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Geothermal Power Estimation with a Single Fracture Circle Model in Enhanced Geothermal Systems

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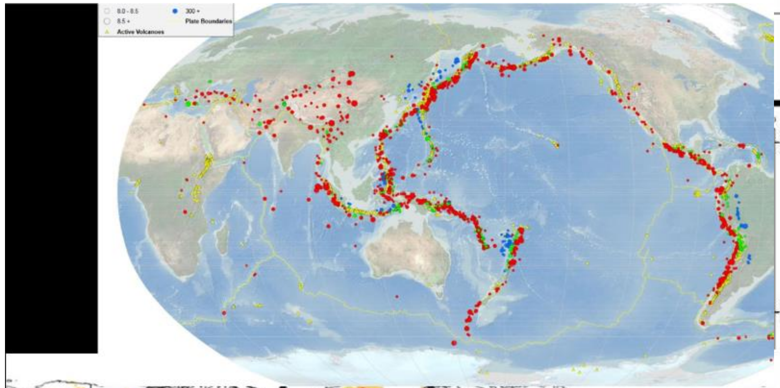
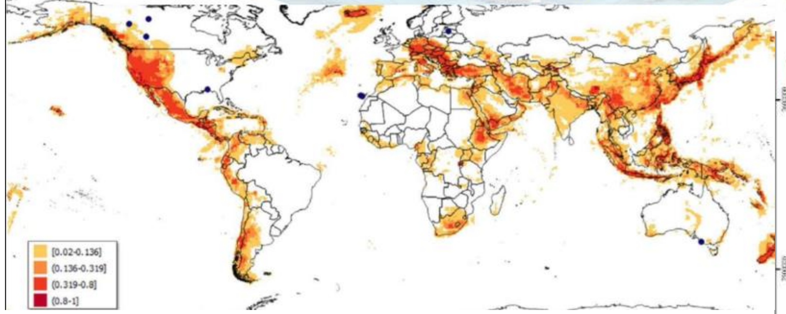
Outline

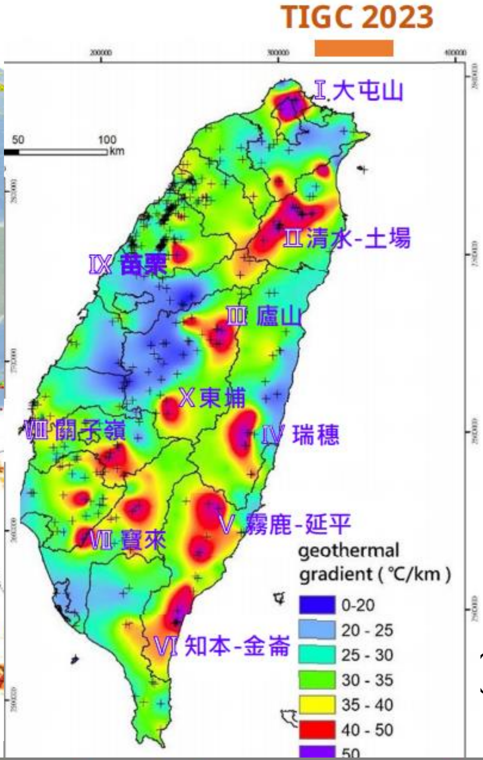
- Introduction
- Methodology
- Results and Discussion
- Conclusions
- Future Works

Geothermal Potential in Taiwan

- The National Energy Program (NEP) calculated Taiwan's deep geothermal potential to be 33.6 GWe in 2012.
- In 2013, a study by Li,Ching-Jui from ITRI estimated the deep geothermal potential of Taiwan's top nine geothermal areas at 31.8 GWe.
- Chen,Chi-Hsuan from the Central Geological Survey reported in 2023 that the latest calculation of deep geothermal potential is 39.7 GWe.
- Overall, Taiwan's deep geothermal potential is estimated to be around 30 to 40 GWe.







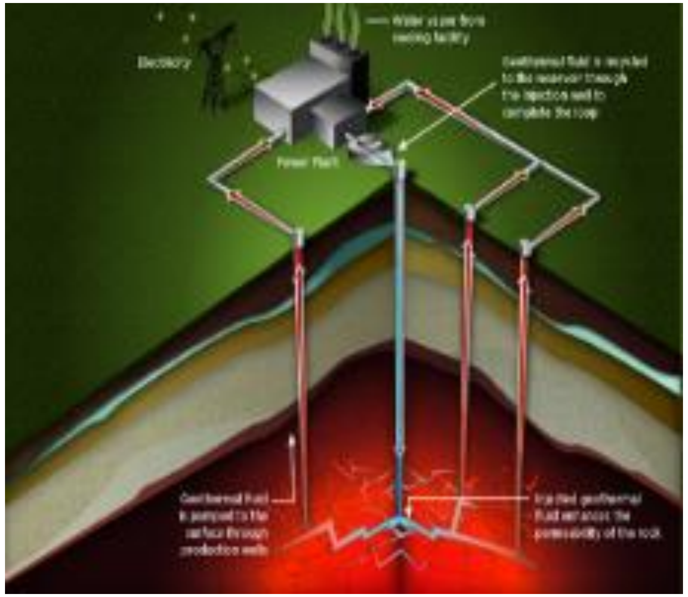
(GMMSA,2024)

