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# Geothermal Resources

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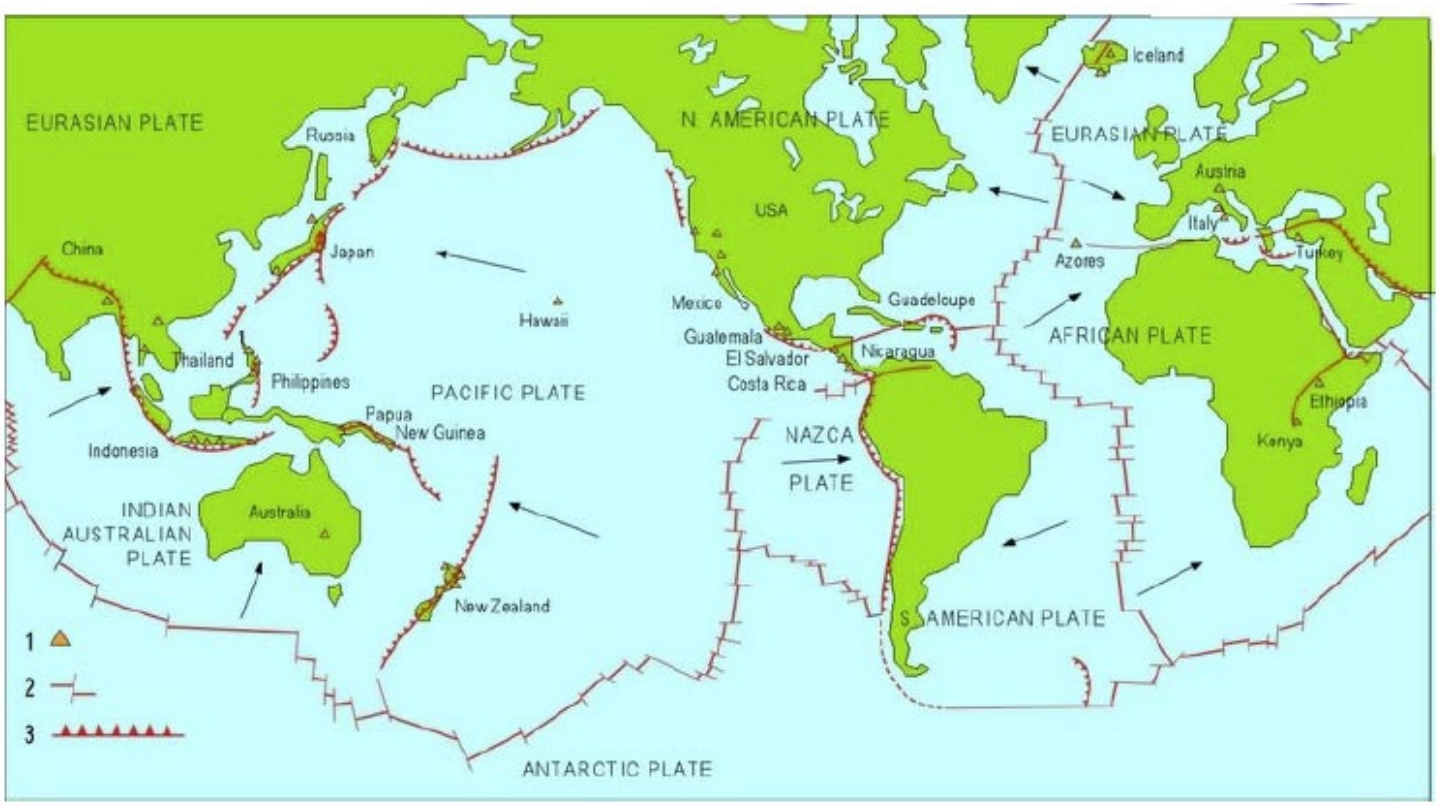
# Presentation Plan

- Background on geothermal energy
- Numerical modelling of geothermal reservoirs (UoA)
- Ramble through a few thoughts on geothermal energy

