JEOTERMAL ENERJİYE YENİ BİR BAKIŞ

Profesör Dr Halim Gürgenci

Queensland Geothermal Energy Centre of Excellence

www.uq.edu.au/geothermal

7 Jan 2009

NİÇİN JEOTERMAL ENERJİ?

- Kömür, petrol ve doğal gaz fiyatlari artıyor
- CO_2 atık bedelini odemeleri istenirse, fosil yakıtlardan elektrik üretimi çok pahalı hale gelebilir
- Fosil yakıta rakip:
  - Günes
  - Rüzgar
  - Hidroelektrik
  - Jeotermal
  - Nükleer
- Sadece son üçü temelyük (baseload) üretimine müsaittir
- Yalnızca jeotermal enerji
  - 100% atıksız ve çevre dostu elektrik üretir
  - Bütün dünyaya yüzyıllarca yetecek kadar çoktur
  - Bilinen ve kanıtlanmıs teknoloji kullanır

MUAZZAM BIR KAYNAK MI YOKSA TEFERRUAT MI?

- Türkiye MTA envanteri (geleneksel jeotermal enerji) [4]
  - 31000 MWt (0.0001 EJ) toplam
  - 500 MW elektrik üretimi potansiyeli → □□□□□□□□□□
- ABD de 3 ila 10 km arasında ulasılabilecek ısı rezervi[1]
  - 14 milyon exajul (EJ)
- 2005 senesi ABD toplam enerji tüketimi[1]
  - 100 EJ
- Yani, 3-10 km derinlikteki jeotermal enerji tüm ABD nin enerji ihtiyacını binlerce sene karsılayabilir
- Avustralya icin benzer bir tahmin[2]
  - 22 bin EJ
- Avustralya 2005 toplam enerji tuketimi[3]
  - 5.5 EJ
- ABD ve Avustralya benzeri yöntemlerle hesaplanan Türkiye rezervi[5]
  - 400000 EJ
  - Sadece Türkiye degil tüm Avrupa'ya binlerce sene yetecek bir rezerv
- Tarihi MTA envanterine gore, Turkiye'nin jeotermal enerji potansiyeli küçümsenebilir. Ama ikinci tahmine gore bu mümkün degil.

Tester, J.W., Panel Chair (2006) "The Future of Geothermal Energy". MIT

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Yenilenebilir Enerji Teşvikleri Jeotermal Enerjiyi Kapsamıyor

- Mevcut mevzuat:
  - elektrik dağıtım şirketleri sattıkları elektrik miktarının, ülkede satılan toplam elektrik miktarına oranı kadar yenilenebilir enerjiden üretilen elektrik satın almak zorunda
  - Fiyatın 1 kWh elektrik için 5-5.5 euro cent aralığında olması gerekiyor.
- Gündemdeki yasa değişikliği taslağı, bu fiyata teşvikli alım garantisi getiriliyor:
  - Rüzgar icin 8 eurocent/kWh
  - Günes enerjisi : 25-28 eurocent/kWh
- Jeotermal enerji icin tesvik yok cunku mevcut anlayışa gore "31 bin 500 MW düzeyinde bulunan jeotermal enerji potansiyelinin elektrik üretimi için uygun olan 500 MW'lik bölümü" icin teşvik gerekmiyor.
  - Derin jeotermal kaynakların ticari olarak değerlendirilebilmesi icin, güneş enerjisi benzeri bir teşvik gerekiyor.
  - Aksi halde, Türkiye büyük bir fırsat kaçırmış olacak

http://www.istegundem.com/news_detail.php?id=22716

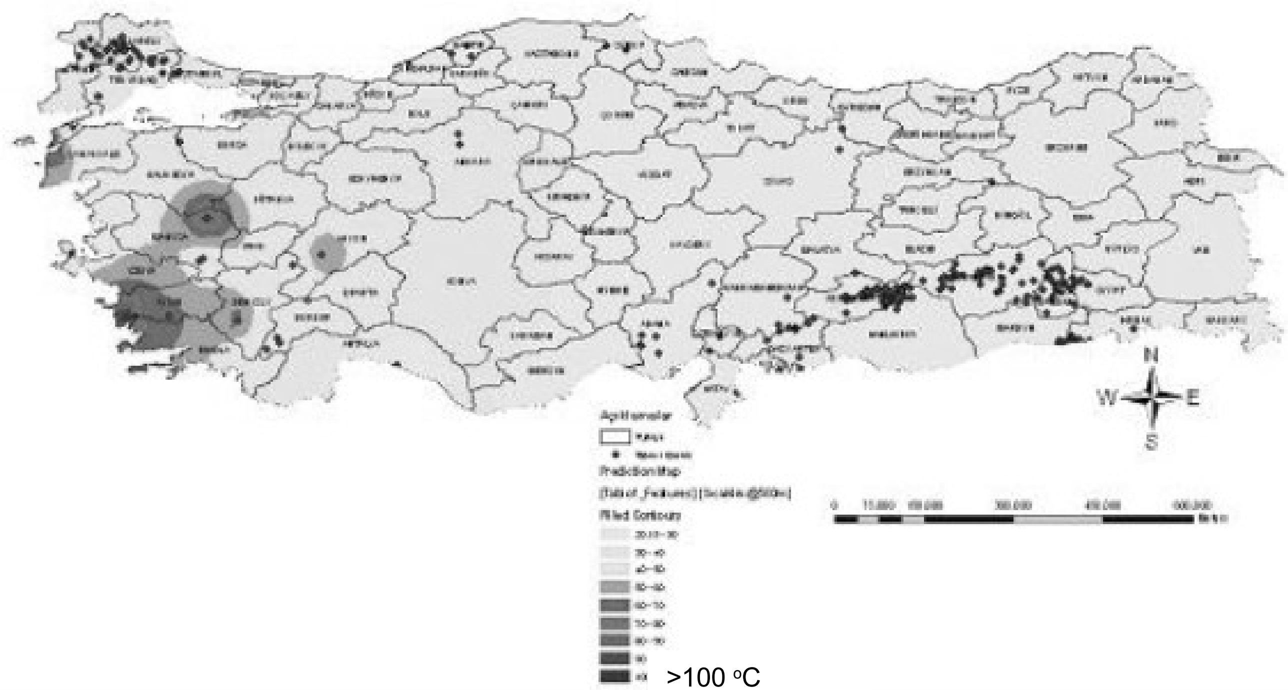
Hilmi Güler - 2009 Bütçe Konuşmasından

- *Jeotermal kaynaklardan uzun yıllar … kaplıca/ılıca, hamam gibi uygulamalar dışında faydalanılmamıştır. Ancak dünyadaki son yıllarda artan temiz enerji ihtiyacı ve ısıtma amaçlı kaynak kullanım çeşitliliğine yönelik araştırmalar ve çevre kirliliği yaratmayacak enerji kaynaklarına yönelim, jeotermal kaynakların önemini daha da artırmıştır.*
- *Türkiye jeotermal potansiyelde dünyada 7., Avrupa'da 1.dir. Ülkemizin jeotermal potansiyeli 31.500 MWt'dir. Bugüne kadar potansiyelin %13'ü (4.000 MWt) kullanıma hazır hale getirilmiştir. Hedefimiz 2013'te kullanıma hazır kapasiteyi 7.500 MWt'ye çıkarmaktır. Son 4 yılda toplam görünür kapasite %9'dan %15'e çıkarılmış; yılda 2.000 m olan sondaj 20.000m.'lere ulaşmıştır.*
- *Ülkemizde yer alan jeotermal kaynaklara ait envanter MTA Genel Müdürlüğü tarafından hazırlanmış jeotermal kaynaklara ilişkin mevzuat bu dönemde tamamlanmıştır. Ayrıca Türkiye'de ilk defa jeotermal ve doğal mineralli sular kanunu bu dönemde çıkartılmıştır. Böyle bir kanun dünyada sadece birkaç ülkede mevcuttur. Düzenlenen bu kanun doğrultusunda, yüksek sıcaklığa sahip sahalardan 6 tanesinde elektrik üretimine yönelik olarak ihaleye çıkılmıştır.*
- *Elektrik enerjisinde kaynak çeşitliliğine ve arz güvenliğine katkı sağlayacak olan nükleer güç santrallarının hayata geçirilmesini teminen başlatılan çalışmalar titizlikle sürdürülecek, ithal bir kaynak olan doğal gaza aşırı bağımlılığı azaltmak üzere yerli ve yenilenebilir kaynakların elektrik enerjisi üretimi amaçlı kullanımına hız verilecektir.*
- *Nükleer enerji yatırımları yanında, sınırlı kömür ve hidrolik kaynaklarımızın Avrupa Birliği'ne katılım öncesi ilave çevresel yükümlülük ve zorlamalar ile karşı karşıya kalmadan bir an önce ekonomik olarak kullanılması önem arz etmektedir.*

http://www.enerji.gov.tr/duyurular

Türkiye – 500 m sıcaklıkları (Veri Set #1)

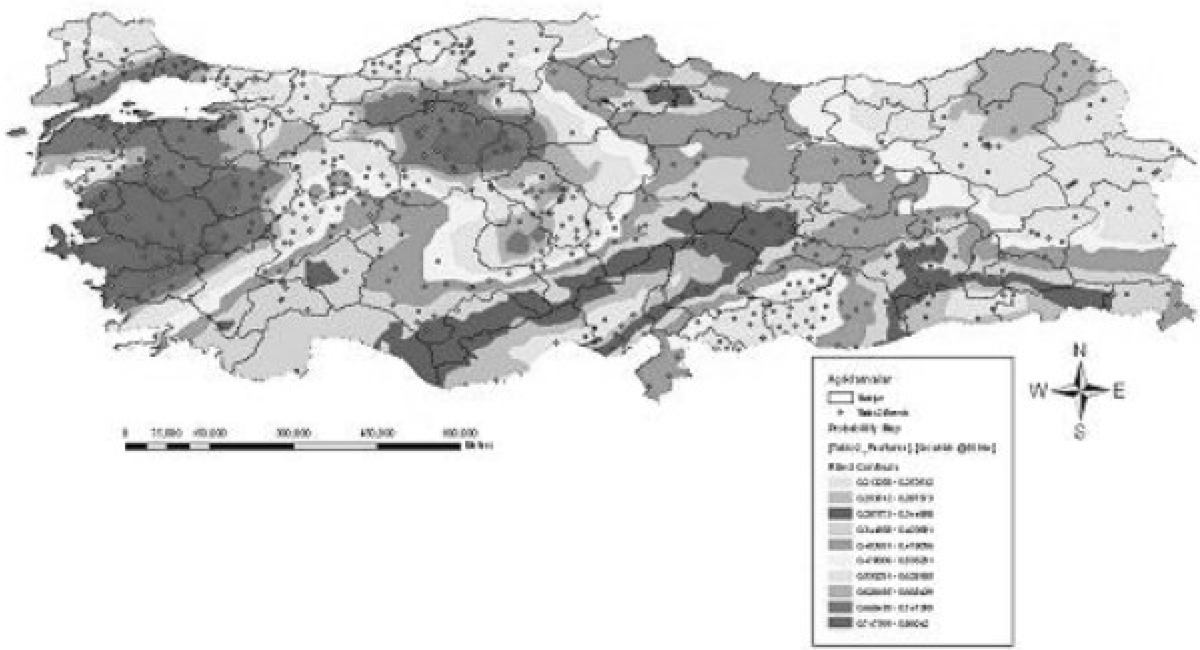
Mıhçakan vd., 2006 çalısmasından yararlanılarak olusturulan settir. Daha çok Trakya ve Güneydogu Anadolu'ya ait -1000 m ve daha derinden yapılan 241 sondajlardan elde edilen sıcaklık gradyanlarının enterpolasyonu ile elde edilmistir.



Turkiye'nin Yeralti Sicaklik Haritasi ve Tahmini Isi Icerigi, D Basel, K Cakin, A Satman, 7. Ulusal Temiz Enerji Sempozyumu, 17-19 Aralik 2008, Istanbul

Türkiye – 500 m sıcaklıkları (Veri Set #2)

Veri Seti #2, Ilkısık vd., 2005 çalısmasından derlenmis 100-150 m derinlikteki ısı kuyuların jeokimyasal analizi sırasında elde edilen gradyan degerlerinin 500 m derinlige enterpolasyonunun yapılması ile bulunan degerleri içermektedir. Veri Seti I'e göre göreceli olarak daha homojen olup, bu setteki toplam veri sayısı 543 adettir.



Turkiye'nin Yeralti Sicaklik Haritasi ve Tahmini Isi Icerigi, D Basel, K Cakin, A Satman, 7. Ulusal Temiz Enerji Sempozyumu, 17-19 Aralik 2008, Istanbul

Türkiye Toplam Jeotermal Kaynak Değerlendirmesi (<3 km)

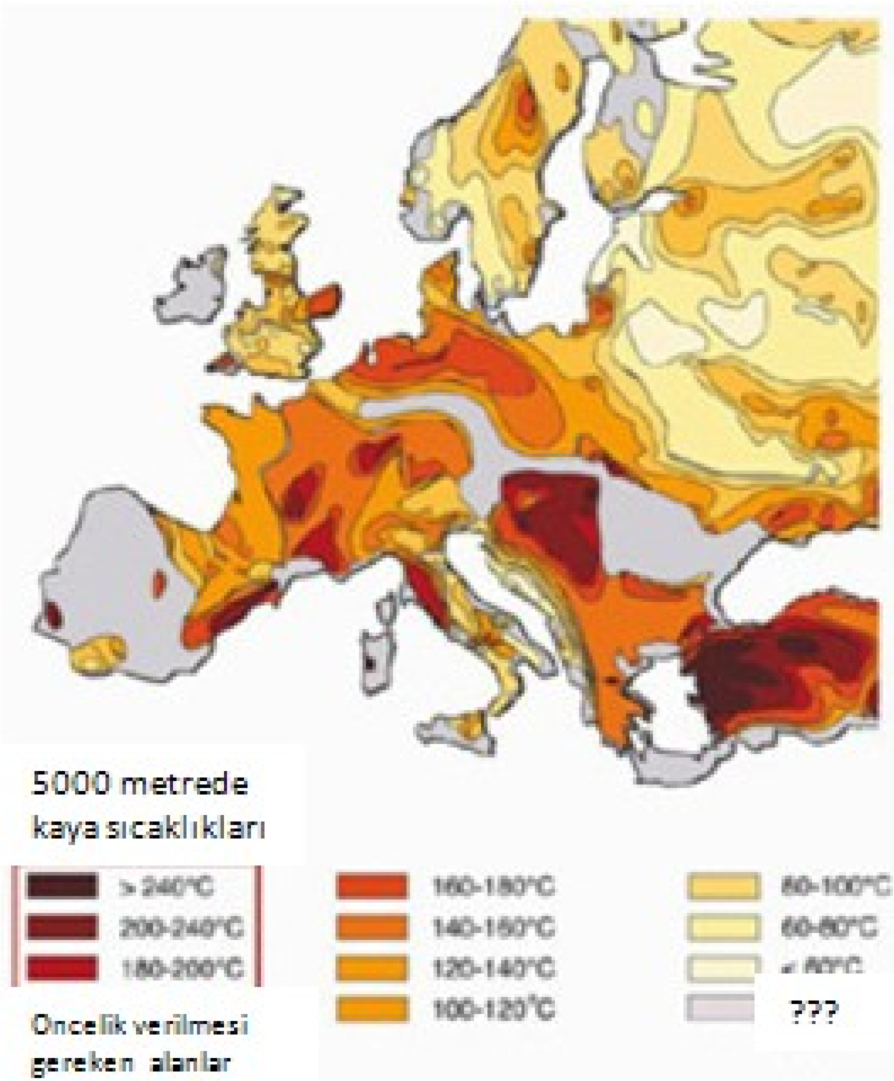
Tablo 2. *Türkiye'nin Jeotermal Potansiyeli, J*

