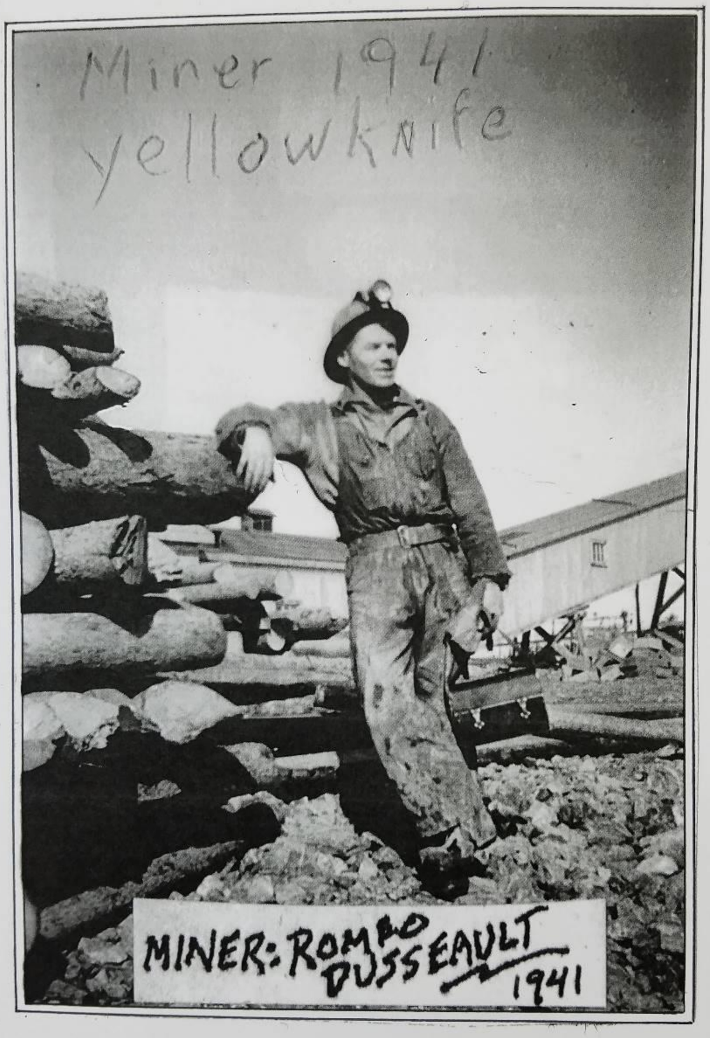
Drilling Technology and Other Engineering Issues in Geothermal Energy

YGF Geothermal Workshop

Maurice Dusseault
University of Waterloo

Romeo the Miner

- Romeo went from a bartender at the Oilsands Hotel to a job on NT barges
- He ended up in Yellowknife in 1938
- First as a timber cutter
- Then as a miner
- And as a blaster…



Buckham Lake 1939

- Romeo Dusseault – 36 years old

Where is Buckham Lake?

The Four Geothermal Pillars

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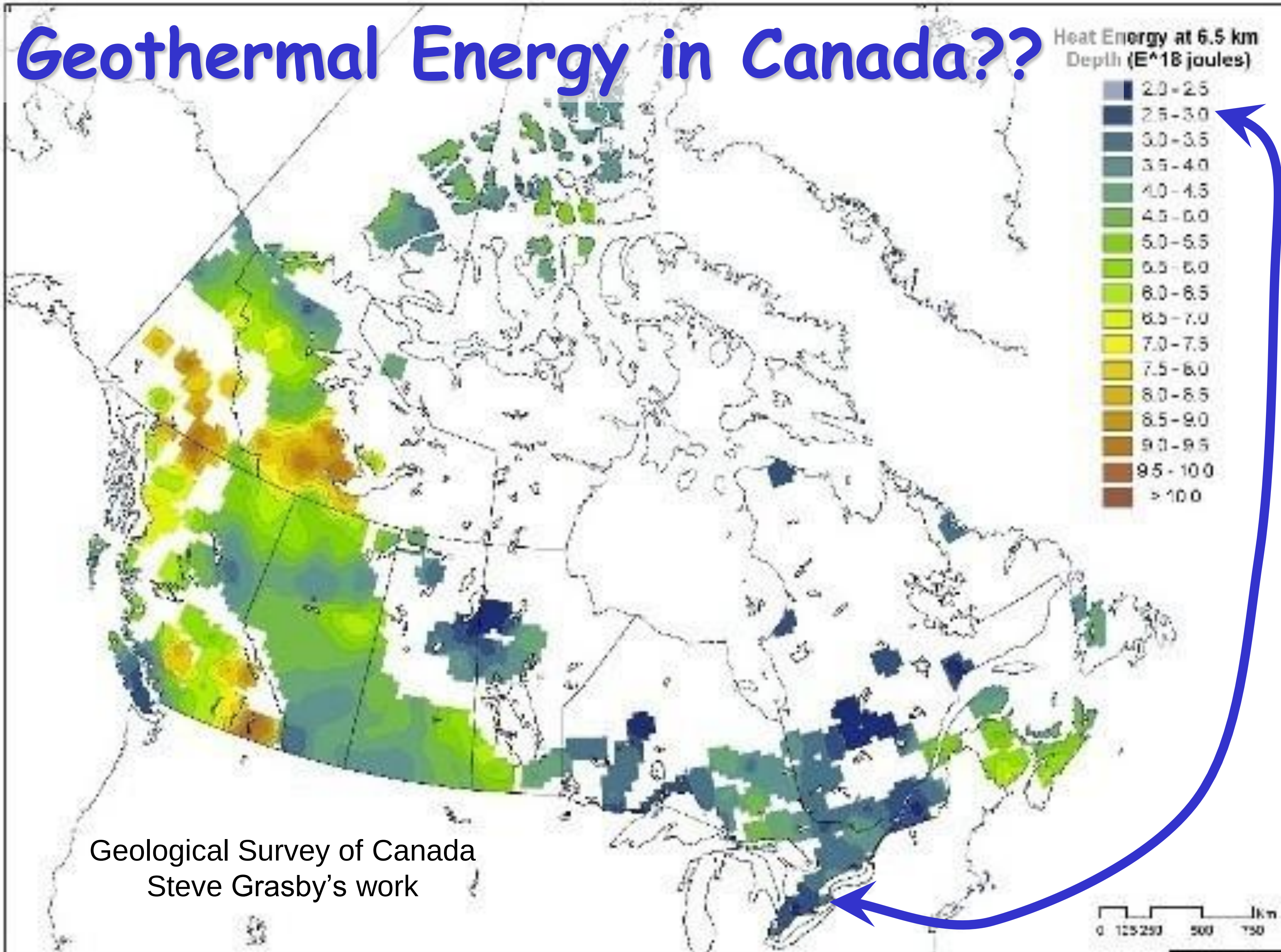
1. **High-grade geothermal** where steam is generated to drive turbines: ~T>140°C
2. **Warm fluids** in porous and permeable strata: ~T = 70-140°C
3. **EGS** – Enhanced Geothermal Systems, warm, low permeability: ~T = 70-140°C
4. **Shallow, heat-pump based geothermal**, storage of heat in the upper ~500 m
   - ⇨ Below ~70°C – "district heating" or direct use of heat for drying, greenhouses, etc.

Geothermal Energy in Canada??

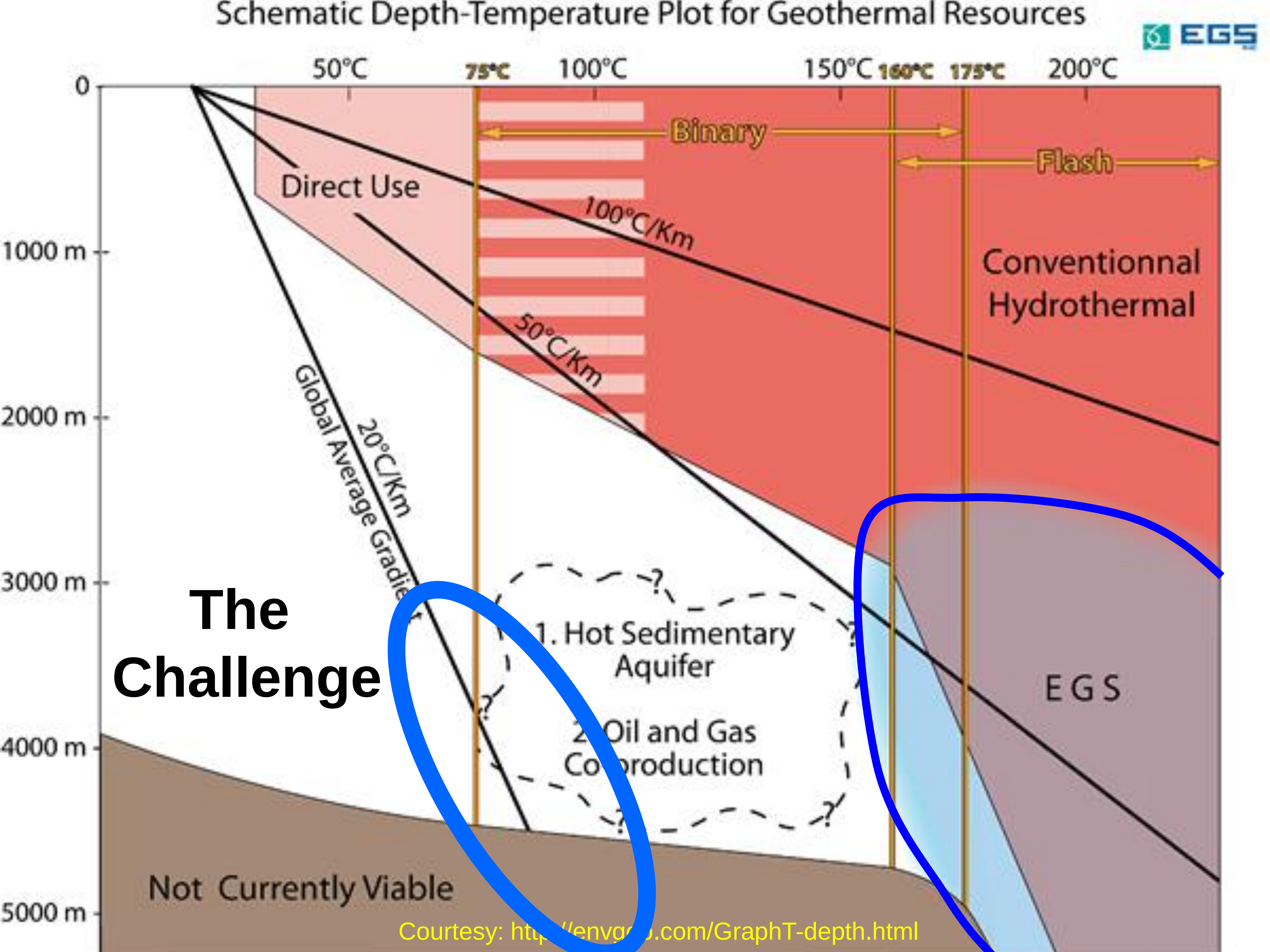


Geological Survey of Canada
Steve Grasby's work

Pembina

Geothermal Heat in Canada?

- In climates with cold winters – both heat + power are needed
- The need is highest Nov-April
- The power/heat ratio changes seasonally
  - Summers require little home heating
  - …but electricity for cooking, tools, lighting…
- A geothermal system must be designed to meet the needs in the critical months
- …and a "hybrid" system is best, with…
- …**primary** energy sources + heat **storage**



Schematic Depth-Temperature Plot for Geothermal Resources
EGS
50°C
75°C
100°C
150°C
160°C
175°C
200°C
0
1000 m
2000 m
3000 m
4000 m
5000 m
Binary
Flash
Direct Use
100°C/Km
Conventionnal Hydrothermal
50°C/Km
Global Average Gradient
20°C/Km
1. Hot Sedimentary Aquifer
2. Oil and Gas Coproduction
E G S
Not Currently Viable
The Challenge
Courtesy: http://envgeo.com/GraphT-depth.html

How Much Energy do we Need?

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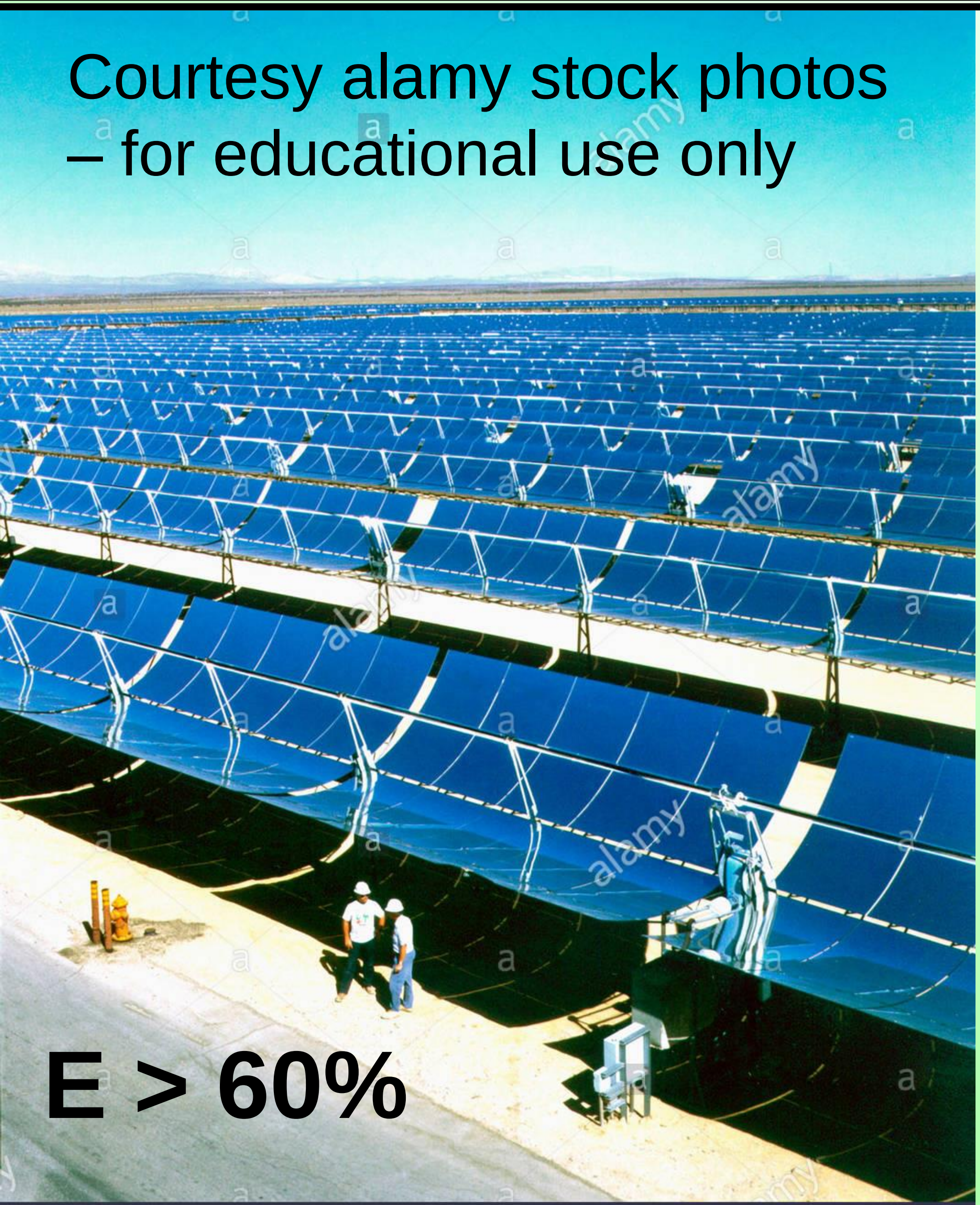
- ~120 GJ/yr per well-built home
- ~6 TJ/yr for a 50 separate home community, ~4 TJ/yr for apartments
- ~80,000 m^3 of granite with a ΔT of 30°C
  - Assuming 75% efficiency
  - This is a cube with L ~45 m
- …but part of this must be power, part of it must be heat, mainly in winter
- Solar? In May-August it can provide heat and power but not in January

