GEOTHERMAL INNOVATION FOR EAST AFRICA ECONOMIC GROWTH

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Geothermal resources tend to be viewed as a mechanism for providing undifferentiated power for the grid at large. However, innovations from the current state-of-the-art in the design of the power plant can provide greater power output as one option. In addition, geothermal power plants can be designed to provide economic benefits beyond power as a way to stimulate and support the socio-economic development of countries in East Africa. An understanding of these options can inform the development strategy to maximize the benefit during the design phase. But the ideas presented here are also all applicable to existing power plants, but naturally as will all retrofit projects, it is more expensive than greenfield construction.

KitzWorks LLC (Kevin Kitz, P.E.) uses existing technology in innovative ways to create commercial energy investment opportunities. Mr. Kitz worked as a specialist in geothermal development for over 30 years with a successful career in creating new value and improving geothermal cost-competitiveness. His work has encompassed the gamut of the geothermal power industry from reservoir engineering, to drilling, pipelines, power plants, PPAs, and O&M. Recently KitzWorks has had a lead technical role on teams to commercialize (a) geothermal hybrid plants using solar thermal heat, (b) injecting solar thermal heat to create synthetic geothermal resources for seasonal storage of solar energy, (c) District Energy Systems comprising geothermal heat pumps, and shifting time-of-use to increase electric utility valuations, including seasonal storage of cold in the middle east, (d) a cost-effective dry-cooled steam condenser for conventional power plants and for geothermal steam power plants.

Webinar Topics

- The "Right Question"
- Solar Thermal + Geothermal Hybrid
- Fossil Fuel (+ Solar Thermal) + Geothermal Hybrids
- Retrofit (& New)High Performance Direct Contact Steam Condensers
- Dry Cooling of Geothermal Steam Power Plants
- What can be delivered besides power for economic growth.
- Geo-Cold geothermal seasonal energy storage

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The focus of the presentation is innovative technologies, but for these ideas to find use in geothermal developments in East Africa, it is critical to start with the right questions.

Workshop Task:
What is this famous geothermal landmark?

Old Faithful Geyser is the most iconic symbol of geothermal energy in the U.S., if not the world.

The Old Faithful candy bar is the world’s first (and best) geothermal candy bar. It has been made by the Idaho Candy Company since 1925. My dentist’s husband owns the Idaho Candy Company . . . Talk about vertical integration!

The Right Question will produce the Right Answer. But the trick is to understand what is the Right Question

What is the "Best Vehicle"? Is a question that has many possible answers. But if we are discussing environmental impact, the question "What vehicle has the least CO2 emissions per passenger mile? Will produce the answer "a bus".

When it comes to renewable energy the Right Question is critical

Workshop Task:

What is the right question to understand the value geothermal?? Bonus: What is the wrong question?

- **The wrong question:**

What is the LCOE ($/MWh)?

LCOE = Levelized Cost of Electricity

- **The right question(s)**

Cheapest way to remove 100 Gtonne CO_2 from grid?

Lowest Total Grid Cost to meet load growth?

Maximum Economic Benefit to Country?

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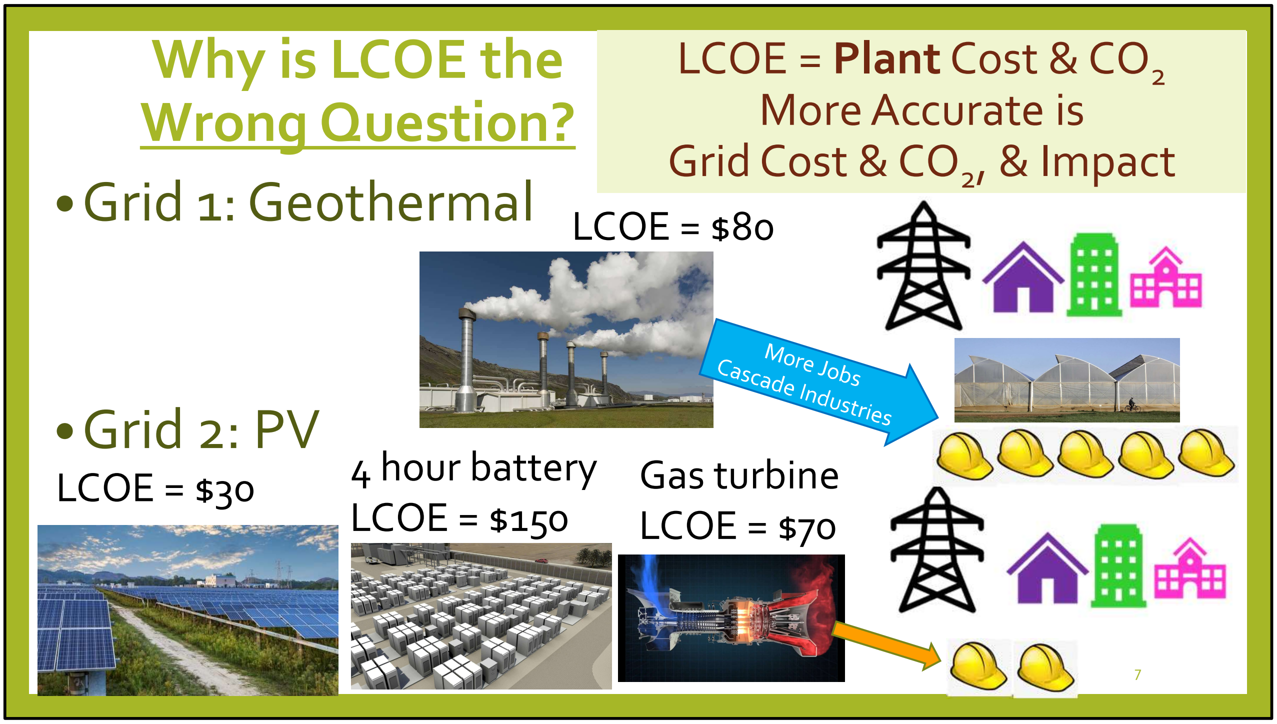
LCOE is a very poor measure of value for renewable energy. It fails to capture the very large impact beyond the power plant.

For example, the recent price of PV power in Saudi Arabia had a LCOE of US$16/MWh and through much of the rest of the world it is $30/MWh, or less. Geothermal power will NEVER EVER be able to achieve $30/MWh, nor does it need to. It does not need to because we all know that a grid cannot be cost-effectively built on PV alone. The reasons for this is that none of the following are included in the "PV LCOE".

- Batteries are very very expensive and only typically good for 4 hours
- The backup power plant that is required beyond 4 hours is not included
- The CO_2 emissions are not included from that backup plant
- The seasonal variation is not included (less output in the winter)
- Etc.

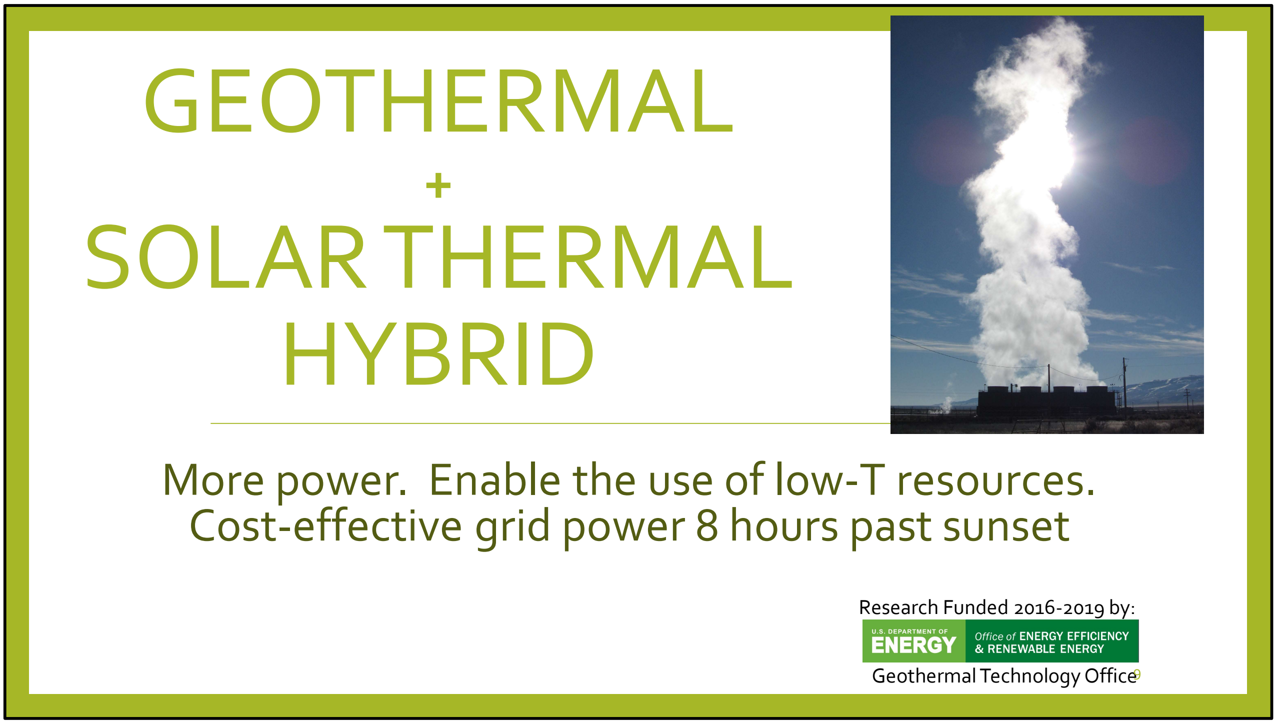
For geothermal power to be the answer, the right question has a more holistic basis. In the US, geothermal will come into play much more quickly with the 1st "right" question. In East Africa with growing load, the second "right" question is valuable. Also in East Africa, the third "right" question invites the discussion about the value of geothermal to step beyond power and look at the socio-economic impact that geothermal energy can provide beyond the electric grid, especially if we look to value that is beyond the pro-forma for financing the power plant.



LCOE is an easy quantity to calculate, but not a very useful parameter for optimizing the grid, and almost always fails to consider the cost of consequential grid CO2 emissions (fossil fired backing of PV and wind).

LCOE also says nothing about the impact of different power generation options on the overall GDP from more jobs, potential cascade industries, transmission system congestion, or anything else besides the price at the delivery point.

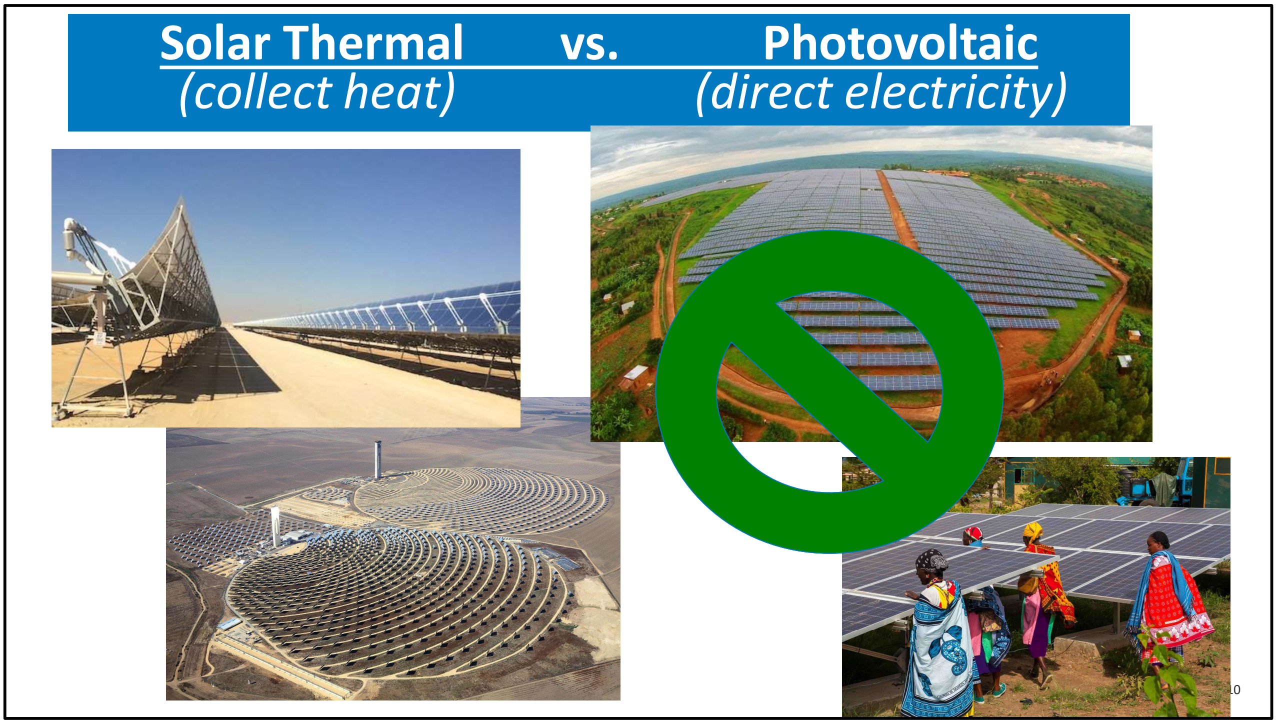
It is important to note that the famous duck-curve of California, caused by very large deployment of PV requires the daily use of tens of thousands of MWh of power from gas turbine and coal power around the western grid. Incorrectly, these are termed "grid emissions" instead of PV emissions. The failure to treat those emissions as being caused by PV creates a huge market distortion that works in favor of PV, and against plants capable of supplying continuous power like geothermal and biomass.