Sıcaklık, °C	Grup 1 T<100	Grup 2 100<T<150	Grup 3 150<T<250	Grup 4 T>250	Toplam
EPRI, 1978	1.9×10^{23}	8.4×10^{22}	2.3×10^{22}	1.4×10^{21}	3.1×10^{23}
Serpen, 1996	1.6×10^{23}	9.3×10^{22}	3.2×10^{22}	-	2.9×10^{23}
Serpen-Mıhçakan, 1999	7.1×10^{22} *(T<100)*	1.1×10^{23} *(100<T<180)*	1.5×10^{22} *(180<T<250)*	-	2.0×10^{23}
Satman, 2007	1.8×10^{23}	1.2×10^{23}	6.3×10^{22}	6.9×10^{20}	3.7×10^{23}
Bu çalışma	1.7×10^{23}	1.3×10^{23}	6.4×10^{22}	3.02×10^{22}	3.96×10^{23}

Turkiye'nin Yeralti Sicaklik Haritasi ve Tahmini Isi Icerigi, D Basel, K Cakin, A Satman, 7. Ulusal Temiz Enerji Sempozyumu, 17-19 Aralik 2008, Istanbul

Yaklaşık 400000 EJ

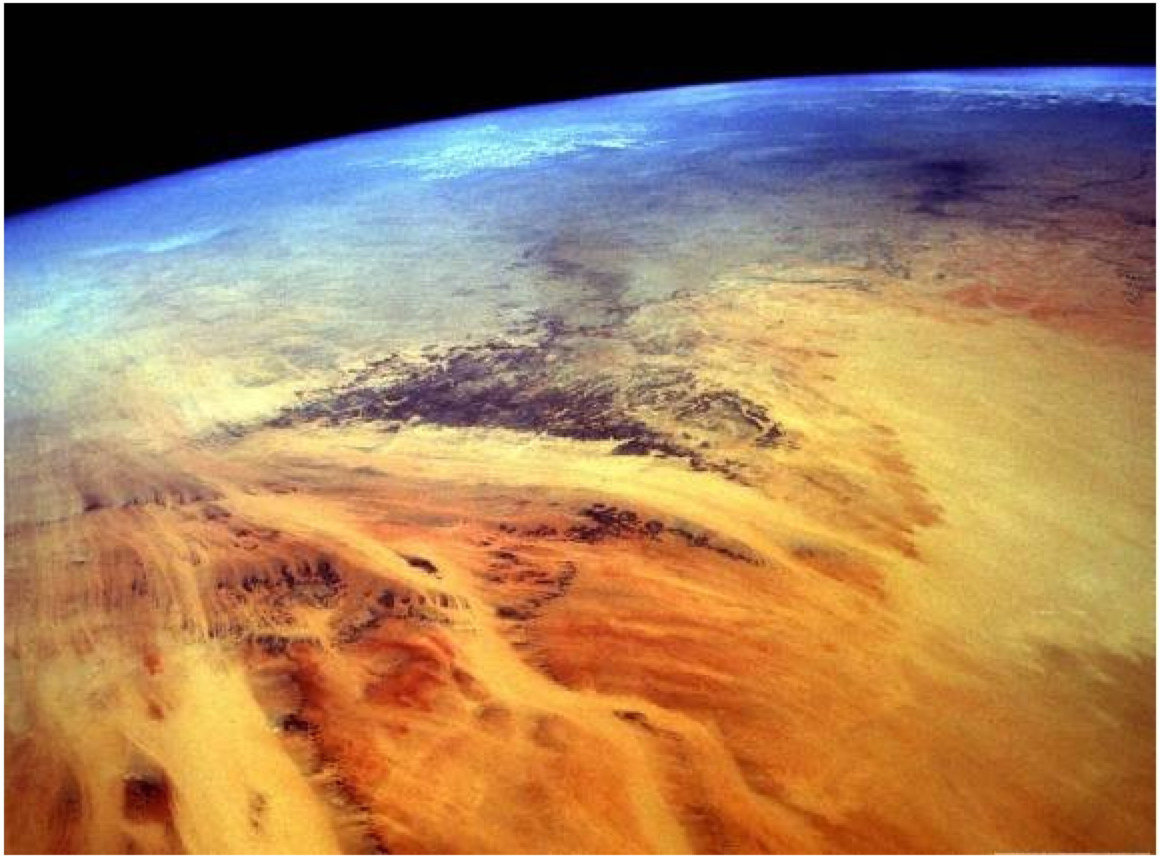
AB Kaynaklarından 5000 metre derinlikte kaya sıcaklıkları



Yer yüzeyinin beş kilometre derinligindeki sıcaklıkları gösteren bu haritadan anlasıldıgı gibi, “Derin Jeotermal” ya da “Geliştirilmiş Jeotermal Sistemleri” icin Avrupa’daki en elverişli ülke Türkiye bütün Avrupa’ya jeotermal kaynaklardan 100% atıksız elektrik üretebilir.

http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_geo/images/carte_potentiel_europe_gb_1428.jpg

IS GEOTHERMAL ENERGY "RENEWABLE"?

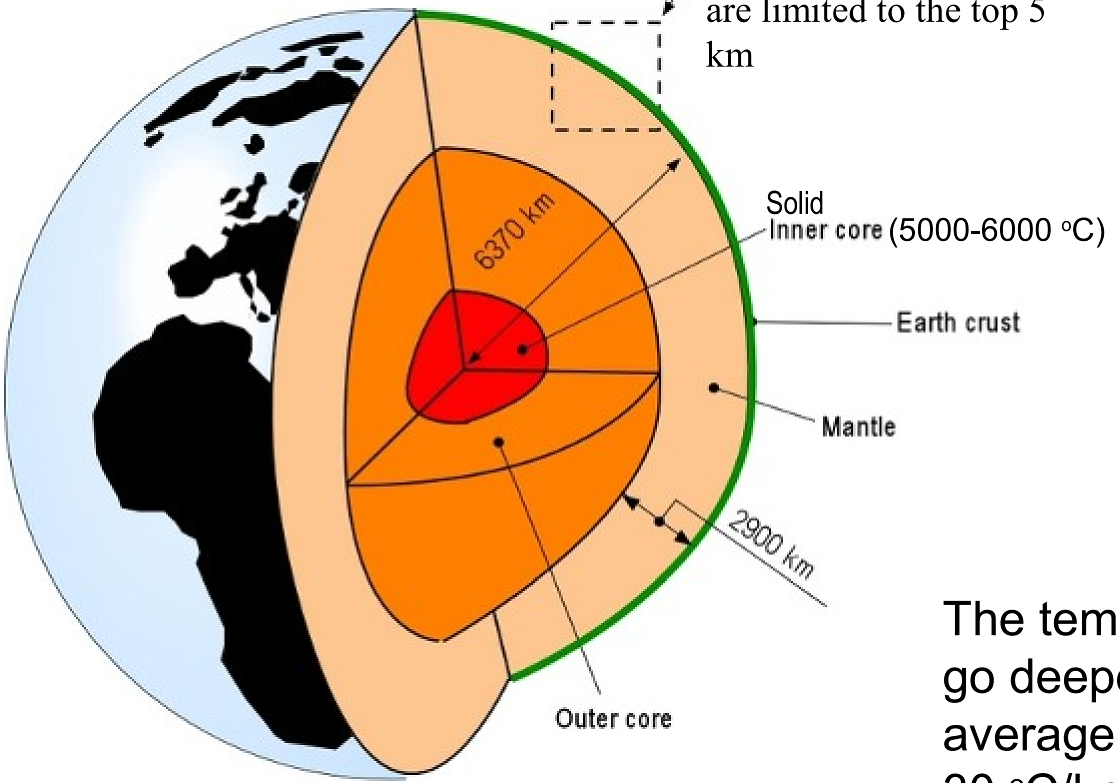


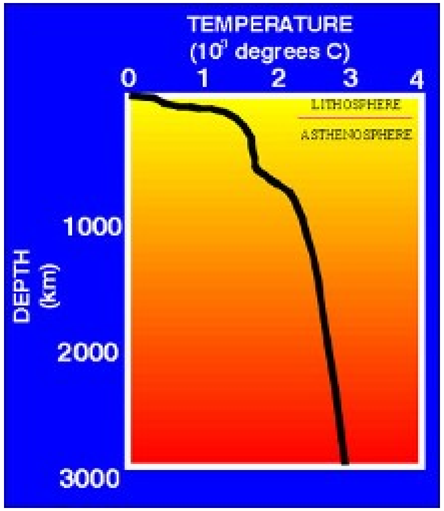
The earth is slowly cooling. Its internal heat is leaks to the surface and is radiated to the outer space.

The rate of this radiation is about 2.5 times mankind's total energy consumption rate (2004 figures).

The time required for rejuvenation of a "depleted" reservoir depends on the heat transfer mechanisms but is finite.

AVERAGE TEMPERATURE GRADIENTS

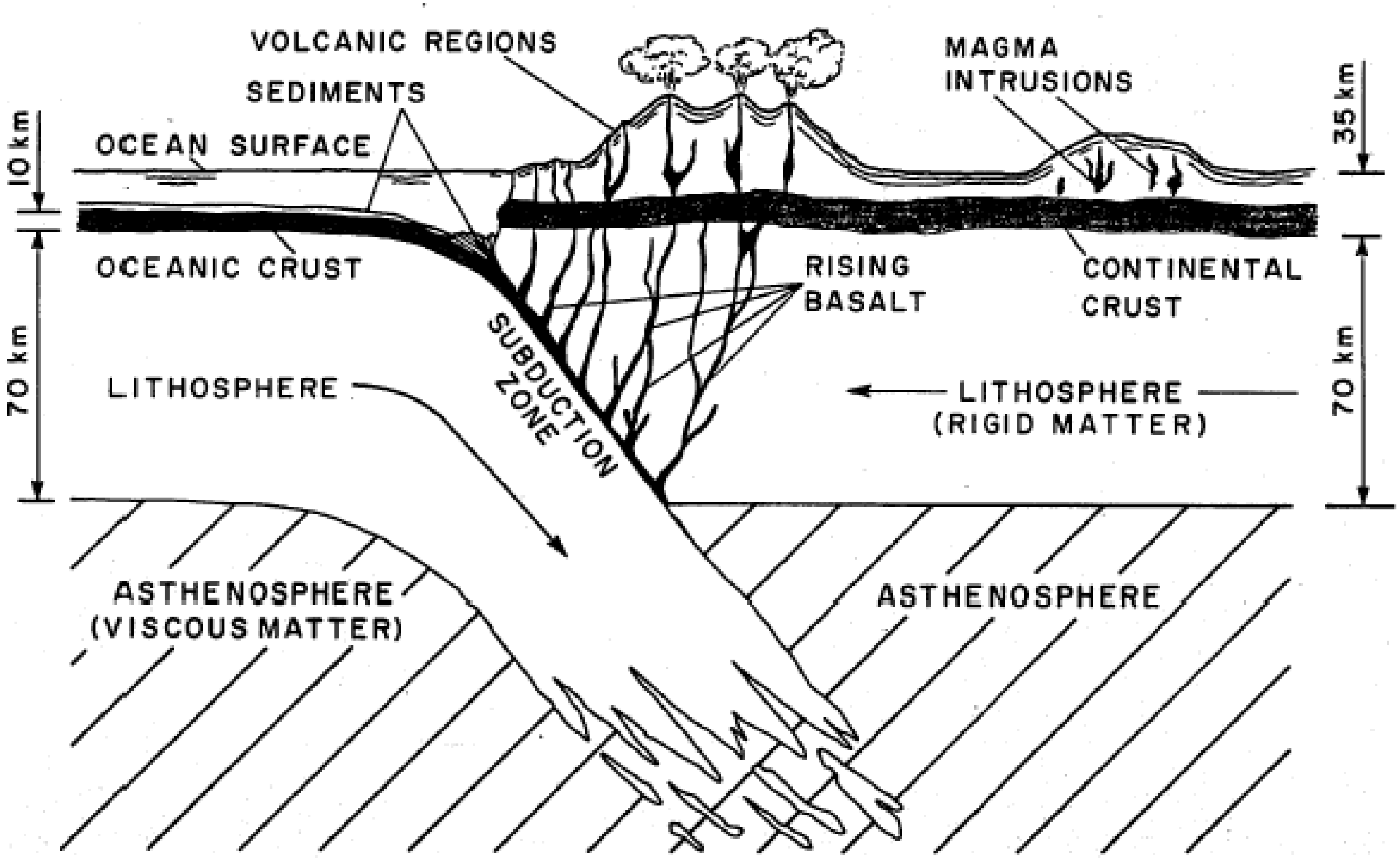




The temperature increases as we go deeper into the crust. The average rate of increase is about 30 °C/km over the first 100 km.

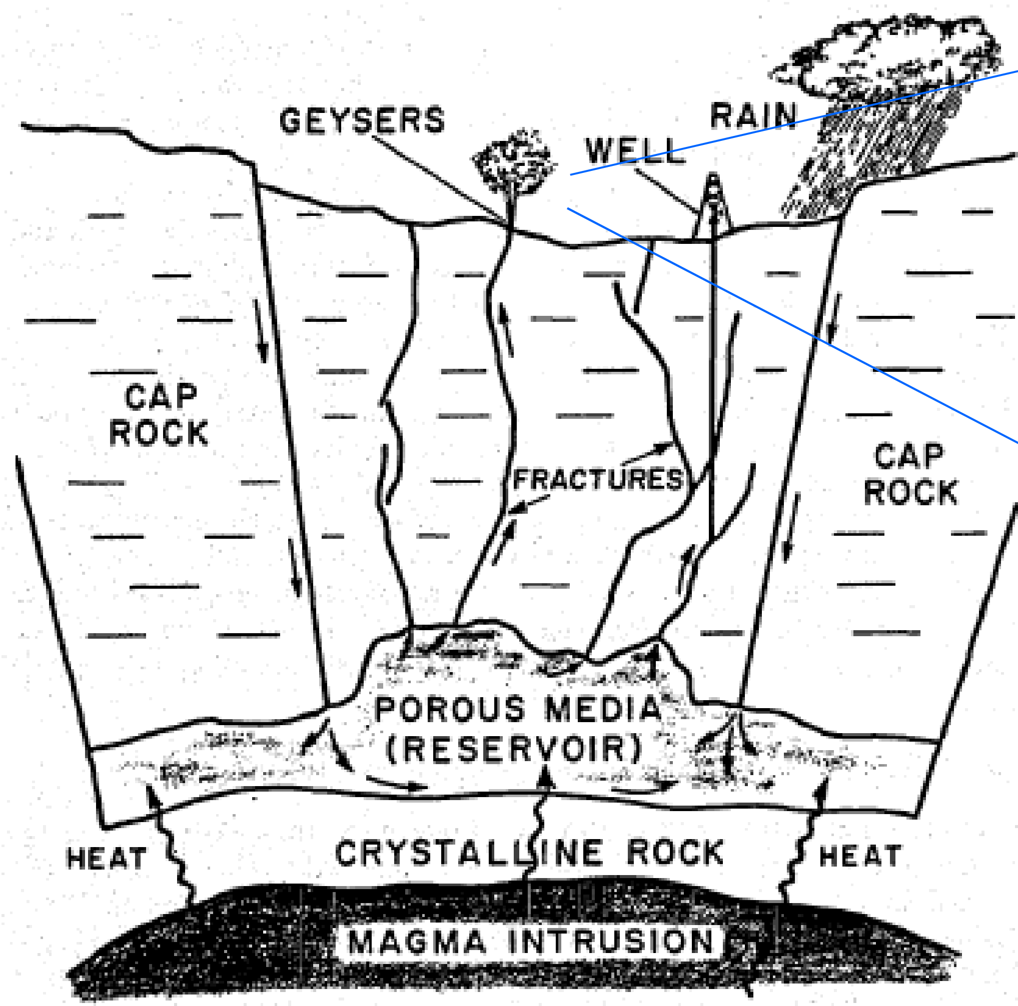
One would need a hot source of at least 150 °C for economic electricity generation using present technology. To get down to that temperature, <u>on average</u>, one needs to drill 5 kilometers.