# Background on Geothermal Energy

# Geothermal Resources

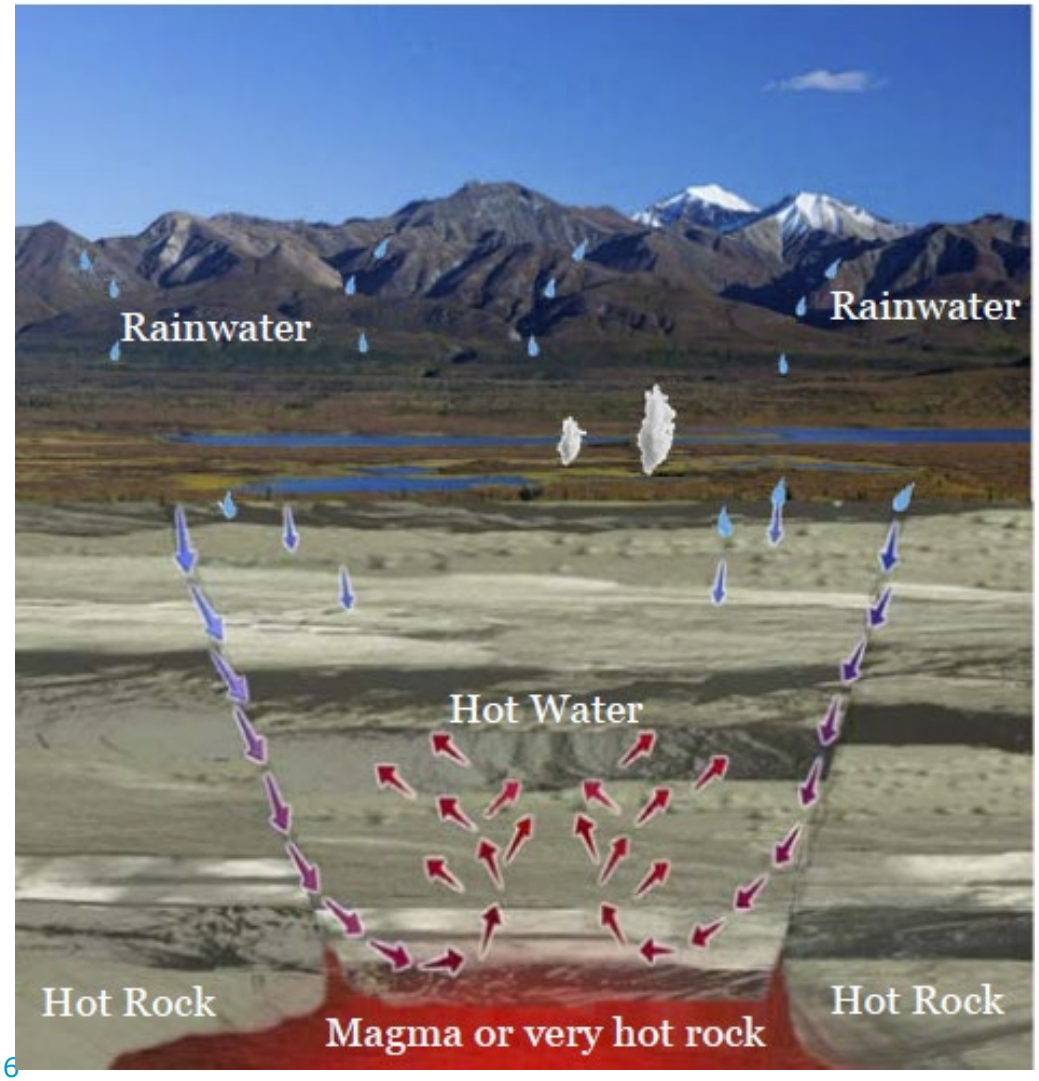
- Worldwide average heat flow is ~65mW/m$^2$
- In geothermal systems, heat flow is much higher (mostly at tectonic plate boundaries)



# Heat transfer mechanisms

- Conduction – heat flows from high temperature to low temperature. There is no movement of mass
- Convection - Water (and maybe steam) are moving around underground and heat energy moves with the mass flow
- Counter-flow - In a two-phase zone water trickles down and steam rises giving an upwards flow of heat with little or no flow of mass.