Solar in the Summer…

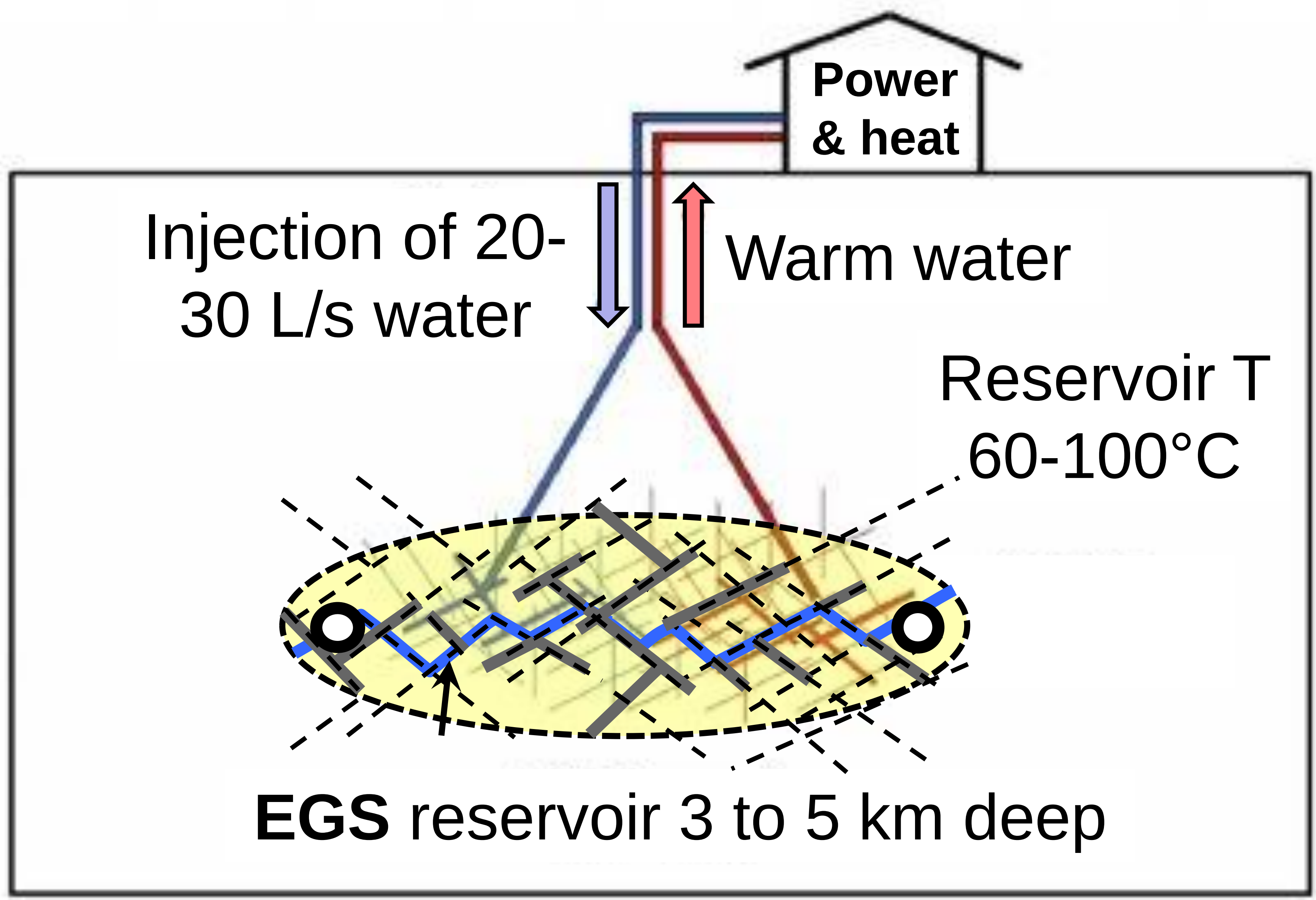


Courtesy alamy stock photos – for educational use only

E > 60%

E < 15%

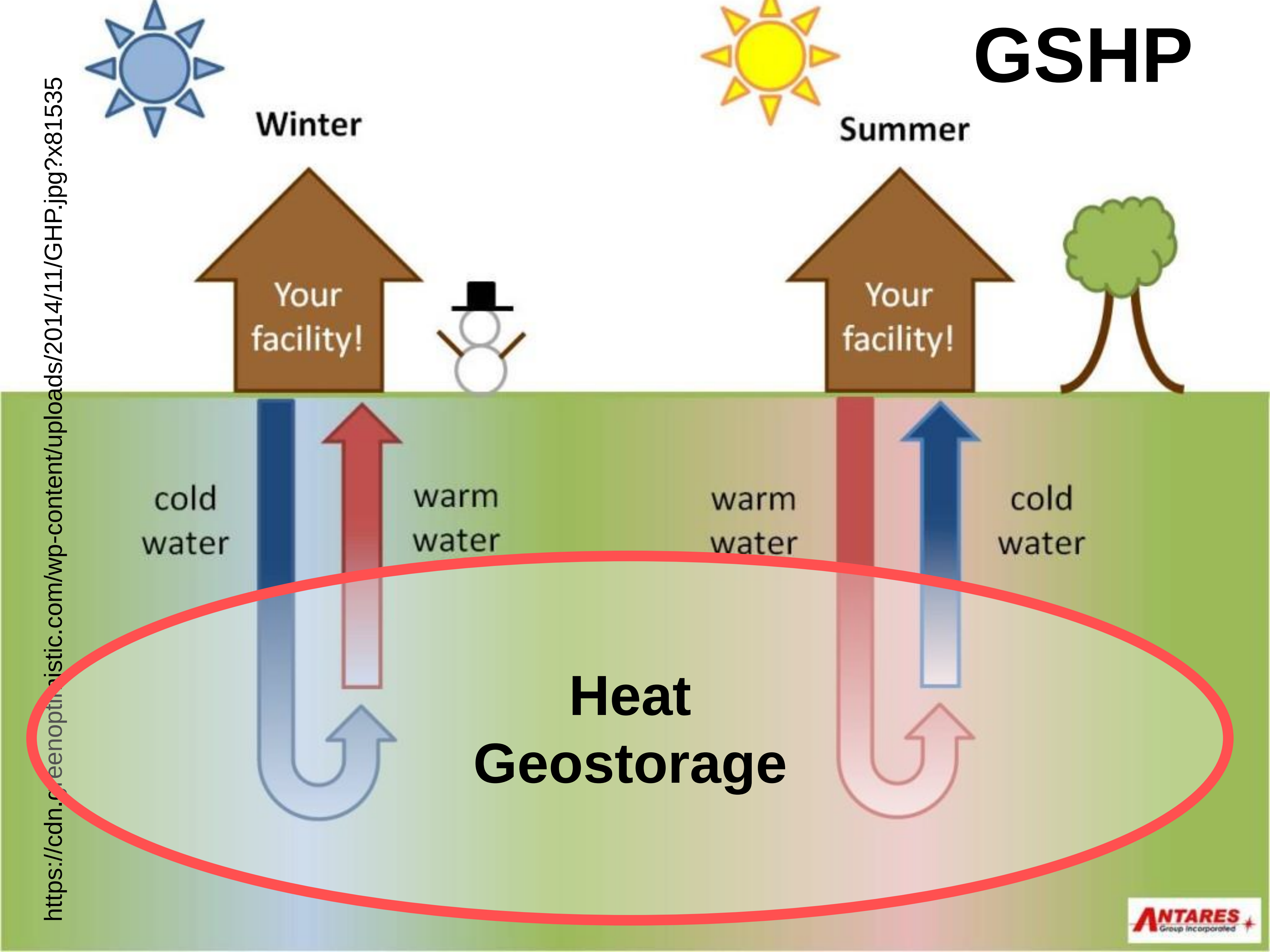
Deep Primary Heat Source



Deep EGS in Low-k Rocks

- The Major Issues…
  - **Cost of deep drilling** to access heat because of a low geothermal gradient
  - Hydrofrack **well stimulation** required
  - **Fluids** from depth cannot be disposed of into rivers or lakes (must be recirculated…)
  - **Scaling** of pipes in the primary loop must be managed
  - Access to a **large enough volume** of rock is needed to make it viable for >30 years
  - Must meet January needs **0.3-3 MW ?**
- Steady, reliable, no-C, small footprint…

GSHP



https://cdn.greenoptimistic.com/wp-content/uploads/2014/11/GHP.jpg?x81535

GSHP – Shallow Geothermal

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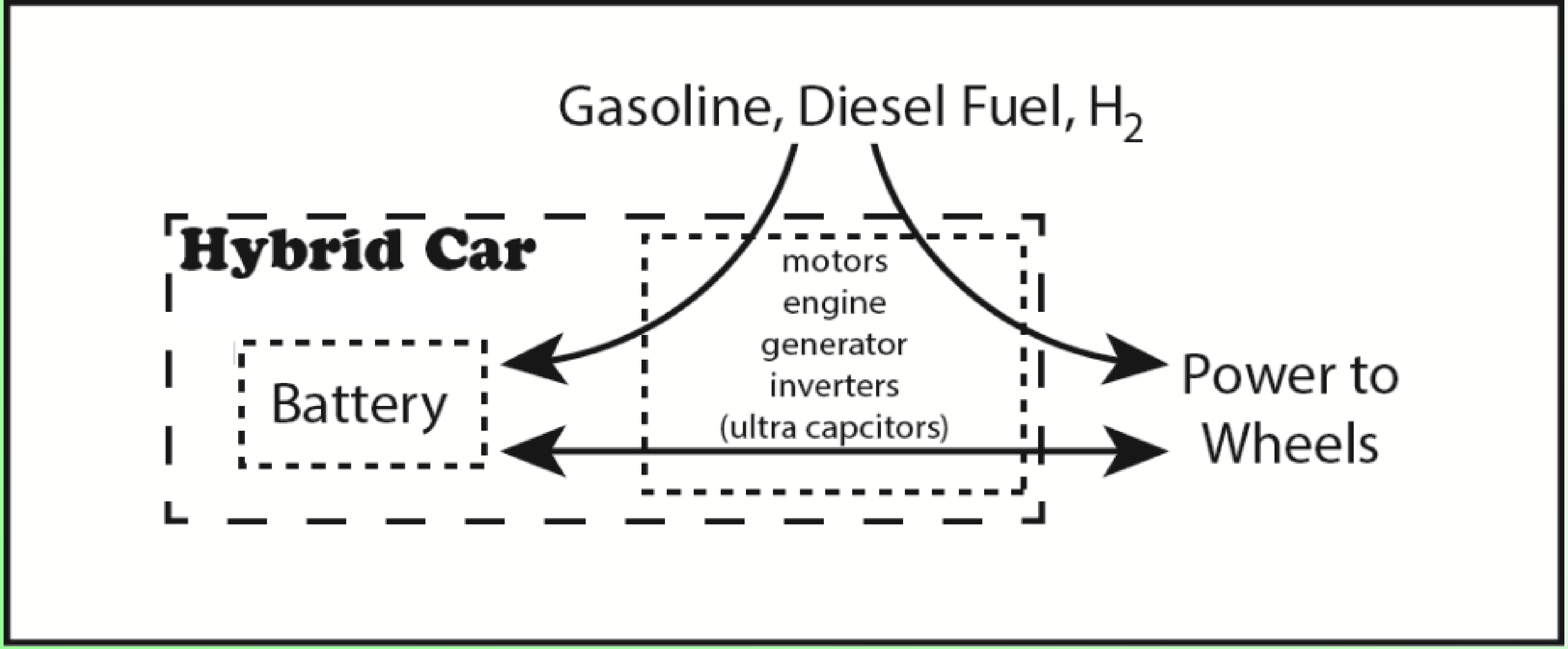
- The Major Issues…
  - **Cost of multi-well repository** to store heat seasonally for winter use (…for 50 homes?)
  - **Conductive** heat transfer? Is convective feasible?
  - **Cooling** of the repository because more heat is withdrawn each year (must “recharge” the heat)
  - Access to a **large enough volume** of rock is needed to make it annually viable (depends on V, ΔT)
  - Must meet substantial percentage of January heat needs **~8-12 GJ/month**
- Steady, reliable, no-C, small footprint…
- Utilidors for separate homes?

This is Like a Hybrid Car!

- Heat geostorage is the **battery**
- EGS is the **gasoline** driving the system
- Solar heat or waste heat may be used to charge the battery ("a **plug in** hybrid")



The Hybrid Car Analogy

- Heat geostorage is the **battery**
- EGS is the **gasoline**
- GSHP is the **converter**

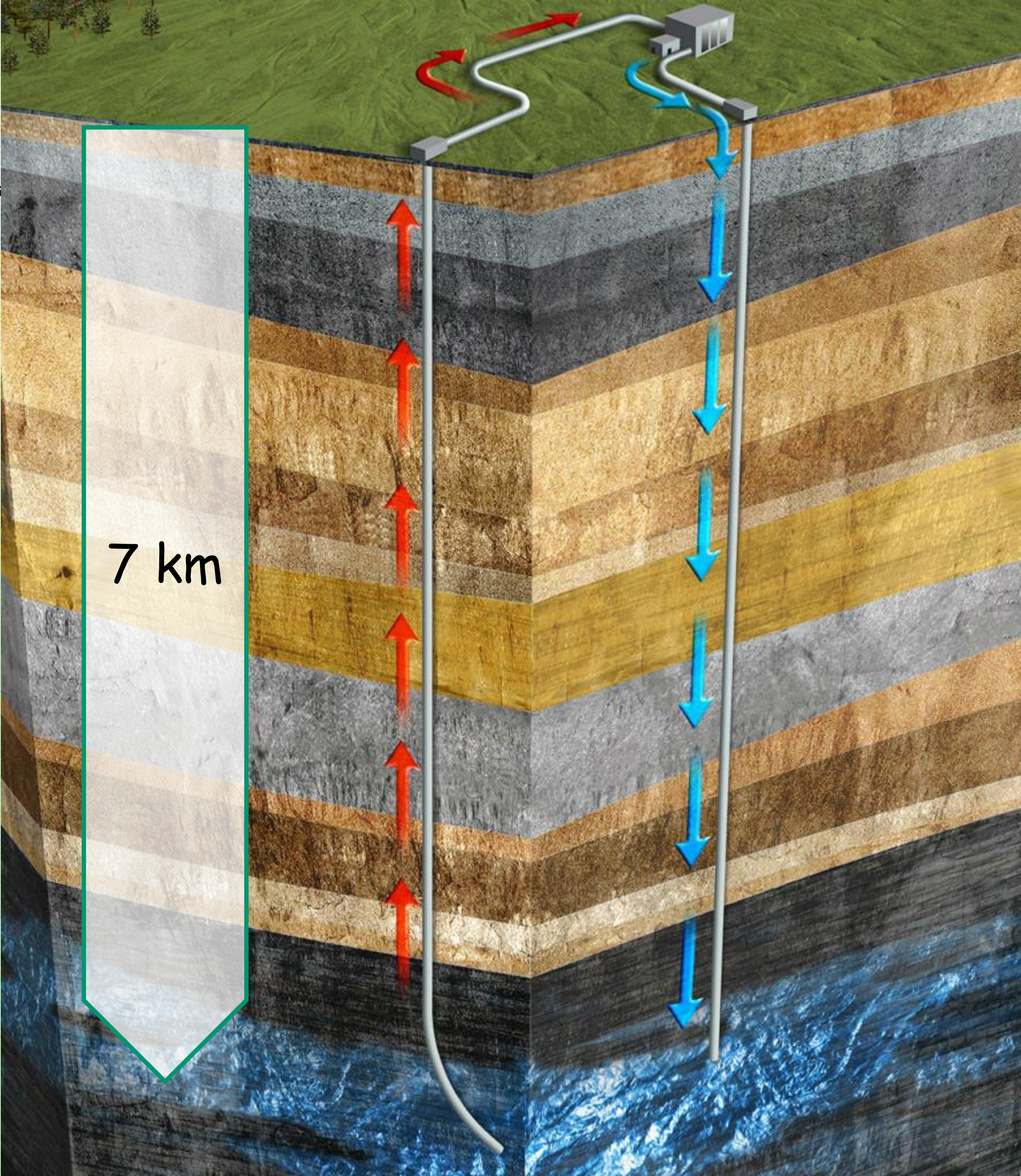
7 km deep
40 MW
granite

Strada Energy

- Geothermal drilling
- Claims up to 25 m/hr in granite at 1 km depth, air hammer
- Double drill pipe, reverse circulation
- Espoo project – 7 km deep, 2 wells
- 40 MW heating

Finland

OTA-1 drill site concept



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Air and water hammer drilling, 7 km deep wells in granite