This is a topic that has received a lot of attention over many years, and yet has only been implemented once under the economic incentive of massive financial penalties for non-delivery. (The ENEL Stillwater plant in Nevada).

The fundamental reason it is uneconomic in every evaluation is that the wrong technology approach has been considered.

In East Africa that all-important "right question" will be critical to the adoption of a solar thermal hybrid. This will most certainly not have a lower LCOE than a moderate temperature geothermal resource. But a higher LCOE does NOT mean that it is an unattractive option. In fact it must be compared to other options for supplying the grid with power, reducing CO_2 emissions, and other grid costs to understand whether more at a higher price is better than less at a lower price.



The analysis that was done considered solar trough only. However, all types of solar thermal collectors could potentially be used: trough, linear Fresnel, power tower, etc.

An interesting and valuable continuation of the research would be to evaluate the use of flat panel collectors to generate steam at about 180 – 200 ℃ (up to 400 ℉) as this heat is much less expensive than concentrating solar power systems. The solar steam turbine would still be used, but the amount of power extracted from it would be less. And the efficiency would be lower because of the lower inlet temperature, but it may have the potential to be an attractive option.

Concepts and Goals for Geothermal Solar Thermal Hybrid

Concepts

- Solar thermal energy (not PV) to Boost Geothermal output
  - Collect at high temperatures (400°C = 750°F)
- Avoid low geothermal conversion efficiency
- Increase capacity factor to improve economics

Implementation goals

- Lower the cost of geo-solar hybrid, compared to previous
- Create a valuable generation asset for grid

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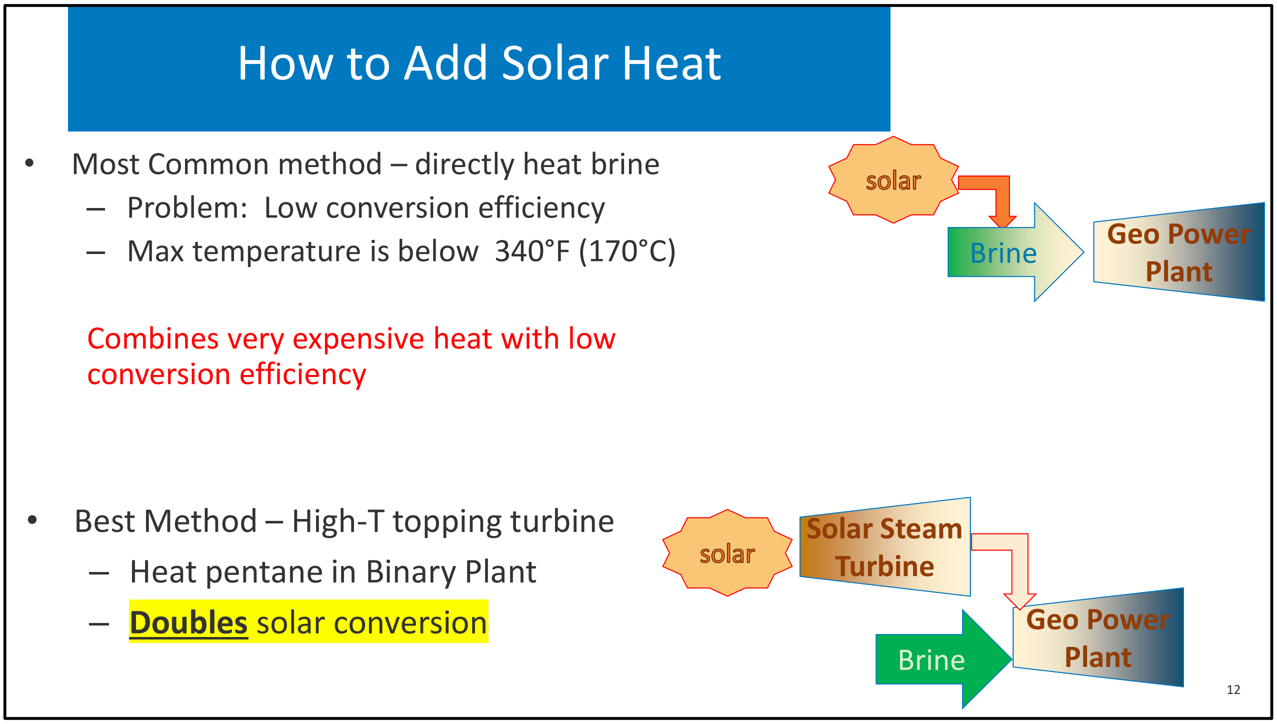
This was the vision that was used to set-up the investigation.



The first case is where solar energy is used to heat the brine. This may be either a pure binary resource (which is what the study involved) or it may be the solar heating of the brine from the 1st stage separator. In both cases this is not a viable approach and is not worth consideration. As the text in red implies, this effectively combines the two worst features of these two technologies. Geothermal has low conversion of heat to power, and solar-thermal is very expensive heat.

In the bottom case, the cycle is actually much more complex than indicated. The superheated solar steam enters the turbine at approximately 300 – 350 °C and approaching 5000 kPa (700F and 600 psia). The steam expands in the steam turbine to about the pentane turbine inlet temperature. The steam then boils the pentane that has been heated to close to the turbine inlet temperature.

The cycle is even more efficient when it is designed as a grassroots plant, rather than as a retrofit as was done in the first study.

In the cycle studied, the more efficient use of the solar heat results in 100% more net power than in the brine heating service. This kind of small backpressure steam turbine is very inexpensive, as are the steam to pentane heat exchangers. Note that the heat exchanger has boiler quality steam on one side and clean pentane on the other. So there is no scaling or fouling of the heat exchanger. It could reasonably be done with low cost fully welded and sealed plate and shell exchangers.

Carnot Efficiency

(a theoretical value)

$$\eta = \left[1 - \frac{T_{cold}}{T_{hot}}\right] \times 100\,\%$$

- T_{cold} is atmospheric temperature (°Kelvin)
  - For comparison among options ➔ Assume 25C=298K
- So, the only variable is T_{hot}
- If solar collectors at T_{hot} =
  - 160 °C (433 °K, 320°F) ➔ *η = 31% (A real ORC is about 12%)*
  - 400 °C (673 °K, 750°F) ➔ *η = 56% (A real CSP is about 30%)*

NREL | 13

A purely theoretical calculation,
but it reveals what is important and why.

In real power plants, going to higher temperature increases the conversion of heat to electricity by 150% (2.5 times more power)

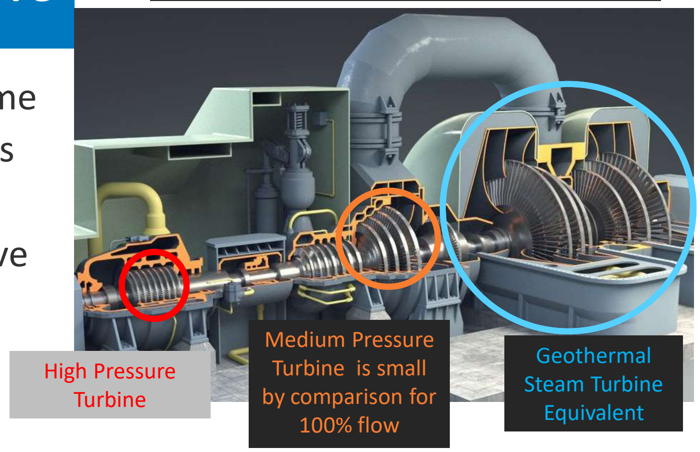
This theoretical formula shows why, thermodynamically the solar energy must be created and used at a high temperature.

Medium Pressure Steam Turbines are Inexpensive

- High-Pressure = Small volume
- Small Volume = small blades
- Small blades = light weight
- Light and small = inexpensive

- The solar steam turbine is NOT sized for 100% flow So is even smaller & cheaper

Fossil Fuel Steam Turbine



NREL | 14

Because the high-purity steam turbine for the solar steam topping turbine operates at high pressure, the volume of steam is small and so the turbine is small. Thus the cost of these types of high-pressure back-pressure turbines are inexpensive, and widely used in the manufacturing industry.

The photo below shows one such option, a Howden steam turbine, capable of more than 10 MW of net power.

Capacity Factor Affects Economics

- Capacity Factor
  - $total\ actual\ generation \div (rated\ capacity(MW)\ * 8760)$
  - Typical geothermal > 95%
  - Typical solar thermal < 25%
- High-temperature thermal storage raises solar thermal capacity factor
  - May increase solar field cost
  - Adds storage system cost
  - Does not increase power cycle equipment cost

NREL | 15

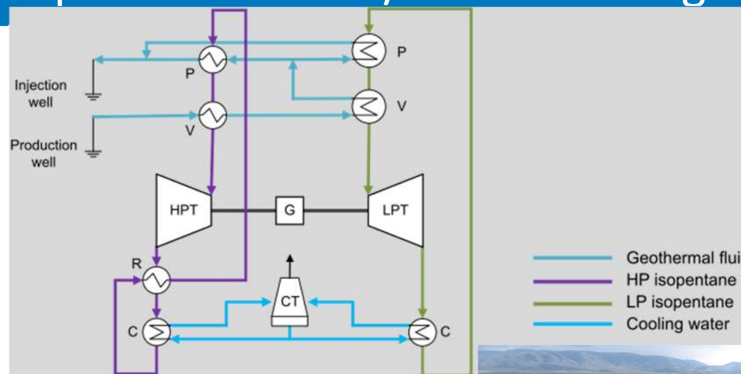
The increase in capacity factor is more valuable than the additional capex to add thermal storage. The probable thermal energy storage mechanism is two tanks. The hot oil is stored in one, and as it is withdrawn and used, the oil flows to the “warm” tank.

The Raft River power plant was a typical Ormat 2-level iso-pentane ORC w/ water cooling

The hot brine and power cycle:

- Hottest Brine boils HP pentane
- The Brine boils LP pentane
- The brine heats the pentane in preheaters

- Design brine injection T = 66C (150F)
- Actual brine injection T = 55C (130F)



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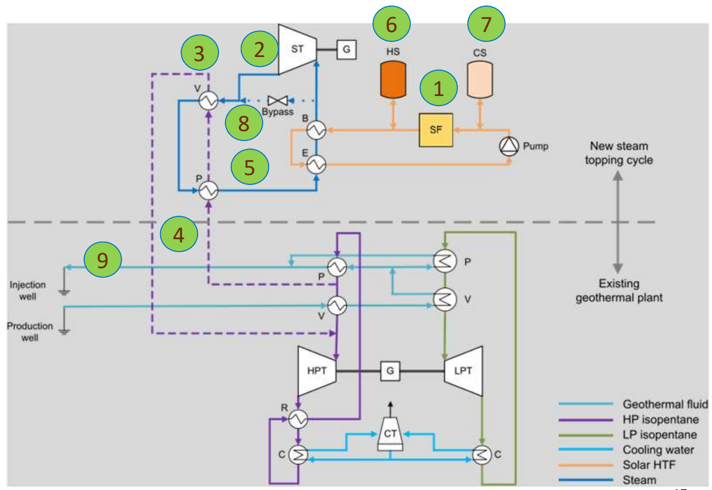
The Raft River geothermal project is a 12.5MW (net) Ormat power plant. Unfortunately, there was not enough brine to run it at full load, so a solar-thermal + geothermal hybrid was evaluated to increase output.