# Convective geothermal system




Wairakei - natural flow: 400kg/s, 600$MW_{th}$

# Warm water system

Geothermal pool in Hungary

# Hot water system

Hot water beach, New Zealand

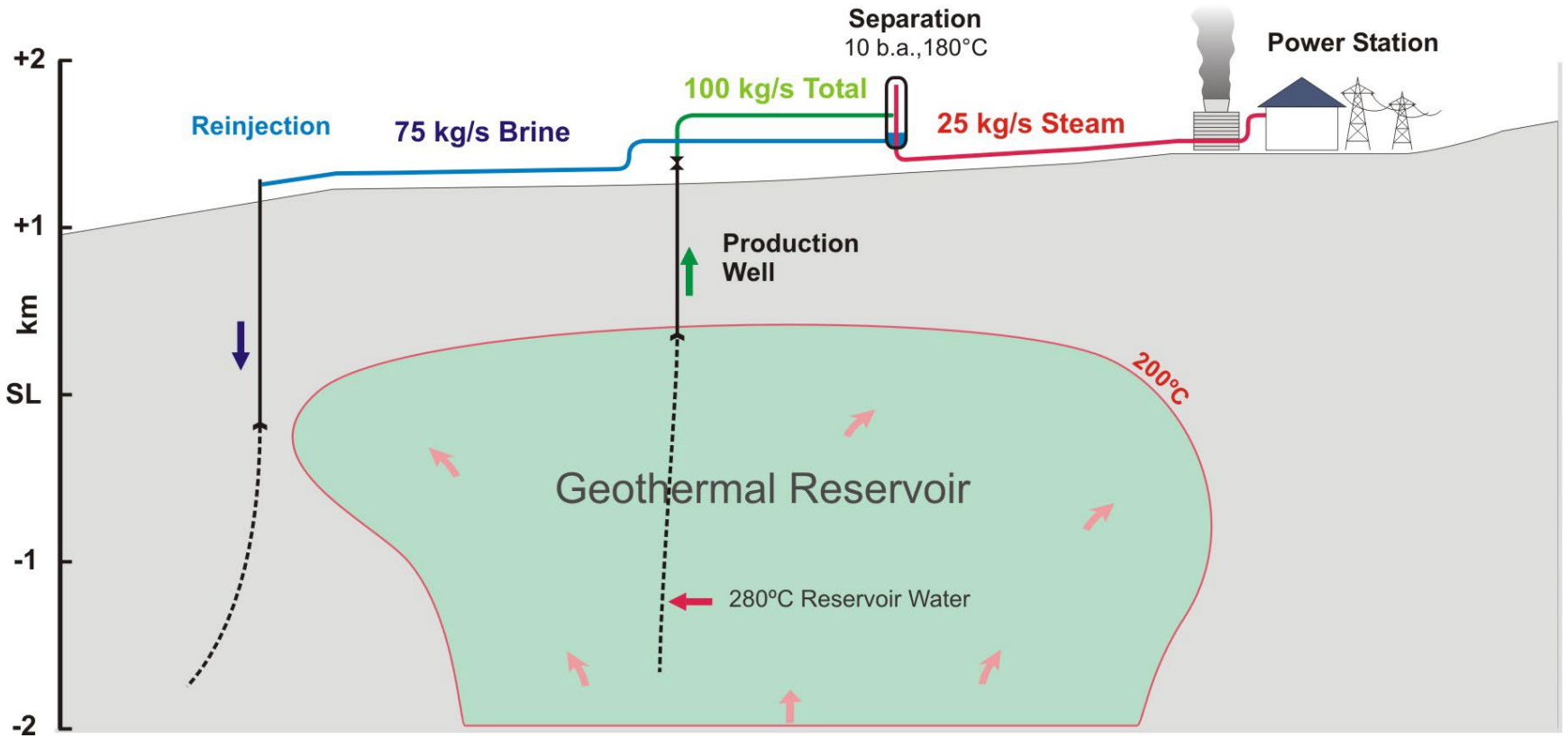
# Two-phase system

Wairakei, New Zealand

# Vapour dominated system

The Geysers, California

# Wairakei type of project

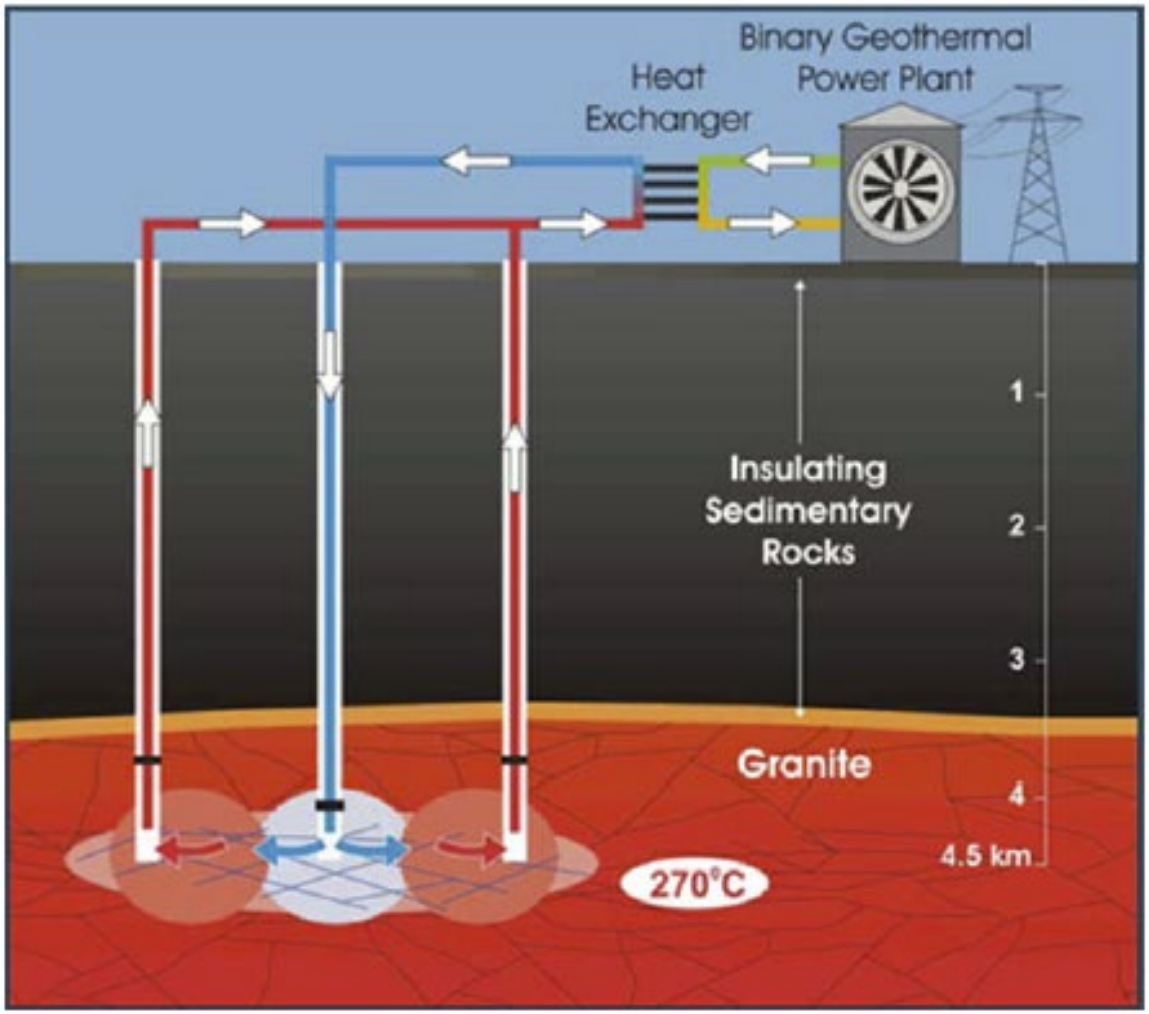



Also, some shallow steam zones producing dry steam

# Enhanced Geothermal system (EGS) or hot dry rock

- There are very large reserves, worldwide, of hot, low-permeability rock
- For an EGS project the idea is to drill a well, then carry out hydro-fracking to produce a cloud of permeability
- Then drill a second well (or more) to intersect the permeable zone
- Pump cold water down one well and get hot water from the second well