7 km Deep Drilling Rig…

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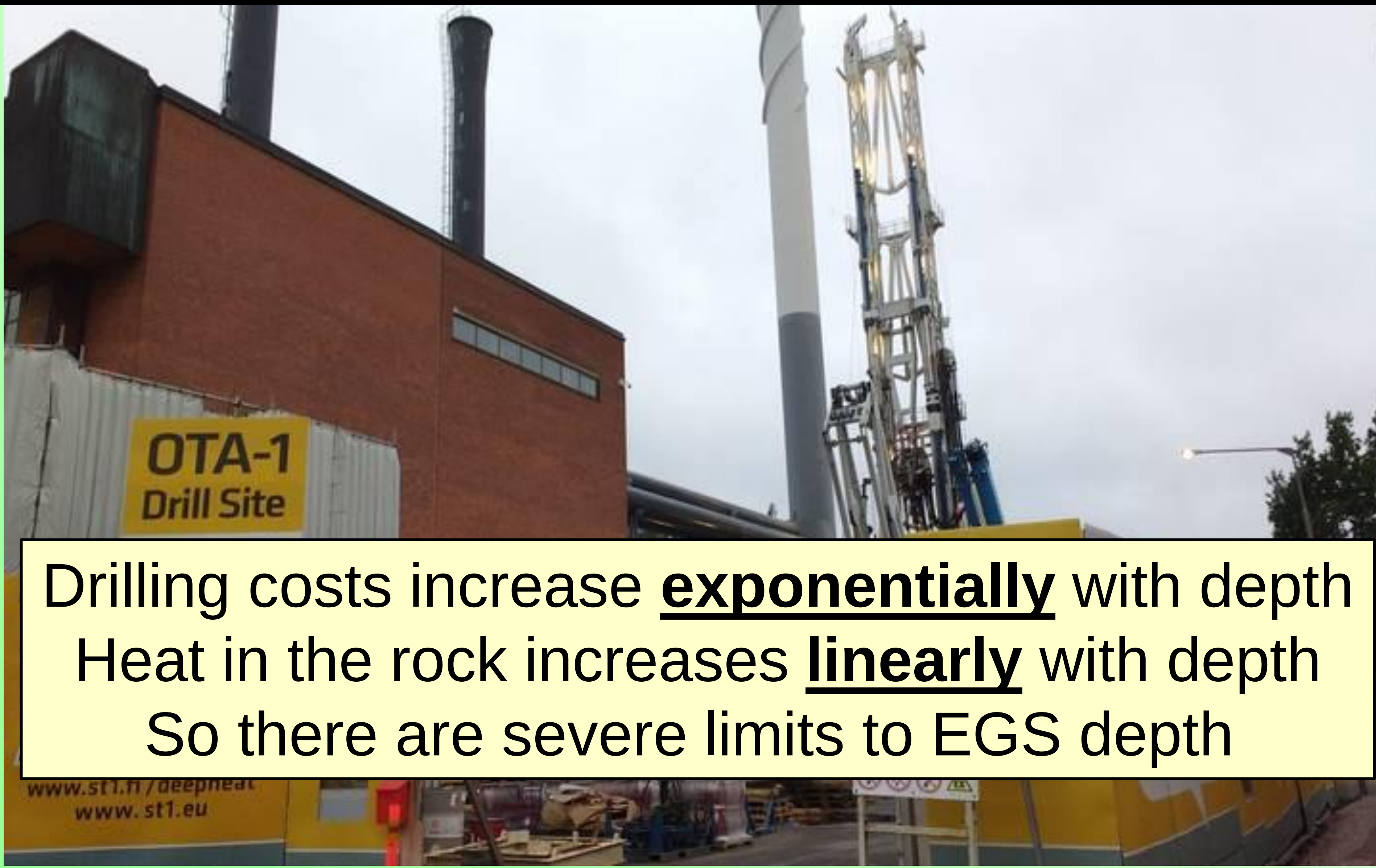

Drilling costs increase **exponentially** with depth
Heat in the rock increases **linearly** with depth
So there are severe limits to EGS depth

Drilling Costs

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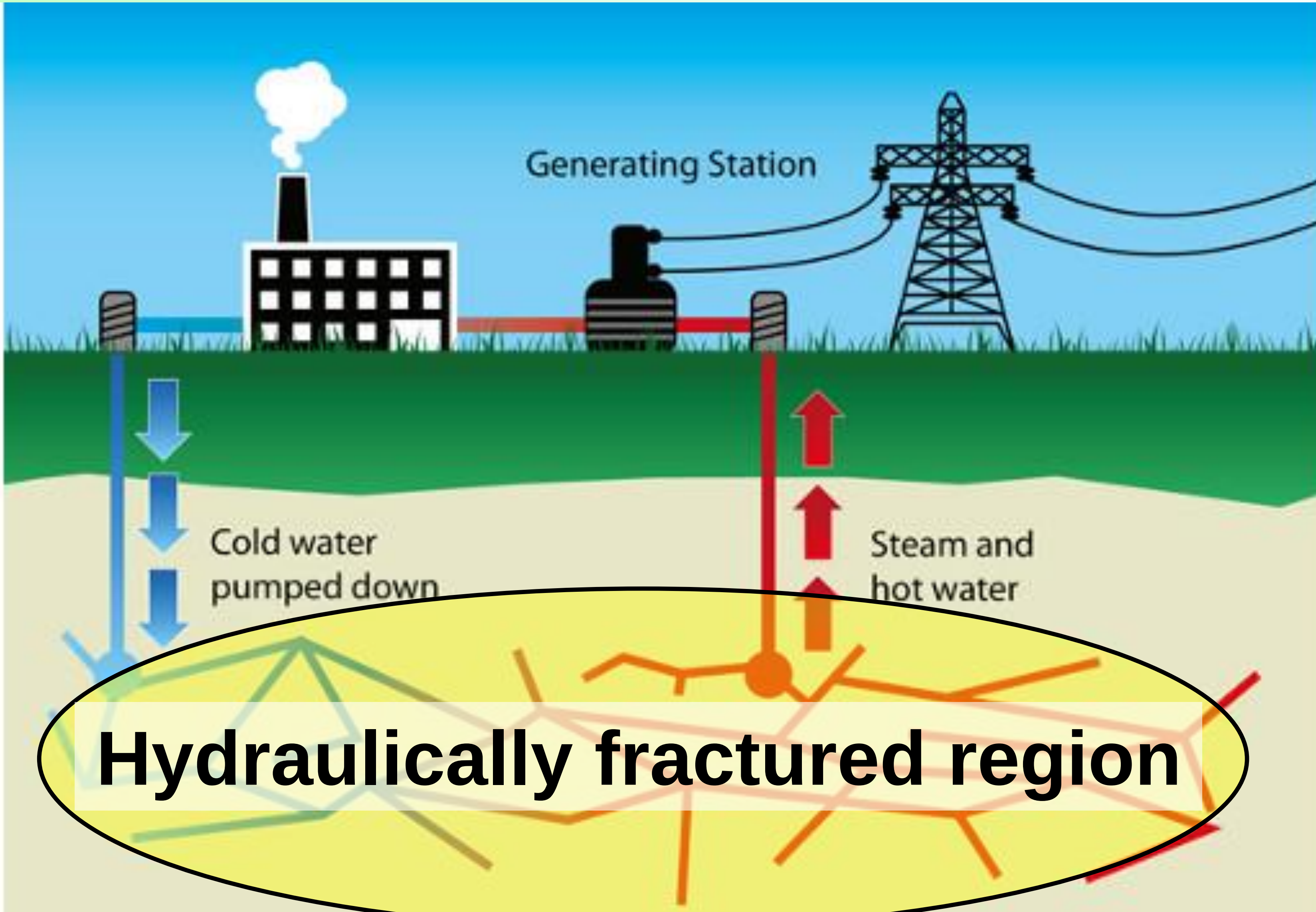
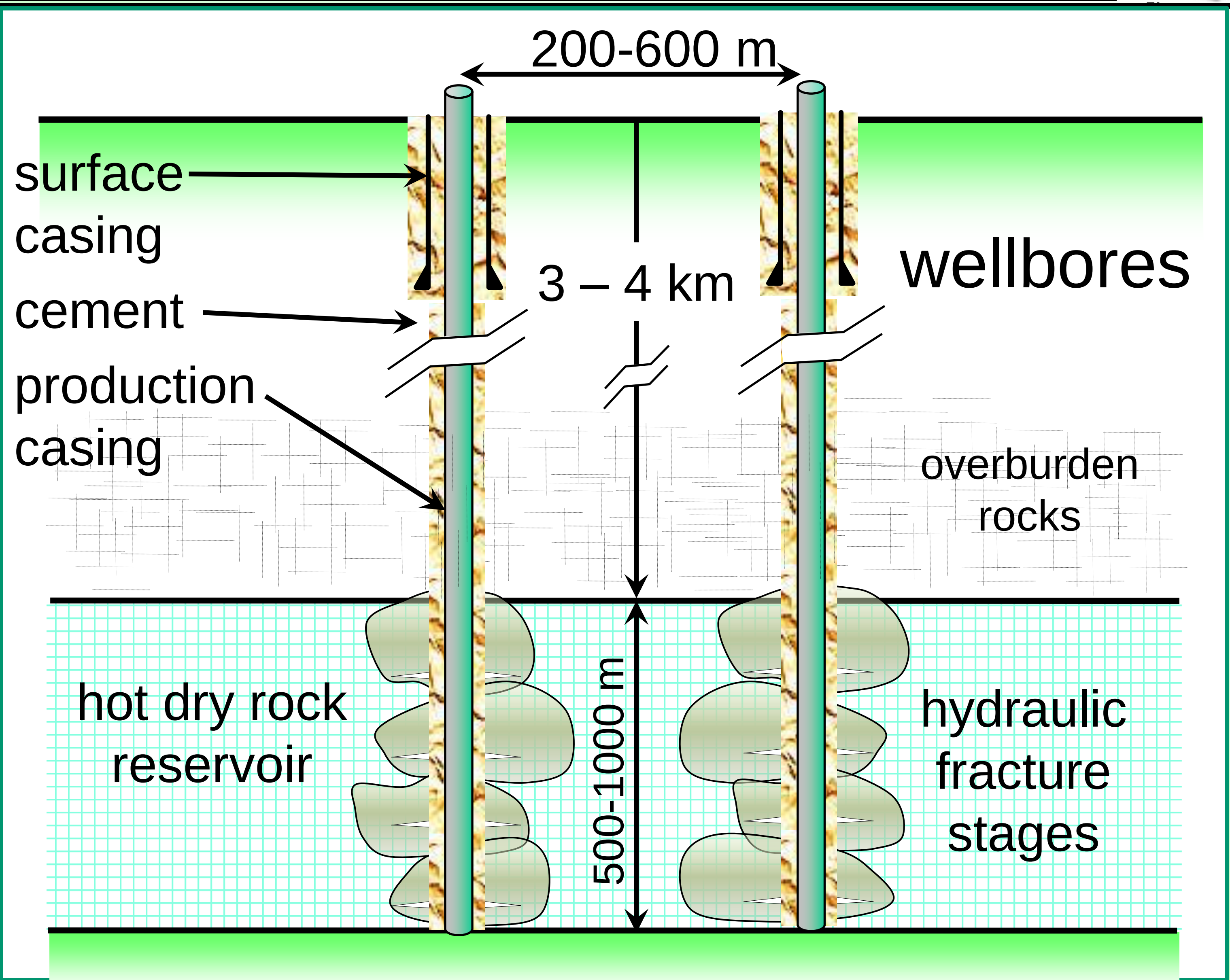
- The primary cost factor in hybrid EGS
- But, in air and water hammer drilling, technology advances means that $dz/dt]_{ave} \rightarrow$ 4-5 m/hr might be possible
- This means that a 4 km hole would take 50 days (including surface casing, logging, running deep casing…)
- …other methods (rotary, plasma…)?
- …and with modern rigs, there is more and more automation – so… **<u>STAY TUNED</u>**