The final power cycle designed for the geo-solar retrofit (4 separate fluid)

1. Solar heat is collected in a hot oil loop and used to boil high-purity water.
2. That solar steam is then passed through a high-temperature pressure steam turbine which exhausts at about 120 °C.
3. The exit steam is used to boil pentane
4. The pentane is preheated by brine and after vaporizing is sent to the ORC turbine
5. The condensed steam is pumped back to the steam vaporizers and is not mixed with either geothermal fluid or pentane.
6. 7. Hot and cooled oil storage tanks increase the capacity factor of the hybrid equipment
8. Excess solar steam bypasses the turbine
9. Injection temperature goes DOWN when solar boost comes on



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This was the final concept. Slight variations were evaluated between the initial concept and the final design to simplify the cycle and capture both better efficiencies and lower cost.

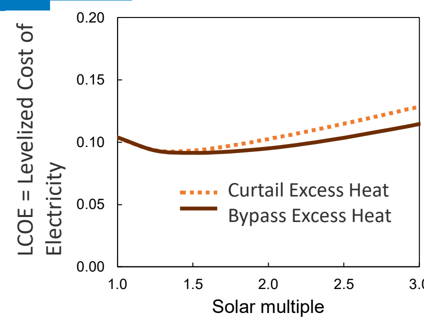
A different design (not shown) is used for a greenfield project to maximize the geothermal benefit and size of the solar collector.

The hybrid was not constructed however because the market in Idaho in the U.S. was strongly affected by inexpensive natural gas and a lack of a commitment to reduce CO2 emissions, and a general focus on LCOE rather than grid value.

For a greenfield plant, the entire geothermal flow would be integrated into the solar thermal cycle.

Oversize Solar Field to Increase Capacity Factor & Capacity

- Improve power plant capacity factor by increasing solar field size above design value
  "Solar multiple" = actual size / design size

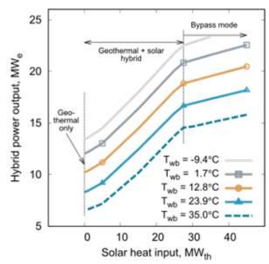


CSP Disadvantage

- Too much heat at high solar multiples
  - Must curtail the solar field - often

Geo-Solar Hybrid Advantages

- Bigger solar fields can be installed for the same LCOE.
- Bypass excess heat to the binary plant
- Never curtail



Why is LCOE only an ***OK*** parameter to measure here?

It compares costs within the same plant, ***but still doesn't evaluate the benefit of more power to the grid, or when that power is delivered***

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The geo+solar hybrid makes it cost-effective to oversize the solar field above the design point for 100% output.

The excess solar collector area

- keeps the plant at full load when solar energy is reduced from the design condition
- Allow the steam turbine to run at it's usual allowable 10% overgeneration.
- Provides a means to charge the thermal storage tank
- Can be delivered straight to the geothermal power plant when the steam turbine and storage tanks cannot accept more energy.

Thermal Storage Duration

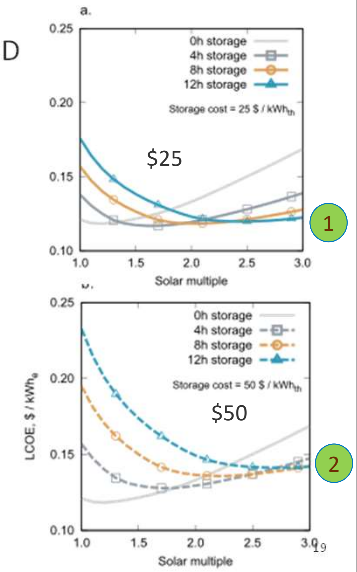
How many hours can the geo-solar hybrid run after sunset?

Raft River, ID

Geo-Solar Advantages w/ 4-12 hours of storage

1. $25/kwh-th - LCOE is flat to very large solar multiples
2. $50/kwh-th - LCOE <10% more, justifies 3X solar field

- Raft River in Idaho is a poor solar resource area
- Costs would be much lower for an area with good solar, like East Africa because there are fewer days with poor solar insolation and so the benefit of an oversized solar field is reduced.



Advantages of Including Thermal Storage

Thermal Storage:

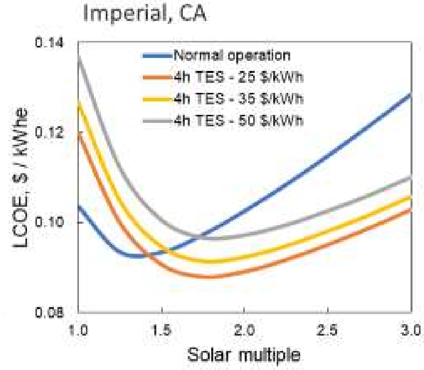
- Stores high temperature solar heat
- Allows dispatchable power
- Can lower the cost of power (LCOE)

Geo-Solar Advantages:

- Adding storage makes geo-solar hybrid cheaper than PV + Batteries

$50 - Commercially available, low cost adder
$35 - Storage is the same LCOE as no storage
$25 - Storage lowers the cost of geo-solar

Imperial, CA



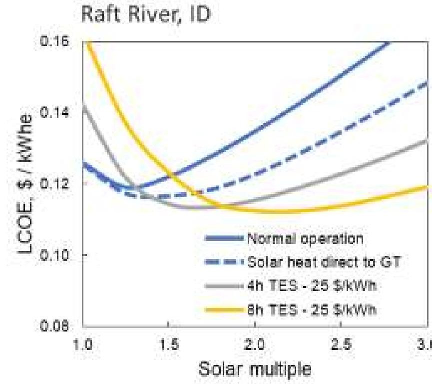
Thermal Storage Duration

How many hours can the geo-solar hybrid run after sunset?

Raft River, ID

Geo-Solar Advantages

- 4-8 hours or more can lower the LCOE
- Offers one of first economically viable all-night zero-carbon solar power options
- Cost effective storage solutions are required



Adding Storage lowers the cost of the geo-solar hybrid

PV + Battery Disadvantage

- Little cost reduction with longer storage
- Battery cost is directly proportional to duration
- Batteries usually limited to 4 hour duration

Geo-Solar Hybrid Advantage

- Larger Capacity Factor for Geo-Solar Hybrid w/ Solar TES
  - Can store more heat from larger solar multiples
  - amortizes fixed costs of the power plant over more hrs/day
- **First all-night (12 hour) storage option with low grid cost and CO_2?**

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It is common now to read about PV + storage that is very inexpensive. However, this is a dilution effect.

Very large quantities of very inexpensive PV (MWh) and pretty small quantities of VERY expensive storage MWh. When the two are mixed together the overall price remains low, even though the battery storage cost is very high.

Geo-Solar Hybrid with Thermal Energy Storage
vs.
Photovoltaics and Battery Energy Storage

		Geo-Sol	PV	G-S + TES	PV + BES
Storage Time	hours	0	0	4	4
Raft River LCOE	$/MWh$_e$	**116**	**74**	**118**	**187**
Storage Adder	$/MWh$_e$	-	-	2	113
Solar Land Area	m^2	-	-	100,000	140,000
Imperial LCOE	$/MWh$_e$	**92**	**63**	**91**	**148**
Storage Adder	$/MWh$_e$	-	-	*none*	85
Solar Land Area	m^2	-	-	100,000	160,000

- PV and Solar Thermal arrays deliver the same annual power

Conclusions:
- PV will always be the least cost $/kWh, when integration is minimal
- Geo-Solar Hybrid systems with TES has <66% the LCOE of PV+BES
- PV uses ~40% to 60% more land area than Geo-Solar hybrid

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This is the results from the study of the retrofit of a solar thermal hybrid steam topping turbine and pentane boiler at the Raft River geothermal power plant in Idaho, US. It is an area with only a moderate quality solar resource. To evaluate the effect in a better solar location, we re-ran the model using the Imperial County, Californial weather, which is in the desert and is a very good solar resource. Note that the power plant cooling system was not resized to account for the hotter weather, but still the effect of the better solar resource is evident.

Of course in East Africa the solar resource is even better. And solar thermal technology has advanced since the study.

Key points. The LCOE of PV is far lower than the Geo-Solar hybrid. But when battery energy storage (BES) is added to the economics so that the plant is useful beyond sunset, the tables turn, and the hybrid system is far cheaper. At 8 hours of storage, the LCOE of the PV would go up above the $148/MWh while the geo-solar hybrid with thermal storage would actually go down below the $91 shown for Imperial.

The use of land is also dramatically different for PV vs. solar thermal hybrid. There are more jobs, by far in a geo-solar hybrid plant than a PV plant, and there are opportunities for spin-off value from the hybrid plant.

In this case, the LCOE of the geo-solar hybrid with storage is lower than PV+BES, but LCOE is not the only consideration for why the hybrid is better.

Geothermal + Solar-Thermal Technical and Economic Studies

Work To-Date

- Carnot Efficiency informs us that we must go to high temperature with the power cycle.
- Adding energy within the ORC allows more energy to be extracted from the geothermal brine (2X more than solar brine heating)
- Oversized solar field and TES increase capacity factor and allow larger installations for better economics. (2/3 of PV + BES)
- Creates options for reliable nighttime power
- Greenfield Hybrids take a different approach and get even better thermal and economic performance
- **Better performance and cost than PV + Battery**

Additional Areas of Innovation

- Further cycle optimization
  - Direct steam vs. thermal oil in solar collectors
  - Greenfield Optimization
  - Evaluate potential of flat plate collectors
  - Integration with Other Power Technologies
- Economics
  - Detailed capital cost estimate
  - More detailed comparison to PV+BES
  - Thermal storage dispatch – time of delivery scheduling and impact on grid assets
- Deployment
  - Demonstration project on existing plant
  - Greenfield project

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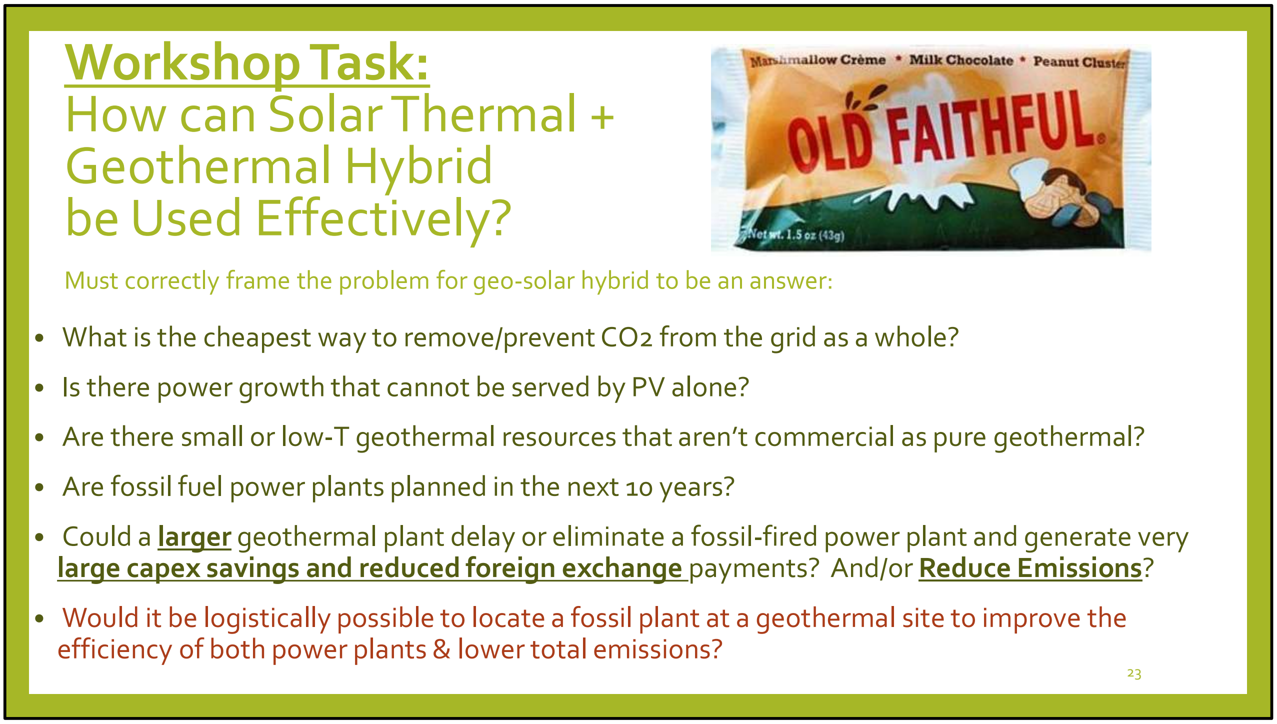
This is 100% commercial technology.