EVEN HOTTER IN SOME PLACES



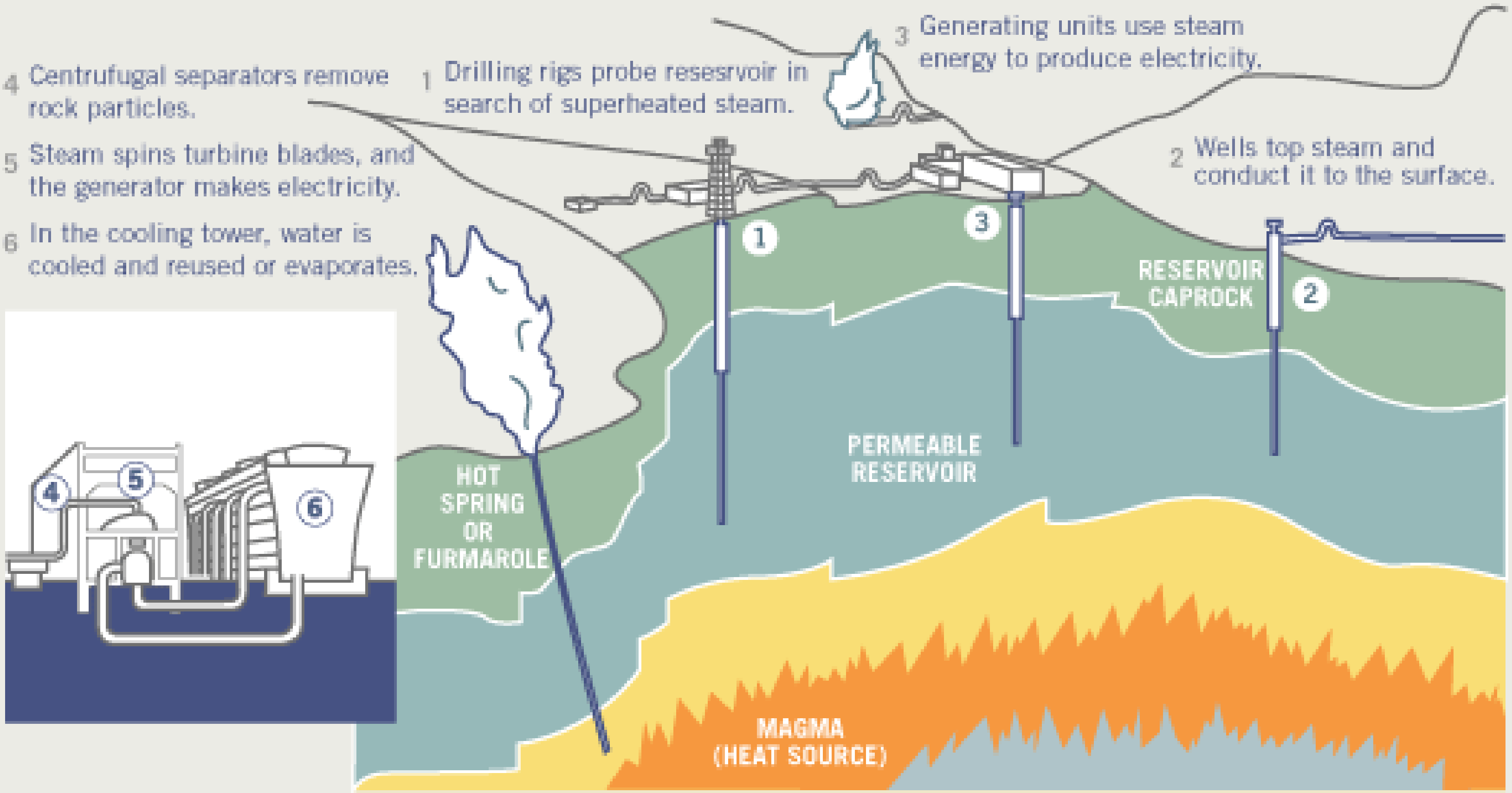
R DiPippo, Geothermal Energy as a Source of Electricity, 1980.

HYDROTHERMAL GEOTHERMAL RESERVOIR



R DiPippo, Geothermal Energy as a Source of Electricity, 1980.

ELECTRICITY FROM A HYDROTHERMAL RESERVOIR



Calpine Corporation, The Geysers, California, USA

H Gurgenci (h.gurgenci@uq.edu.au)

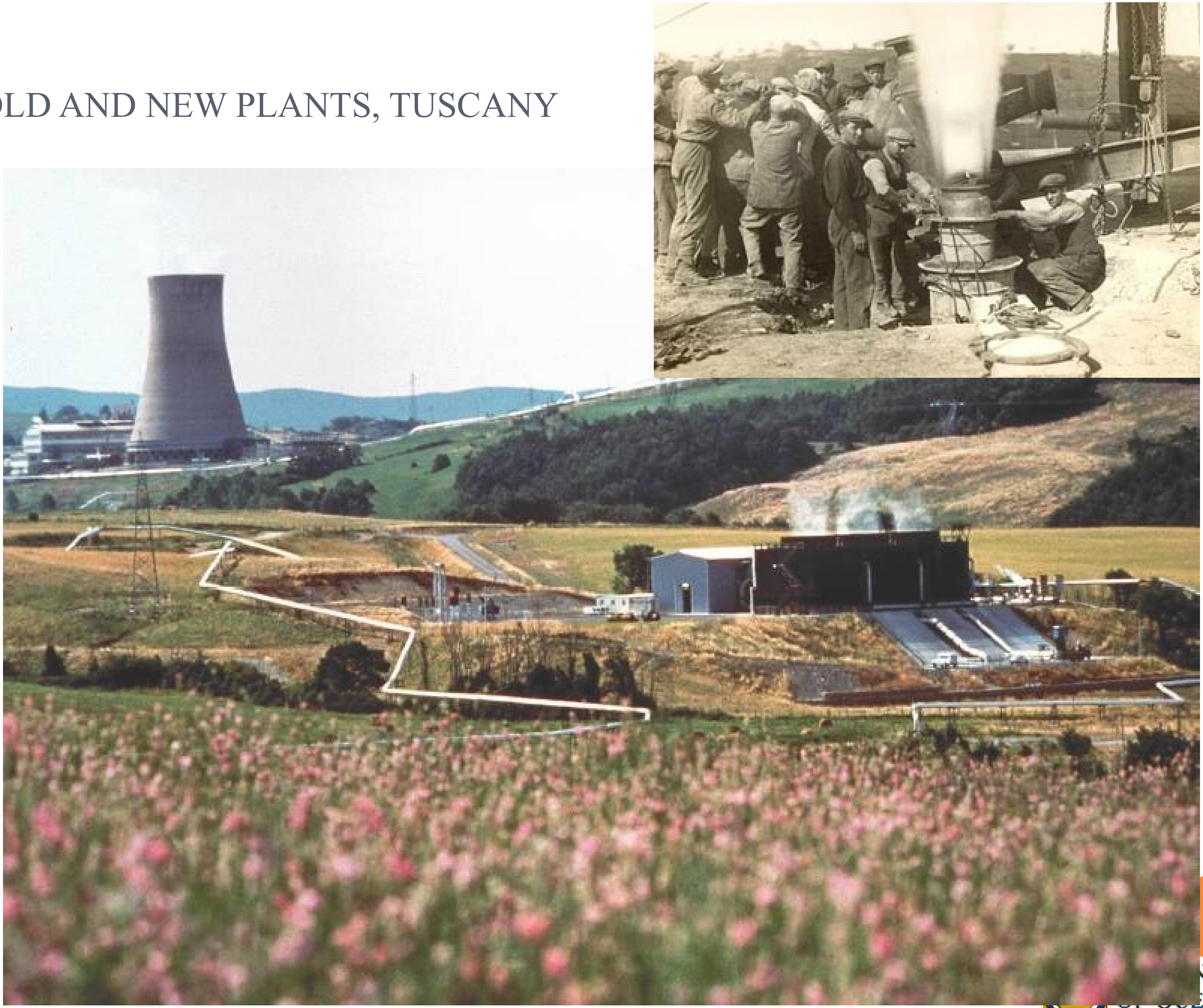
The Geysers operating capacity in 2007 = 750 MWe