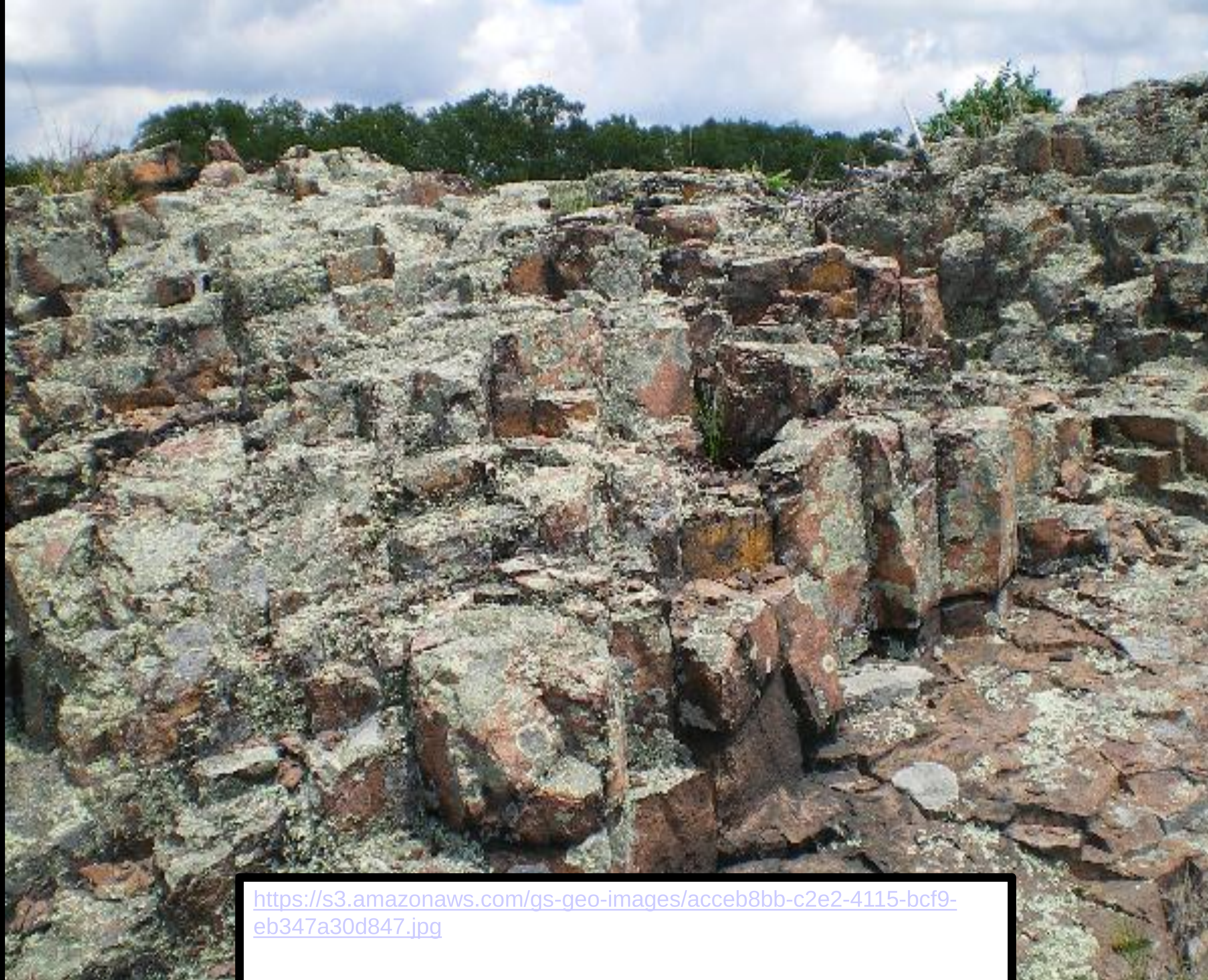
Developing EGS…



http://ieet.org/index.php/IEET/more/grasso20141010

Interwell Communication…

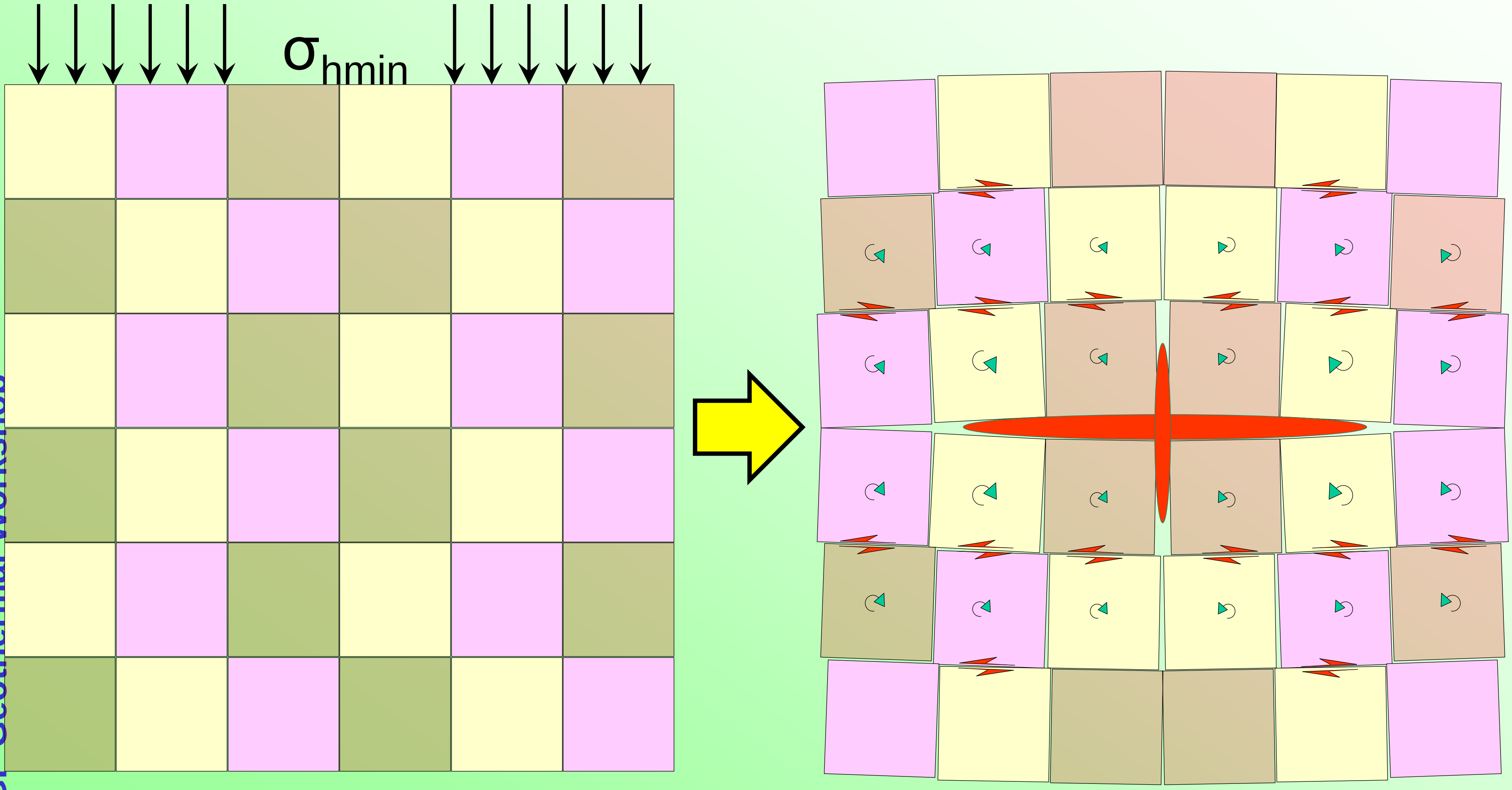




https://s3.amazonaws.com/gs-geo-images/acceb8bb-c2e2-4115-bcf9-eb347a30d847.jpg

Enhanced Flow Capacity

- The effect of HF and Hydroshearing



Shear Dilation of Joints

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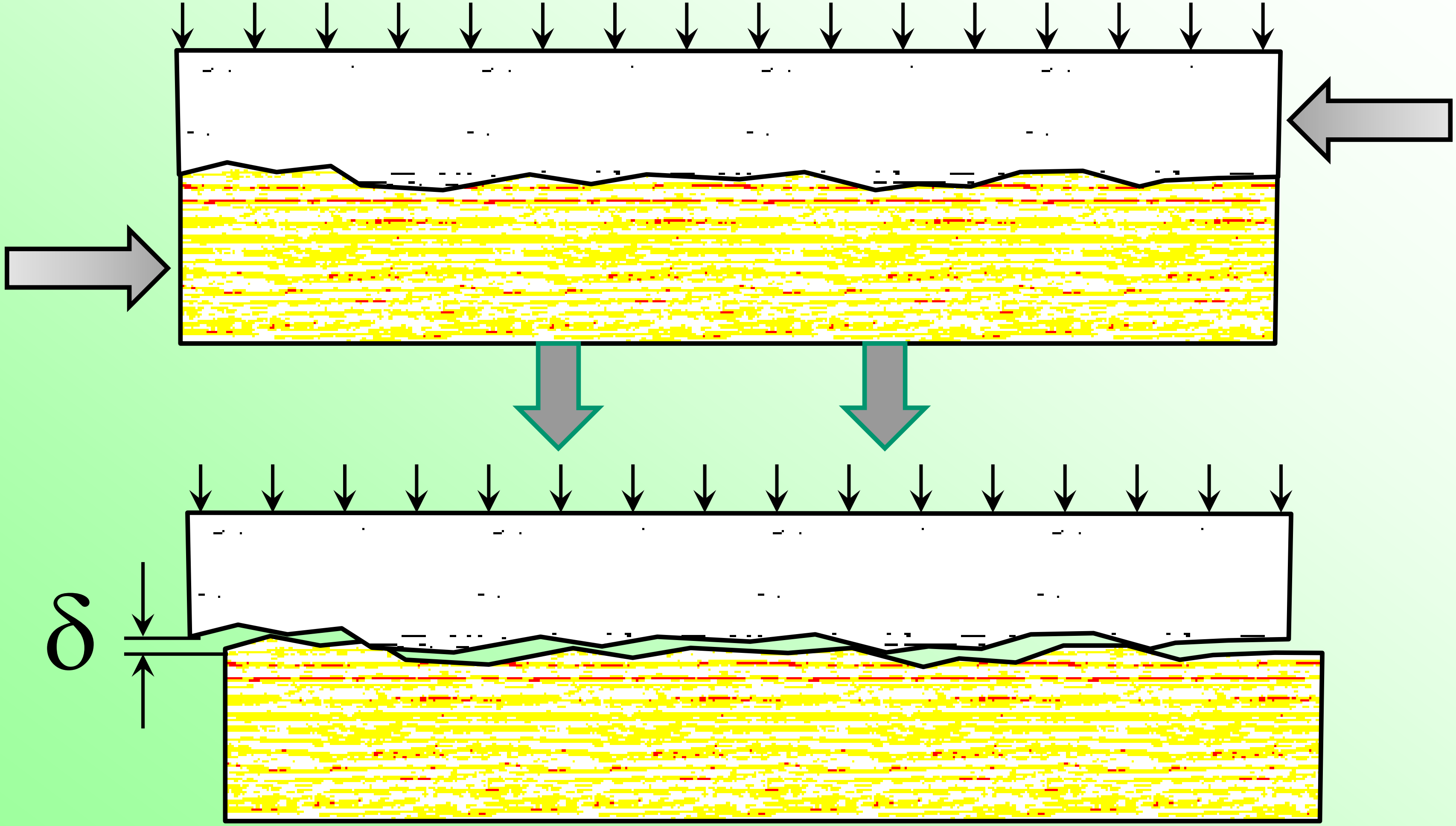

- Hydroshearing enhances flow capacity

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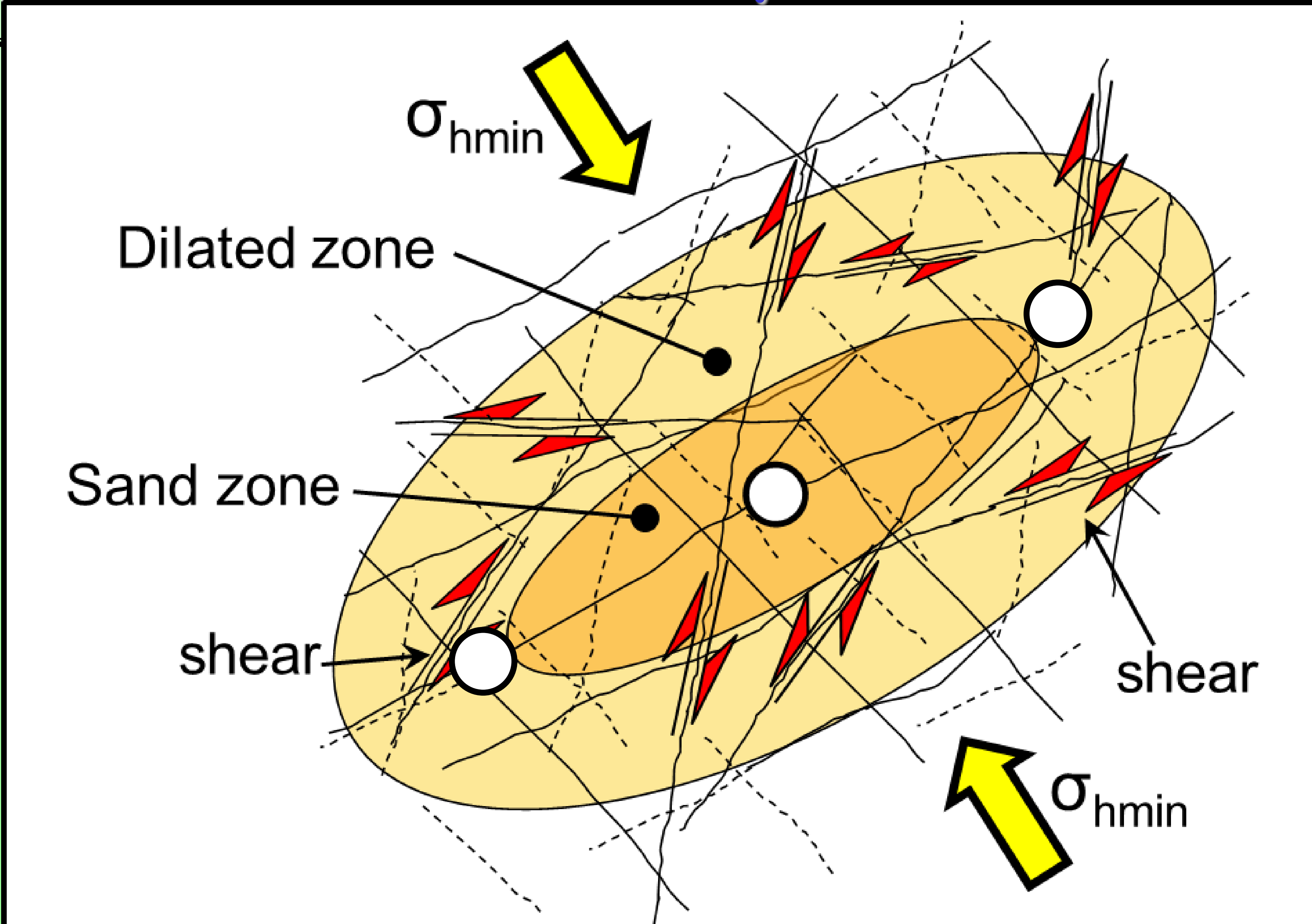
Enhanced Conductivity Zone



Hydrofracking/Hydroshearing

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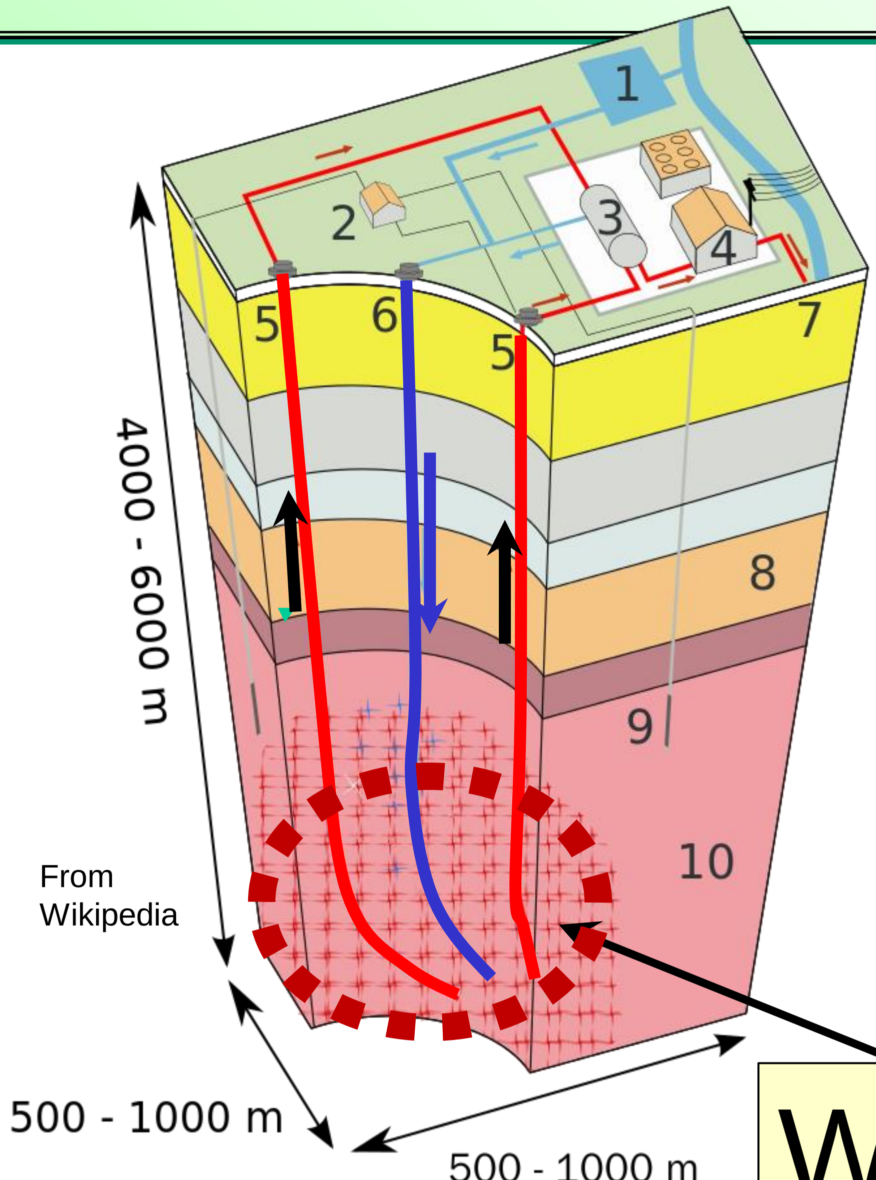
- We know how to link wells by HF/HS
- Wells must be aligned properly in the stress fields (aligned normal to σ_3)
- HF should open up as many joints in the naturally fractured rock mass
- In impermeable rock, this can actually be achieved relatively economically using water and sand as a proppant, but
- Deployment in the North is always $$

The EGS Volume at Depth…



From Wikipedia

1 Water lagoon
2 Pump house
3 Heat exchanger
4 Turbine hall
5 Production well
6 Injection well
7 Hot H_2O to district heating
8 Porous sediments
9 Observation well
10 Crystalline bedrock

What V is needed?

Primary Loop Pipe Scaling

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- Mineral scaling may be an issue
- Rate of scaling (applied geochemistry)?
- Plastic casing? Surface treatment?

Canada's Quandary

- Canada does not have much good high temperature geothermal resources in the areas where needed…
- Geothermal use across Northern Canada means T(liquids) < 100°C (realistically)
- So, to use this energy, we need---