Solar steam and steam turbine
Geothermal power plant
TES – Thermal Energy Storage

So implementing this technology is not a research project, it is simply bolting existing power generation parts together in a new way.

The areas of additional innovation are really areas of optimization. They do not involve creating technology but rather fitting it to the specific needs of the project.



A study has been done that integrated a gas turbine with 100 °C geothermal fluid using the same high-pressure topping turbine. In this case the geothermal fluid was only used to preheat the binary fluid (propane) and the steam turbine boiled the propane. The net result was more power than either a stand-alone geothermal power plant and a stand-alone combined cycle plant, and also more power than if the heat from the gas turbine was used directly in the binary power plant.

This result suggest that perhaps 3-fuel hybrids in countries, like those in East Africa, could benefit from integrating geothermal, solar-thermal, and gas turbine to maximize the local energy content, to minimize CO2 emissions and foreign exchange purchases of oil, but still provide a much larger base-load power plant than would be possible with a geothermal plant alone.

As the study of the gas turbine hybrid shows, this technique can make a large increase in output from either low-flow geothermal resources or low temperature resources.

Integrate Solar-Thermal Energy and/or Fossil-Fired Combustion Turbines

OPPORTUNITIES

- Geothermal Resource
  - Need to Maximize power generation
- Need Dispatchability/Flexibility
- Transmission Capacity not full
- Grid Load Growth calls for
  - Fossil PP expansion
  - And/or Storage Assets

SOLUTION CONCEPTS

- Add Solar-Thermal Hybrid Integration (not PV)
  - Solar heat is added to geo PP
  - $/MWh decreases w/ thermal storage
- Add Fossil-fired Power
  - Use with or instead of solar-thermal
  - heat added with similar steam turbine
  - Fully dispatchable
  - Can reduce cost of solar-thermal system
  - Lower CO2/MWh than separate geo and fossil power plants (synergy)

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The concepts discussed are for both retrofit of existing as well as new geo powerplants.

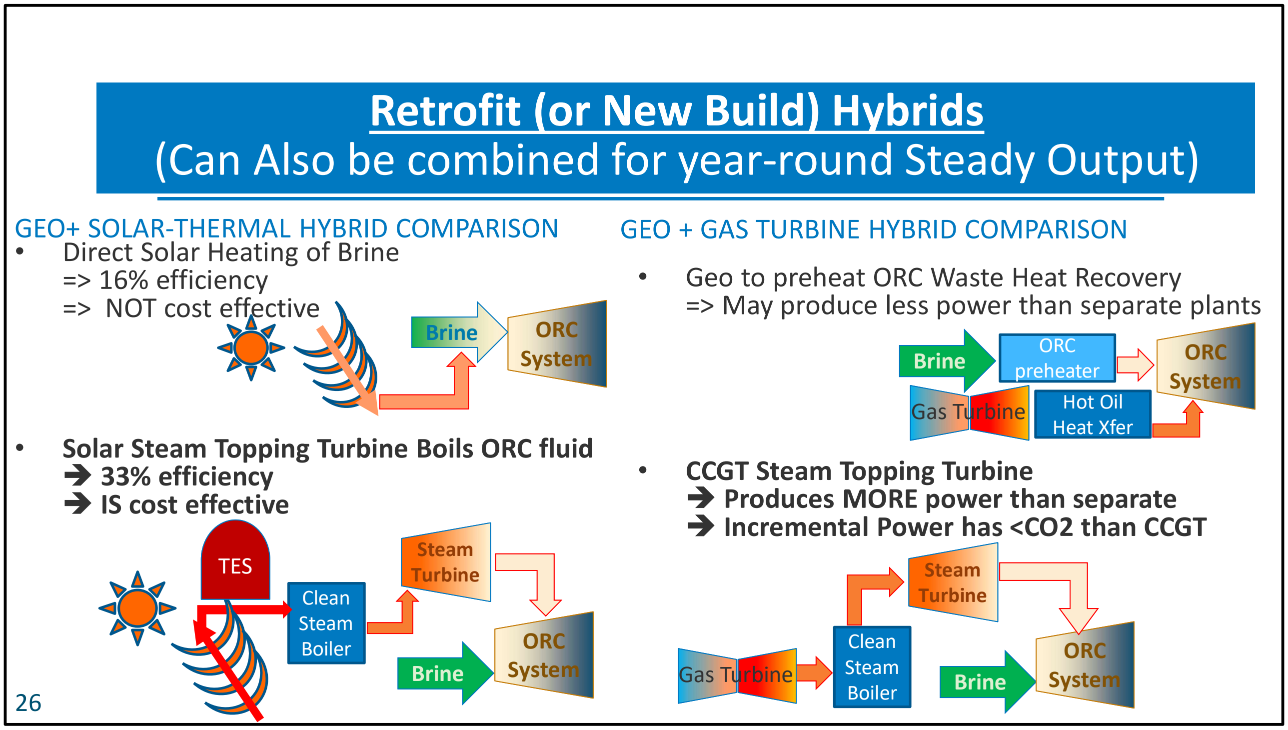
As a geothermal power plant declines in output the sun is an option for additional “fuel”. This has been generally accomplished by the heating of the brine going to the plant. This combines the very expensive solar heat with very low efficiency geothermal power plant conversion to power. As such it has never been shown to be cost effective.

In other cases the electric market and the availability of fossil fuel may supplement the sun to make-up for a declining resource or to create new dispatchable power opportunities.

Adding a high pressure steam turbine matched to the geothermal power plant offers a way to efficiently and cost-effectively add additional heat to the geothermal plant. The basic concept is that the additional steam turbine is a closed-loop high-purity, high-temperature and pressure unit that exhausts as a back-pressure turbine to the geothermal power plant where the steam is used to boil either the binary plant working fluid or flashed brine.

In a solar hybrid, the solar collectors heat the steam. Steam can also be made from a heat recovery boiler off of a gas turbine exhausta large recipiprocating engine.

These concepts, when applied to new geo power cycle design would be adjusted to make a better integration between the different “fuel” sources. The huge advantage of such hybrids on new-build is the ability to increase the size of the plant, making it more cost effective. For example a study of the integration of a new-build moderate temperature geothermal resource with solar thermal almost tripled the output of the hybrid plant, and the integrated plant produced more power than a separate solar plant and a separate geothermal plant, at lower total cost.



The top left is a commonly considered method to add solar thermal heat to a geothermal power plant. One of the ways to see that this is a very inefficient process is that when the solar thermal collector starts-up, the injection temperature also goes up. This heat is completely wasted, and contributes to why the energy efficiency is so low.

By adding the clean steam turbine (lower left), the efficiency of solar energy conversion is more than doubled. The brine injection T drops when the hybrid cycle is operating, increasing cycle efficiency. Not shown on the slide, but described in the papers, is that adding thermal storage LOWERS the cost of the hybrid system (basically by increasing capacity factor). The return of the condensed clean steam to the steam boiler is not shown in this simplified poster version.

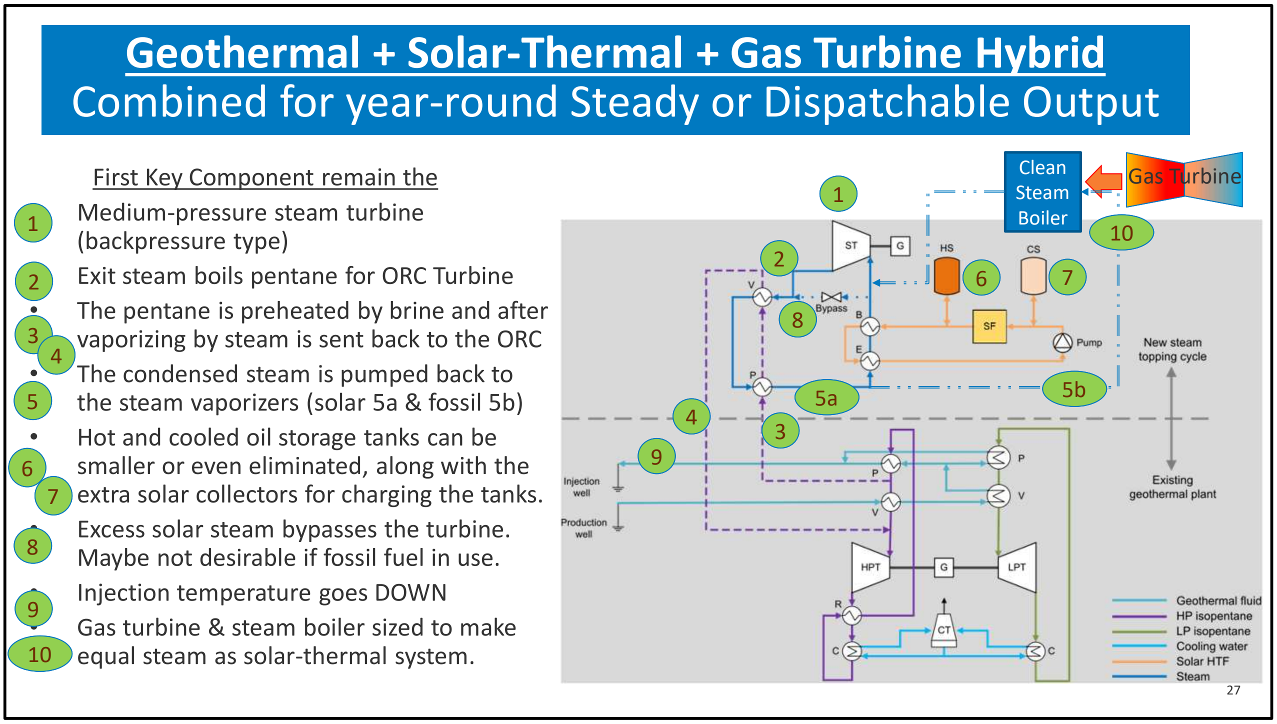
Geo + gas turbine waste heat hybrids have been considered (upper right). Because ORCs are a low-temperature cycle, their efficiency is limited by the turbine inlet temperature.

Water is a nearly ideal heat transfer fluid for high-temperature applications (which of course is why every large combined cycle plant in the world is based on steam and not on an ORC cycle). A better Geo + gas turbine hybrid cycle is shown on the bottom right building on the concepts of the solar-thermal steam turbine hybrid on the left. Again the clean steam is closed loop.

A back-pressure steam turbine does not the large expensive blades of a condensing turbine. So even on a very large installation, the steam turbine would be inexpensive. In smaller ORC applications, widely available industrial back-pressure steam turbines have low capex.

There are many factors that go into the economics, but a key element of the retrofit option is that unused geothermal turbine, generator, and cooling system equipment is returned to full capacity at low capital cost and low incremental staffing cost.

The cycle shown is ORC, the two bottom options are both adaptable to flash steam plants as well.



This has not been studied in great detail.

However a geothermal resource of only 100 °C was studied with a gas turbine, and this concept produced more power than any other hybrid or separate configuration.

Key concepts:

Improve economic and plant performance by:

- Using a 300 °C steam topping turbine
- Oversizing the solar field by a much smaller amount (probably)
- A 300 °C solar thermal storage, would be smaller or possibly eliminated.
- The gas turbine boils steam and generates power with the same turbine as the solar steam turbine.

Fossil-fuel only:

- Eliminate the solar thermal system and instead make the fossil power plant more efficient whenever it is required to run for grid power.

HIGH-PERFORMANCE GEOTHERMAL STEAM CONDENSER

For new or retrofit direct contact geothermal steam condensers

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This innovative dry cooled system was developed for a project at the Geysers that needed to have close to 100% reinjection. It was not built, unfortunately, but it was almost fully engineered.

A key concept is

1) Structured packing makes steam condensation more efficient.
2) Inside a direct contact condenser, it does not have to be one big mixing pot. Different contaminants in the geothermal steam enter the cooling water at different times. For example boron and arsenic (plant and animal poison respectively) both go into solution as the steam condenses in the turbine. On the other hand the CO_2 and H_2S don't enter the cooling water until the very end of the gas cooling zone of the condenser.