# Enhanced Geothermal system (EGS) or hot dry rock



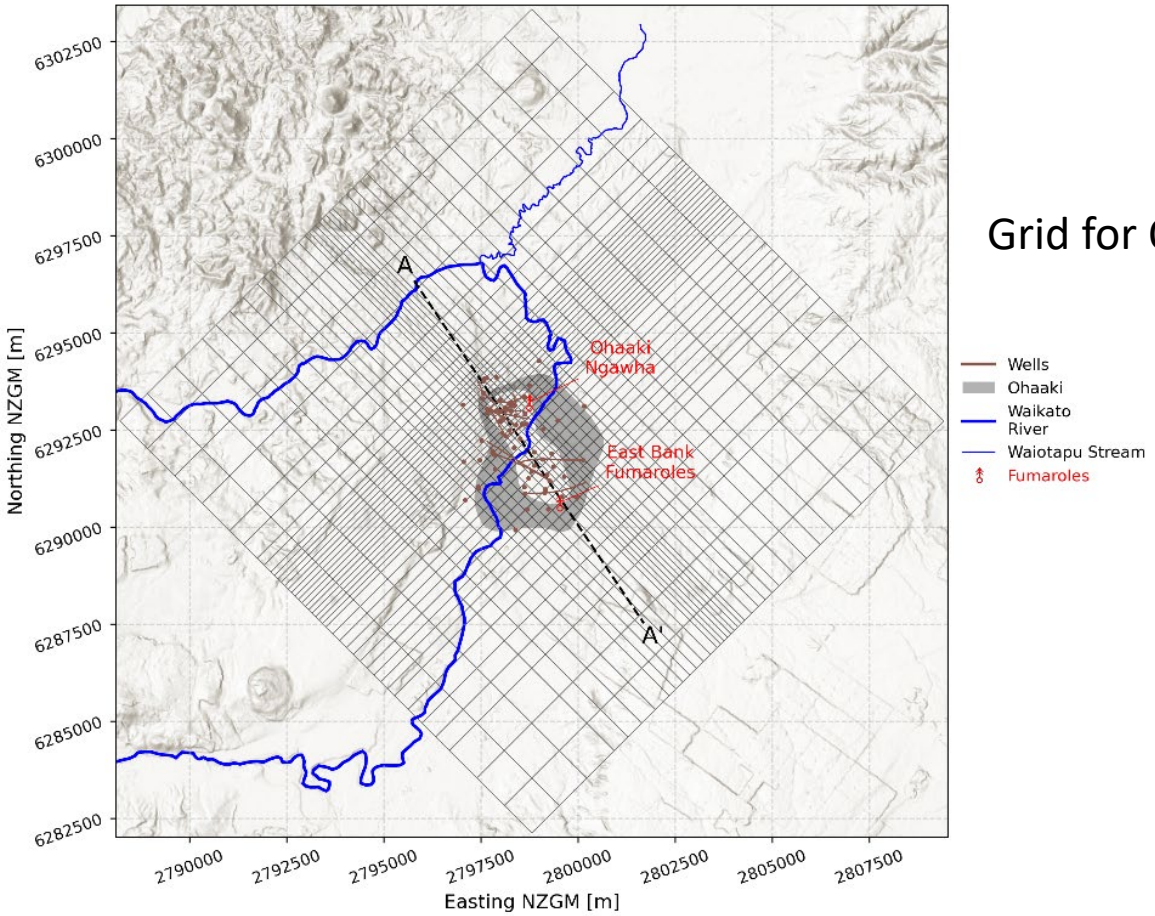

Many problems and no-one has got it to work very well

# Development options for geothermal

- Do nothing – preserve the geothermal system in its natural state because of it scientific value, cultural value, or value for tourism
- Electric power production
- Direct use

# Natural features

# Geothermal Modelling at the University of Auckland




Grid for Ohaaki model

# Main issues with geothermal development

- How large should the project be?
- How should it be managed in terms of production and reinjection?
- How long will it last?

Reservoir modelling is the tool that can be used to answer these questions

# Geothermal modelling at the UoA

❖ **Software development**

- New highly parallelized simulator called Waiwera (funded by MBIE, joint project with GNS Science). 50-100 times faster than TOUGH2 (industry standard code)
- New simulator for transient flow in a geothermal well
- Integrated modelling framework: digital conceptual model in Leapfrog, transferred to a TOUGH2 or Waiwera numerical model, model creation and visualisation managed with python scripts, data in standard json files
- Library of model management tools – pyTOUGH
- Visualisation package TIM
- New equations of state, e.g., supercritical capability

# Geothermal modelling at the UoA

❖ **Recent commercial projects**

- Wairakei, Ohaaki for Contact Energy Limited
- Kamojang, Lahendong, Karaha, Bukit Duan, Sungai Penuh for Pertamina Geothermal Energy (PGE), Indonesia
- Bacman for Energy Development Corporation (EDC), Philippines
- East Brawley, USA for Phoenix Lithium
- San Jacinto, Nicaragua for Jacobs and Polaris Energy
- Lihir, PNG for Newcrest Mining
- Salton Sea, USA for LBNL and US Dept. of Energy