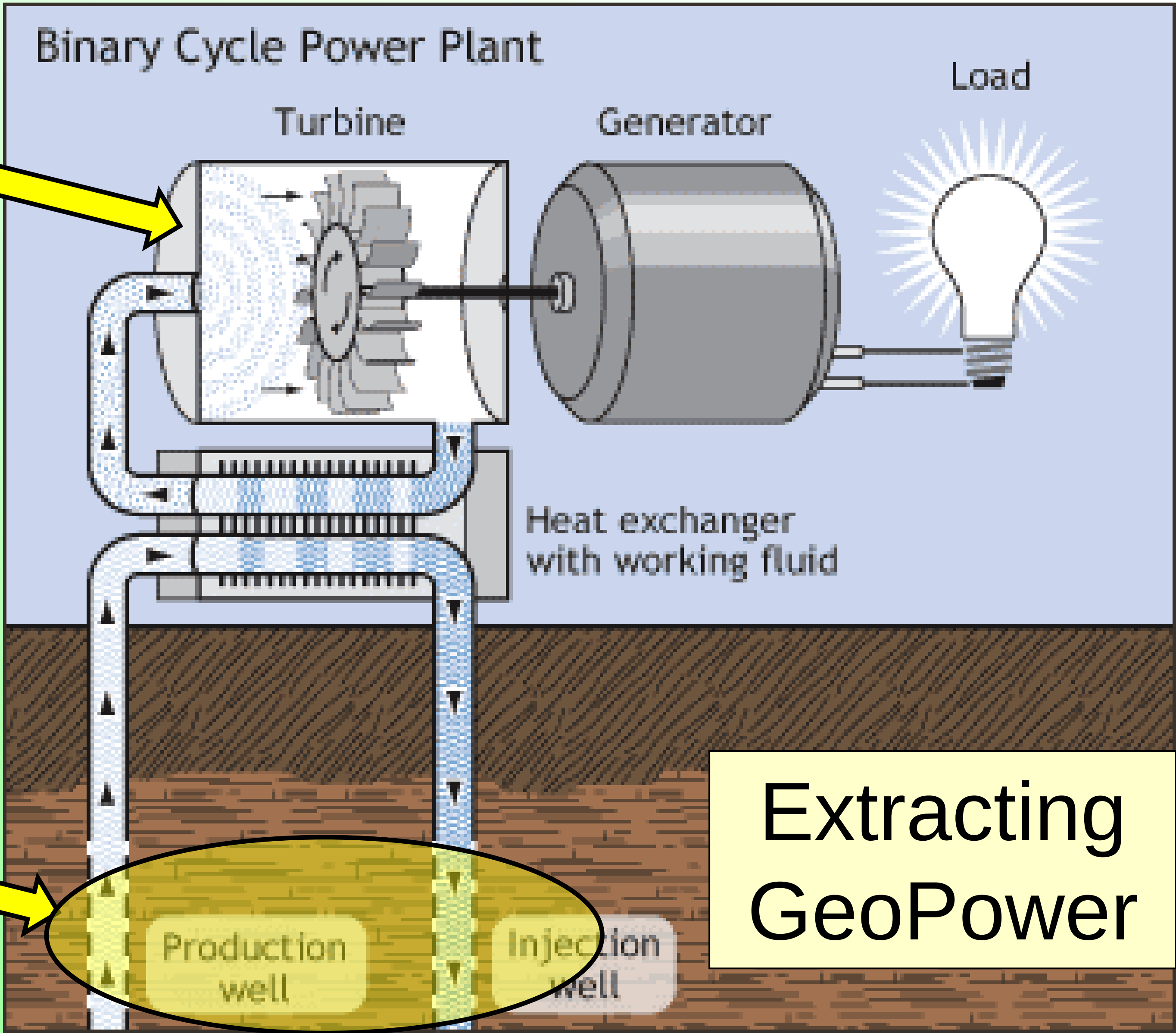
…or some other type of engine…

+

Direct heat use for buildings and homes

Binary (Two Loop) EGS Cycle

Special low T engine



https://serendipitousscavenger.wordpress.com/tag/enhanced-geothermal-systems/

Stimulated region

Extracting GeoPower

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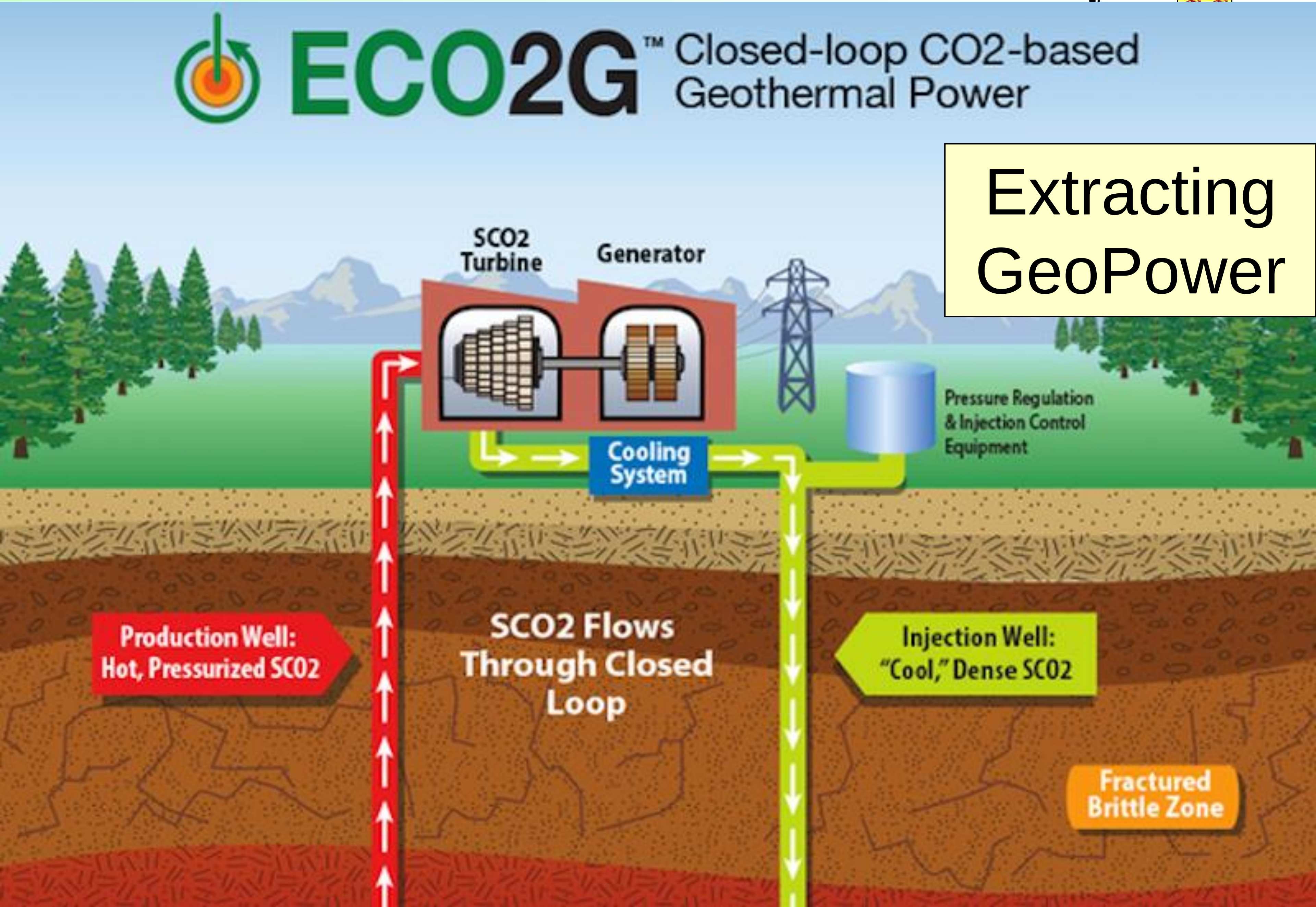
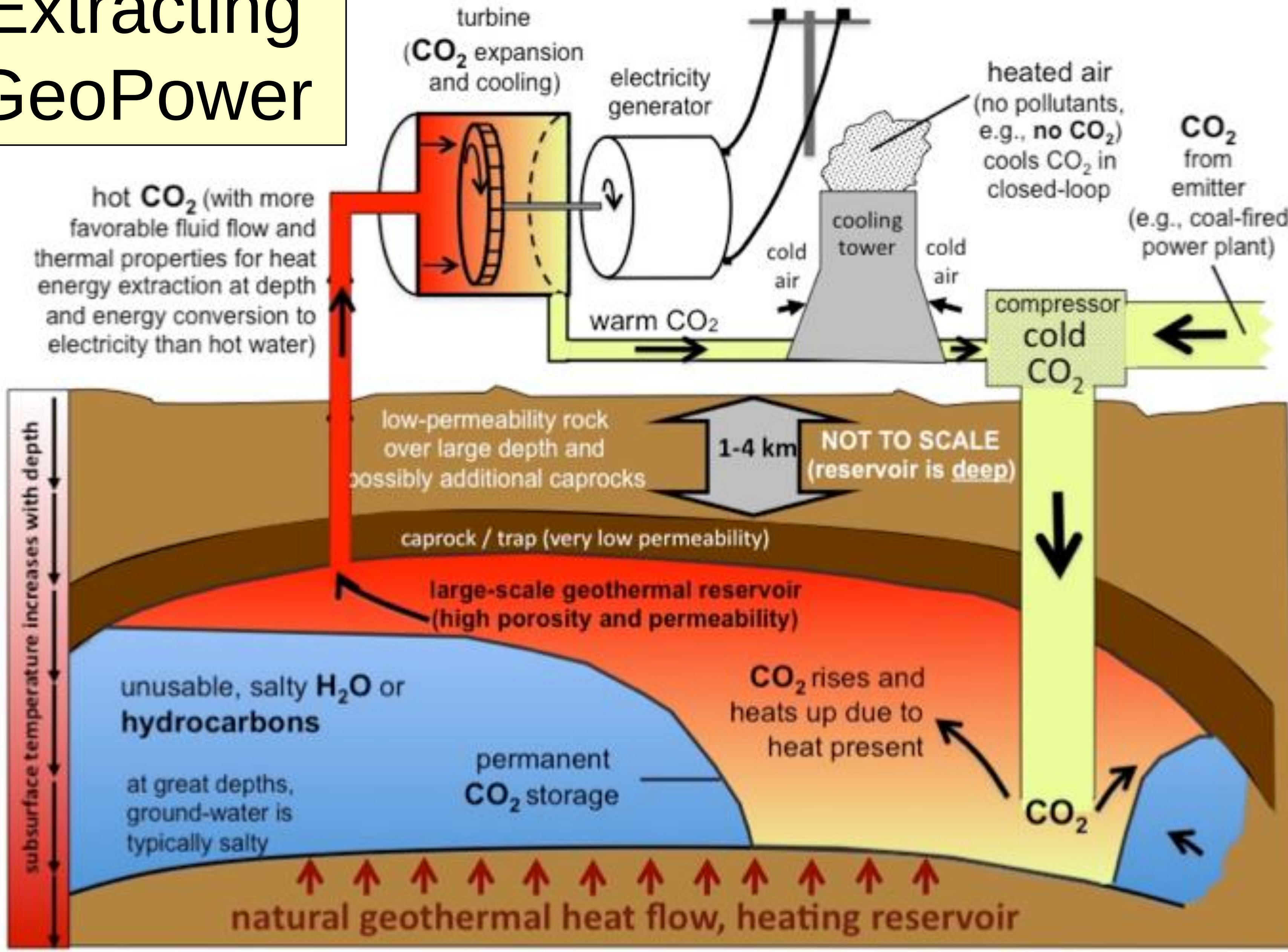
Extracting GeoPower



Extracting GeoPower



Hot Fluids EGS

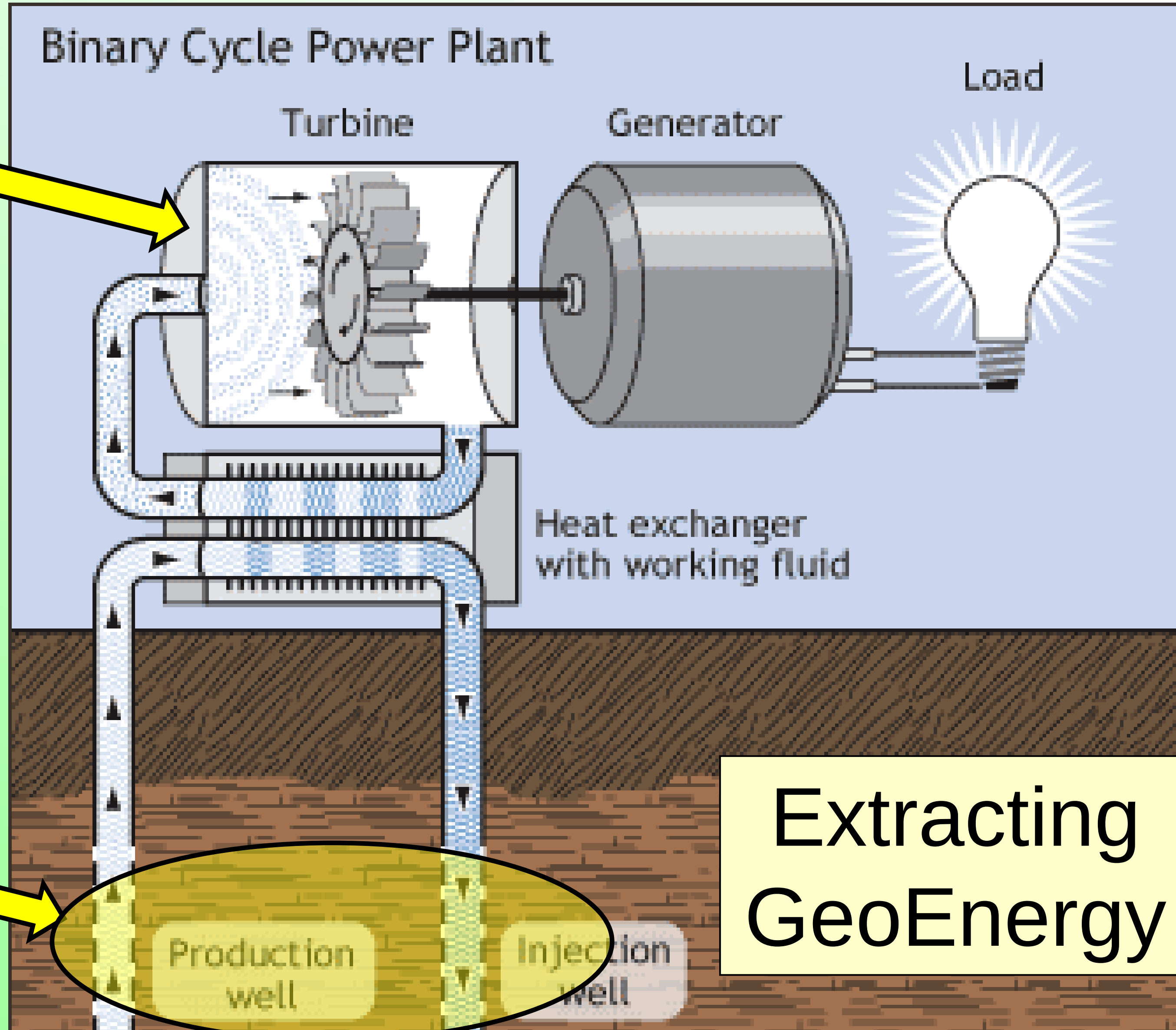
- Organic Rankine Cycle engines "standard"
- Example of a project in Saskatchewan
  - DEEP Corp. project near Estevan SK
  - 3.3 km deep in the Williston Basin
  - T of reservoir fluids 118°C
  - 40 m thick sandstone, reasonable ϕ & k
- Contract up to 5 MW with Sask Power
  - Choice of system for power generation
  - T output from system ≈ 65°C, $\Delta T \approx 50°C$
  - No planned use for the remnant heat at this time
  - Fluid disposed into a shallow formation
  - 210 L/s (0.21 m^3/s) needed for 5 MW

The Binary EGS Cycle

Special Rankine engine

https://serendipitousscavenger.wordpress.com/tag/enhanced-geothermal-systems/

Fractured region



Extracting GeoEnergy

Rankine Cycle Use

- Rankine cycle use depends on
- T of fluids
- Ambient T
- Cycle ΔT
- Liquid rate

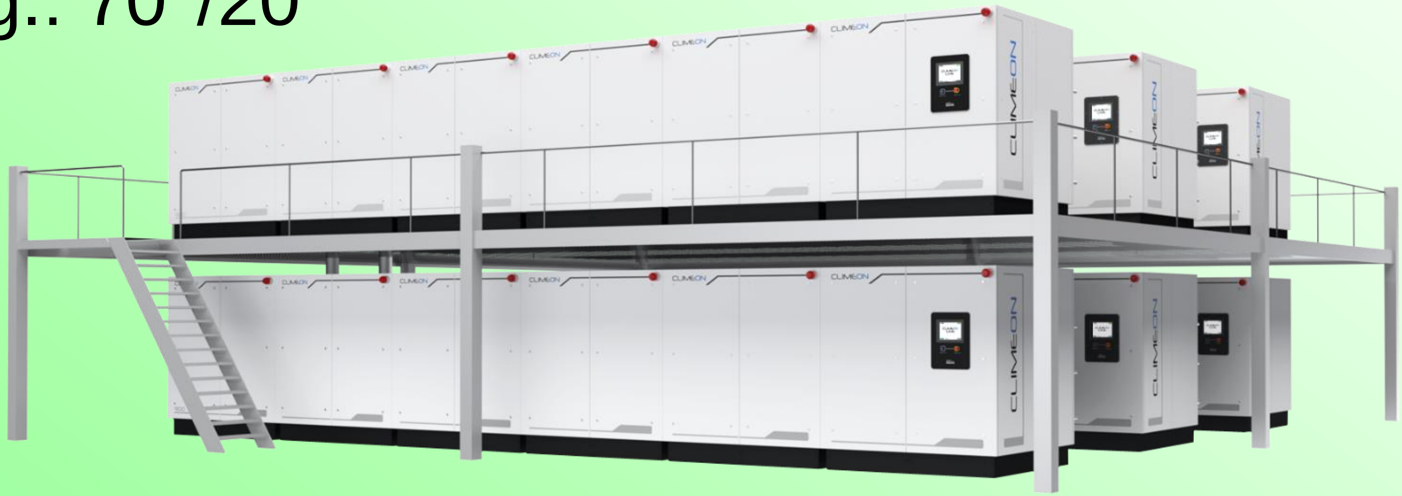
Site	Yellowknife	Estevan SK
Fluid T	70°C	115°C
Ambient T	-20°C (winter)	+20°C (summer)
Efflux T	20°C	65°C
Delta-T	**50°C**	**50°C**

- Rankine cycle efficiency is OK at low T!
- Low-T condensing fluid needed
- Efflux has a reasonable T
- We can **recharge the thermal battery** and also generate EGS power in winter!

Climeon™ ("climb-on")

- Scalable and modular (150 kW)
- Low-pressure (vacuum), low-T alcohol-type working fluid
- Can operate at ΔT of 50°C: e.g.: 70°/20°

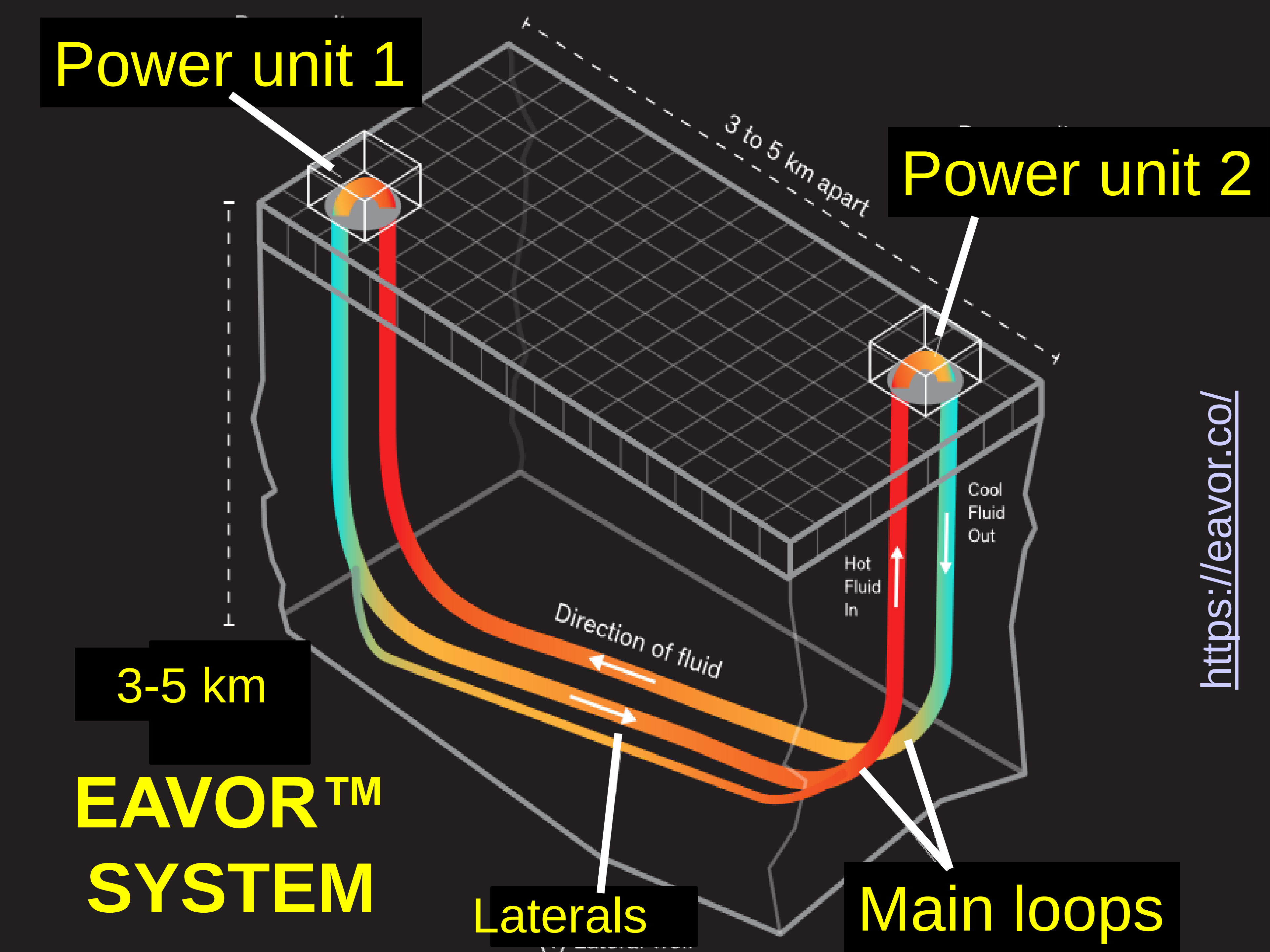
https://climeon.com/



Climeon claims 2× efficiency of a "classic" ORC system!