KRAFLA GEOTHERMAL PLANT IN ICELAND

NESJAVELLIR GEOTHERMAL POWER PLANT IN ICELAND

MUTNOVSK GEOTHERMAL POWER PLANT, KAMCHATKA, RUSSIA

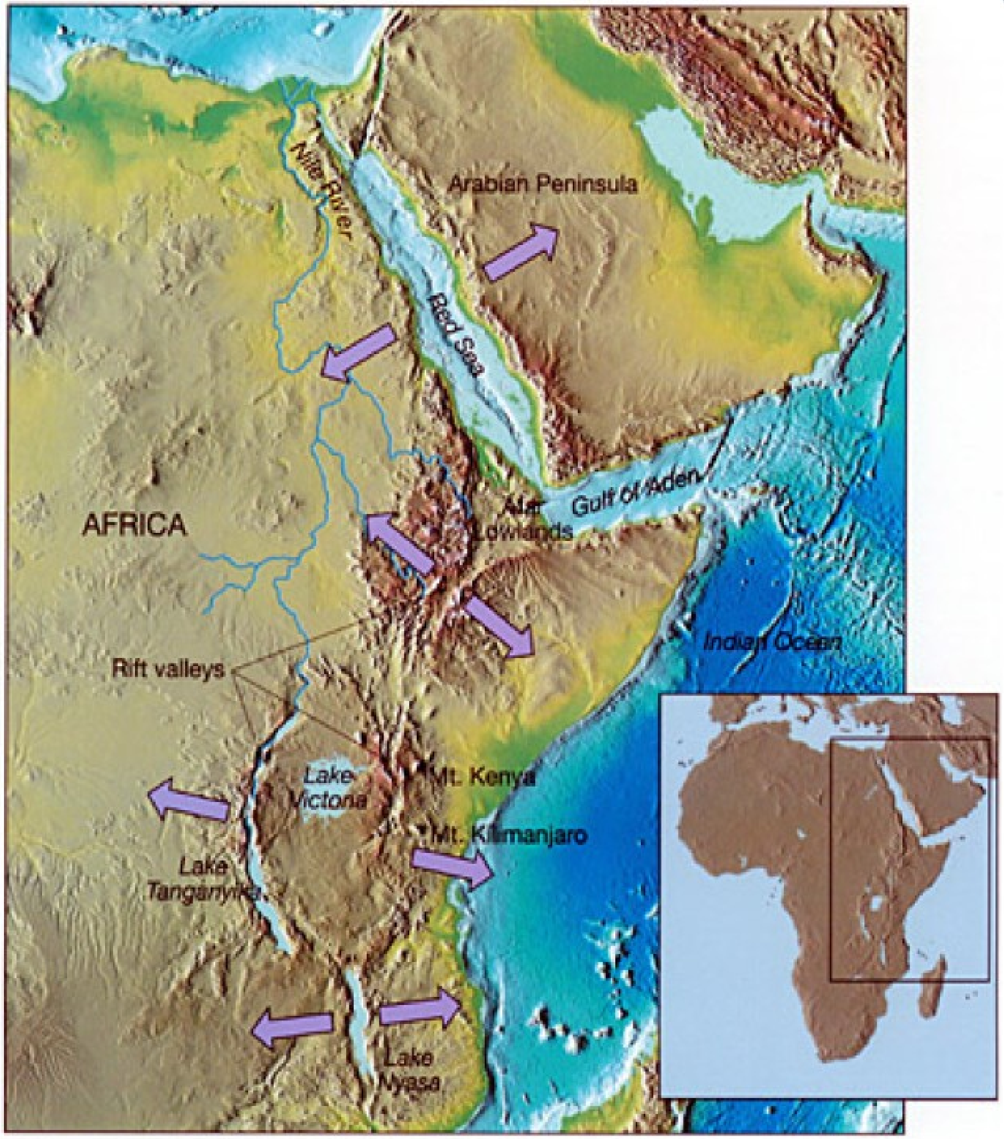
OLD AND NEW PLANTS, TUSCANY

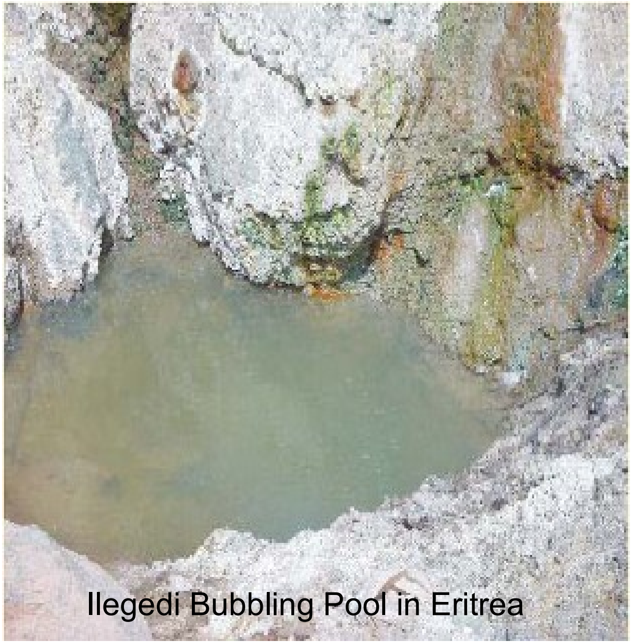


WAIRAKEI, NEW ZEALAND


MINDANAO, PHILIPPINES

NORTH-EAST AFRICA




Ilegedi Bubbling Pool in Eritrea

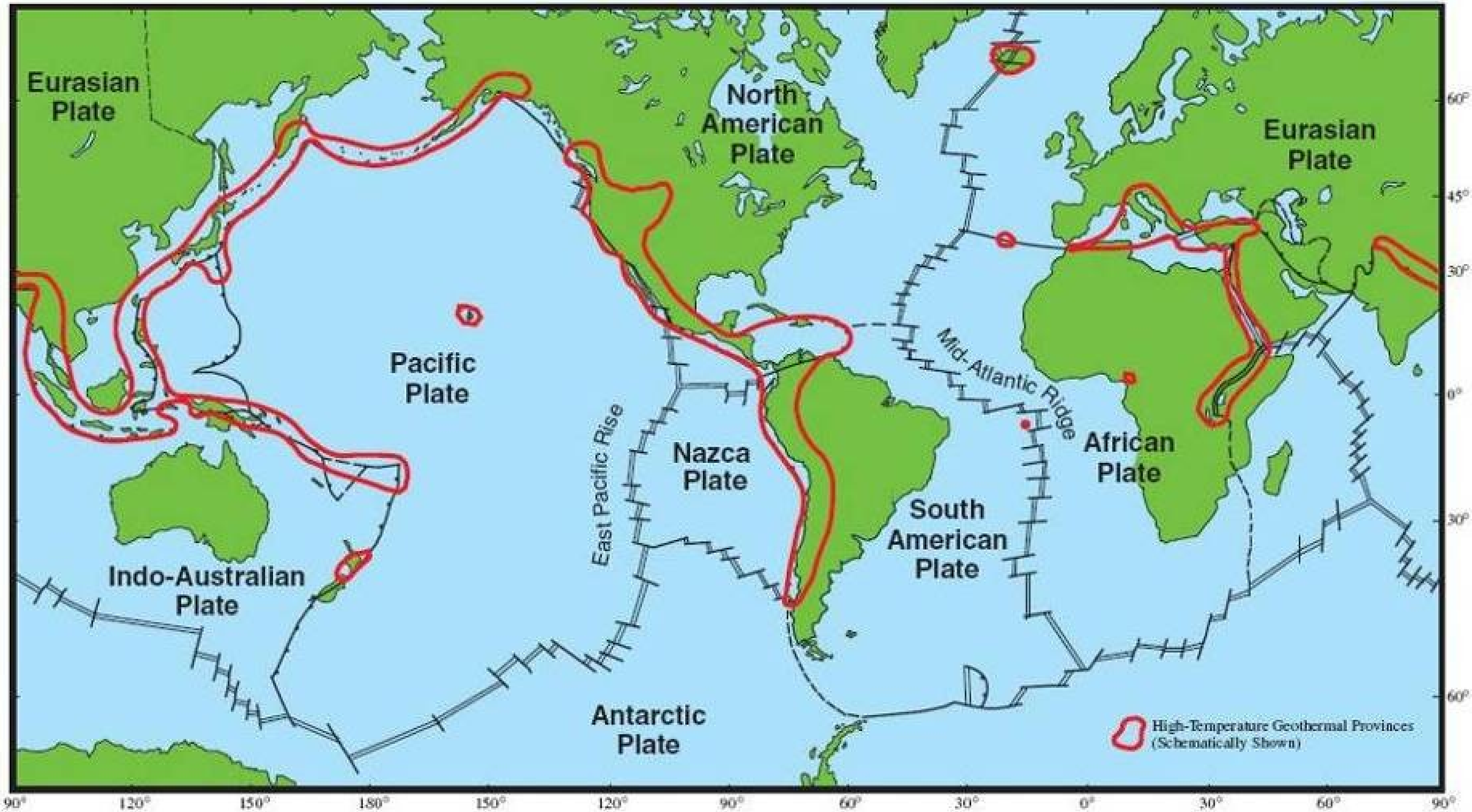

Fumarole (steam vent) in Eritrea

EXISTING GEOTHERMAL ENERGY SITES

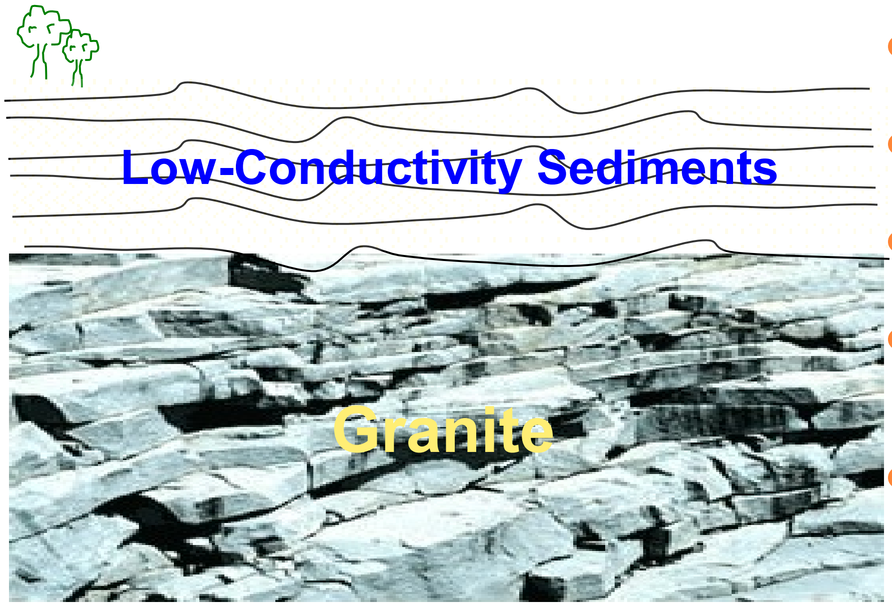
- California, USA
- Tuscany, Italy
- New Zealand
- Japan
- Iceland
- Kamchatcka, Russia
- Phillippines
- Eritrea

What is common about these locations?

WORLD VOLCANIC GEOTHERMAL RESOURCES



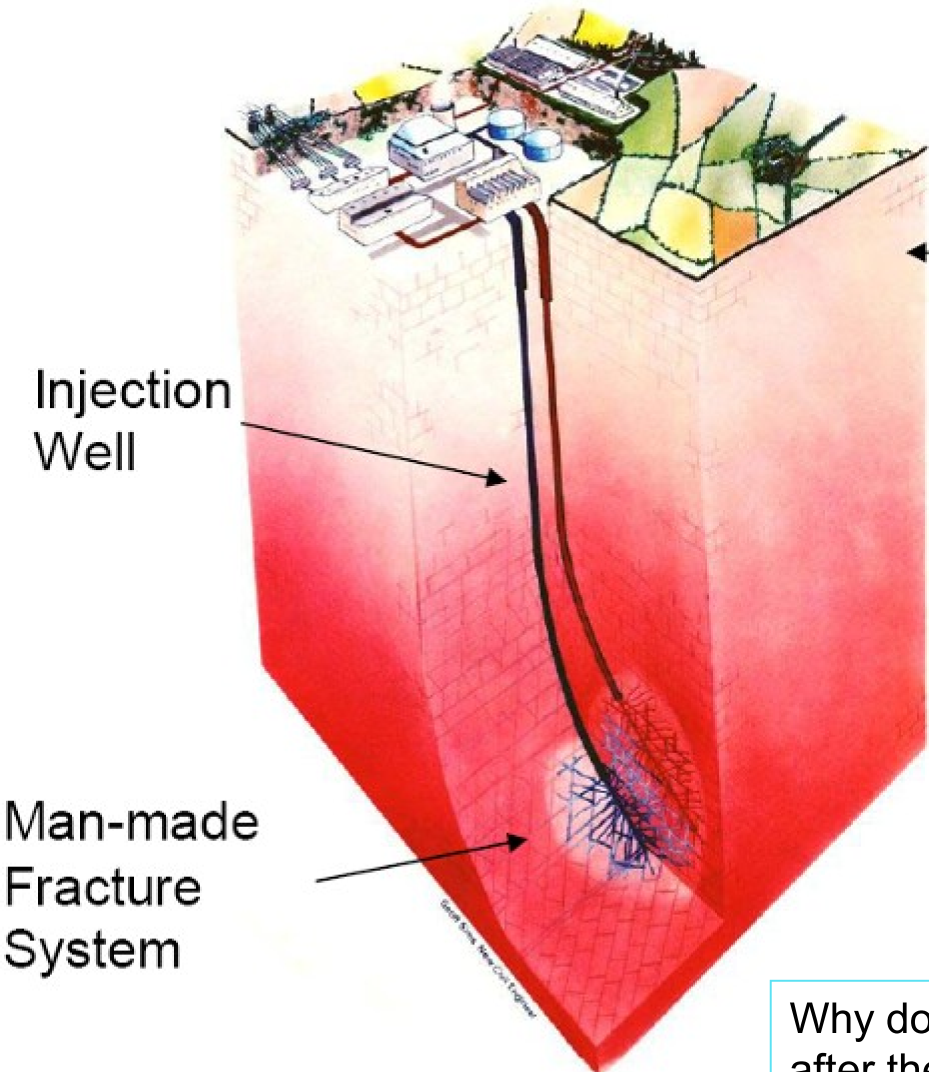
GEOTHERMAL RESOURCE IN AUSTRALIA



- Thick granite basement has been producing heat over geological times
- Caused by low-level radioactive decay
- Sedimentary cover with low thermal conductivity acts as a blanket and traps the heat inside the granite layer

- To access the granite reservoir, one needs to drill down to 5 km
- Granite is fractured but fractures are closed under depth
- One injects a high-pressure fluid to open the fractures
- Once the fractures are opened, they usually stay open even when the high pressure is removed.
- Such systems are called Engineered Geothermal Systems (EGS).

ENGINEERED GEOTHERMAL SYSTEMS (EGS)



- The underground fracture system connects the two wells together.
- Cold fluid is injected down the injection well
- The fluid is heated while passing through the fracture system
- It is pumped up the production well
- The preliminary fracturing work on the reservoir is called “reservoir stimulation”

Why do the cracks remain open even after the pressure is released?

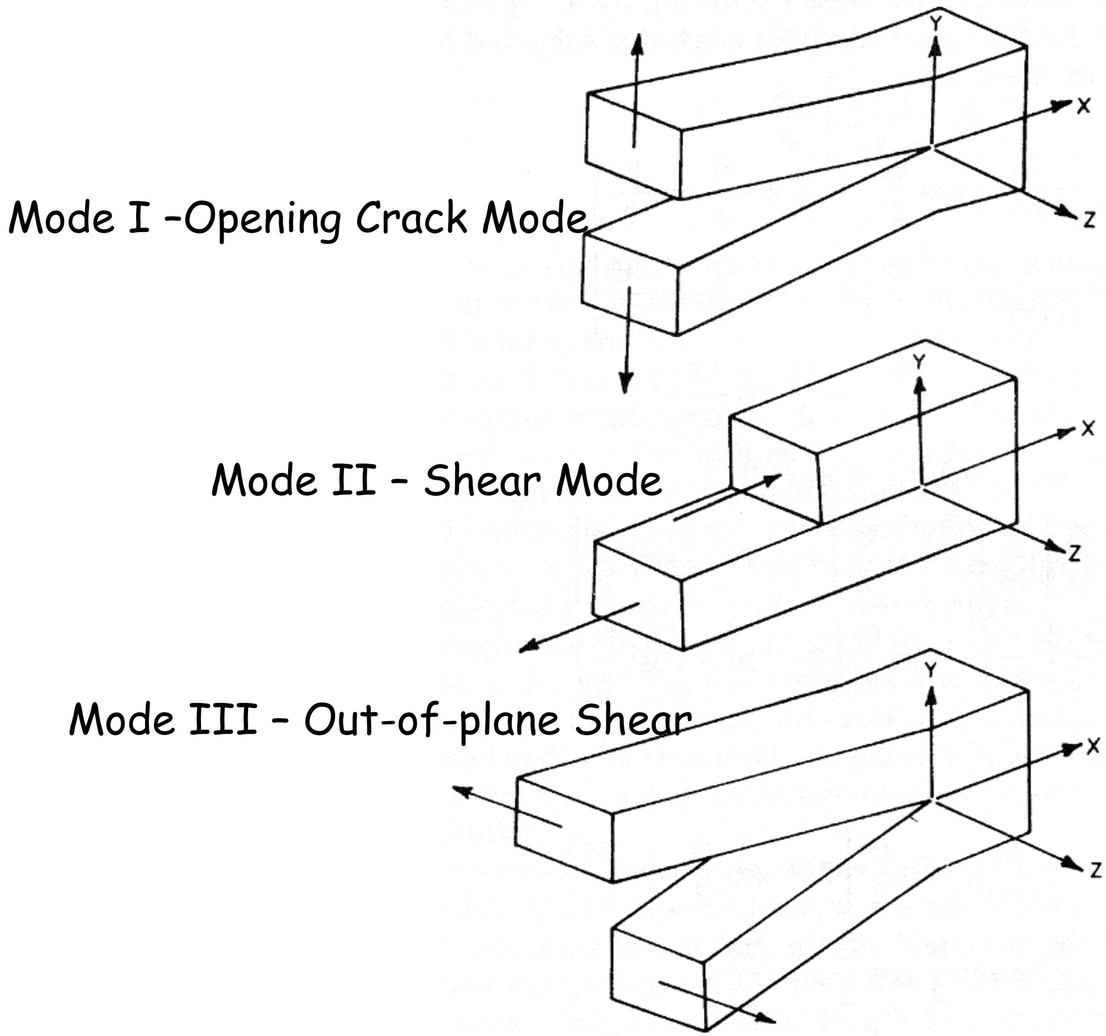
MODES OF FRACTURE

Application of hydrostatic pressure during reservoir stimulation opens the existing cracks (Mode I).

However, once the crack are open, the planes slip under the action of horizontal stresses.

When the pressure is removed, the cracks try to close but, since the plates have shifted, irregularities in the new contact areas prop the cracks open.

CAUTION : This model may not apply to all reservoirs.



HABANERO STIMULATION

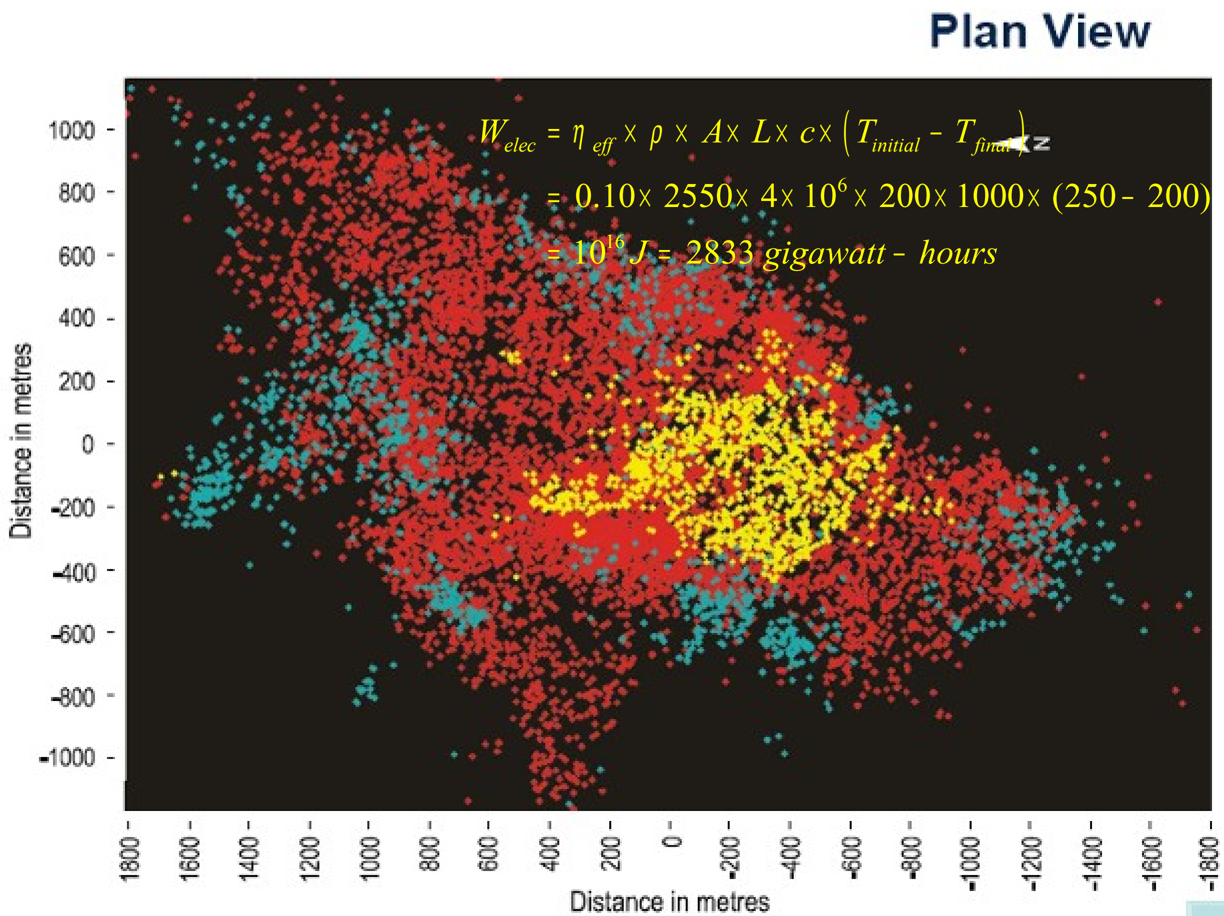
Hydraulic stimulation

(from oil and gas industry)

