Introduction to Geothermal Energy:

1. Basics
2. Resources and locations
3. End-uses
4. Electricity generation technologies
5. Costs and sustainability
1. Geothermal Basics

Geothermal = Greek words

geo (earth)
therme (heat)

Geothermal system:
A system of processes involving heat transfer to the earth’s surface
1. Geothermal:

* Earth’s interior=heat; @6,000 km deep: 5,000 °C

* All around the world heat flows to the surface (av.~65mW/m2 ~ temperature gradient of 30°C/km (depending on the thermal conductivity of the rock).

* In geothermal areas (at plate boundaries etc) heat flow is much greater than 65mW/m2
1. Heat Transfer:
   - Conducts rock
   - High temp/pressure:
     - Mantle rock melts and become magma
   - Lighter/less dense than surrounding rock
   - Move slowly toward the earth’s crust
1. Heat Transfer
- Magma may remain below the crust
- Heating nearby rock and water
- Geothermal water travels back up through faults and cracks
- If it reaches the earth’s surface: springs/geysers
- Or trapped in cracks and porous rock (geothermal reservoir)
1. Heat transfer mechanisms

* **Conduction:** heat flows from a hot temperature rock to a cold temperature (no fluid movement);

=> Heat flow = conductivity x temperature gradient

* **Convection:** in hot geothermal systems there is a large scale movement of water (convection), with hot water (&heat) rising.

=> Heat flow = mass flow x enthalpy; requires pathways for water to move (= PERMEABILITY)

* **Counter-Flow:** in some geothermal systems there is a boiling zone containing water and steam: water trickles down and steam rises.

* => Heat flow = steam rising - water trickling down

  Transfers heat (even though it may not transfer much mass) because the enthalpy of steam is higher than the enthalpy of water. Also requires pathways (permeability)
1. Geothermal System
with heat source, conduction & convection & recharge

(Dickson and Fanelli, 1995)
## Main categories of Geothermal Systems

<table>
<thead>
<tr>
<th>Category</th>
<th>Temperature (T)</th>
<th>Production Enthalpy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm water (low temperature)</td>
<td>$T &lt; 125^\circ C$</td>
<td>$h &lt; 600$</td>
</tr>
<tr>
<td>Hot water (intermediate temperature)</td>
<td>$T &lt; 225^\circ C$</td>
<td>$h &lt; 1000$</td>
</tr>
<tr>
<td>Two-phase (high temperature)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>low-enthalpy (very hot water)</td>
<td>$225^\circ C &lt; T &lt; 270^\circ C$</td>
<td>$1000 &lt; h &lt; 1300$</td>
</tr>
<tr>
<td>high enthalpy (boiling water and steam)</td>
<td>$250^\circ C &lt; T &lt; 330^\circ C$</td>
<td>$1300 &lt; h &lt; 2500$</td>
</tr>
<tr>
<td>vapour – dominated (dry steam)</td>
<td>$250^\circ C &lt; T &lt; 330^\circ C$</td>
<td>$2500 &lt; h &lt; 2800$</td>
</tr>
</tbody>
</table>
## Main heat transfer mechanisms

<table>
<thead>
<tr>
<th>Category</th>
<th>Heat transfer mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm water (low temperature)</strong></td>
<td>Conduction</td>
</tr>
<tr>
<td><strong>Hot water (intermediate temperature)</strong></td>
<td>Convection</td>
</tr>
<tr>
<td><strong>Two-phase (high temperature)</strong></td>
<td></td>
</tr>
<tr>
<td>low-enthalpy</td>
<td>Strong convection</td>
</tr>
<tr>
<td></td>
<td>Some counter-flow</td>
</tr>
<tr>
<td>high enthalpy</td>
<td>Moderate convection</td>
</tr>
<tr>
<td></td>
<td>Counter-flow</td>
</tr>
<tr>
<td>vapour-dominated</td>
<td>Negligible convection</td>
</tr>
<tr>
<td></td>
<td>Counter-flow, conduction</td>
</tr>
</tbody>
</table>
Fluid mass needed per MWe generated

- Hot Water
- 2-phase low enthalpy
- vapour dominated
- 2-phase high enthalpy
Geothermal Power:

MidAmerican Energy Geothermal Plant Virtual Tour (4.46 mins)
www.youtube.com/watch?v=FKXcLa88GhQ

Energy 101: Geothermal Energy (3.47 mins)
www.youtube.com/watch?v=mCRDf7QxjDk
SO needed for a Geothermal System:

Heat source

Water (recharge = inflowing; discharge=outflowing water)

Permeability structure
New Zealand’s first geothermal generator was commissioned at Wairakei in 1958.
Geothermal resources located in Environment Waikato boundaries
Engineered Geothermal Systems (hot dry rock)

- Japan (Hijiori, Ogachi)
- France (Soultz Sous)
- Australia (Cooper Basin)
- US (Fenton Hill, NM)
- England (Rosemanowes)
- Sweden (Fjallbacka)
- Russia (Tirniauz)
- Germany (Neustadt-Glewe)

The idea:
* Drill two wells
* Use hydraulic-fracturing to create a permeable zone connecting the wells
* Pump cold water down one well and produce hot water from the other
* Many problems: no-one has got it working well
* Esp right distribution of fractures
A geothermal reservoir is quite different from an oil or gas reservoir, or even a ground water reservoir.