New Developments

- Extracting power from ΔT using new or combined cycles is an area of continuing development (see next slide…)
- It is reasonable to expect…
  - Increased efficiencies (fewer system losses)
  - Lowered costs, size reductions
  - Improved modularity & transportability
- If drilling costs also decline… …EGS looks better with time


Power unit 1
3 to 5 km apart
Power unit 2
Cool
Fluid
Out
Hot
Fluid
In
Direction of fluid
3-5 km
EAVOR™
SYSTEM
Laterals
Main loops
https://eavor.co/

Interim Conclusions…

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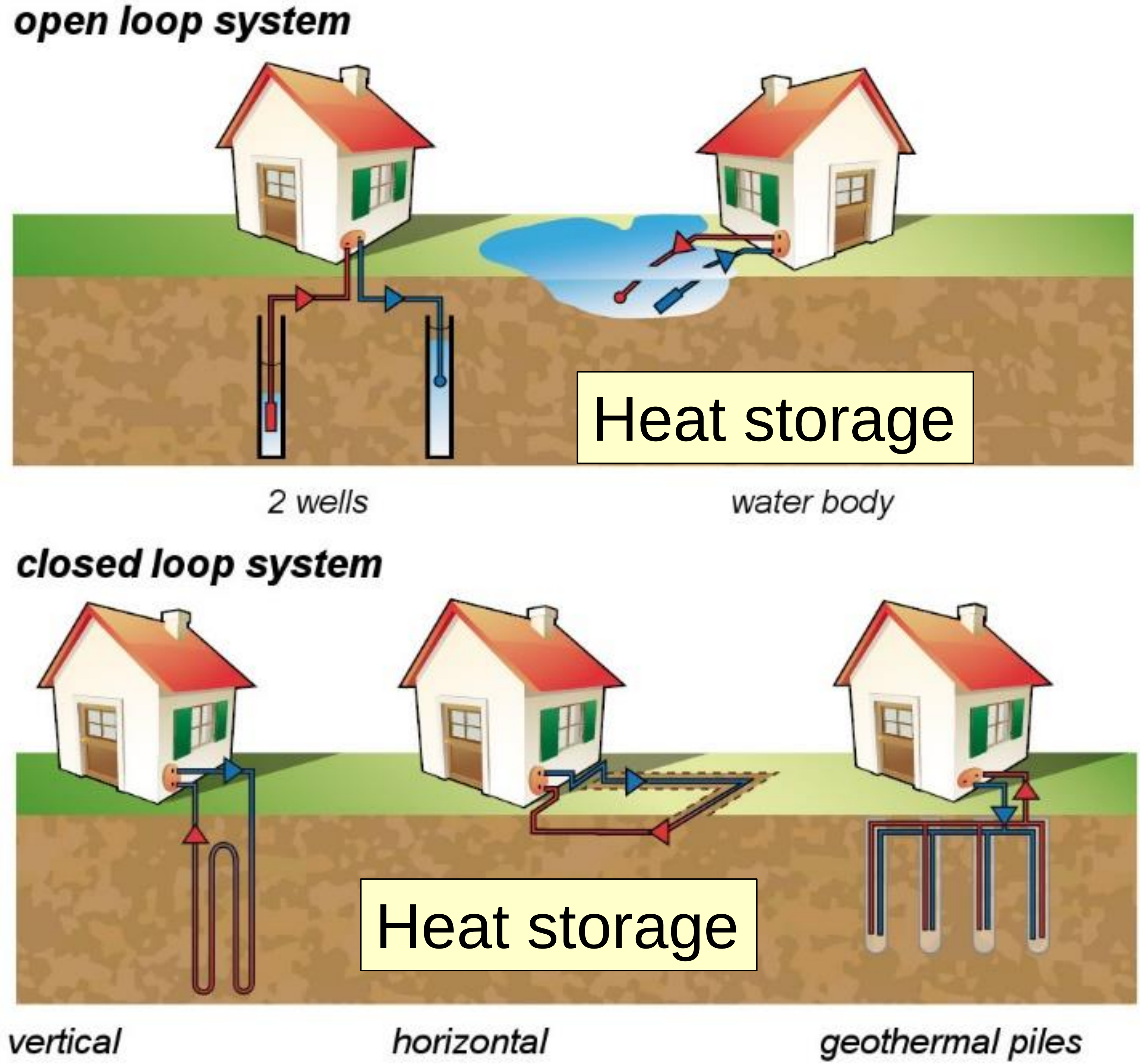
- A "Hybrid" EGS/GSHP system has definite advantages over a simple EGS
- Technology is evolving:
  - Cheaper deep drilling
  - Better energy extraction systems
  - Better GSHP systems
  - Potential novel concepts
- In the North, competition is with diesel, perhaps at costs of $0.50-1.50 /kWh
- Is it time to revisit geothermal systems' suitability for remote communities?



http://iter-geo.eu/shallow-geothermal-systems-how-extract-inject-heat-into-ground/

Drake Landing – Okotoks AB

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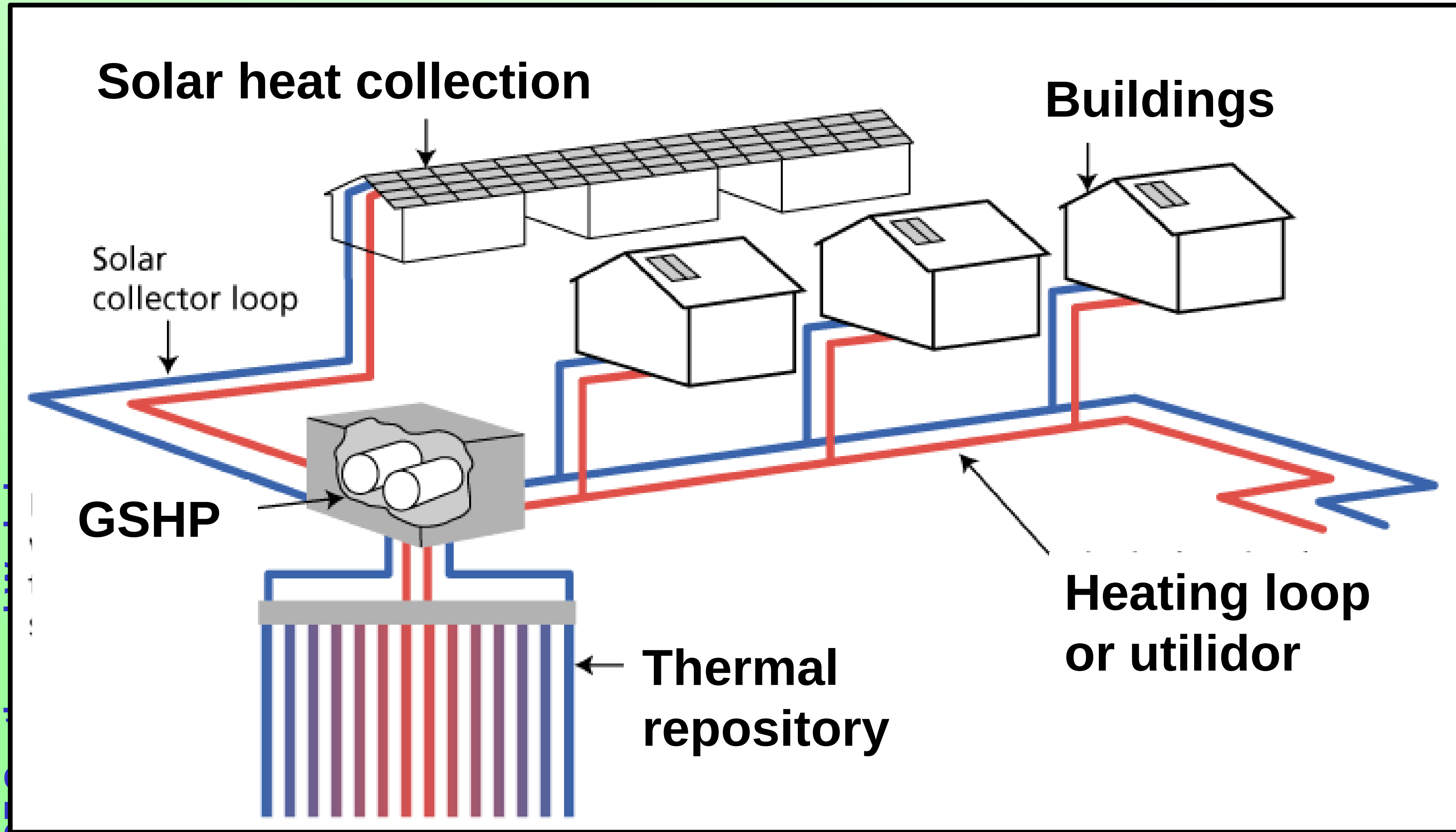


Geothermal North Project

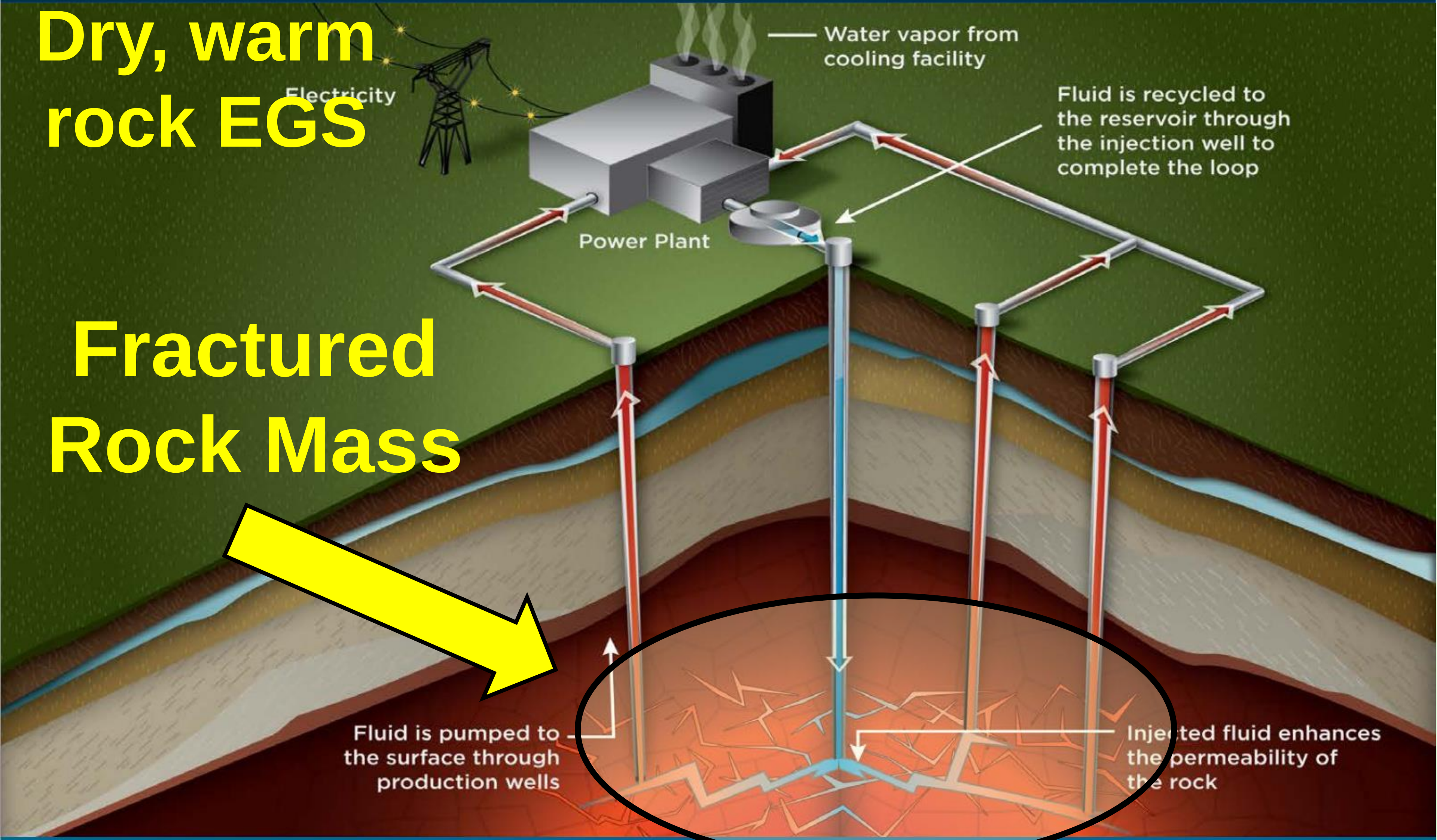
- Deep geothermal energy extraction from "**warm dry rock**"
- Co-generation: electricity + heat
- Ideal for cold climate communities
- Integrated with **shallow heat pumps**
- Holes with new drilling developments
- Hydraulic fracturing to link wells
- Environmentally sustainable, resilient, suitable for communities and companies

Now – Some Challenges

Enhanced Geothermal Systems

The Future: Creating power from hot, tight rocks

EGS uses advanced technologies to access the heat of the earth and produce electricity.



Geomechanics Issues

- **THM coupling** in jointed rock masses
  - Highly non-linear joint conductivity
  - Conductive-convective heat transport
  - Strong density effects if SC-CO_2 used (positive…)
  - Channeling through dilated fractures
- **Induced seismicity** predictions
  - No good link between MS and RM
  - Incapable of predicting P(Mmax), recurrence
- **Monitoring**
  - Microseismic monitoring is not good enough
  - Deformation monitoring is needed for geomechanics
  - Fibre optics, tiltmeters, LIDAR (surface)…?

Weak Surfaces, Strong Matrix

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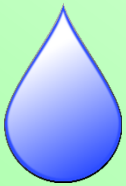
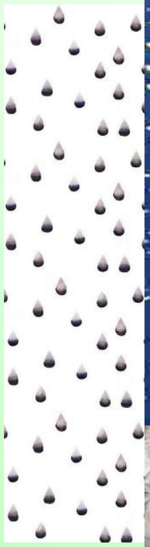
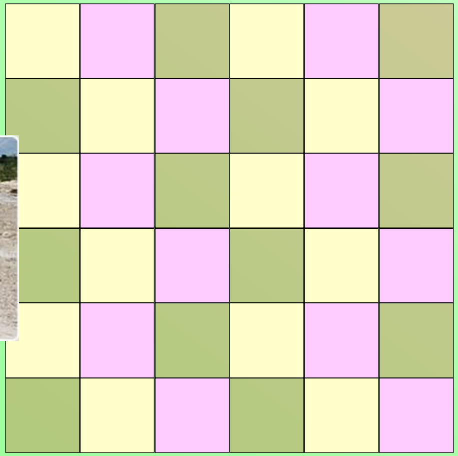
Some Challenges in Evaluation

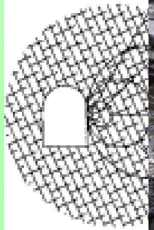
- **MODEL-BASED** assessment is vital…
  - To assess the life evolution of the system
  - To perform sensitivity analysis (which parameters are dominant, when, and how they evolve)
  - To make economic predictions
- **BUT**, this is far more challenging than it sounds.
- I will describe three big issues in modeling that face us…

Scale and Analysis (Simulation)