# Geothermal modelling at the UoA

❖ **Current research directions**

- Uncertainty quantification (UQ) – statistical distribution of forecasts rater tha single curves
- Inverse modelling (IM or automated calibration)
- Cloud computing – we use NESI, Azure and Amazon for parallel simulations with Waiwera and for the multiple runs required for UQ and IM
- Integration of reservoir, well bore and surface equipment models (digital twin of a whole geothermal project)
- Extra injection into vapour-dominated systems (Kamojang)
- Better equations of state for water/ CO2 mixtures
- Very long-term behaviour of geothermal systems

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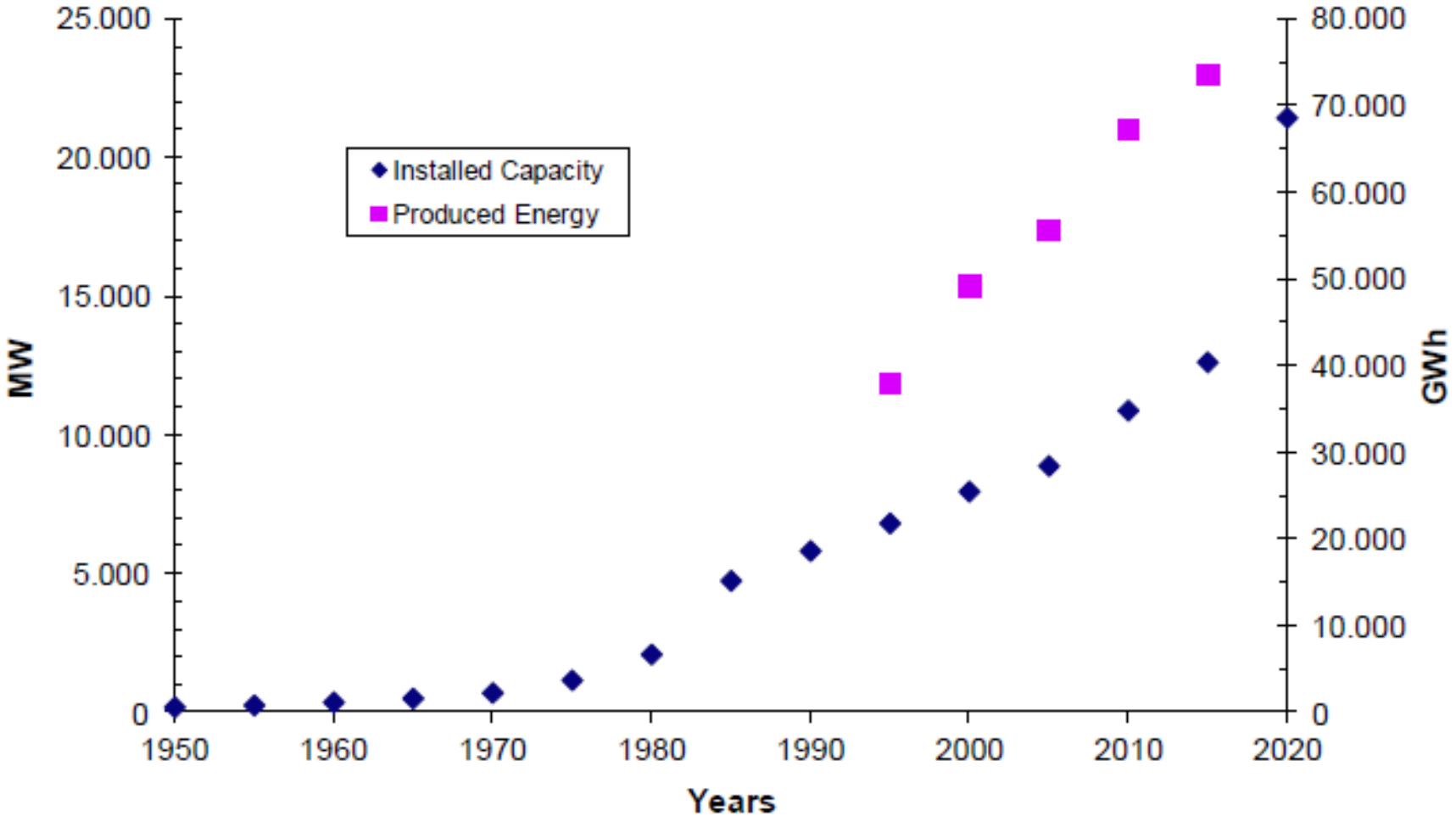
# A ramble through some ideas on geothermal energy