Total : ~ 40 GWe in 10 potential areas

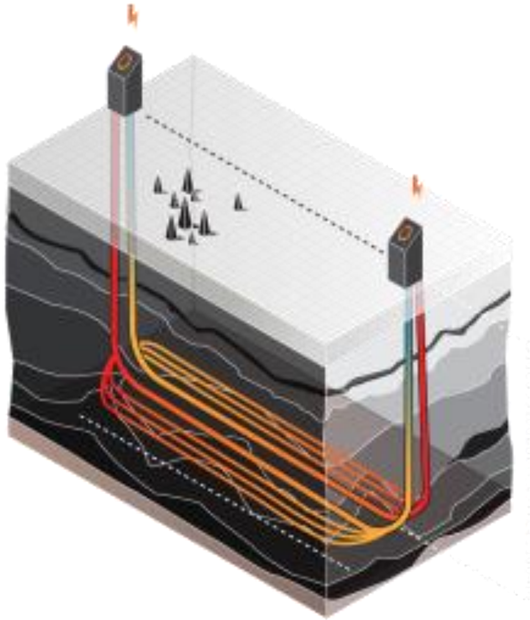
No.		I	II	III	IV	V	VI	VII	VIII	IX	X
Name		Tatun	Chinsuei-Tuchang	Lushan	Reisuei	Wulu-Yenping	Chiben -Jinlun	Baolai	Guanzilin	Miaoli	Dongpu
Volume	km^3	809	2774	1096	1237	1900	2011	1412	1254	431	780
Average T	°C	235	227	236	219	225	215	212	215	217	219
Heat content	10^{18}J	245.2	795.0	332.0	334.7	530.8	531.1	360.2	324.3	113.6	209.2
Power available	GWe	2.7	8.5	3.7	3.5	5.6	5.4	3.6	3.3	1.2	2.2

How to product deep geothermal energy

- Key points for developing geothermal power plant : Heat source, Reservoir(fracture), Liquid
- Deep Geothermal : Only need Heat source
  - EGS : Create Fracture and inject liquid
  - AGS : Closed wellbore
- How Deep?
  - 3000m
  - Next-Generation



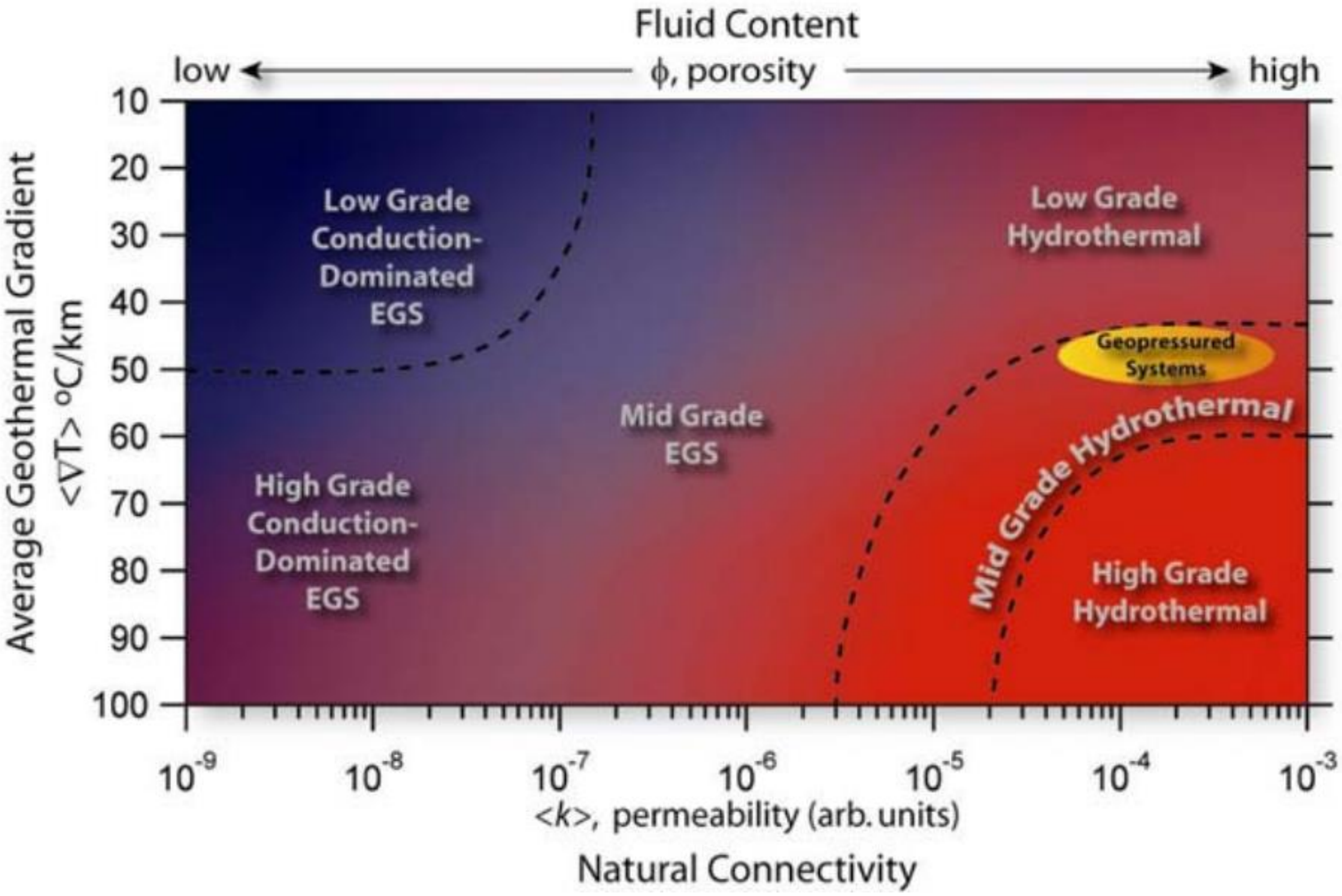
增強型地熱系統
EGS(Enhanced Geothermal Systems)