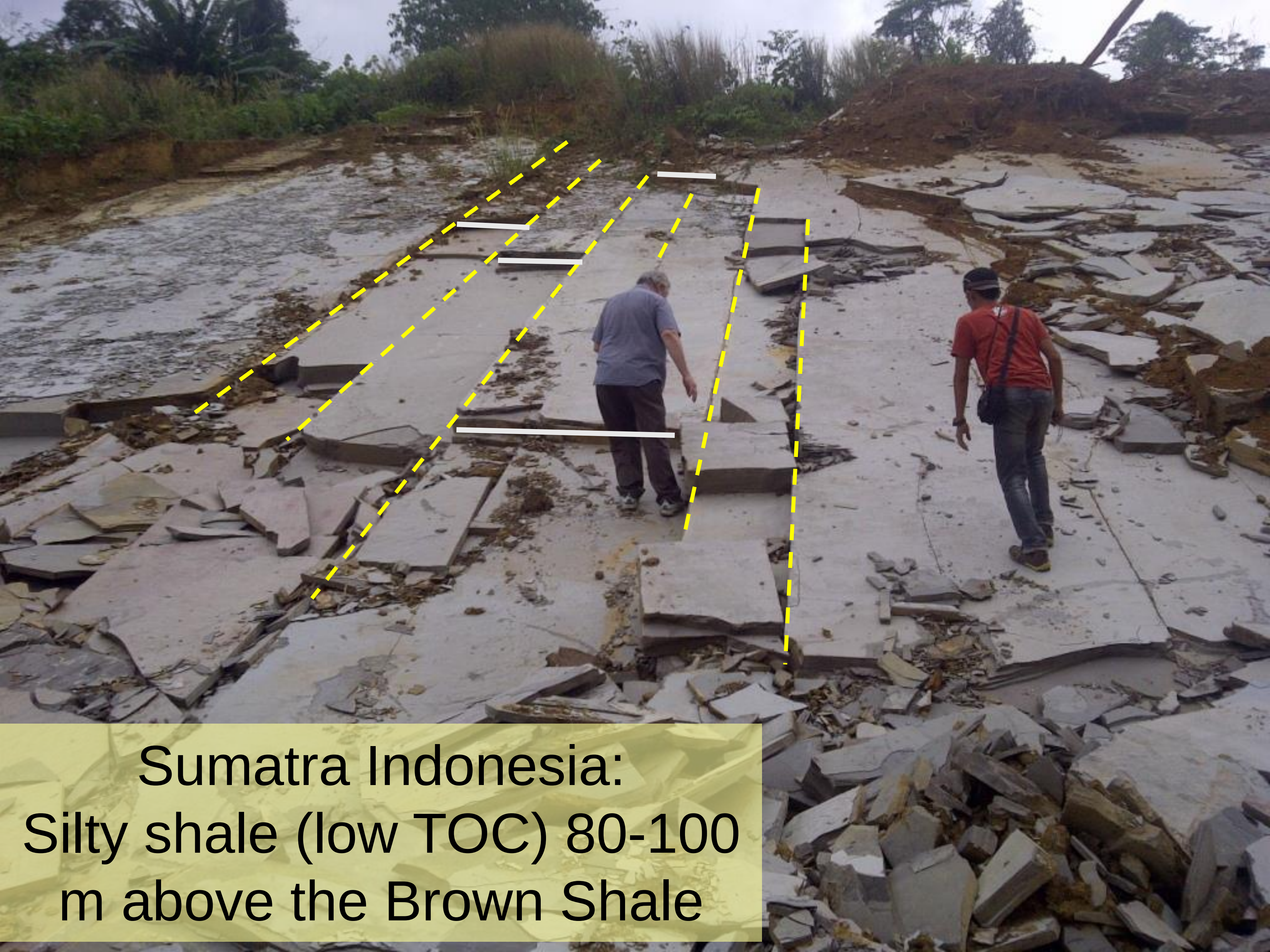




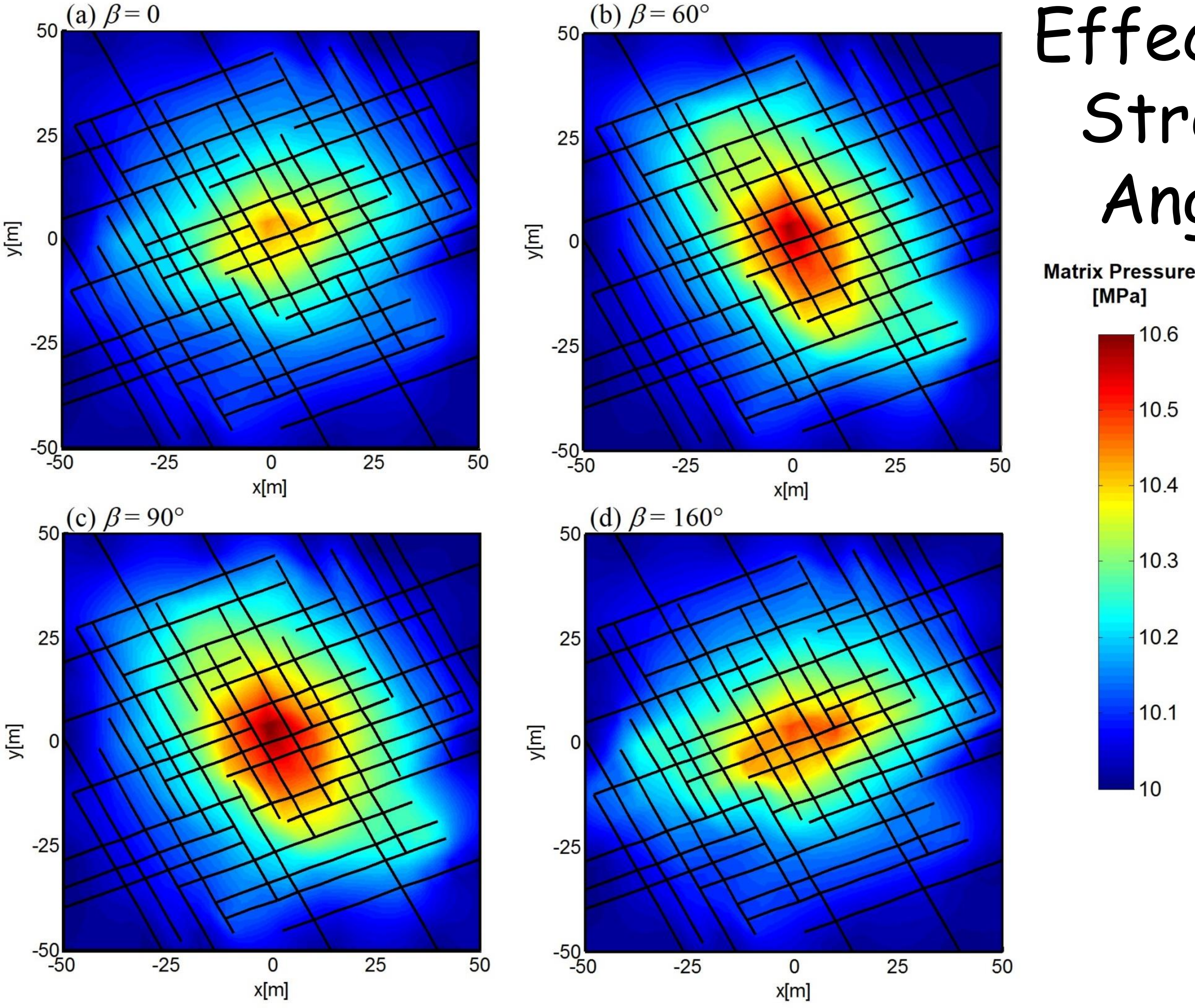




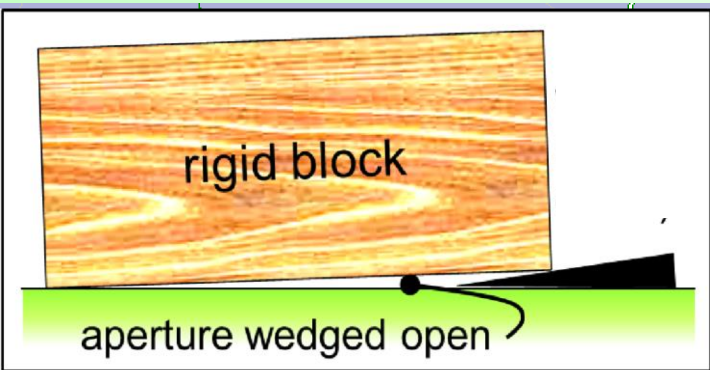
Wang, Zhac
Engineer

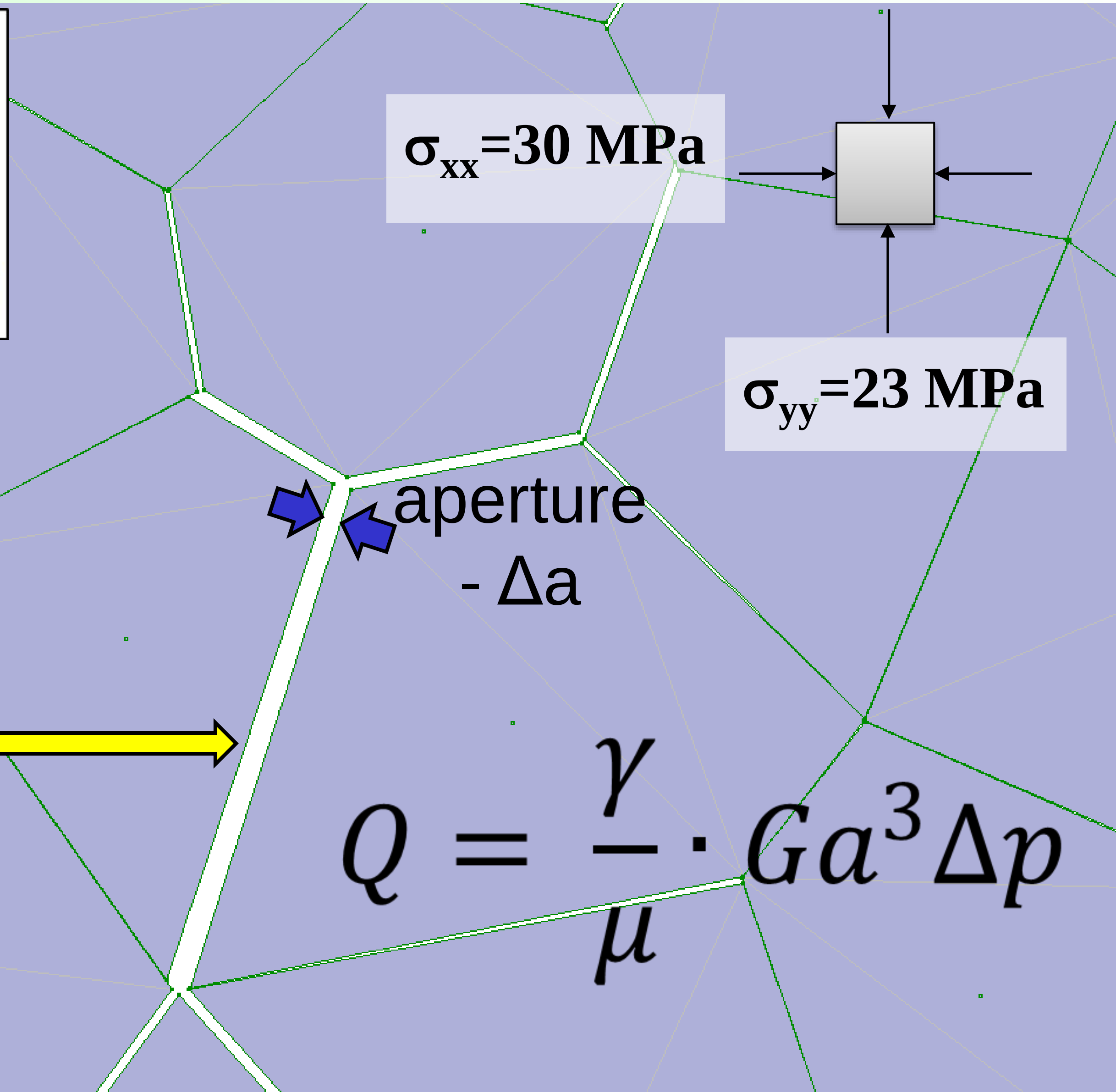

Sumatra Indonesia:
Silty shale (low TOC) 80-100 m above the Brown Shale

Effect of Stress Angle



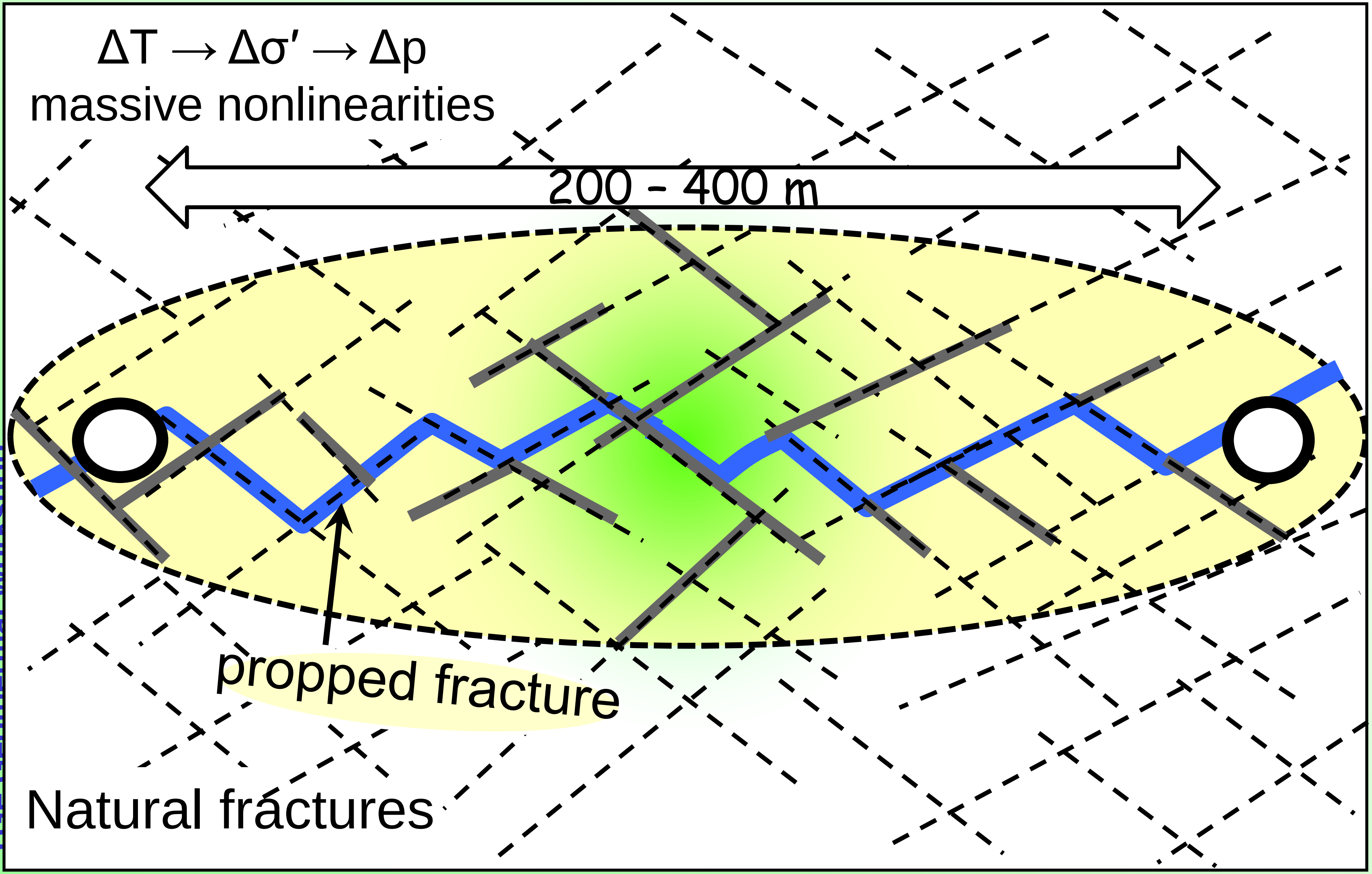
Changes in Properties (DEM)





$$Q = \frac{\gamma}{\mu} \cdot G a^3 \Delta p$$

Thermoelasticity & Channelling



Research Problem #1…

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- Injecting cold water to extract heat can lead to "short circuiting"
- Cooling of the rocks leads to preferred expansion of a single fracture path
- Flow becomes concentrated along the single fracture path
- So the heat exchange with the rock mass declines, …
- …and the system loses efficiency

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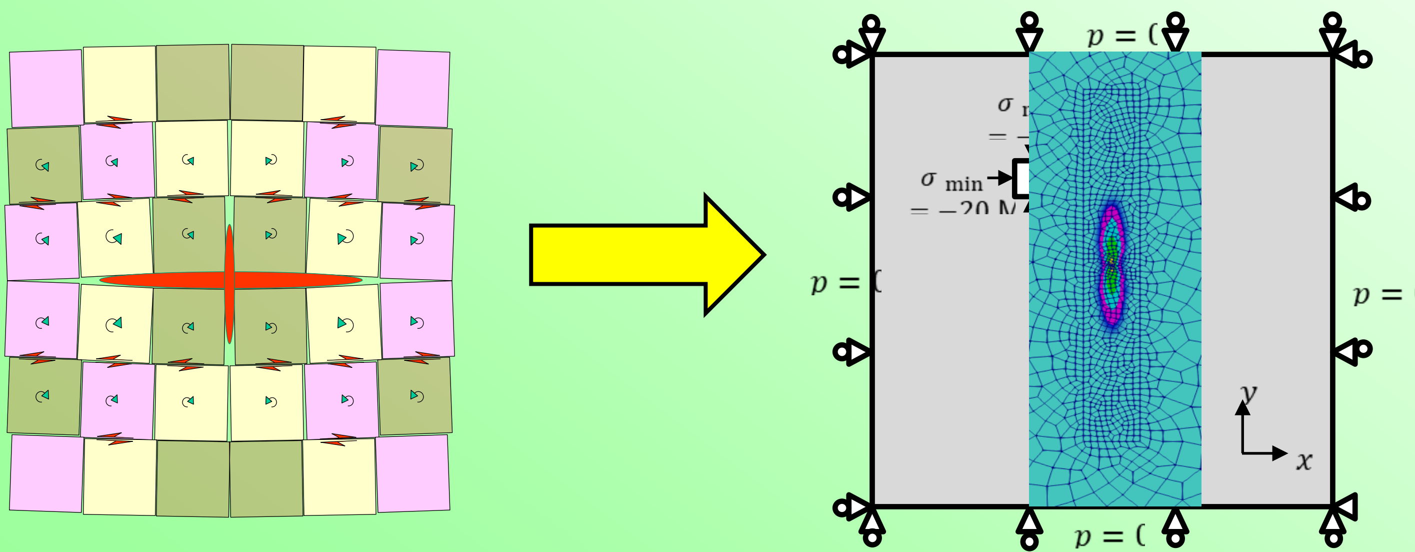
Comments on Where We Are…