Condenser Type:

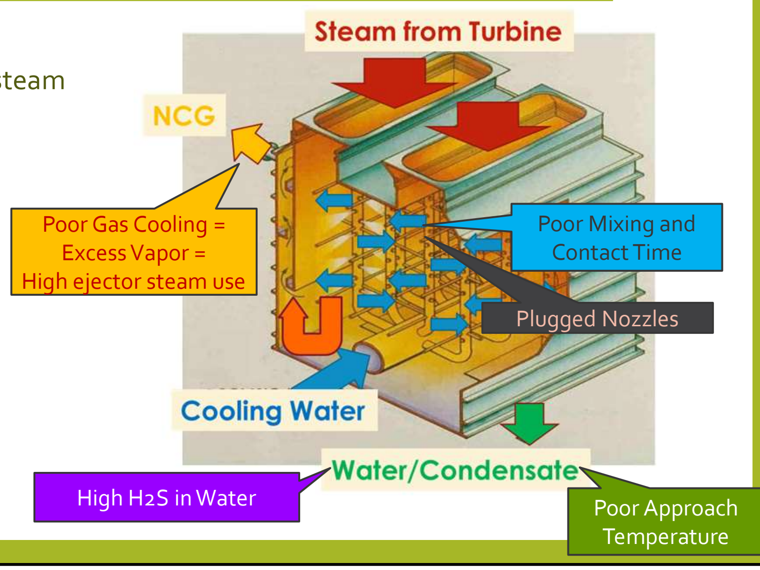
Steam Spray (Jet) - Direct Contact Condenser

Spray-Type

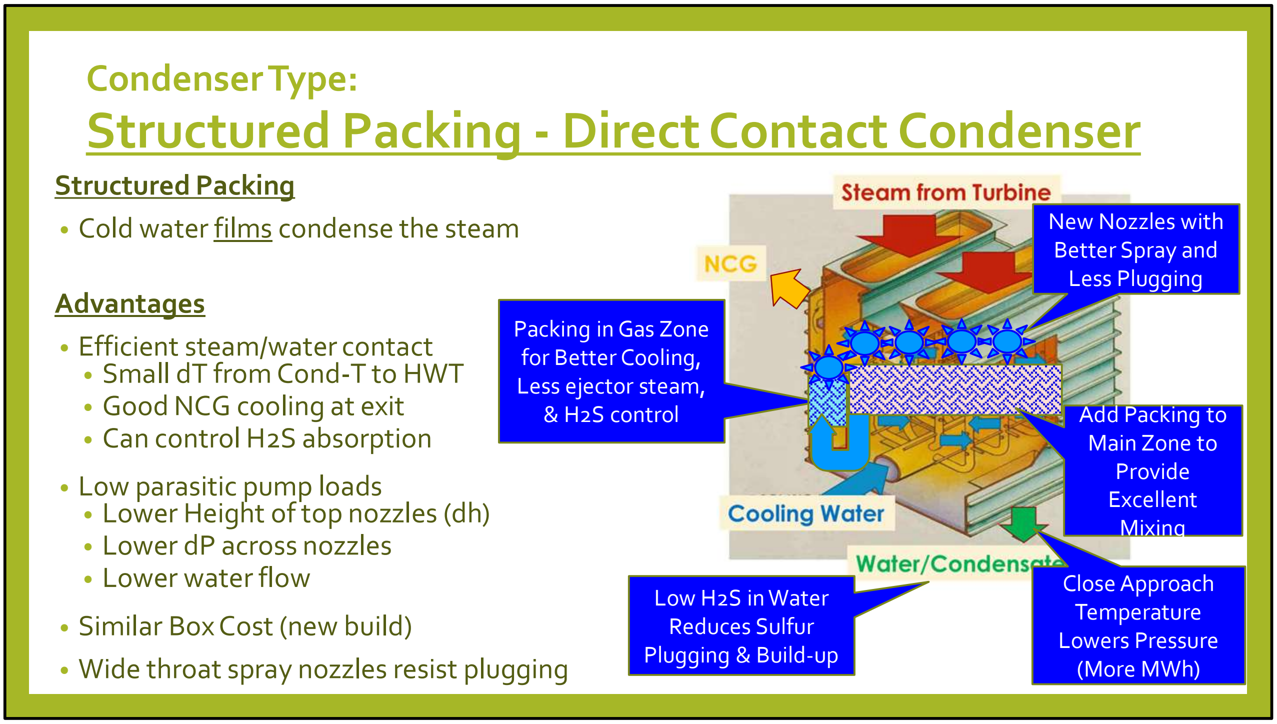
- Cold water droplets condense the steam

Disadvantages

- Inefficient steam/water contact
  - Large dT from Cond-T to HWT
  - Poor NCG cooling at exit
- High parasitic pump loads
  - Height of top nozzles (dh)
  - dP across nozzles
  - High water flow
- Large Box = Expensive for new
- Plugged Nozzles

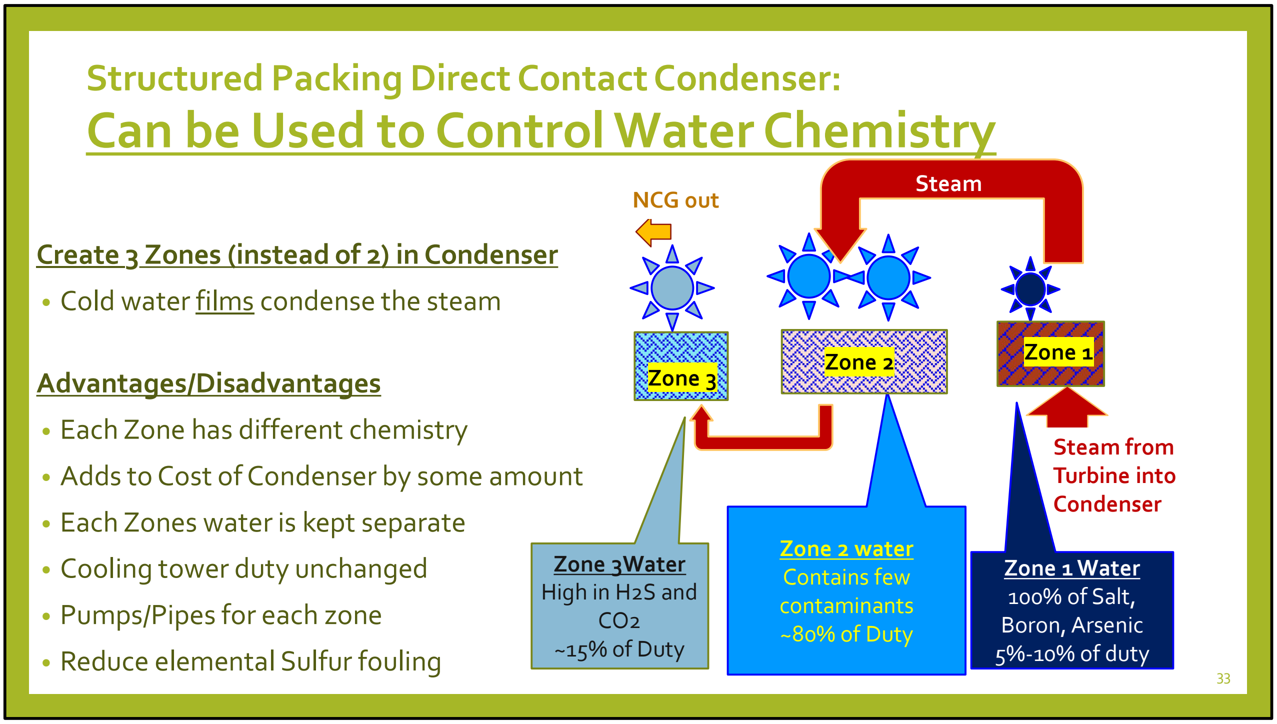


This is a direct contact condenser similar to that in almost every geothermal steam power plant in the world unless there is a very important reason to do otherwise (US = H2S abatement and Nesjavellir Iceland for district heating)



Retrofit of packing into an existing geothermal steam condenser can lead to an increase in power plant output (lower condenser pressure and less ejector steam). It can also help mitigate certain operational problems.

The buildup of elemental sulfur in the cooling tower basin of many geothermal power plants creates hazardous waste, not because of the sulfur, but because of the contaminants that the sulfur holds onto, like arsenic, mercury, and other heavy metals. Reducing sulfur formation also reduces hazardous waste.



This is a direct contact condenser similar to that in almost every geothermal steam power plant in the world unless there is a very important reason to do otherwise (US = H_2S abatement and Nesjavellir Iceland for district heating)

DRY COOLED STEAM CONDENSER

For process, reservoir, or fresh water supply benefits

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This innovative dry cooled system was developed for a project at the Geysers that needed to have close to 100% reinjection. It was not built, unfortunately, but it was fully engineered.

A key concept is that inside a direct contact condenser, it does not have to be one big mixing pot. Different contaminants in the geothermal steam enter the cooling water at different times. For example boron and arsenic (plant and animal poison respectively) both go into solution as the steam condenses in the turbine. On the other hand the CO_2 and H_2S don't enter the cooling water until the very end of the gas cooling zone of the condenser.

GEOTHERMAL CONDENSER SYSTEMS

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Steam Turbine

Direct Contact w/ Cooling Towers

(evaporating steam condensate)

Binary

Air Cooled

Olkaria III

The Kenya steam turbine units are all direct contact condensers.

Most binary power plants use air cooled condensers.

BOTH are highly proven technologies.

In gas fired combined cycle plants, both evaporative cooling and dry cooling using A-frame steam condensers are done.

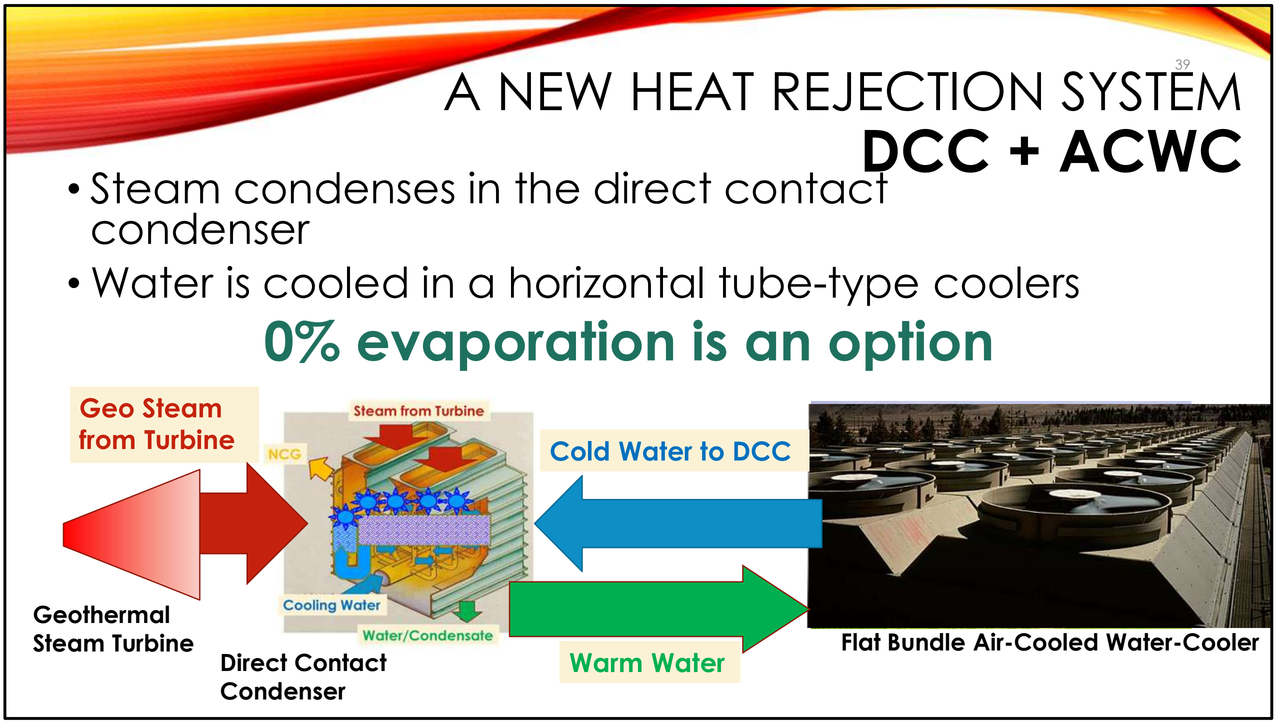
The picture shows that just because water is nearby, doesn't mean that it is either available or desirable to use it for cooling. This is true in the case of condensed geothermal steam as well.

Just because the geothermal steam is condensed, it doesn't have to be used for evaporative cooling of the condensers.