進階型地熱系統
AGS(Advanced Geothermal Systems)

EGS

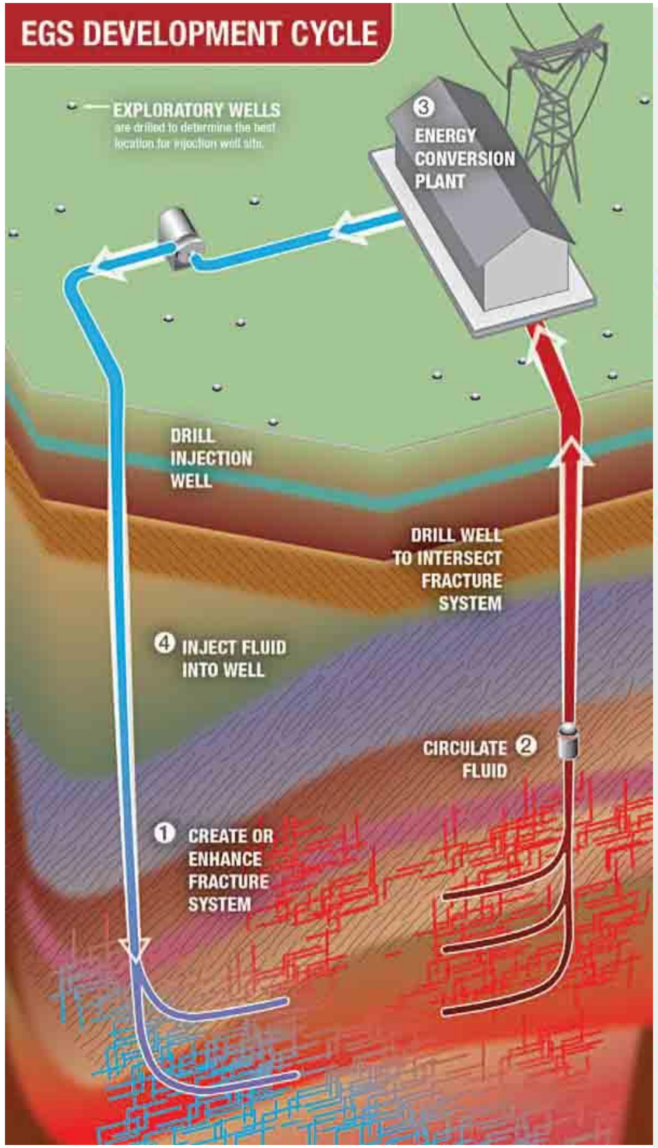
- Low permeability
- Low porosity
- High Geothermal Gradient