# Thoughts on geothermal projects

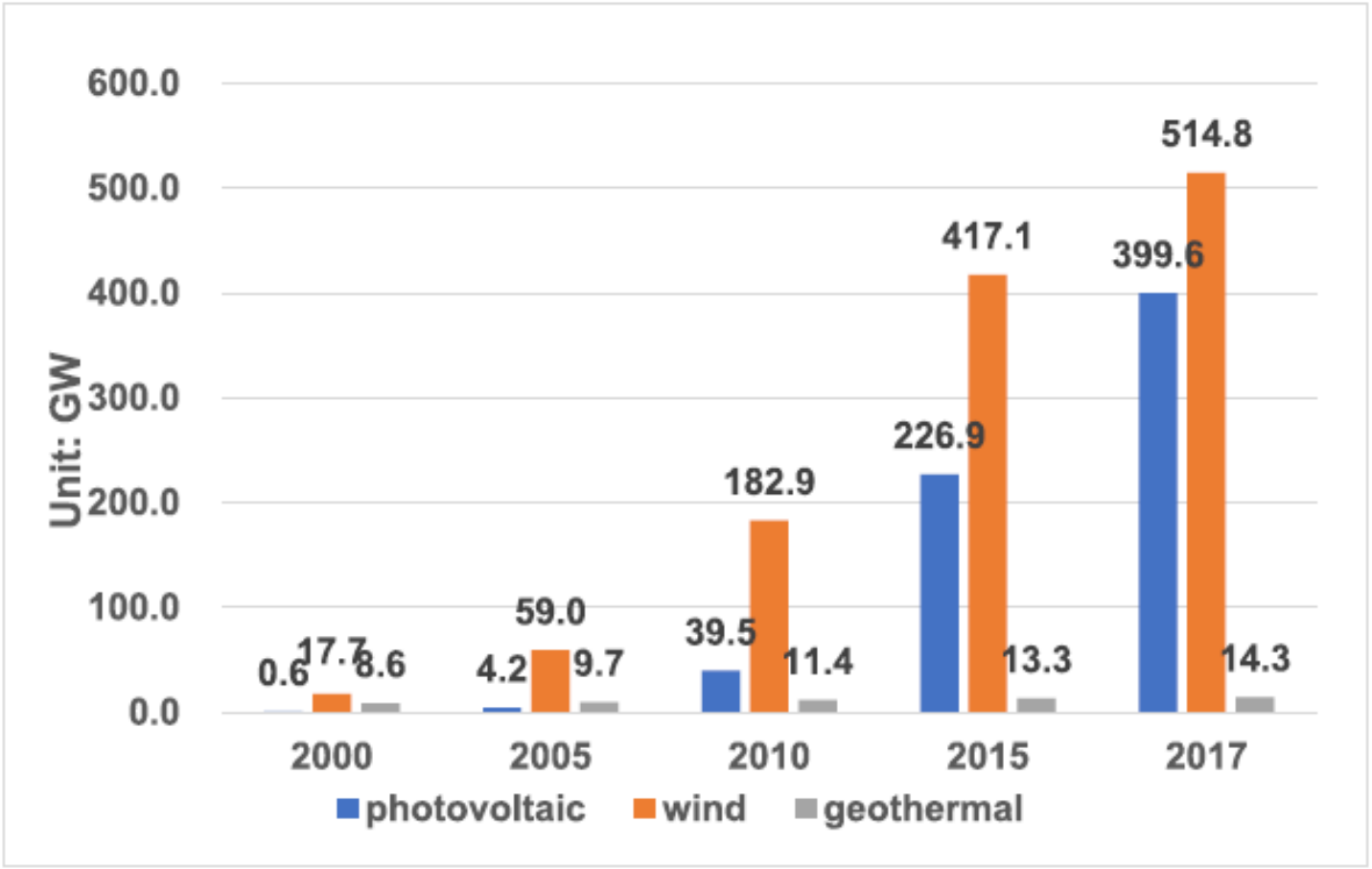
- For many existing geothermal projects early drilling was funded by government agencies, world bank etc
- Worldwide move to privatisation has removed this as an option
- Many of the 'easy' geothermal resources have been developed
- Wind and solar have become cheaper

# Growth in geothermal power production




Bertani (2015)

# Power production – solar, wind & geothermal




Xia and Zhang (2019)

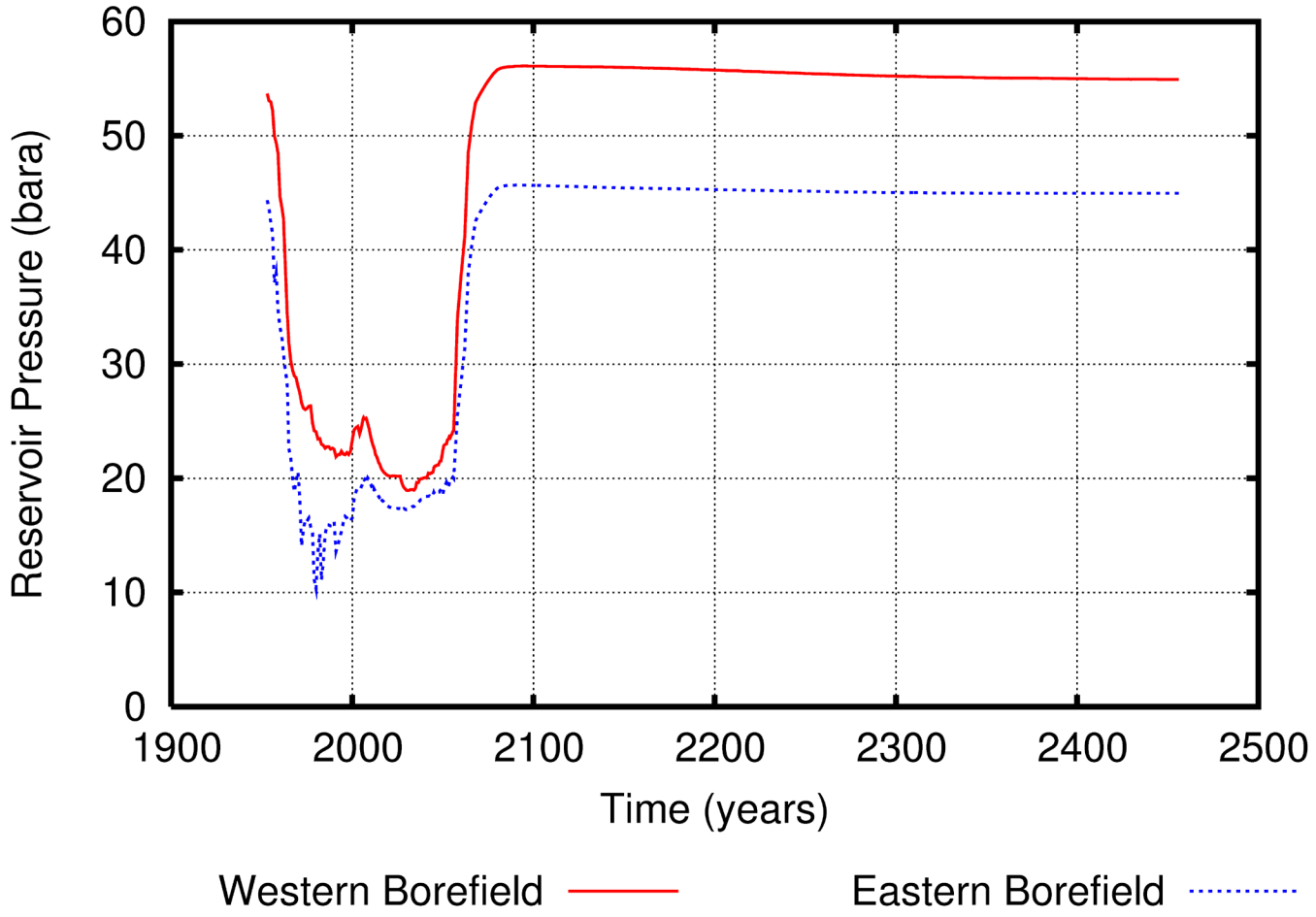
# What is the future for geothermal power production