The very large ACCs of conventional steam power plants will not work for geothermal for 3 reasons:

1) The finned heat exchanger tubes have to be stainless steel, and they are not built anywhere in the world with stainless.
2) They are too expensive for geothermal power with its very large heat rejection needs.
3) Because of the NCG, full condensation may not be possible.

A different and better system is needed for geothermal



The only real change in this picture from a conventional steam condenser system is the use of a finned tube air coolers to cool the water used in the direct contact condenser instead of using a wet cooling tower.

Finned tube air cooled water coolers are available from dozens of manufacturers across the globe. It is completely proven technology in the O&G, power, and chemical industries.

There are specific design considerations in the direct contact condenser and in the flat-bundle air-coolers that can make this a much more cost effective and efficient system.

Those design considerations can also be used to help produce “products” of potential value in East Africa beyond power in supporting the economic growth and poverty alleviation of the countries.

Workshop Task:
How can the Dry-Cooled Steam Condenser be Advantageous?

- **Increase power by adding condensed steam back into brine**
  - This allows lower 2nd flash pressure or easier chemistry for an ORC
  - It also allows geo-solar hybrid design for a flash steam plant
- **Reservoir Management**
  - 100% reinjection is practical on new power plants
  - Increase injection % at existing plants
- **Can be used to control chemistry**
  - Produce agricultural-quality water by selective condensation (Zone 2)
  - H_2S emission control (Zone 3)
  - Oxygen free water for steam scrubbing upstream of turbine (all zones)
- **Water Distillation**
  - Use waste geothermal heat to boil low-quality water and condense for more ag water 40

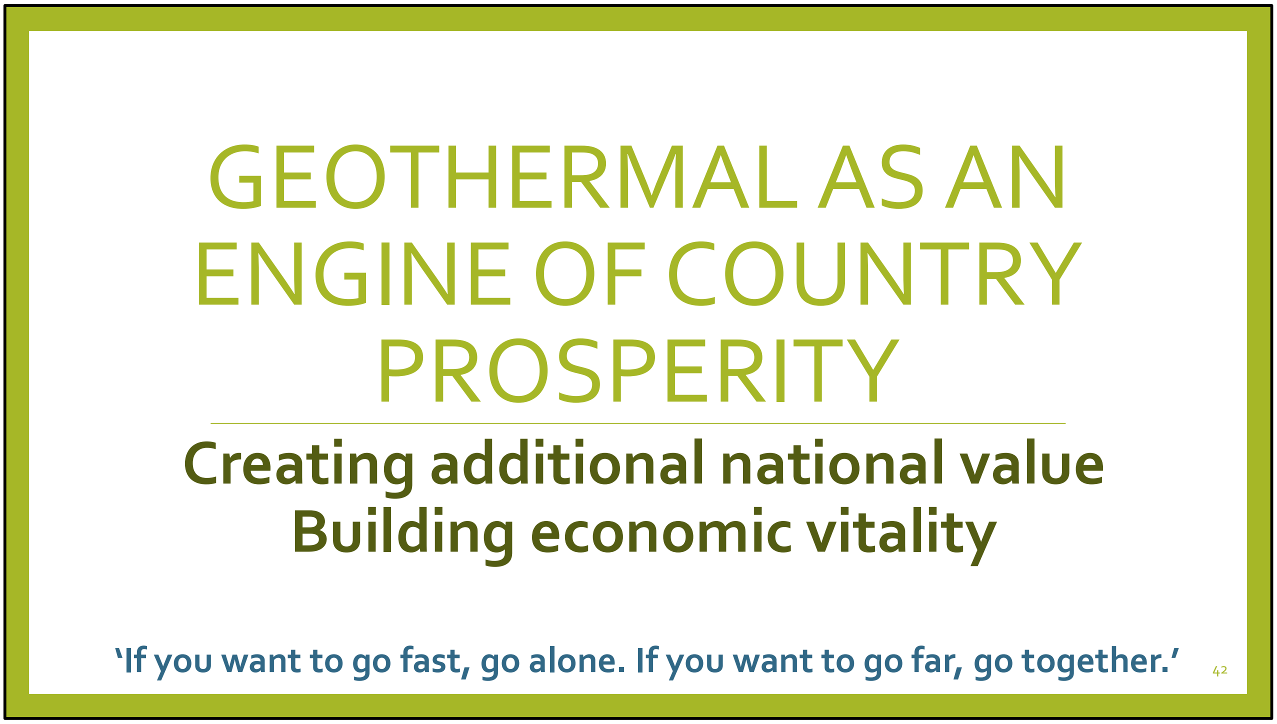
The first two topics relate to making more power from the geothermal system.

- The first one allows more power to be extracted from each tonne of produced fluid.
- The second one is related to reservoir maintenance over the long term, if reservoir modeling shows that 100% reinjection is valuable.

As mentioned previously, the chemistry inside the direct contact condenser can be engineered for different purposes. One of the most promising is to use the geothermal steam condensate to be used for irrigation water by removal of the boron. There is a patent, now expired, that describes this process. Since the arsenic also comes out of the steam with the boron, it is possible that the agricultural-quality water may also be drinking water quality, or could be made that way with activated carbon filters. This is an area for further study.

Lastly, the residual heat in the geothermal brine can be used to boil sea water or other low-quality water. The condensing system size can be in increased to produce more useful water.

If the water is used for other economic value, then of course it will not be able to be used for additional power generation. But the key question for the policy makers are what are the relative priorities?



This saying is also applicable to geothermal development.

If you just want the lowest possible LCOE, then just build the geothermal power plant. (Alone)

If you want the geothermal development to create the maximum economic value possible, then more of the many economic value creation opportunities must be captured. (Together)

Workshop Task:
What are the **Best** Questions when Looking Beyond Geothermal Power?

Narrow-Focus Questions Which Limit Innovation?

- What else can be sold to improve the debt coverage ratio?
- What is the ROI of cascade use?

Open-Ended Questions Which Encourage Creativity?

- What opportunities exist beyond power and revenue?
- What small capex investment can create greater local economic activity?
- Can geothermal heat or cold allow local farmers to produce revenue crops?
- Is there a need for fresh water nearby, either ag or drinking?
- How can geothermal lower grid cost from building energy **useage**?

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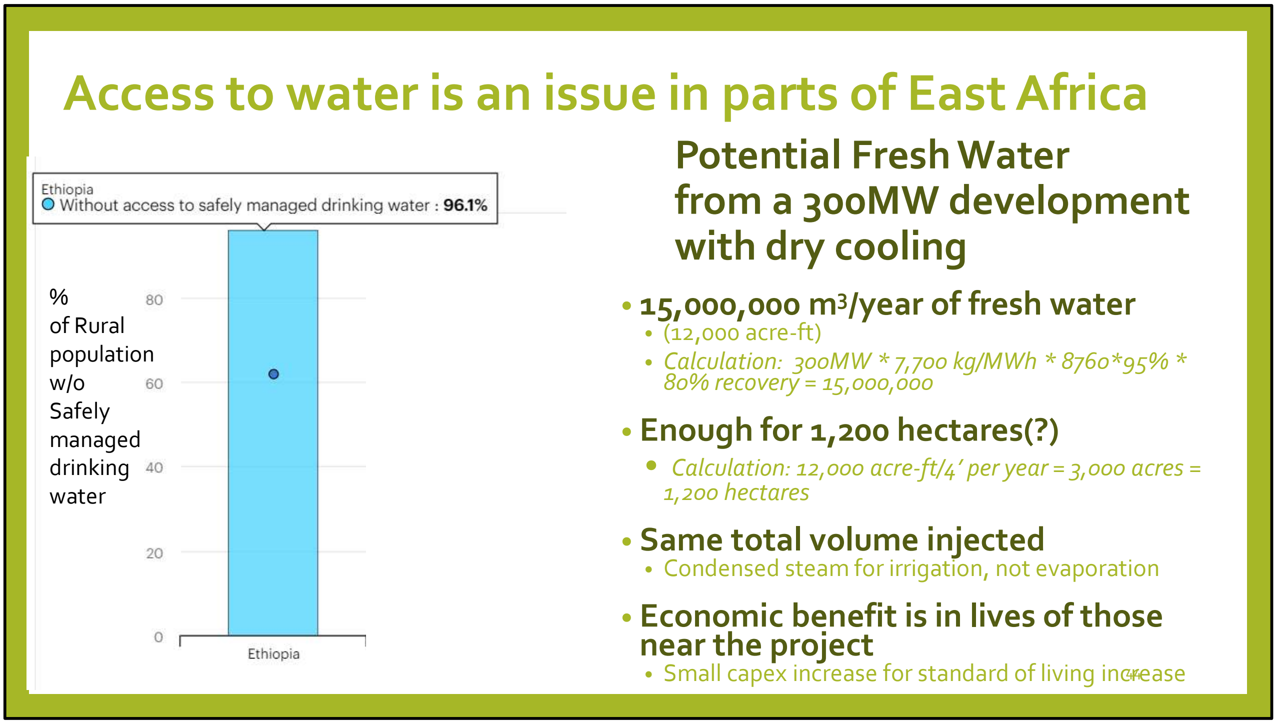
Geothermal power was developed in rich countries (Italy, New Zealand, and the US) in which inexpensive power was really the only consideration. However, in East Africa, there are larger socio-economic drivers that can be served from a geothermal power plant.

These can be pursued.

Note that everyone can see the potential value of geothermal heat, if only a process can be found that needs a lot of heat all year long. This is NOT LIKELY in East Africa. So instead, what other value-creation options are there? Creating clean water is one.

Not all the value of a geothermal power plant can be ascribed to it’s LCOE or the reliable revenue of the pro-forma. Raising the standard of living of those living near the power plants does not help the geo PP lower it’s LCOE, nor does it make much or any difference in the revenue coming in for the debt. However, that does not mean that there is no economic value, nor that the country is best served by pursuing those opportunities.

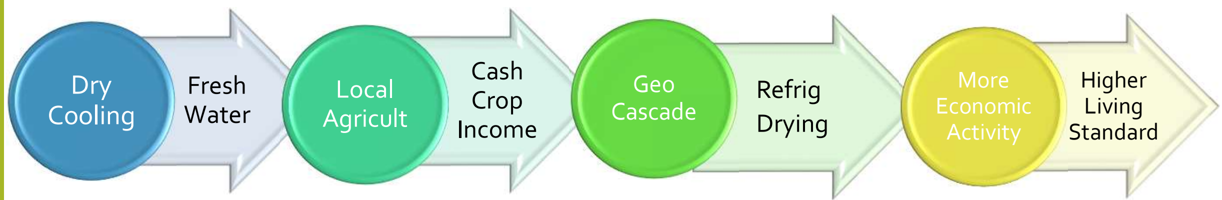


This is not necessarily a proposal to create water for irrigation at the Ethiopia plants. But it is a proposal to consider the value of water at all geothermal power plants.

The steam condenser can be designed to provide ag-quality water. To provide drinking water, additional processing and engineering design would needed.

Water can clearly make a difference in the economic vitality of a region.