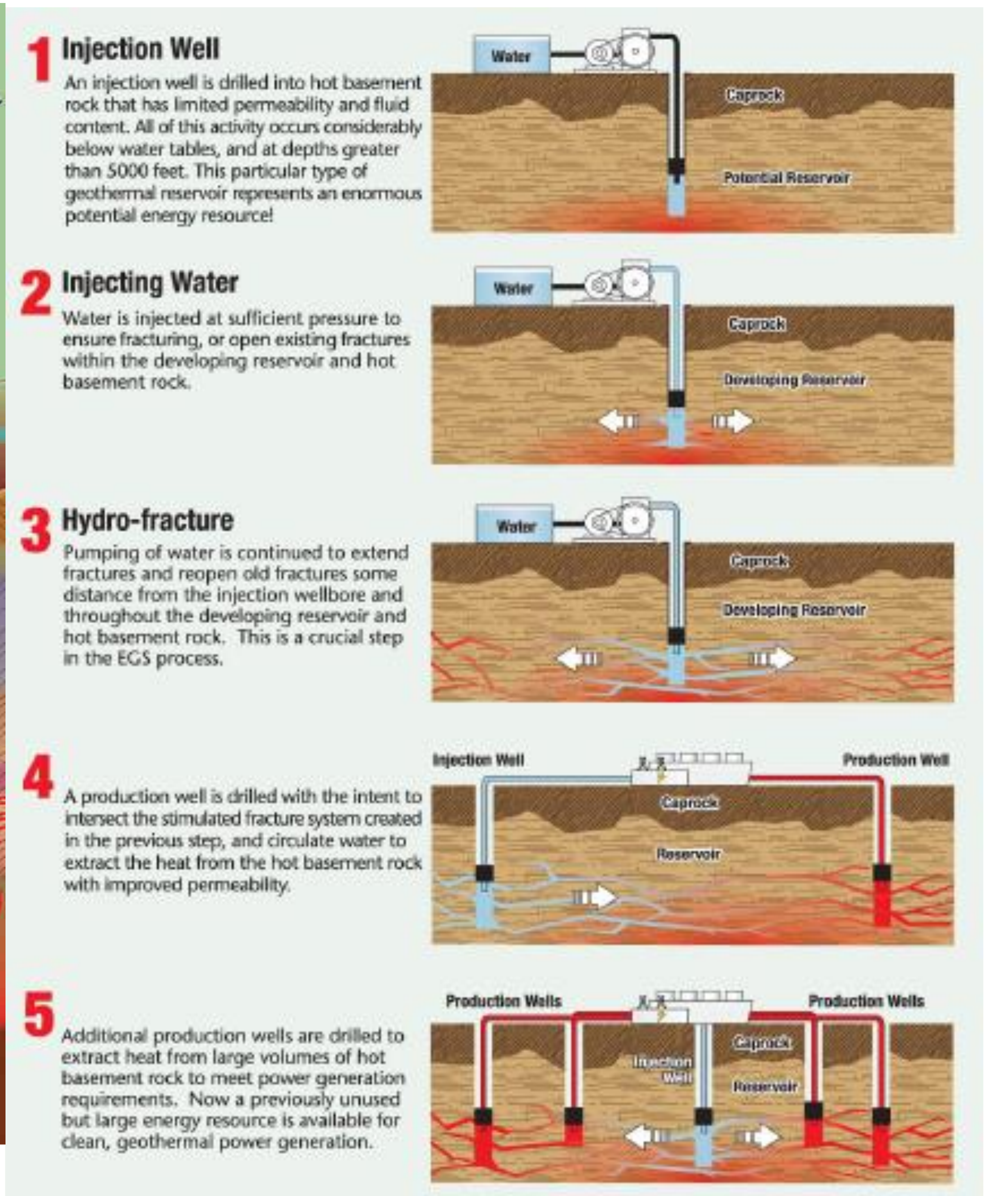


Usually EGS

- ➢Injection well
- ➢Injection water
- ➢Hydro fracture
- ➢Production well
- ➢Stable injection-production system

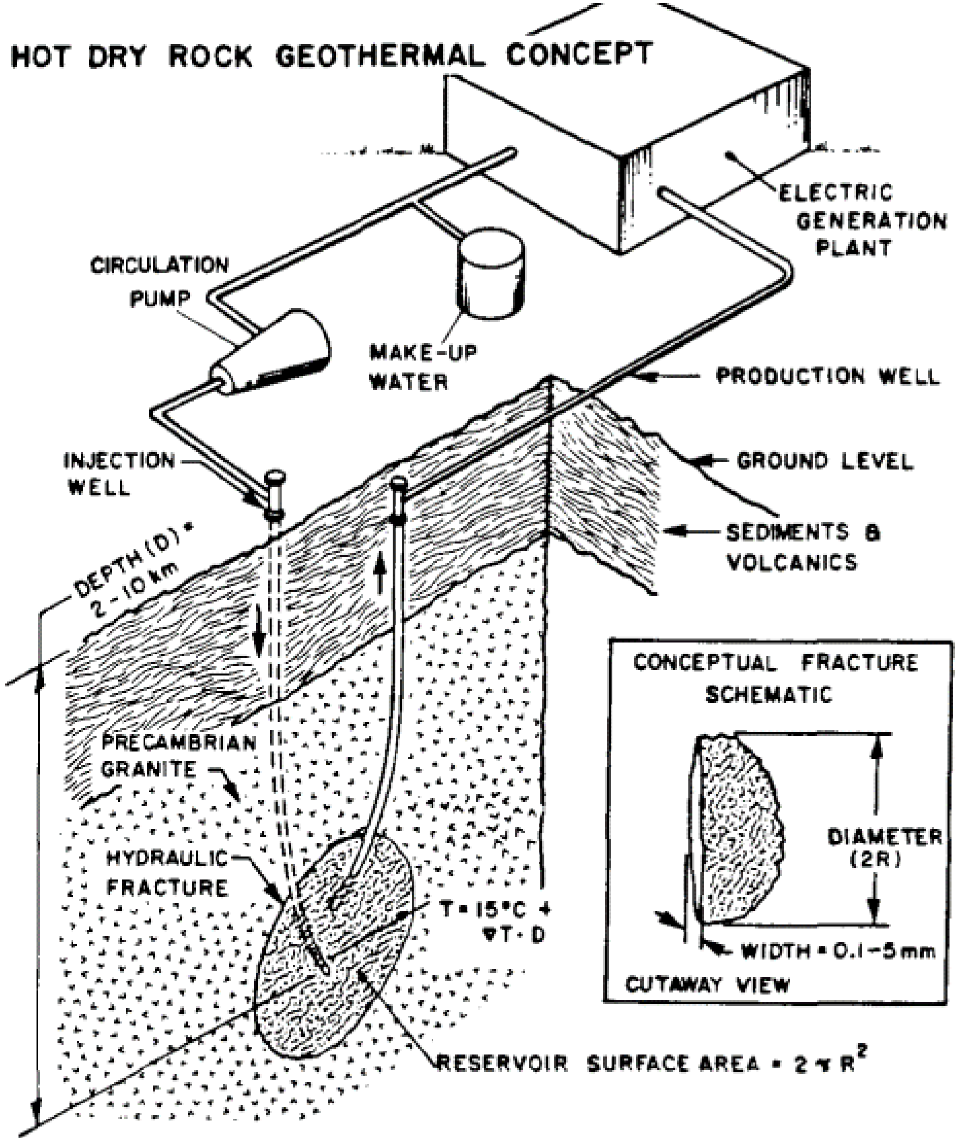
Idea of deep hot dry rocks heat mining was described Konstantin Tsiolkovsky ，1898 ; Charles Parsons ，1904 ; Vladimir Obruchev ，1920