- Many optimistic forecasts have been made for the future growth in geothermal power production in New Zealand and elsewhere. What is likely to happen?
- At present the installed capacity for power production in NZ is ~1000MW. How much more can be achieved?
- Another 200-500MW are planned
- Can we achieve 2000MW?
- Much potential for more direct use

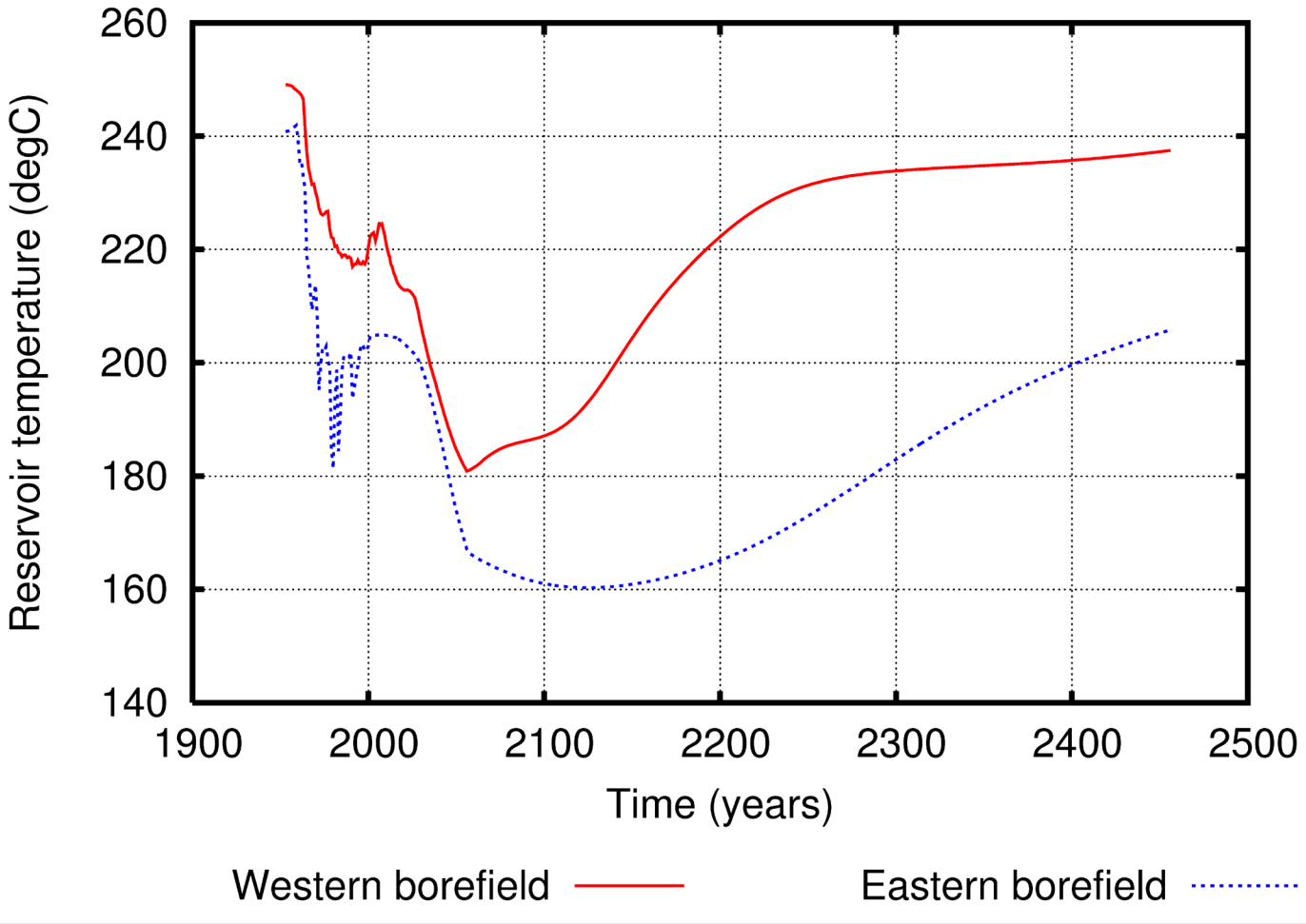
# Sustainability, renewability of geothermal power production