- Upscaling is a useful option
- Computationally tractable for large cases
- Allows detailed stochastic analysis of many cases for risk analysis
- …but these are early times as well…



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Research Problem #2

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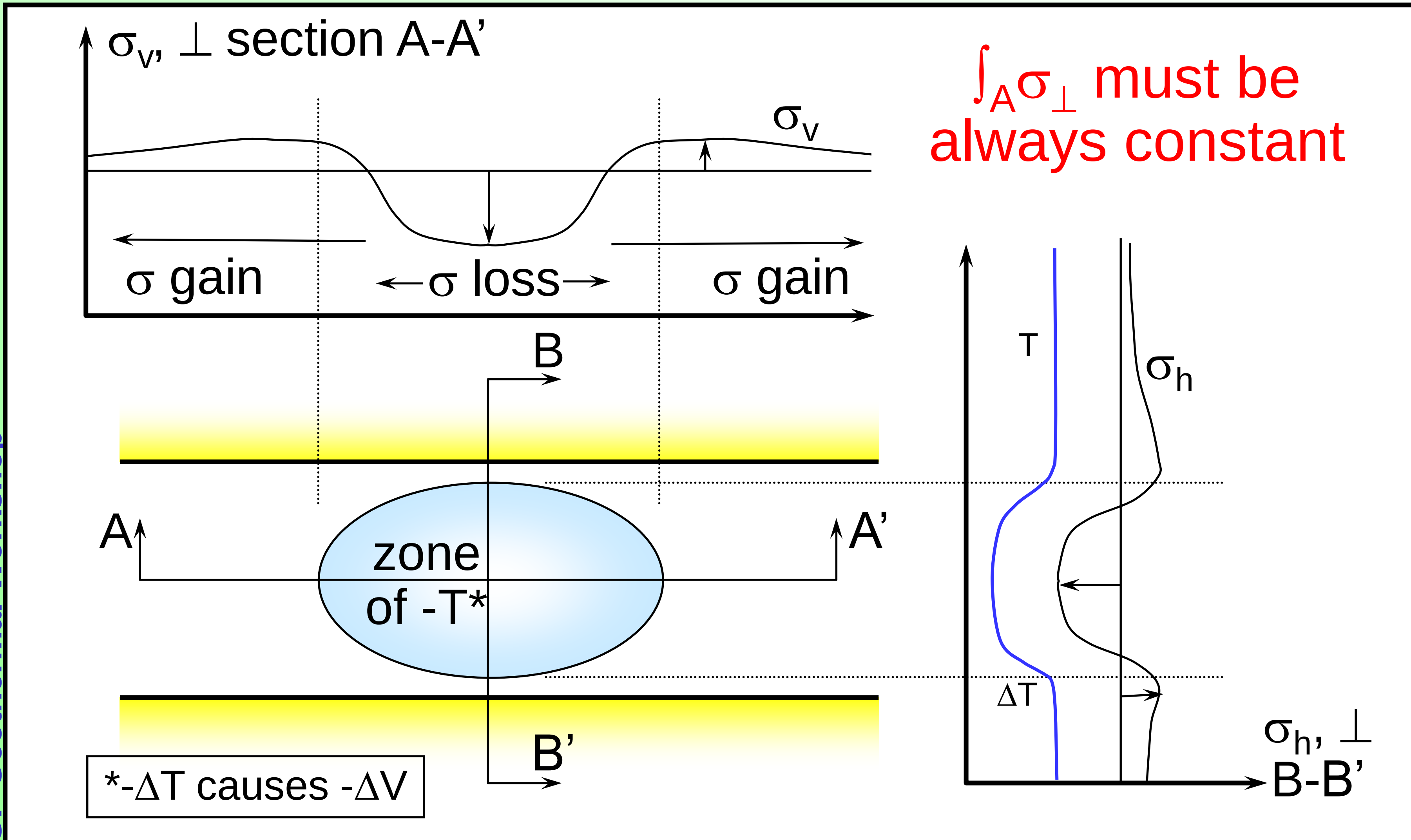
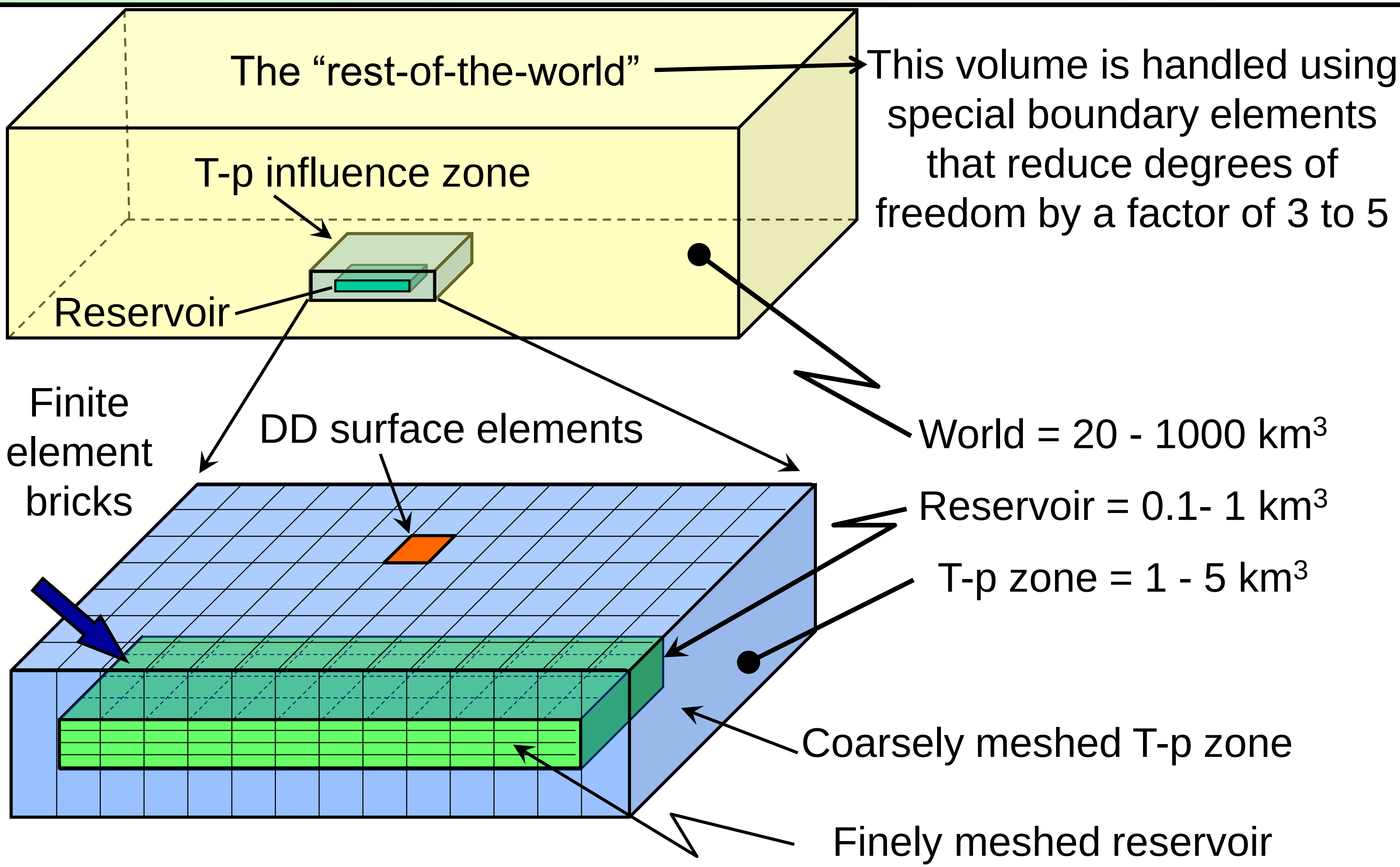
- Large T changes will cause thermoelastic contraction
- This leads to large stress changes
- If the size of the project is large… **<u>seismicity will be generated</u>**
- Can we predict this?
- How large, how often?
- Can we control it?
- This is an important issue.
- Modeling and measurements are needed

Example of σ Redistribution



Hybrid Coupled Simulations…



Monitoring the EGS System

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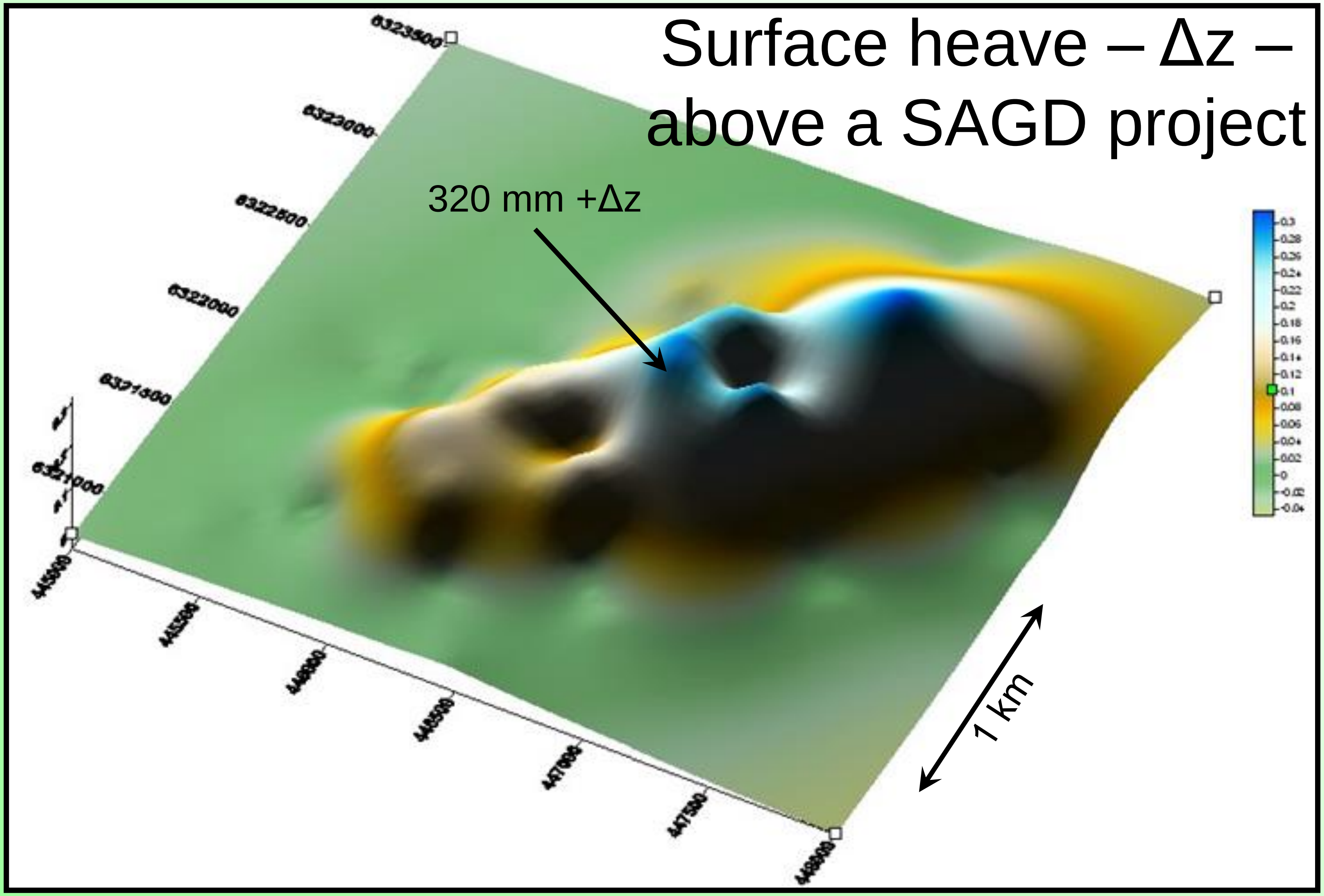
- P, T, rate are standard
- Microseismic monitoring is good, but…
- We need **deformations** in order to:
  - Track what is going on at depth
  - Calibrate and use geomechanics models
- Options?
  - Precision tilt measurements
  - Fibre-optics cables in shallow slim holes
  - 3-D active seismics

Surface Heave from ΔT & Δp



Deformations to monitor deep projects

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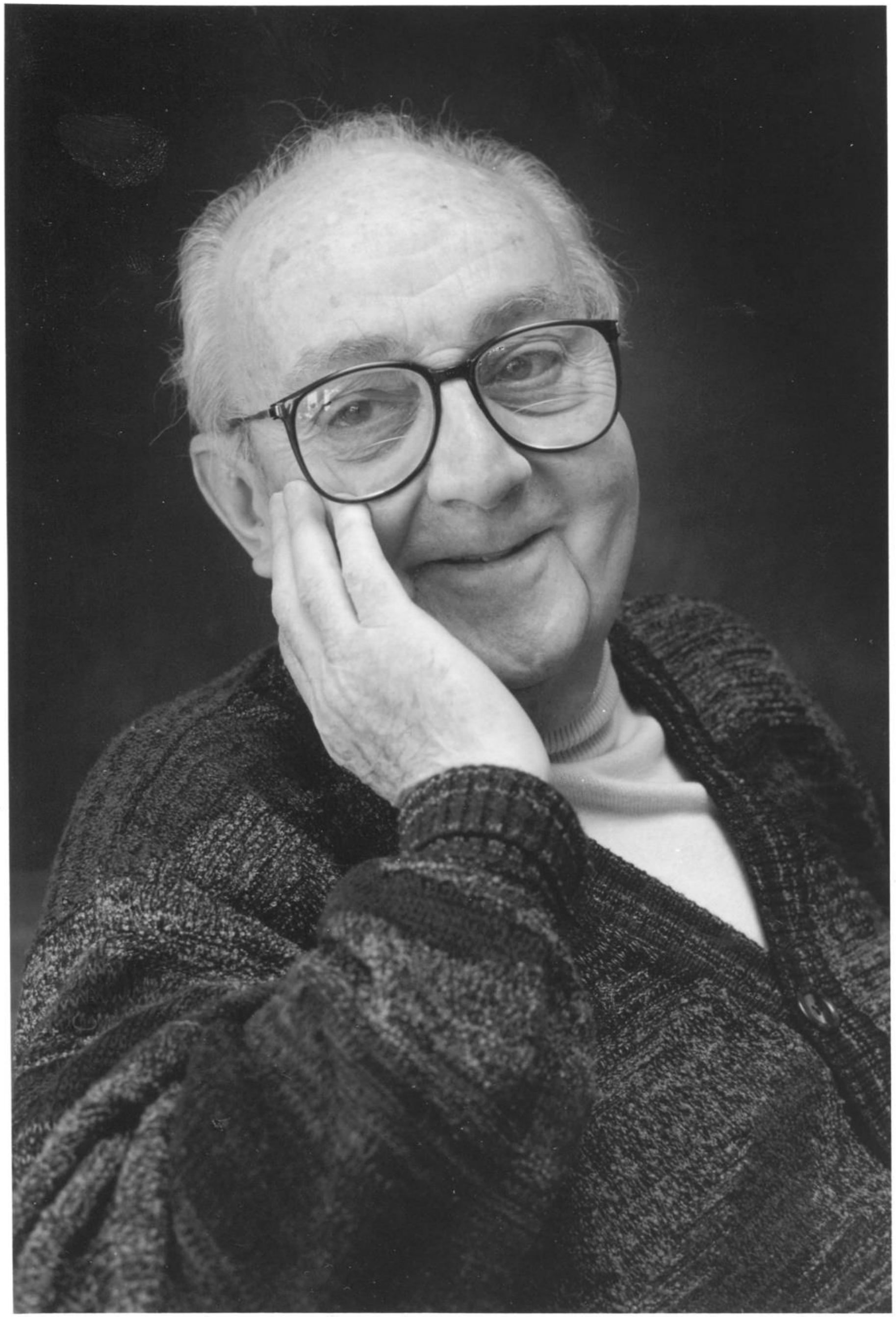
Models

"All models are wrong but some are useful…"

George Edward Pelham Box: Oct 18, 1919 – Mar 28 2013



Future Directions

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- Buildings & new project development
  - ⇨ Preinstall shallow geothermal
  - ⇨ Reduce costs of retrofitting
  - ⇨ Build district heating and cooling capability
- Larger-scale district heating
  - ⇨ Heat mining – intermediate-grade geothermal heat
  - ⇨ Heat storage potential – high efficiency thermal solar collectors and deep heat storage
- Electrical Power
  - ⇨ Low-temperature Rankine Cycle Engines
  - ⇨ New ways of integration with heat pumps & storage