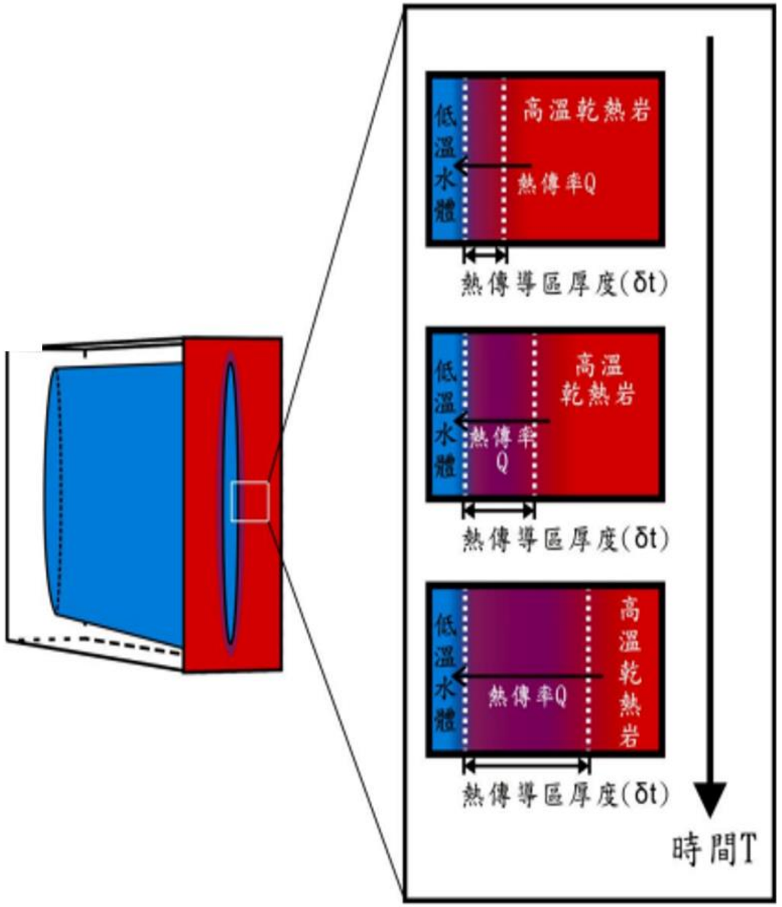
Single Fracture Circle System

- The single fracture cycle is a simplified model of a complex hot dry rock extraction system. It is represented as a single, elliptical, lead-shaped fracture, with the injection well, fracture zone, and production well forming a complete thermal energy extraction loop (Tester and Smith, 1977).
- In this model, cold water is injected into the elliptical fracture, where it exchanges heat with the surrounding hot rock. The heated water is then recovered through the production well.



Heat transfer from rock to water

- The mechanism by which rocks transfer heat to water is typically simplified as a process of heat transfer from a constant-temperature, high-temperature reservoir to a constant-temperature, low-temperature reservoir.
- The rate of heat conduction is proportional to the contact area between materials and their thermal conductivity coefficient. This approach assumes that water circulates continuously and acts as a constant-temperature heat reservoir. Additionally, the hot dry rock far from the wellbore is assumed to behave as a constant-temperature, high-temperature heat source. Heat transfer occurs due to the temperature difference between these two reservoirs.
- As the low-temperature water continuously extracts heat from the formation, the depth of the thermal conduction zone increases over time.



Lin,2014

Calculation method

1. Thermal diffusivity

$$\alpha = k / \rho c$$

α =thermal diffusivity (m^2/s)
K=Thermal conductivity (W/m.K)
ρ=rock density (kg/m^3)
c=specific heat of rock (J/kg.K)

2. Penetration depth

$$\delta = 2\sqrt{\alpha t}$$

δ=penetration depth (m)
α =thermal diffusivity (m^2/s)
t=time(s)

3. Minable volume

$$V = 2\,\delta A$$

V=Minable volume (m^3)
δ=penetration depth(m)
A=Creation fracture Area (m^2)