Socio-Economic Benefit of Fresh Water



Dry cooling ➔ Water ➔ ***[Use of Water]*** ➔ Greater Economic Activity and Living Standards

Examples of *[Use of Fresh Water]*

- Tilapia fish farms➔ geothermal absorption cooling to ship fish to high-value urban markets
- Grow potatoes ➔Geothermal heat and power to process potatoes. All farmers can participate.
- Tea growing ➔ Tea drying with geothermal heat

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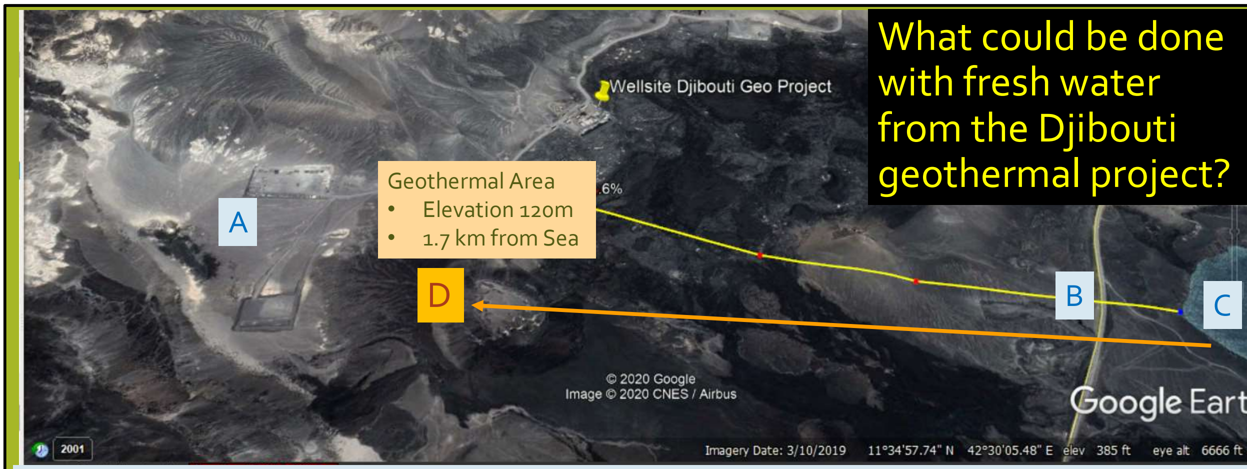
Option 1: (not shown) Revenue to Power Plant

Long-term water sales contract to credit-worthy agricultural business
High Value or Export Crops

Option 2: Local economic development

Fresh water from power plant available for crops and/or drinking water
Crops that can be grown by individual local farmers
Increased local income beyond jobs in the power plant
Geothermal can add additional value with drying or refrigeration.
Geothermal impact on community is not just from power delivered, but also about economic opportunity and prosperity to a much larger segment of the local population. These economic impacts are not part of either the LCOE or the financial pro-forma



- A = New agriculture near site, increasing jobs beyond those of the geothermal plant.
  - Or use this area for a Solar-Thermal Hybrid?
- B = Pipe to road and deliver locally by tanker truck
- C =Pipe to Ghoubbet-el-Kharab (bay on the Red Sea) and barge to Djibouti City (80 km)
- D = Pump sea water to geothermal plant
  - Use waste heat to boil more steam
  - Create more fresh water

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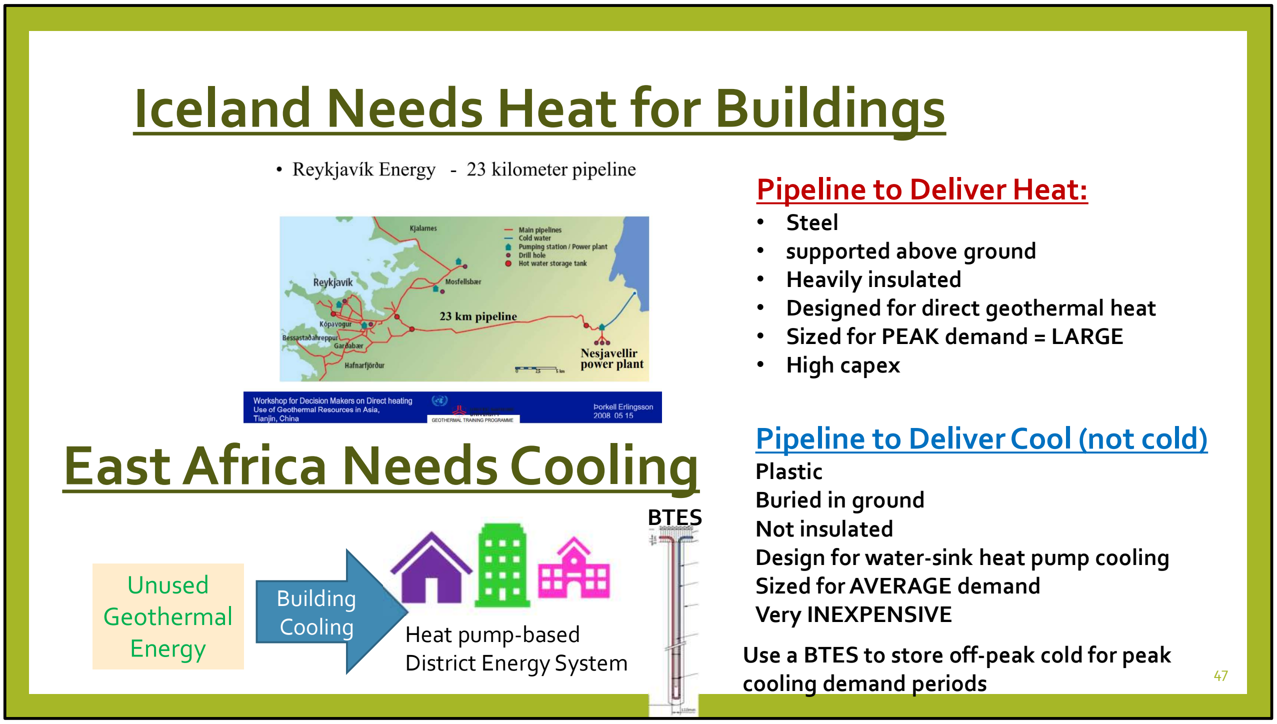
Some possible ways to make use of fresh water from the new Djibouti geothermal plant. These are just a list of brainstormed ideas, and have not been studied for technical feasibility or economics. In a later slide the idea of pipeline delivery of heat and cold is discussed.

A large increase in water production might be possible by delivering ocean water to the power plant, and distilling sea water with leftover brine heat. The steam would be condensed in the dry cooled steam condenser.

Other variations are possible, including building the geothermal plant on the red sea where sea water would be readily available for cooling. Only the steam would be piped to the power plant site. The brine would remain at the geothermal site to be reinjected. By geothermal pipeline standards, this is not a very long steam pipeline.



Leftover geothermal heat can be used to make “cold” using absorption chillers. This cold can be delivered long distances

The inspiration for this is Iceland and the geothermal heating pipeline network that they have constructed.

In East Africa, making “cold” may be viable, especially in conjunction with the creation of fresh water. But there may be other viable mechanisms that can be studied.

The advantage of delivering cooling is that in countries with high and growing air conditioning loads the “cold” that is delivered is exactly the same as building another power plant to provide power for conventional air conditioners. In other words the geothermal chilling system can reduce both the general load on the grid, and more importantly the peak load.

To address both and to keep the system operating at high capacity factor, seasonal storage of the cold is required. By cold, this refers to 2 to 10 °C, not below zero.

Another inspiration for the seasonal storage, like the long pipeline, comes from a country with a very very cold winter.

Olkaria Co-Production *(Possible)*
Heat, Cold, and CO_2

Naivasha Greenhouses Productivity Increase

1. CO_2 enrichment from stack gas: Increases plant growth, and may be eligible for CO_2 offset payment (foreign income)
2. Cold: Dehumidification improves growth & reduces mold damage
3. "Night heat" to stabilize temperatures (T < 13C)

Benefits

Ken-Gen:
- *Revenue*
- *Diversification*

Kenya
- *International Competitiveness*
- *Jobs and GDP*
- *Foreign Income*

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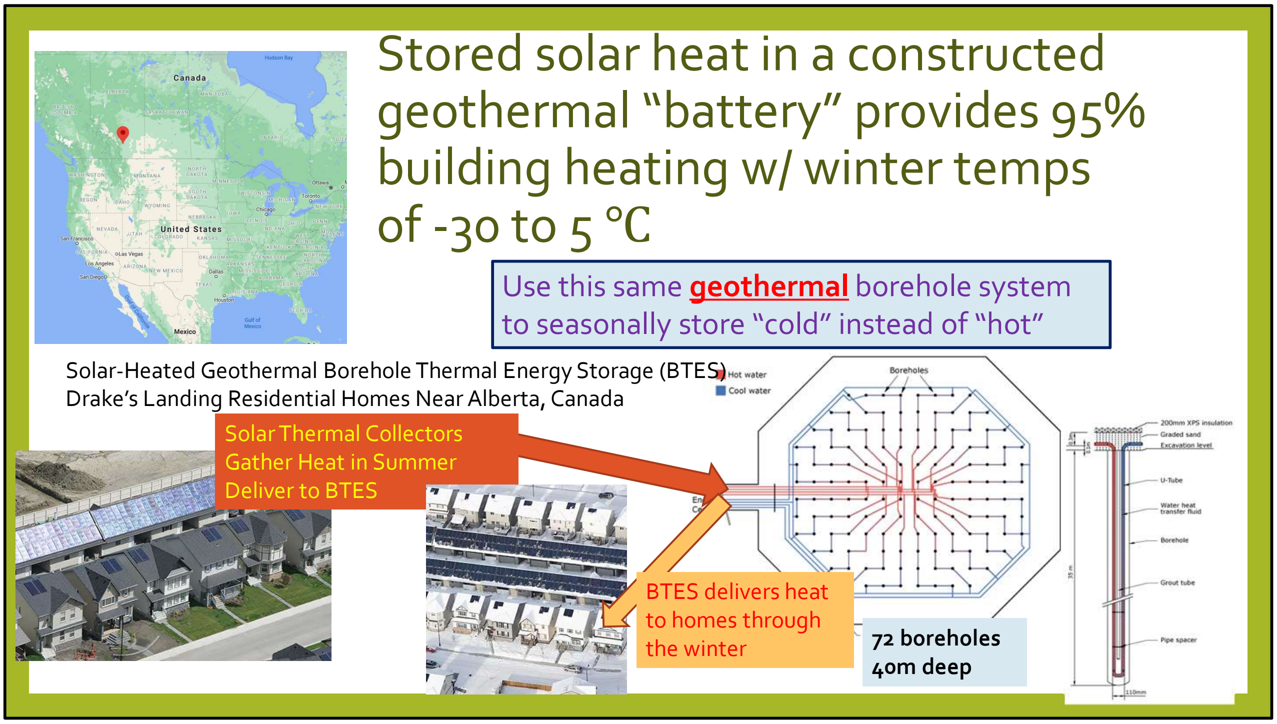
This is an example of how a specific geothermal power plant can deliver a variety of economically valuable products and services outside of the power plant boundary.

Because these products are being sold to credit-worthy off-takers, the revenue from sales may show up in both the LCOE and in the financial pro-forma.

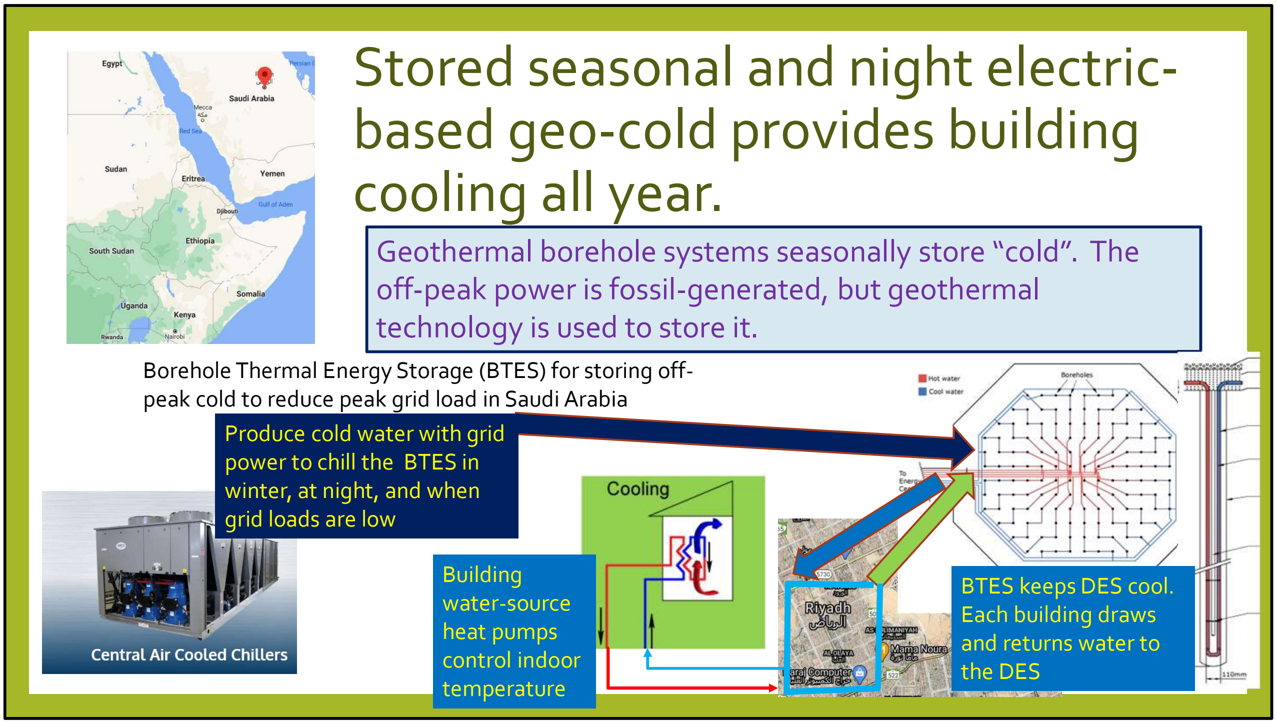


Alberta Canada is very cold in the winter, but there is a demonstration housing development of 52 homes that is 95% solar heated all winter long be storing summer heat and unneeded fall and winter heat in the ground.