Connection between wells

Microseismic monitoring

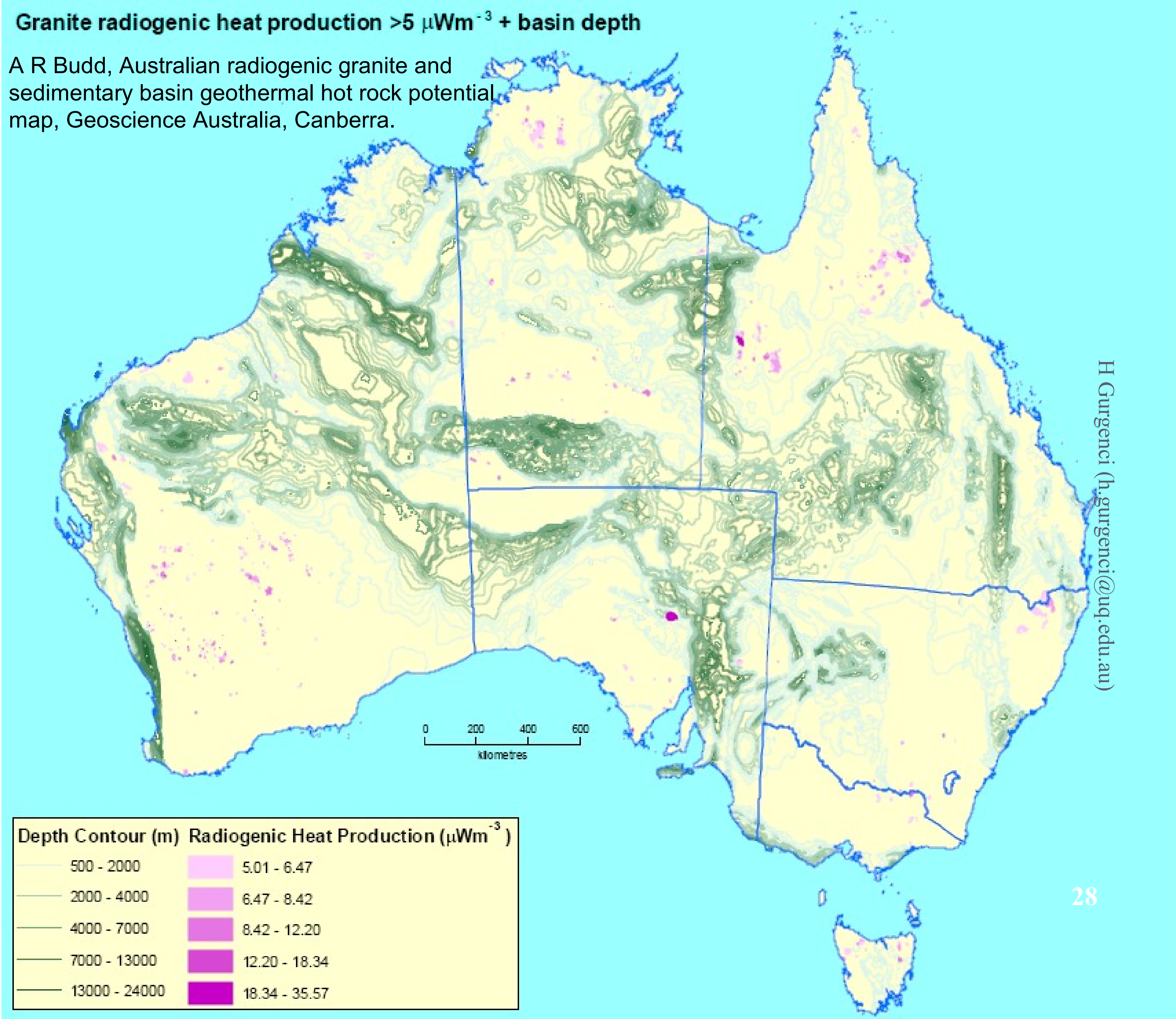
(from Q-con Germany)



Largest developed reservoir in the world

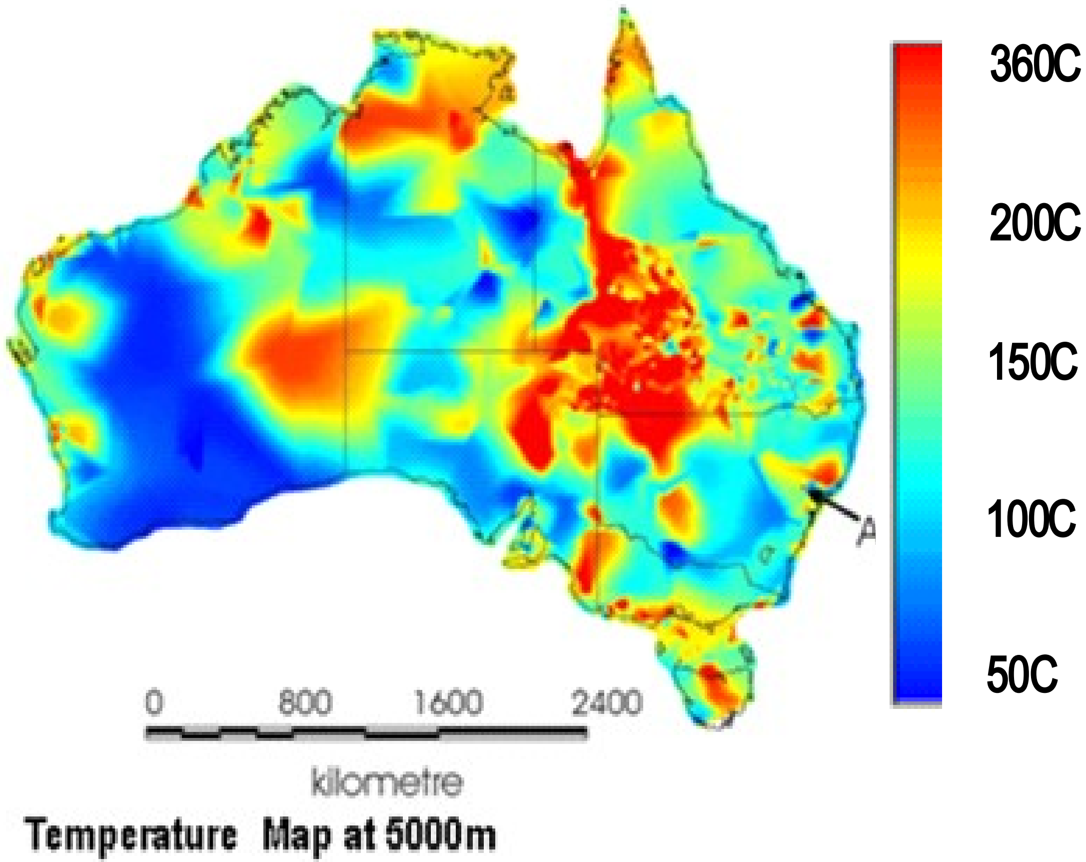
GEODYNAMICS

HEAT PRODUCTION IN GRANITE



H Gurgenci (h.gurgenci@uq.edu.au)

AN EARLIER MAP

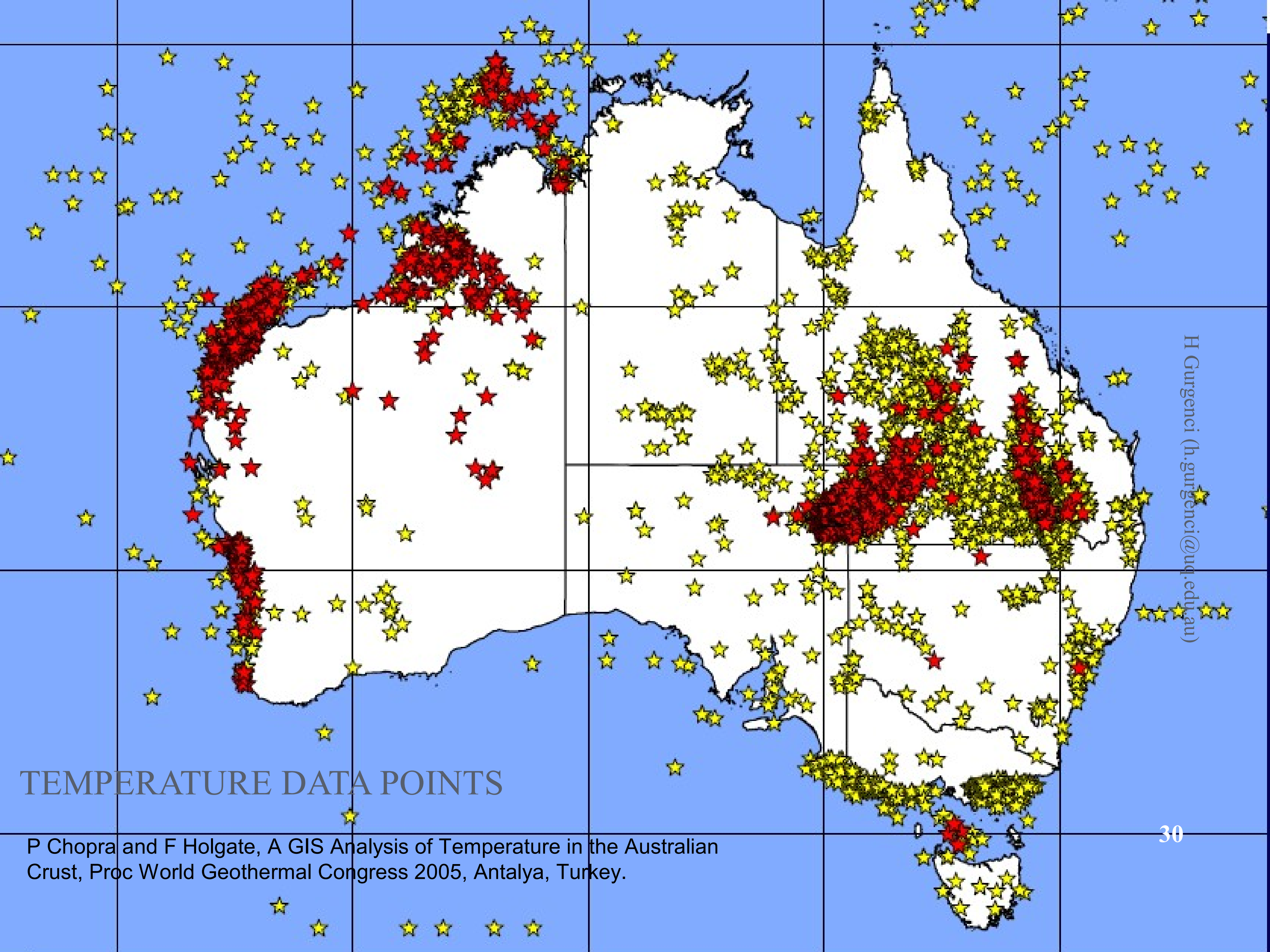


This earlier temperature resource map was generated by Somerville et al (1994) from the Geotherm93 database using a mixture of manual and GIS methods.

This has been updated since then by more temperature data and better interpolation techniques/

P Chopra and F Holgate, A GIS Analysis of Temperature in the Australian Crust, Proc World Geothermal Congress 2005, Antalya, Turkey.

TEMPERATURE DATA POINTS



P Chopra and F Holgate, A GIS Analysis of Temperature in the Australian Crust, Proc World Geothermal Congress 2005, Antalya, Turkey.

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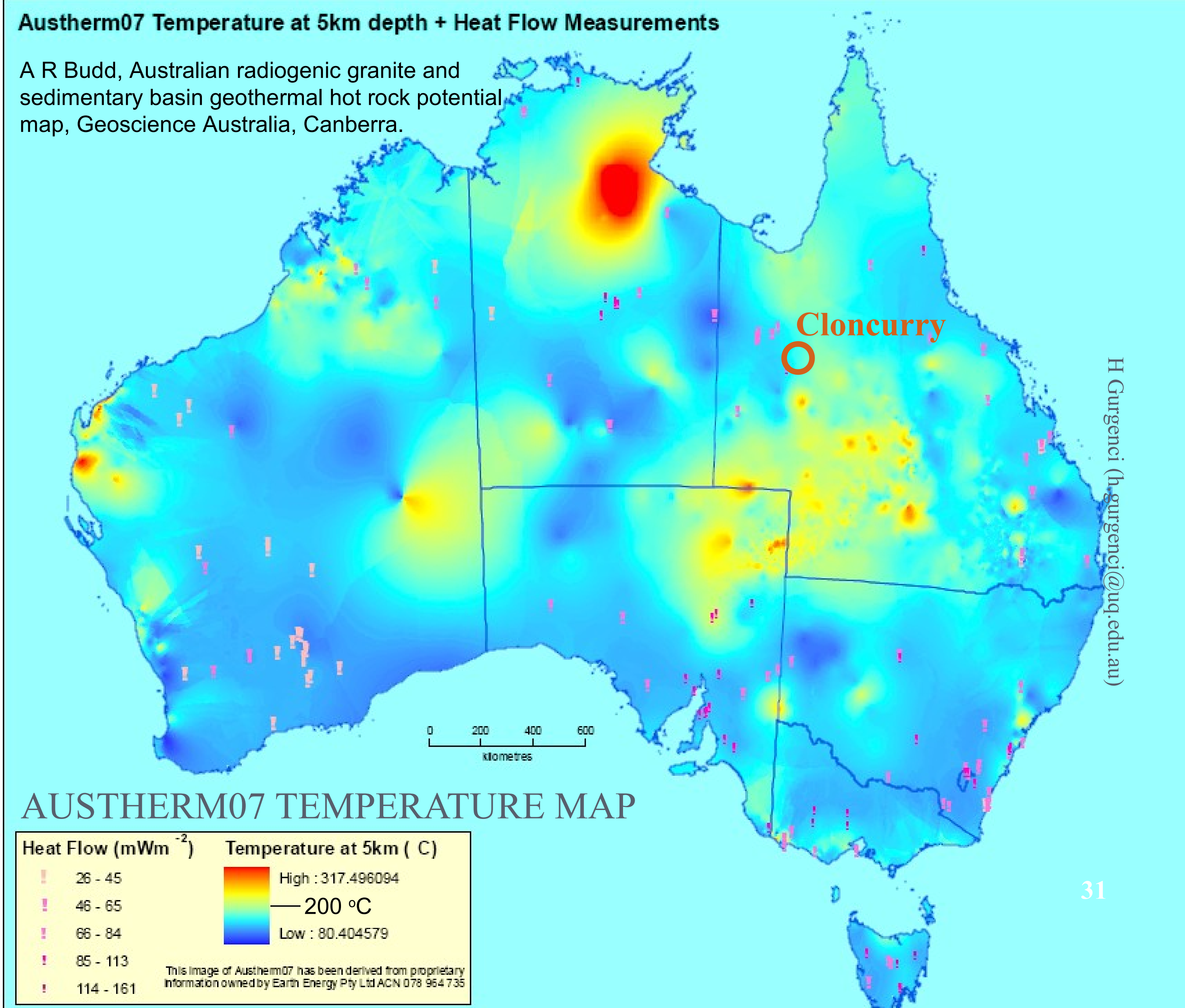
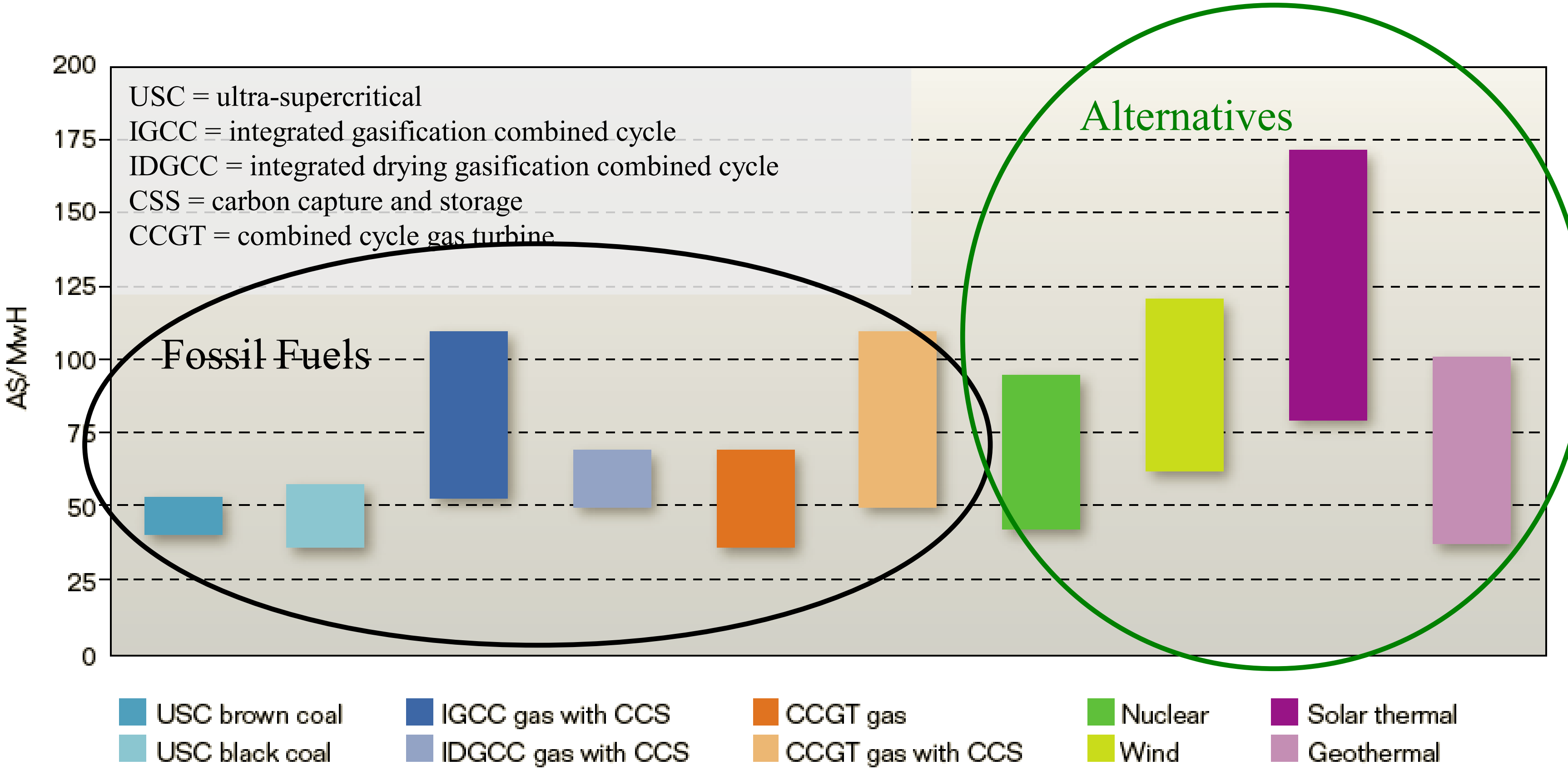
Temperatures at 5 km