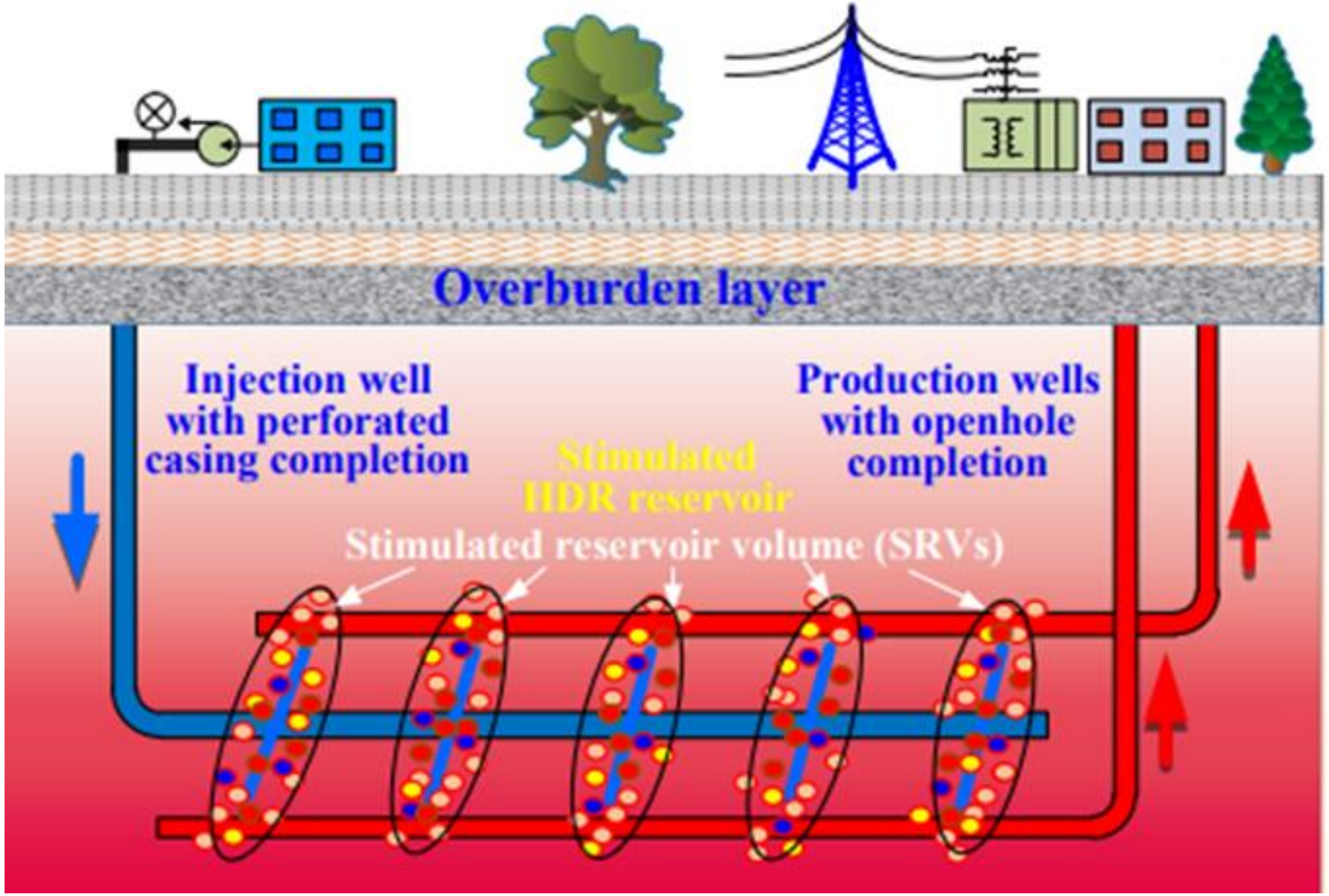
4. Output power

$$P = V\rho c(\mathrm{Ti} - \mathrm{Tf})/t$$

P =Output power(W)
V=Minable volume (m^3)
ρ=rock density(kg/m^3)
c=specific heat of rock(J/kg.K)
Ti=Initial temperature of thermal reservoir (℃)
Tf=Final temperature of thermal reservoir (℃)
t=time(s)

EGS Design

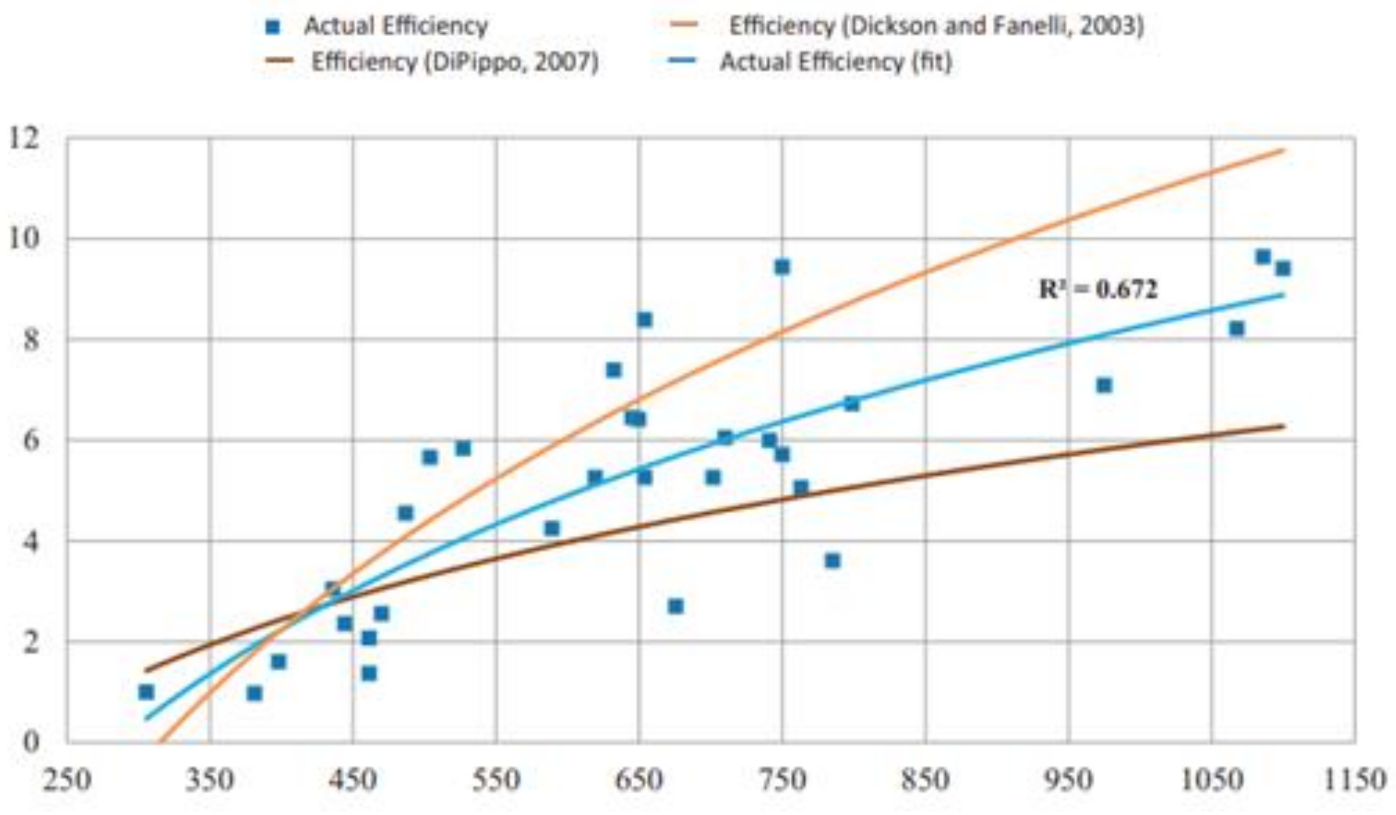
- In EGS projects, a single large fracture is unlikely to form. Instead, multiple small, parallel fractures are used for heat exchange.
- The spacing between two fractures is typically twice the penetration depth. Based on the desired thermal output, the total fracture volume can be estimated, from which the required surface area is calculated. This area, divided by the penetration depth, gives the number of fractures needed.