A geothermal reservoir is usually not a clearly defined highly permeable region confined by low permeability strata.

The quantity to be extracted, namely heat energy, is not contained entirely/mostly in the reservoir fluid (but in the rock).

The production of water and steam from a geothermal well is replaced in the reservoir by surrounding cooler water which is heated by the reservoir rock and then becomes available for production.

This process of recharge is very important in the behaviour of geothermal reservoirs. I.e (possibly) sustainable

In convective geothermal systems the fluid is moving. In an oil reservoir the fluid is stationary. In an oil reservoir, once the oil has been extracted the reservoir is exhausted.
3. Geothermal Uses:

- Electricity
- Hot springs/bath, cooking, medicine
- Heat buildings (ground source heat pump)
- District heating
- Agriculture: glass houses (plants)
- Aquaculture: fish/shrimp farming
- Industry: pulp&paper production, food processing, pasteurize/dry milk
Lindal Diagram

Temperature (°C) 0 20 40 60 80 100 120 140 200 350

- Spa treatment
- Swimming pools
- Snow melting
- Fan coils
- Radiators
- Radiant panels/slabs
- Domestic hot water
- Air conditioning
- Heat pump
- Cereal fodder
- Stable and breeding grounds
- Greenhouses
- Vegetable dehydration
- Food processing
- Soil warming and fish farming
- Copper processing
- Heap leaching (gold)
- Sludge digestion
- Concrete blocks curing
- Oil recovery
- Cloth drying
- Wool washing
- Chemical extraction
- Tappens
- Pulp and paper mill

- Binary power plants
- Conventional power plants
3. World Geothermal Capacity

~100% increase by 2020

From: GNS Science
Heat Pump system:

- Hot water tank
- Heat pump
- Low-temperature underfloor heating
- Borehole heat exchanger
Heating systems in geothermal greenhouses:
District heating system
Value of Geothermal Features: Craters of the Moon (Taupo)
4. Geothermal Electricity Generation:
Production wells
Natural steam
Turbine generator
Condensed in cooling tower
Reinjection
4. Dry steam plant generation
4. Flash steam plant

Flash Steam Power Plant

- Steam
- Turbine
- Generator
- Electricity
- Flash Tank
- Hot Water
- Separated Water
- Condensed Steam (Water)
4. Binary plant
5. Geothermal Sustainability

- Many similarities to Oil&Gas
- But renewable/sustainable (if done well)
- Source regenerates (in human timeframes)
- Low CO2-content (generally)
5. Geothermal Sustainability:

a) External Impacts/effects:
Pressure/Temp changes => affects geothermal features, subsidence

b) Resource itself:
- Often faster draw-down than regeneration
  => controlled depletion (50-100 yrs)
- NZ conserves other resources/fields for future generations
5. Example Sustainability:

Wairakei: 100-200 years to recover after 100 years of extraction
5. Geothermal Regulation
Similar issues as Oil/Gas Regulation

- Underground resource => step-wise exploration
- Ownership/access to resource
- Environmental aspects
- Financial viability (incl power prices & royalties/subsidies)
5. Typical E&P process

1. Start-up & pre-exploration
2. Pre-feasibility
3. Exploration & Appraisal drilling
4. Production drilling
5. Production & processing
6. Decommissioning & rehabilitation

=> Resource Assessment and Economic go/no-go decisions after every step
5. Project Phases, Investment, Risk

5. Geothermal Investment cost

**Figure 1.10**
Investment Cost Breakdown of Utility Scale Geothermal Power Development Based on Data from Iceland

- Power Plant: 35%
- Drilling: 34%
- Steam Gathering System: 13%
- Miscellaneous: 5%
- Interconnection: 6%
- Infrastructure: 2%
- Early Development: 5%

5. E.g. in NZ: Geothermal low LRMC vs Gas/Coal

"Long Run Marginal Cost" of new generation projects ($/MWh)

Refer also to the "Project list" sheet for details of the individual projects and their costs
5. NZ Geothermal Regulation slightly different:

- Based on water & common law: state doesn’t own the resource
- Government manages the resource on behalf of ‘common good’
- Resource Management Act (1991)
- Puts Sustainable Management at the Centre:
  - External effects; and
  - Resource available for ‘future generations’
Wai O Tapu Loop Rd (Rotorua)

Thank You

Questions?