AUSTRALIAN HOT ROCK GEOTHERMAL RESOURCES

- One estimate is 22,000 EJ potentially available for electricity generation.
- At a conversion efficiency of 20%, this would supply all of Australian current electricity demand for 6000 years.
- One ESAA projection is 5000 MWe of geothermal power by 2030.
- The total 2004-05 installed capacity was 45000 MWe

ELECTRICITY GENERATION TECHNOLOGY COSTS



Source: Energy Futures Forum (2007), IEA (2008), Wright (2007) and industry submissions. (Garnaut Climate Change Review, Figure 20.10)

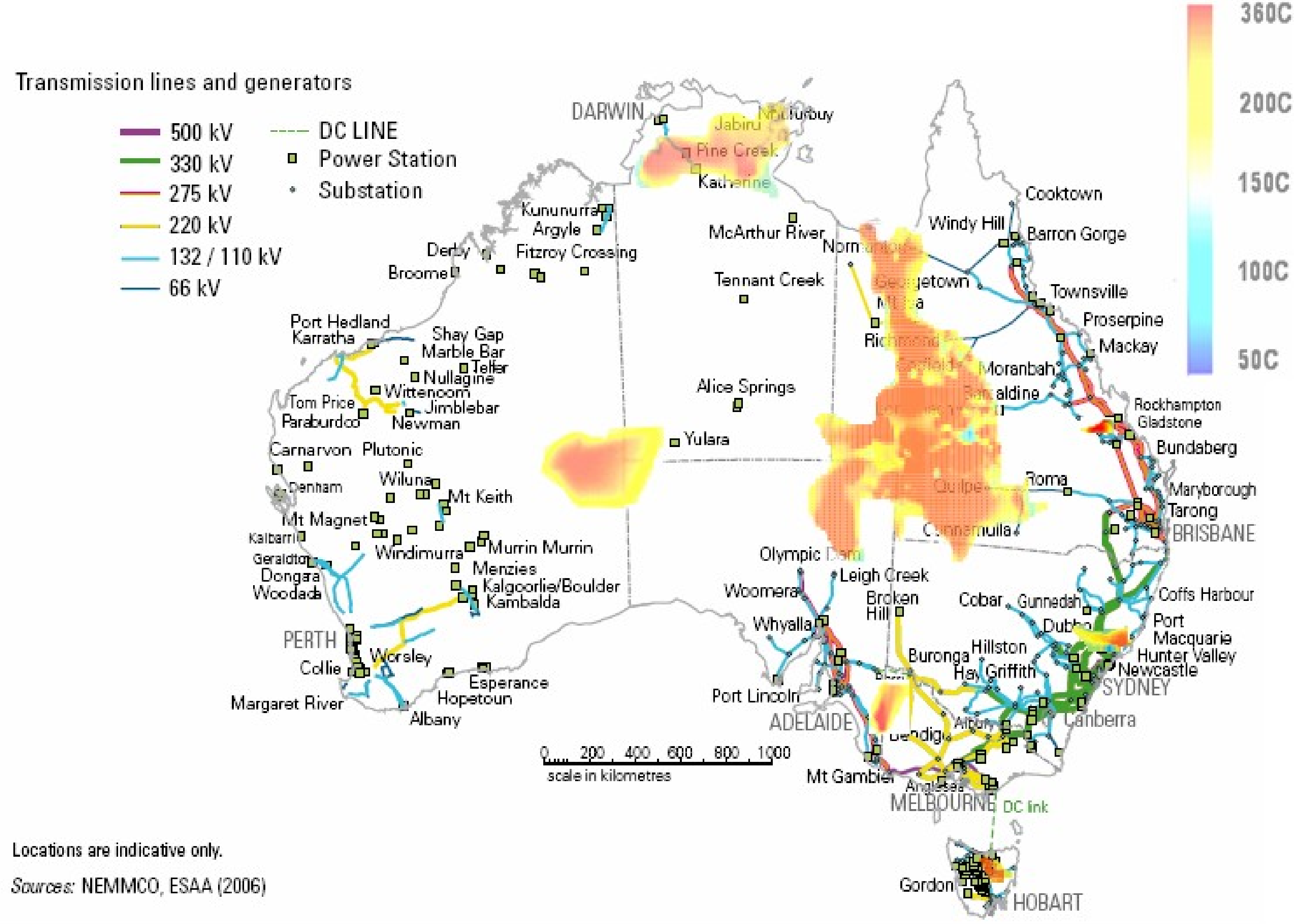
WHERE IS THE CATCH?

If it is so good, why don't we have geothermal power plants all around the place?

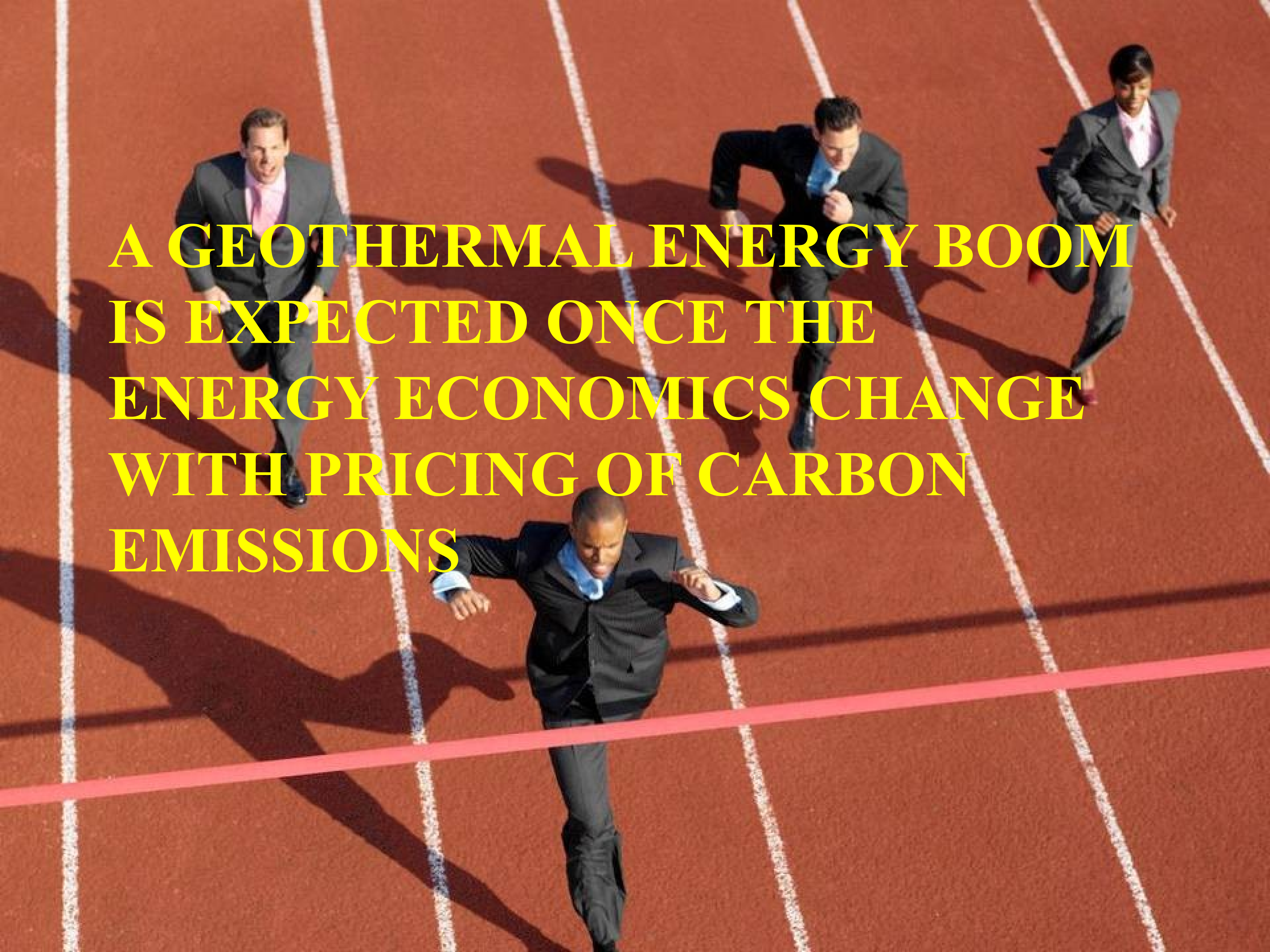
THE IMPEDIMENTS

- Although cheaper against wind and solar, geothermal energy from EGS is still more expensive than fossil fuels
- Drilling technology has become feasible relatively recently
- Temporary condition – Drill rigs and crews hard to find and expensive due to boom in petroleum exploration
- Unlike solar energy, geothermal plants need to be larger than a certain size to be feasible at all. You need to drill at least two holes to access an EGS resource. This means the minimum plant size is 4-10 MWe.
- There are no large geothermal plant provider companies providing turnkey solutions and sharing the generators' risk
- The best geothermal resource in Australia is in the interior of the continent away from the electricity grid

EGS RESOURCES AND THE ELECTRICITY NETWORK

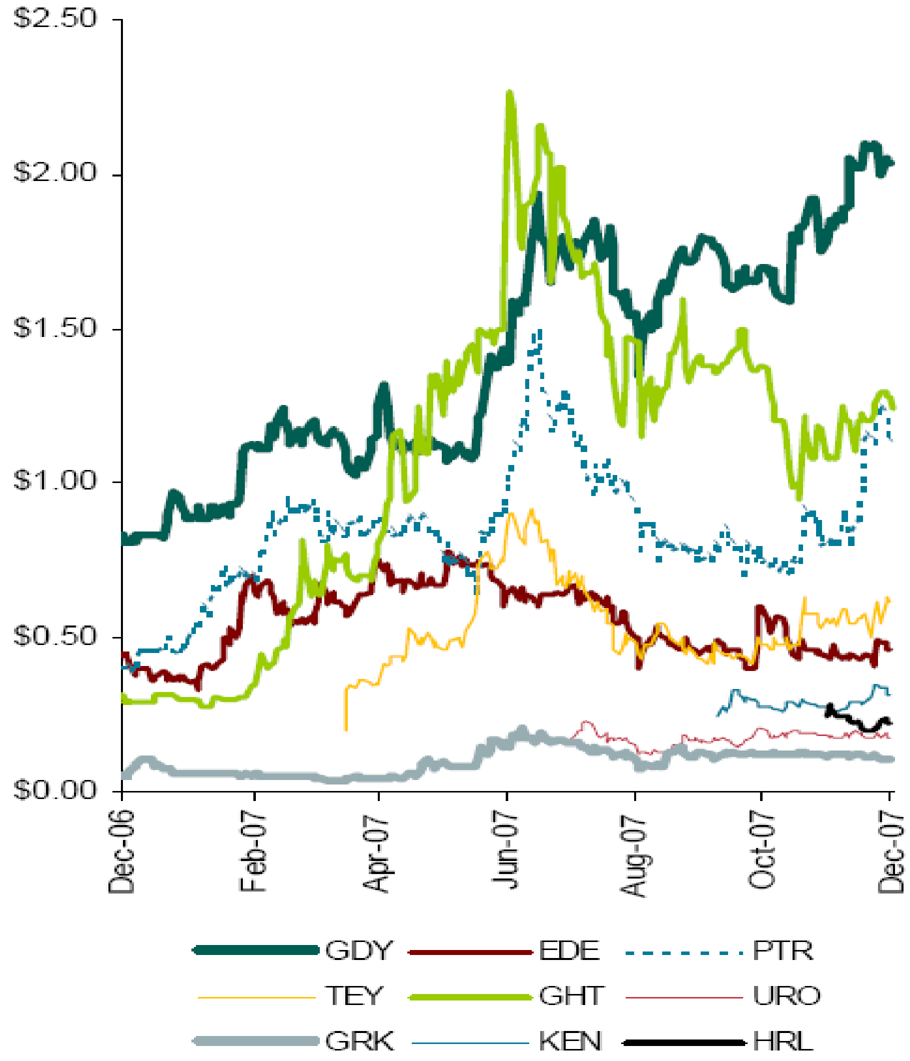


The coloured areas showing the temperatures in selected areas at 5000 m (Swenson, Chopra & Wyborn 2000; and Somerville et al. 1994)



A GEOTHERMAL ENERGY BOOM IS EXPECTED ONCE THE ENERGY ECONOMICS CHANGE WITH PRICING OF CARBON EMISSIONS

AUSTRALIAN INDUSTRY

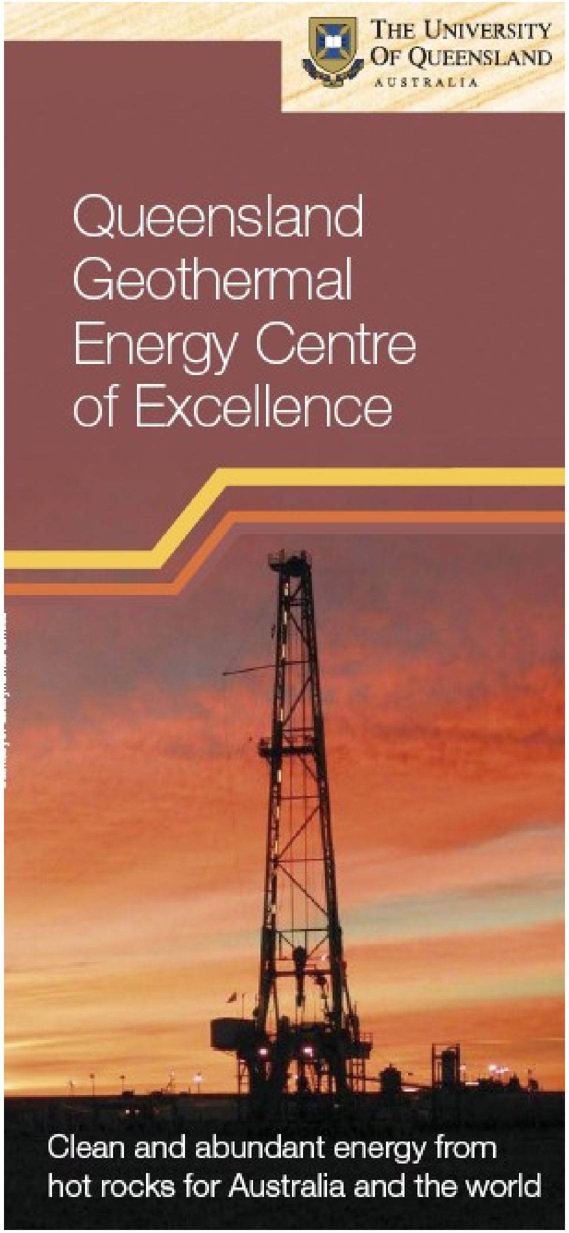


Nine stocks were listed on the Australian Stock Exchange in Dec 2007 with a combined market capitalisation of over $700m.