Han,2019

Binary Generator efficiency

Most EGS test sites use binary generator sets (ORC systems), which operate similarly to air conditioners—using a **low-boiling-point working fluid** to convert heat into electricity. According to Zarrouk (2014), their efficiency depends strongly on the geothermal fluid temperature



η=6.9681ln(Tin)-29.713

Zarrouk,2014

h=Power generation efficiency (%)
Tin=the temperature of the geothermal fluid at the inlet (℃)

Work Flow

Set conditions

- Initial temperature(℃)
- Final temperature(℃)
- Number of production and injection wells
- Power plant capacity(MW)
- efficiency(%)

Collect parameters

- Thermal conductivity(W/m.K)
- Thermal diffusivity(m^2/s)
- Rock density(kg/m^3)
- Two well intervals

Calculate

- Required fracture area(m^2)
- Single fracture area(m^2)
- Number of fracture required
- Thermal wave penetration depth(m)

Results

- The required length of each well
- Fracture intervals
- EGS design

Parameter

As an assumption for the following estimates, a 5 MW EGS geothermal power plant is considered to be built in the slate belt of the Lanyang Plain, with an expected operational lifespan of 20 years.

Thermal conductivity(W/m. K)	Specific heat of rock(J/kg K)	Rock density(kg/m^3)	Thermal diffusivity(m^2/s)
2.784	1,053	2,800	9.44E-7
Power plant capacity(MW)	Thermoelectric conversion efficiency(%)	Initial temperature(℃)	Final temperature(℃)
5	6	250	200
Number of production wells	Number of injection wells	Operation time(year)	Two well intervals in the reservoir(m)
2	1	20	200

Table 3 Thermal parameters of examined slates measured at room temperature

Sample	Thermal conductivity k/W m^{-1} K^{-1}		Anisotropy coefficient of conductivity	Effusivity e/W × s$^{0.5}$ m^{-2} K^{-1}		Anisotropy coefficient\of effusivity	Diffusivity α/1 × 10^{-7} m^2 s^{-1}		Anisotropy coefficient of diffusivity
	k_{II}	$k_\perp$	$k_{II}/k_\perp$	e_{II}	$e_\perp$	$e_{II}e_\perp$	α_{II}	$\alpha_\perp$	$\alpha_{II}\alpha_\perp$
MOK1	3.65	1.61	2.3	2814.6	1798.3	1.6	16.8	8.0	2.1
MOK2	3.92	1.52	2.6	2877.5	1724.83	1.7	18.6	7.8	2.4
ZAL3	3.42	1.43	2.4	2660.4	1674.3	1.6	16.5	7.3	2.3
LHO4	3.70	1.79	2.1	2780.6	1866.8	1.5	17.7	9.2	1.9
CER5	3.61	1.52	2.4	2741.0	1725.1	1.6	17.3	7.8	2.2
CER6	3.58	1.65	2.2	2782.4	1762.8	1.6	16.6	8.7	1.9
CLD7	3.72	1.71	2.2	2775.6	1897.2	1.5	17.9	8.1	2.2
VOD8	3.49	1.51	2.3	2669.5	1726.4	1.6	17.1	7.6	2.2
VEG1	2.86	2.65	1.1	2396.1	2295.3	1.0	14.2	1.3	1.1
TRG1	2.69	2.40	1.1	2319.8	2176.1	1.1	13.4	1.2	1.1
CSTR1	3.02	1.99	1.5	2473.7	1968.9	1.3	14.9	1.0	1.5
KUN2	3.40	3.15	1.1	2650.9	2535.1	1.1	16.4	1.5	1.1