There are many challenges for this type of facility.

- Technical: None in the equipment. However, the need to deliver high-temperature water to the homes even at the end of the winter means that the system has to operate at essentially the design temperature all the way to the end of the heating season. The smaller the system, the more heat loss out the sides. It also seems that boreholes that got deeper toward the outer edge of the field would reduce heat loss out the bottom.
- Capex: the expense of solar thermal panels, number of holes required. The need to deliver high-temperature heat to each building means that the pipelines must all be insulated, which increases their cost.
- Operational: This is a small system, but still must have some amount of O&M (pump seals, motor greasing, etc). Small systems are more expensive and if the system was four times larger, the O&M expense would hardly change at all.
- Financial: It is a very small system for independent financing by a 3rd party. The revenue model has not been discussed, but there has to be a billing system or some homeowners will run the system full-blast with the windows open.
- Reports on this project note that most homeowners have retrofitted conventional air-conditioners to the homes, and the borehole field, since it is a high temperature facility cannot accommodate that

A similar way to do this would be to make the solar heat collectors a PV panel with an air-source heat pump, operating at a COP of 3 to 5. The borefield would still store "hot" but would only operate to keep the loop operating at 20-30 °C. Each home would have a heat pump that would provide both heating and cooling.

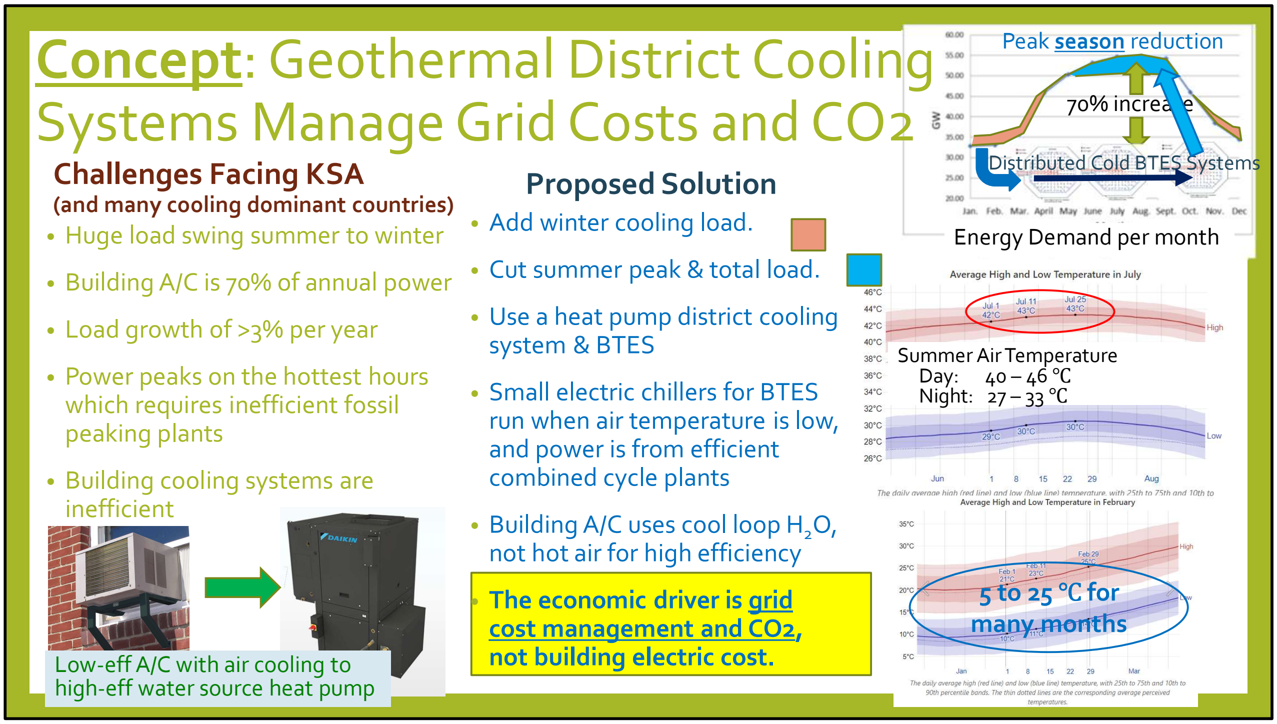


Much of the world is completely the opposite building comfort situation as the Drakes Landing Solar-Thermal BTES in Alberta Canada. In those parts of the world building cooling is dominant. Furthermore, the cooling system must accomplish it's task when air temperatures are least suited for building cooling. In Saudi Arabia, building air conditioning units must operate when air temperatures are highest, therefore requiring more power to perform the same building cooling task. This power is supplied by oil-burning and gas-burning simple cycle gas turbines, which are expensive to build and operate, consume valuable fossil fuel for future generations, and emit high CO2.

The concept for Saudi Arabia, East Africa, and other hot climates, the Borehole Thermal Energy Storage system would store 2 to 10 °C "cold" instead of "hot". Seasonal storage of cold using air-source water chillers increases load on the grid when there is surplus capacity, air is cool, and combined cycle plants are running at their most efficient. For a large system, there would need to be multiple BTES cold storage throughout the DES.

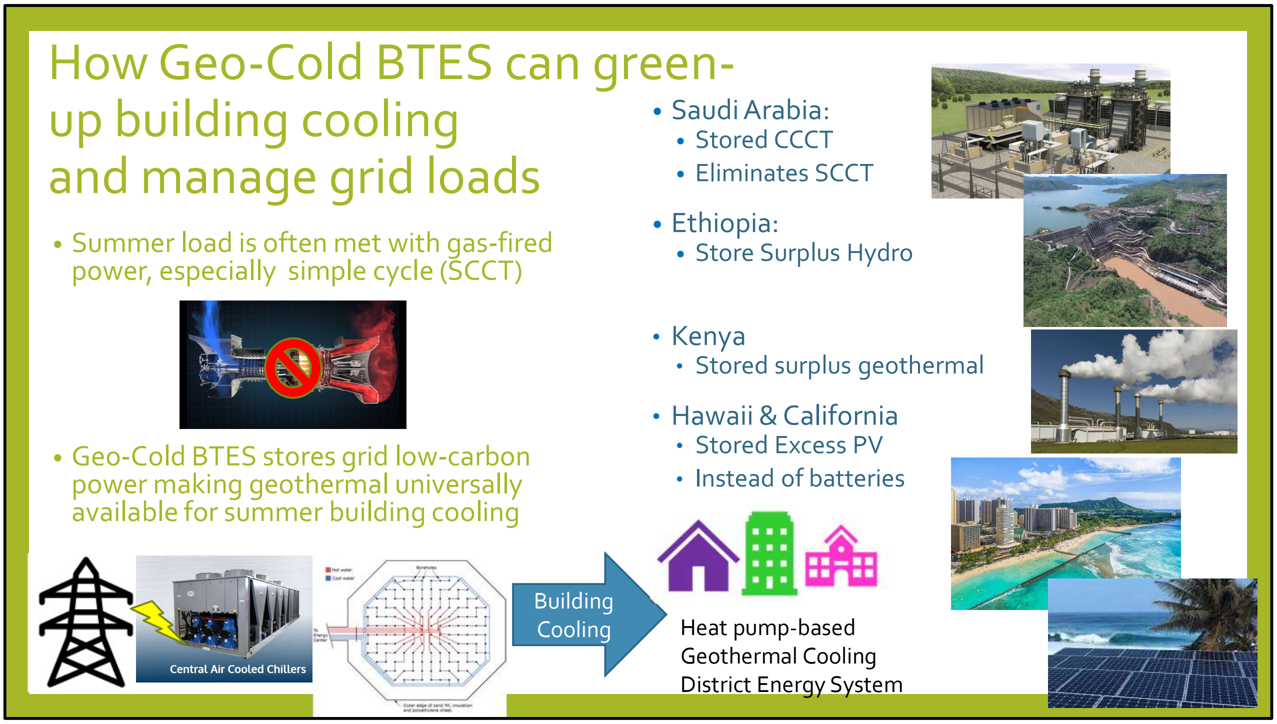
Cold from the BTES is slowly released into the DES. The DES goes through every street with a single pipe much like natural gas system infrastructure.

The heat pump in each building replaces the air-source A/C and moves heat from the building into DES and then into the BTES. This is an important distinction between heating systems in Alberta and Iceland where useable heat is delivered to the buildings.



Utility Perspective:

- Off-peak power is less expensive and existing efficient power plants are not run at full capacity. The incremental cost of running these fossil power plants harder (variable cost) is very low. It would be advantageous to shift cooling load to these periods and store that cold for when it is needed. This is similar to ice storage, and in fact the ground could actually be frozen, but as Drakes Landing has showed, such extreme measures are not needed.
- In some utilities there can be massive unused renewable energy (e.g. California and Hawaii PV). If this power is otherwise curtailed, the energy cost of creating seasonal cold storage is zero or even negative.
- When it is hottest, air conditioning loads soar for two reasons: The increase of heat flow into the building, which is nominally unchanged by this approach, and the increase in electric power required to deliver a kwh of cooling due to increased air temperature and decreased air conditioner capacity at higher temperatures. The A/C unit itself must be oversized to be able to handle the load in the hottest weather, increasing the power draw to achieve the required cooling. The BTES DES uses cool water instead of air as the medium to dispose the heat. The water is cooler than the air, water requires less power than air to get rid of the heat, and the water cooler is not de-rated by the hot air temperature.
- This high load in hot weather must be met by peaking power plants. These are expensive to operate. Since peak load is growing faster than overall load, more and more peaking units are needed at high Capex. And since these are less efficient units, they also emit more CO2, in addition to the higher cost of the fuel.
- When the BTES DES is implemented the utility generates low-cost power from it's most efficient power plants and displaces the most expensive power. The total load is also reduced because heat is rejected to air when the air is cool, and the air-conditioning units are smaller and run for less time because they are being cooled by cool water instead of hot air.
- Conclusion: This is primarily a grid load management tool, allowing a utility to make better use of efficient or renewable power and avoiding the need to build and operate peaking.



On a grid which is dominated by fossil fuel (like Saudi Arabia), simply shifting building cooling loads from peaking plants and air conditioning units operating at high ambient temperature to air chillers operating off-peak and water-cooled building air conditioning units reduces CO2 emissions.

But where there is excess renewable energy that cannot otherwise be used, the savings are even more dramatic. These can include excess hydro, geothermal, and solar PV. At peak hours, building cooling loads that are currently being supplied by fossil fuel now have a very large component of renewable energy.

BTES has a large number of advantages over Batteries for storing excess energy. It not only stores the energy, but it reduces the amount of energy used for building cooling because the heat pumps are a more efficient system Power is stored seasonally, so it can store power 24/7 for weeks at a time, if the power price is advantageous to do so. Batteries do neither of these things.

Excess wind energy is already an issue in the UK, including Ireland with large building heating loads. Seasonal storage of heat in BTES proves a pure-green way to de-carbonize heat with Geo-warm. Heat pumps would still be used in each building, but to provide heat to the building instead of cooling, as in East Africa.

Summary:

1. Ask the right question to find the FULL VALUE of geothermal.
2. A solar thermal and geothermal hybrid can create more capacity and energy and lower GRID COST.
3. A geothermal + fossil fuel (+ solar) hybrid can be used to create more power than is possible from the two systems alone, and provide dispatchability.
4. Packed Direct Contact Condenser can increase output and control chemistry
5. Dry Cooled Steam Condensers offers options for 100% injection or fresh water
6. Geothermal energy can provide economic growth with fresh water, cooling, CO_2. They may or may not improve power plant financial performance.
7. Geo-Cold BTES seasonal energy storage can reduce grid cost, capex investment, and CO_2 emissions for building cooling.

Hope to see you in 2021!

Thank You!

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Geothermal innovation can take the form of economic enhancement in East Africa by recognizing and capitalizing on both the other assets of the country (solar heat for example) and opportunities for economic growth and poverty alleviation through opportunities such as production of fresh water for farming, and geo-cool district cooling systems.