- Geothermal is commonly classed as a renewable energy source
- But most geothermal projects operate as a heat 'mining' process, i.e., they take out more heat than naturally flowed out of the system
- Our modelling shows that on a long-term basis geothermal is renewable, e.g., if Wairakei is operated for 100 years, after ~400 years of lying idle it will come back to its 1950 state

# Pressure changes at Wairakei



# Temperature changes at Wairakei



# Geothermal and $CO_2$

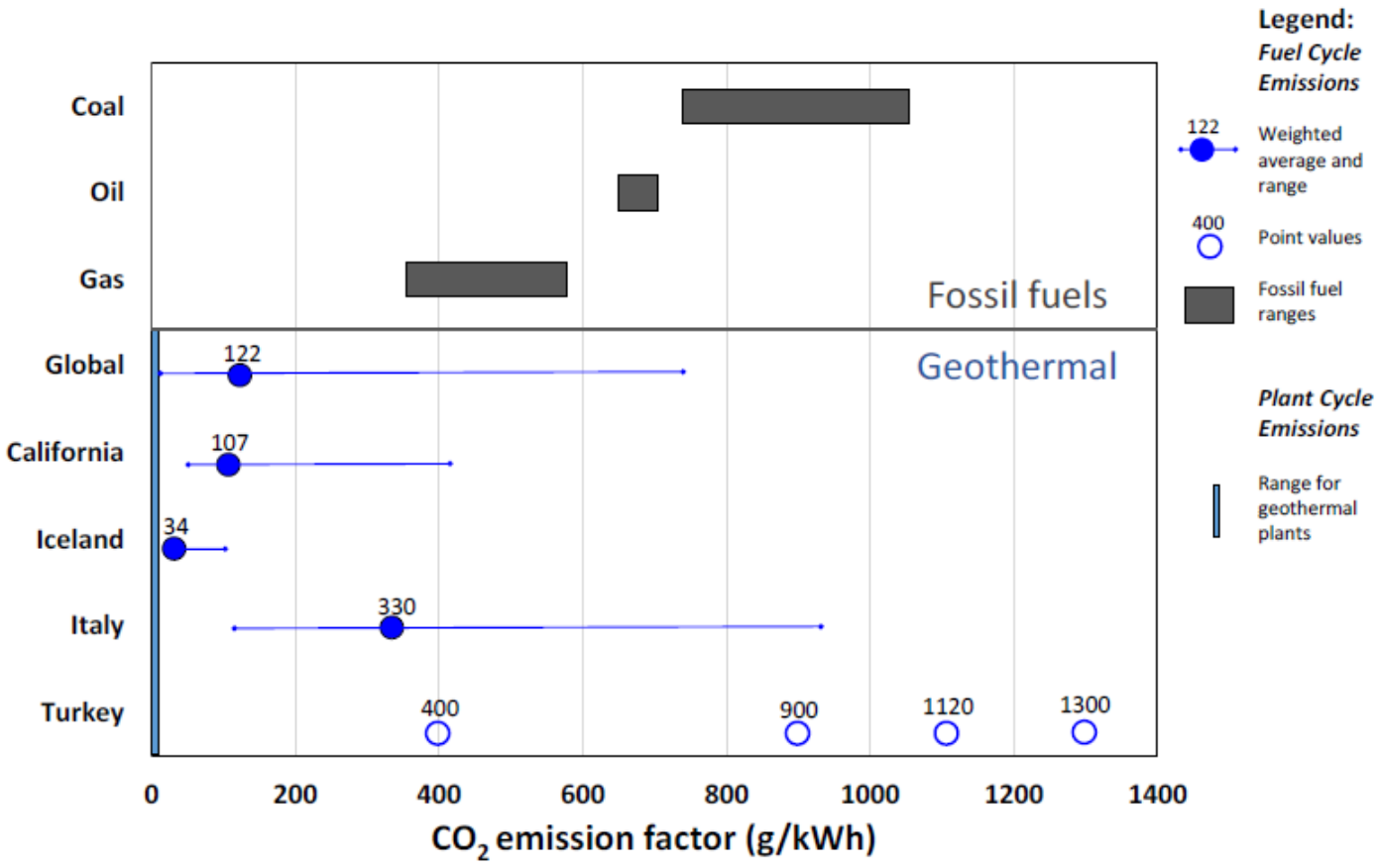



**Figure 3: Weighted average and range of emission factors from geothermal power plants. The range of Plant Cycle emissions is shown with a light blue box. Emission ranges for power plants using fossil fuels are shown with gray bars.**

Fridricksson et al. (2017)

# Geothermal and $CO_2$

- There is much interest, worldwide, in reinjecting $CO_2$ in geothermal fields
- There is a possibly of sequestering the $CO_2$ through reaction with rock
- Sadiq Zarrouk and Eylem Kaya at UoA are working on this topic together with GNS

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