Thermal conductivity and thermal diffusivity of slate (Małgorzata Labus et al., 2019)

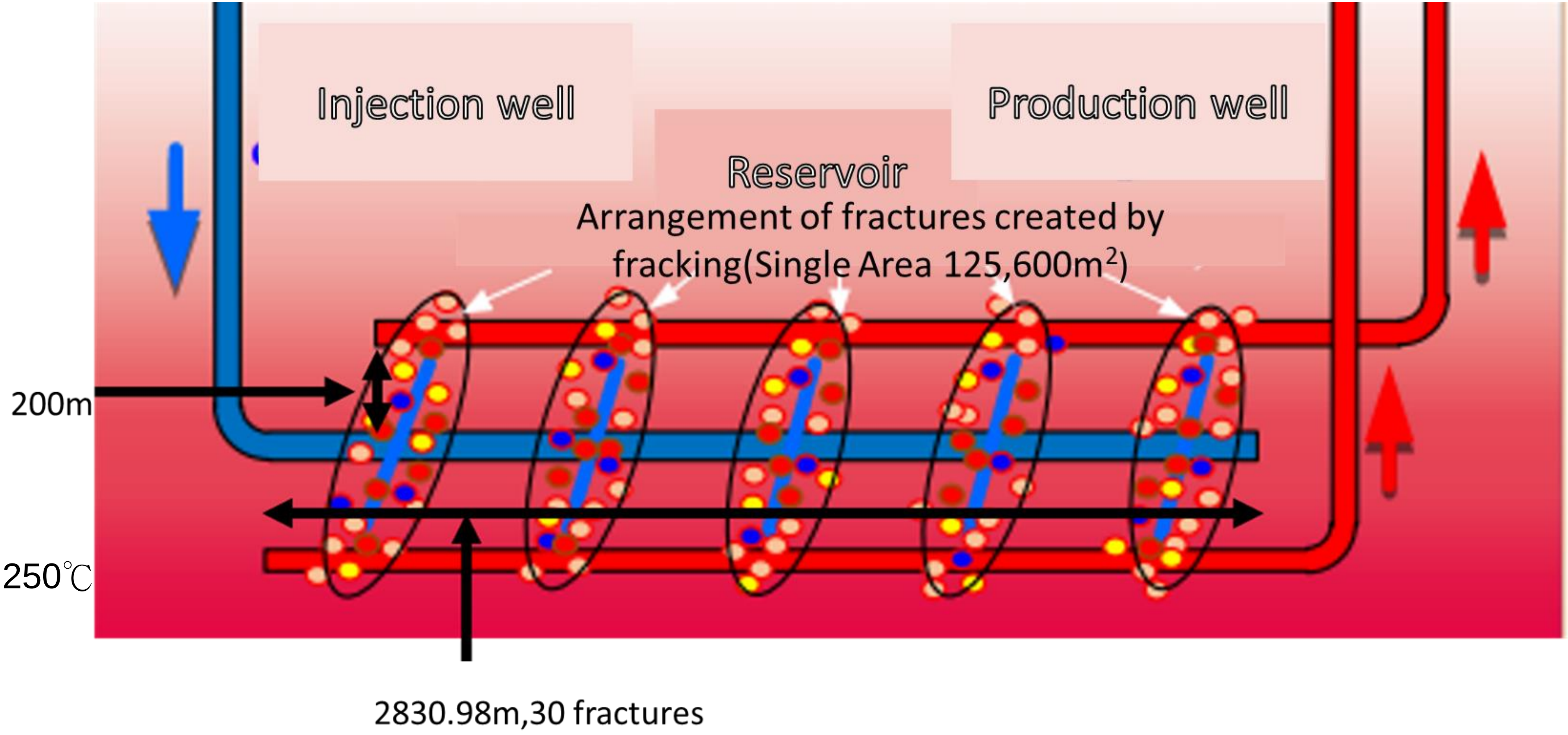
Result

Requirements for a 5 MW EGS Plant in the Lanyang Plain (20-year Operation):

Required fracture area(m^2)	Required heat reservoir volume(m^3)	Thermal wave penetration depth(m)	Number of fracture required
3,660,000	3.6E8	48.81	30
Number of fracture intervals	fracture intervals (m)	Single fracture area(m^2)	The required length of each well in the reservoir(m)
29	97.62	125,600	2,830.98

Result

- EGS Model



Conclusions

- Based on the assumptions in this study, a 5 MW EGS plant would require approximately 3.66 million m^2 of surface area, equivalent to 0.98 km^3 of hot dry rock.
- Assuming a 200 m distance between the production and reinjection wells, and a one-injection–two-production configuration, a bottom well length of 2,831 m is needed. About 30 fractures are assumed to connect the injection and production wells.
- If the water circulation effectively transports heat to the surface, an EGS system can be established under these conditions.
  For example, if the reservoir rock starts at 250 °C and the temperature drops by only 20% over 20 years of operation, a volume of ~1 km^3 would be sufficient to support a 5 MW plant.
- It should be noted that many parameters used here are hypothetical. In future assessments, real field data can be used with simulation tools to calculate flow rates and water volumes for more accurate evaluations.

Future Work

- Other EGS designs
- Numerical modeling
- Financial Model

Thanks for your attention