The sector leader, Geodynamics, represented $435m of this total.

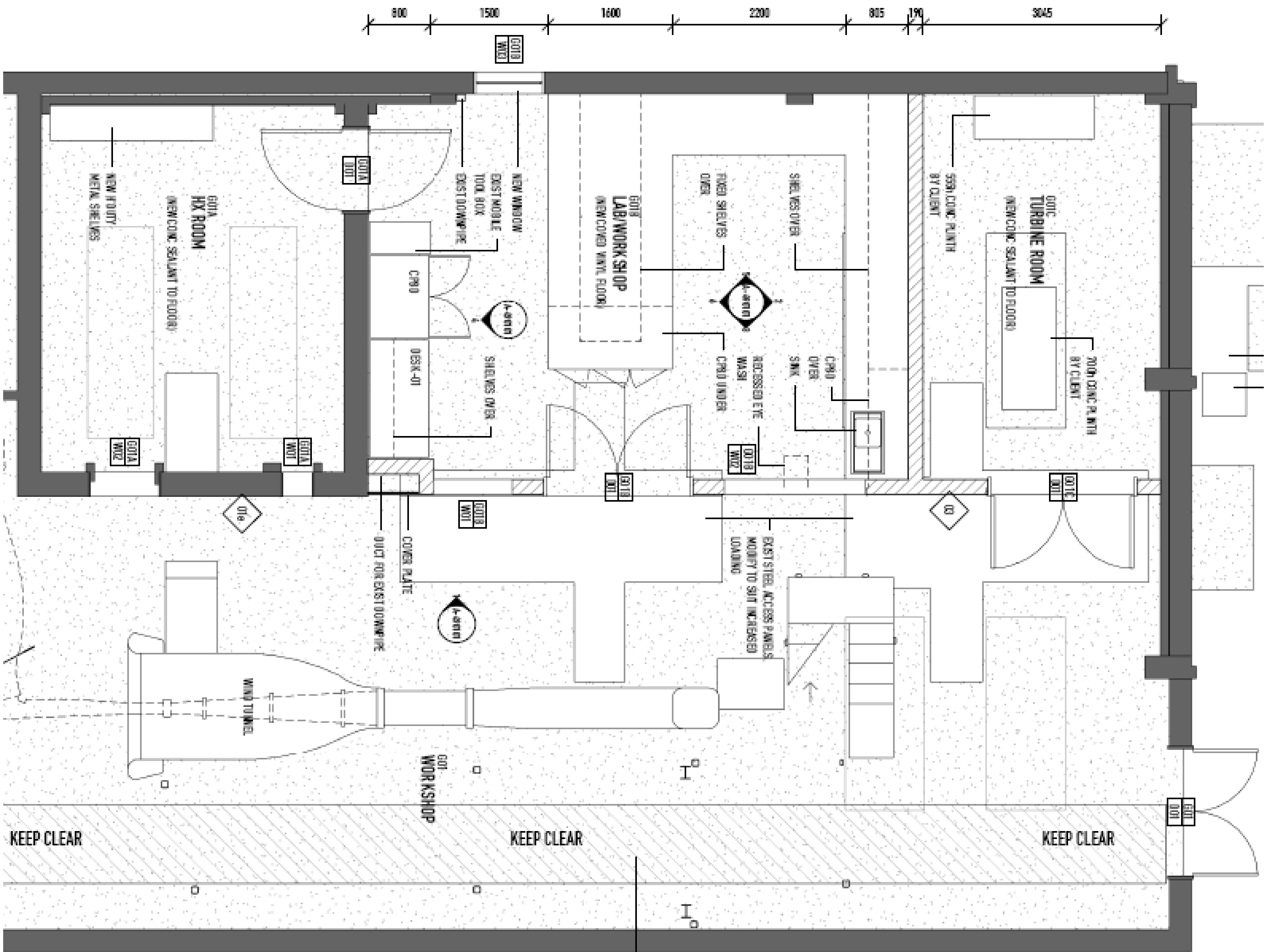
GDY	Geodynamics
EDE	Eden Energy
PTR	Petratherm
TEY	Torrens Energy
GHT	Geothermal Resources
~~URO~~ PAX	Panax Geothermal
GRK	Green Rock Energy
KEN	KUTh Energy
HRL	Hot Rock

QUEENSLAND GEOTHERMAL ENERGY CENTRE OF EXCELLENCE



- To quicken the large-scale utilisation of hot rocks geothermal energy in Australia
- Funding parameters
  - $15m from the State Government plus $3.3m in-kind from UQ over five years
  - additional UQ support through office/lab space
- A vehicle towards a national Centre via support of Commonwealth and other State Governments
- Seeking international collaboration
- http://www.uq.edu.au/geothermal/

CENTRE LABORATORIES – TO BE READY BY FEBRUARY 2009



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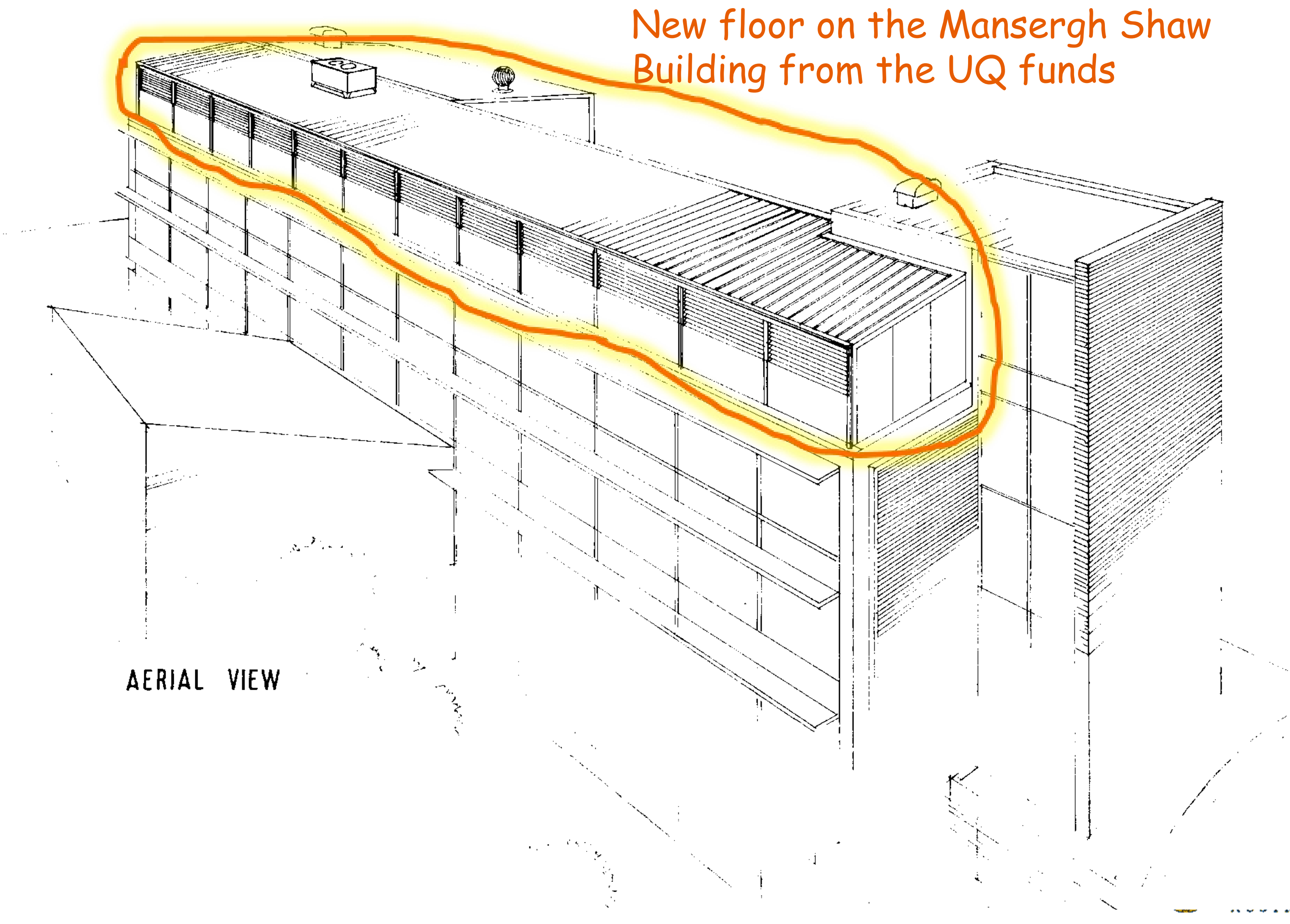
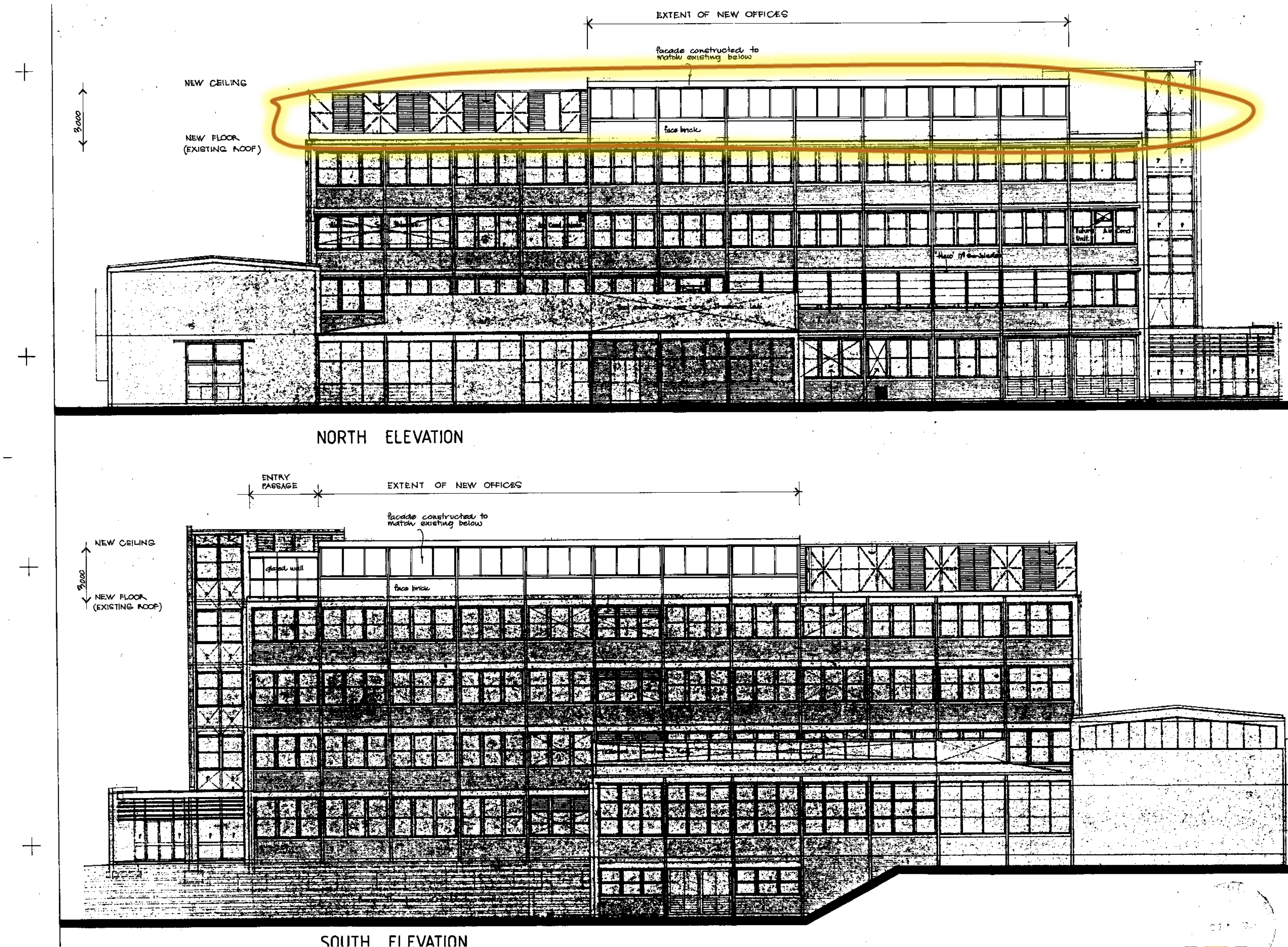
CENTRE OFFICES – TO BE READY BY 2010



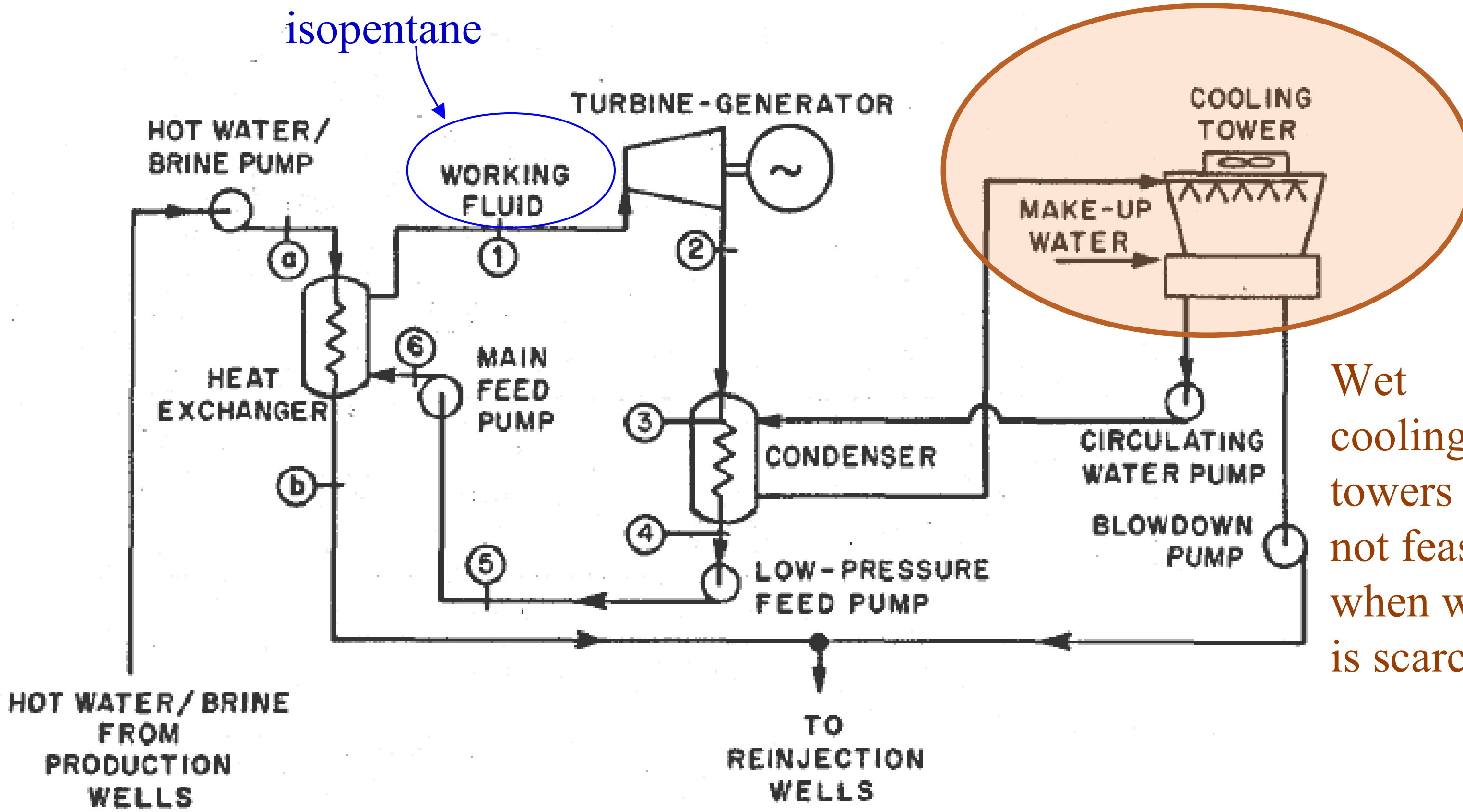
N-S ELEVATION – NEW FLOOR FOR THE CENTRE OFFICES



