Well Site Development	0.67
Well Pumps	10.5
Pipeline	7.26
ORC Equipment	40
Plant Building Construction	1.21
Electrical Grid Interconnection	10.9
Geothermal Permitting and Well Authorizations	0.22
Engineering Fees	13.1
Environmental Fees	0.32
Total	**112**

Low Temperature Energy Conversion

- Organic Rankine Cycle (ORC) - between 200 - 300 °F
- Low enthalpy organic fluids called working fluids (isobutane, isopentane, R-134a, and ammonia), which have a much lower boiling temperature than water, are vaporized to generate energy



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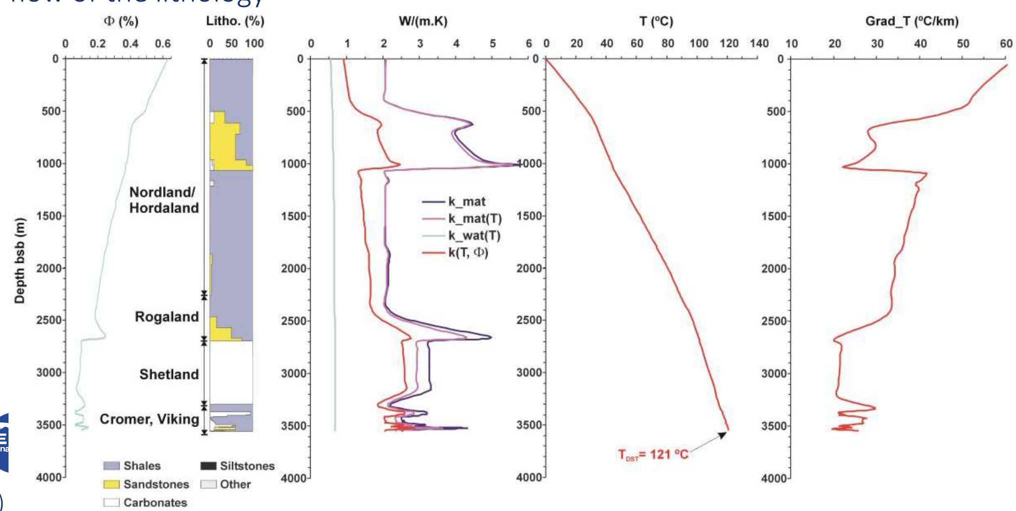
Underground Heat Flow

- High-resolution temperature logging can determine thermal gradient and heat flow of the lithology



(Pascal, 2015)

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Pilot Project - Williston Basin, North Dakota

- Two 8-inch diameter open-hole horizontal wells at 2,300 m and 2,400 m depths with lateral lengths of 1,290 m and 860 m produced water at a combined flow of 51 l/s
- Non-conventional, low-temperature oil wells using binary technology
- Operated for only two days due to frost damage
- Legal and liability challenges in reaching agreement with the well operator


Slickline unit with temperature probe set up over the abandoned well


ORC unit installed after repurposing well

(Gosnold et at. 2019)

Wellbore Integrity Concerns

- Cement systems may show sufficient bond strength at the early stages of setting but will lose their strength in the long term
- Microannuli lead to:
  - Temperature drop along the cement interface
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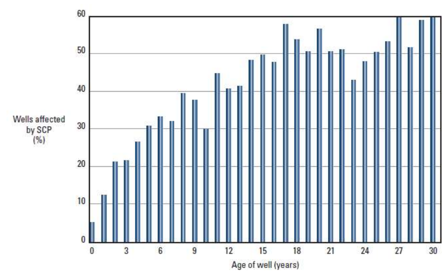

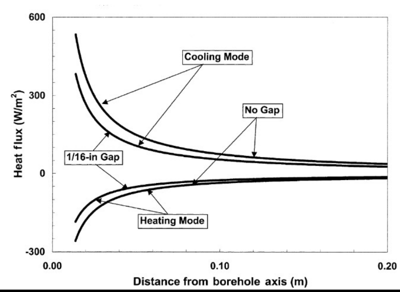

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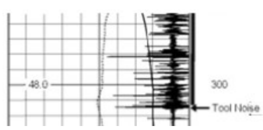
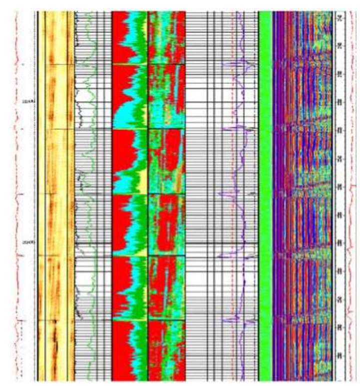
Wellbore Integrity Concerns

- Example - Annular Gas Leaks
  - Horizonal well in Marcellus Shale – 2011 (SPE 153142)
  - 2 leaks: production-intermediate / intermediate-surface annulus
  - Ultrasonic log detected poor cement with channeling



Gas migration evidenced by 200 Hz noise level detected by noise log



Microannulus detected by ultrasonic log. Red represent gas

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