RISK MANAGEMENT

- Surface installations cost 60+% of the total
- Our target is to increase the thermal efficiency by 50%
  - 50% more electricity for the same subsurface investment
  - Equivalent to 50% increase on the price of the electricity sale price
- Higher rewards help the industry tolerate higher risks

A 50-MW GEOTHERMAL POWER PLANT



(five production wells)

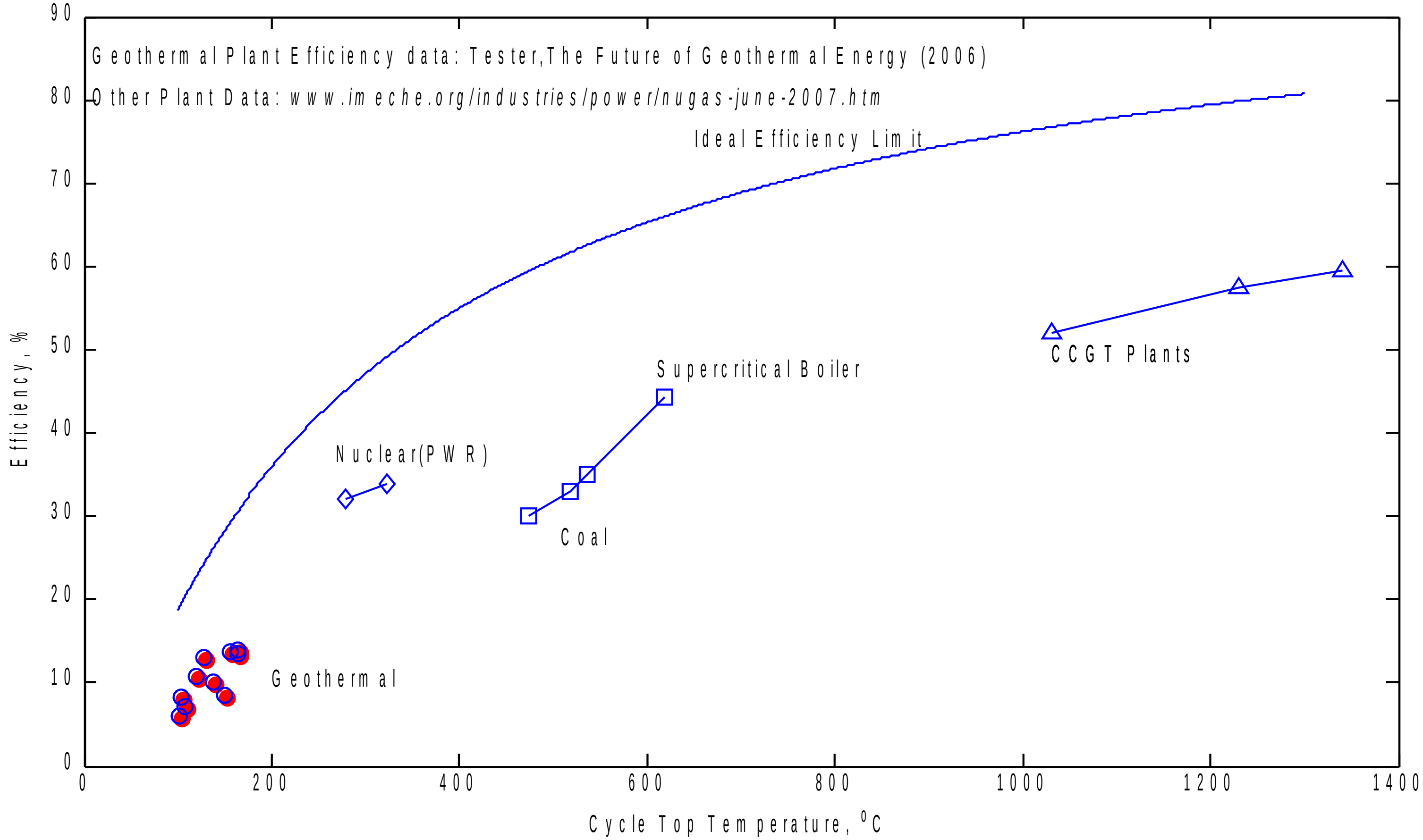
(four injection wells)

Wet cooling towers are not feasible when water is scarce

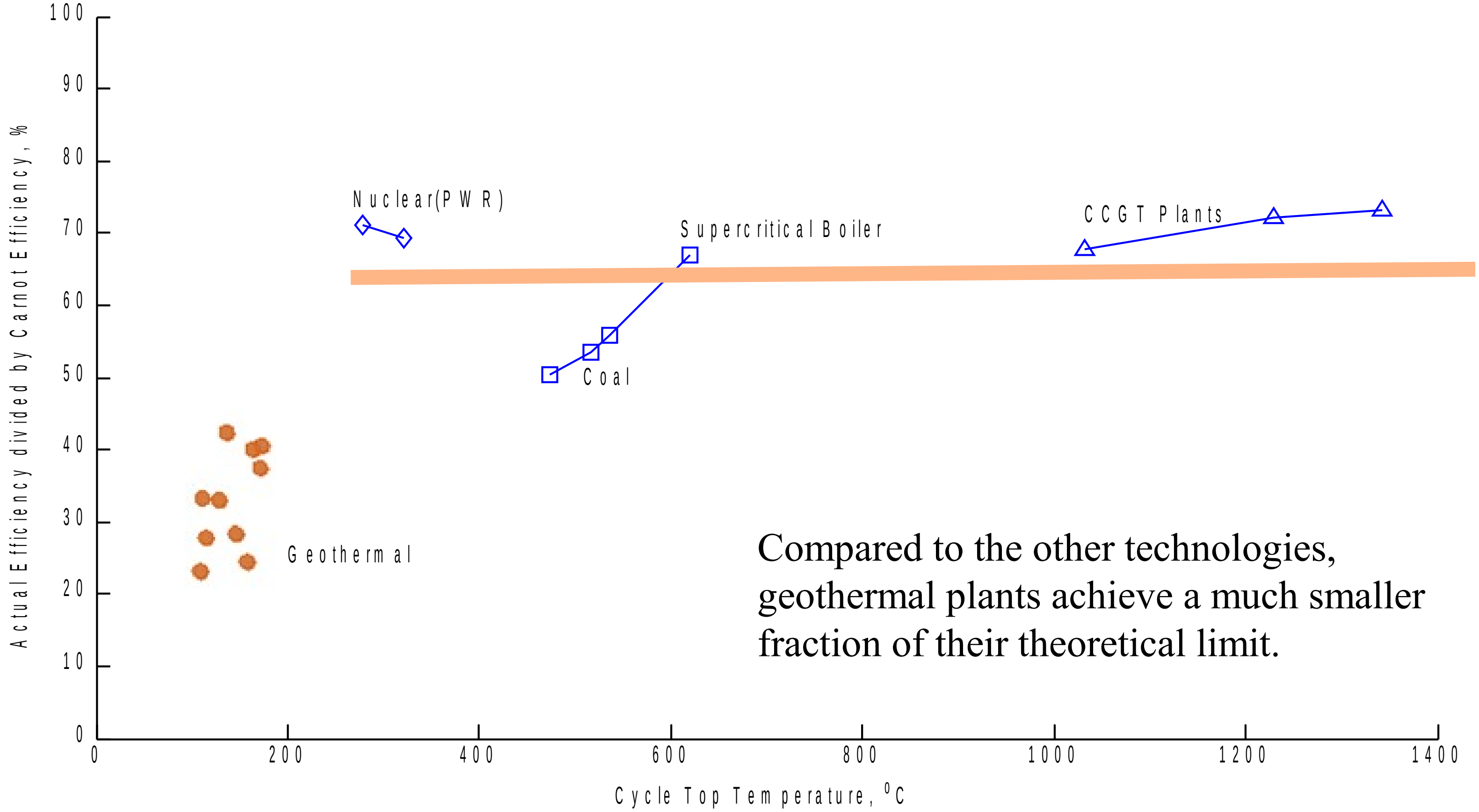
For the sake of this example, assume an efficiency of η =15%. This means to produce 50 MW electricity, the plant must be dumping 283 MW heat.

$$Q_c = \frac{1-\eta}{\eta}\dot{W} = \frac{0.85}{0.15} \times 50 = 283$$

GEOTHERMAL VS. OTHERS - THERMAL EFFICIENCIES



ACTUAL / IDEAL EFFICIENCIES



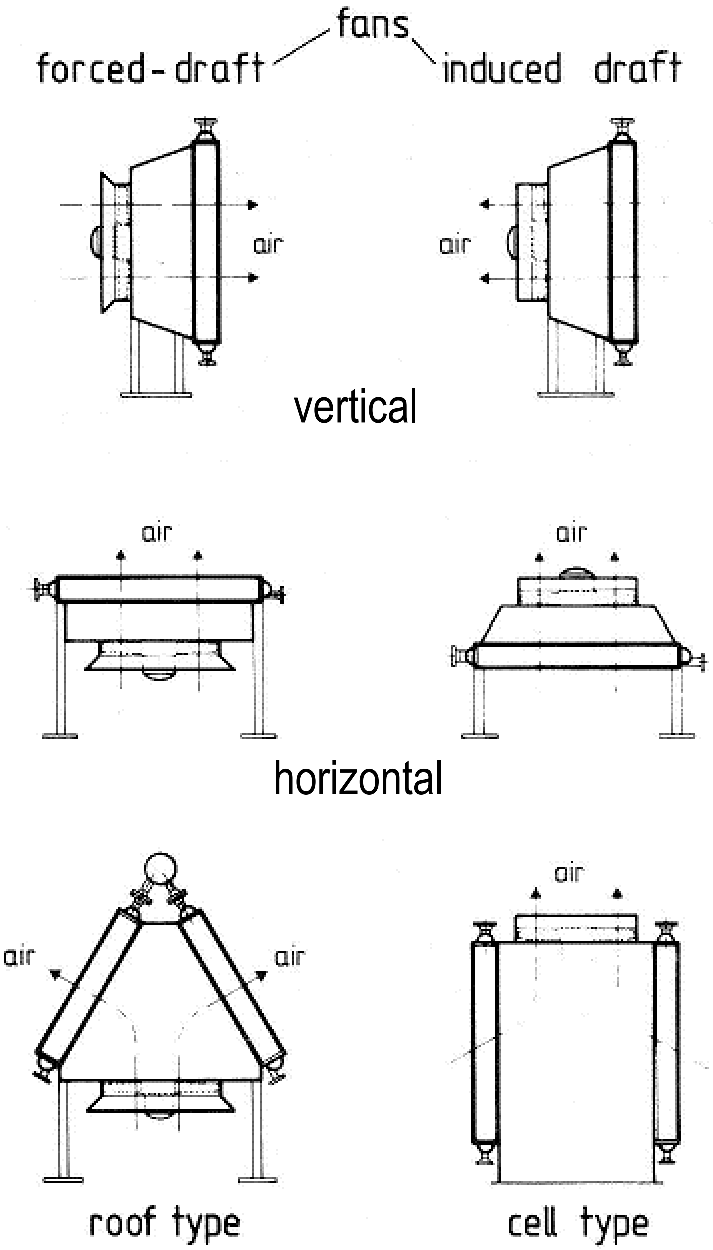
Compared to the other technologies, geothermal plants achieve a much smaller fraction of their theoretical limit.

- Power conversion
  - Off-design turbine performance
  - Explore new geothermal-optimum expander options
    - Supercritical turbines
- Transmission and generation
  - Power network modelling
  - Grid stability, reliability, storage and adequacy, etc
  - Long-distance transmission options
- Reservoir management
  - Innovative scientific approaches for the identification of geothermal resources in Queensland
  - Understanding of long-term effects of water-rock interaction on geothermal reservoir
- **Heat exchangers**

AIR-COOLED ~~CONDENSERS~~ Heat Exchangers

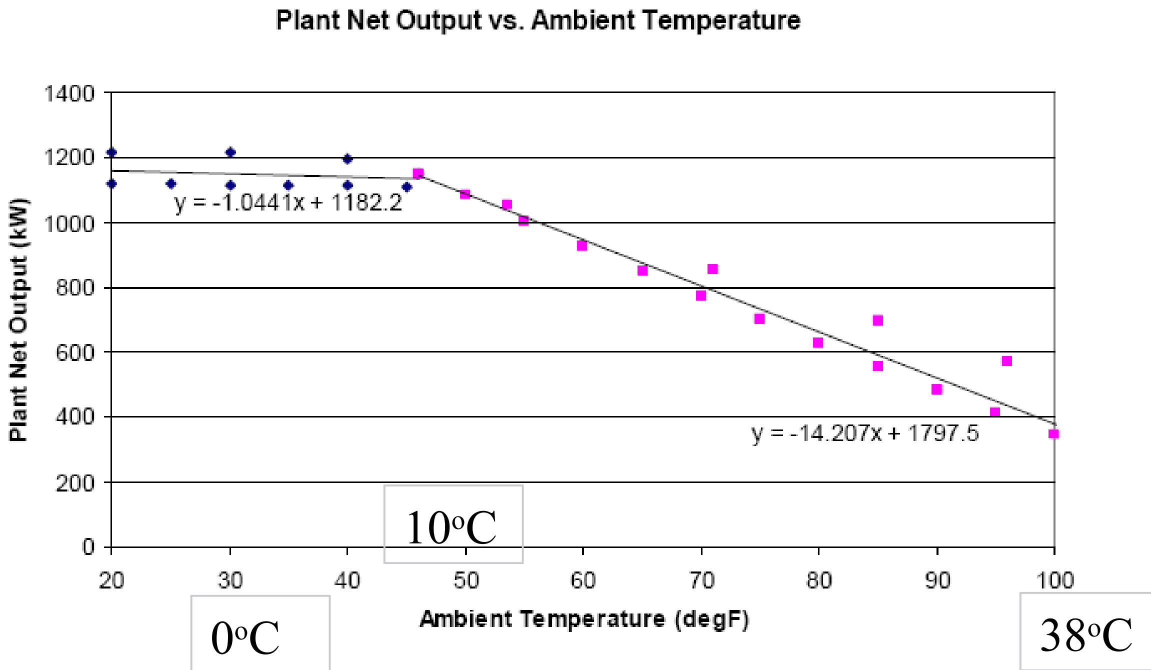
- 50-MW plant → 250-300 MW of waste heat
- Wet cooling towers use too much water
  - 100 kg/s to dump 280 MW or 3.2m tonnes per year
  - Equal to domestic consumption by 62000 people
- Fan cooling entails high parasitic losses
- Natural-draft dry towers preferred, BUT
  - The present best practice is not good enough to support a geothermal power plant in the Australian interior 24 hours a day 365 days a year
- More efficient dry cooling technologies are needed across the industry
  - A research priority identified by the International Partnership for Geothermal technologies

MECHANICAL DRAFT FAN COOLERS



- In forced draft, the fan supplies air at the ambient temperature.
- The fan discharges heated air in induced draft.
- For the same air flow and tube bundle geometry, forced draft needs less power.
- Induced draft arrangement has the following advantages:
  - More even distribution of air across the bundle
  - Protection of the heat exchange surface against climate conditions

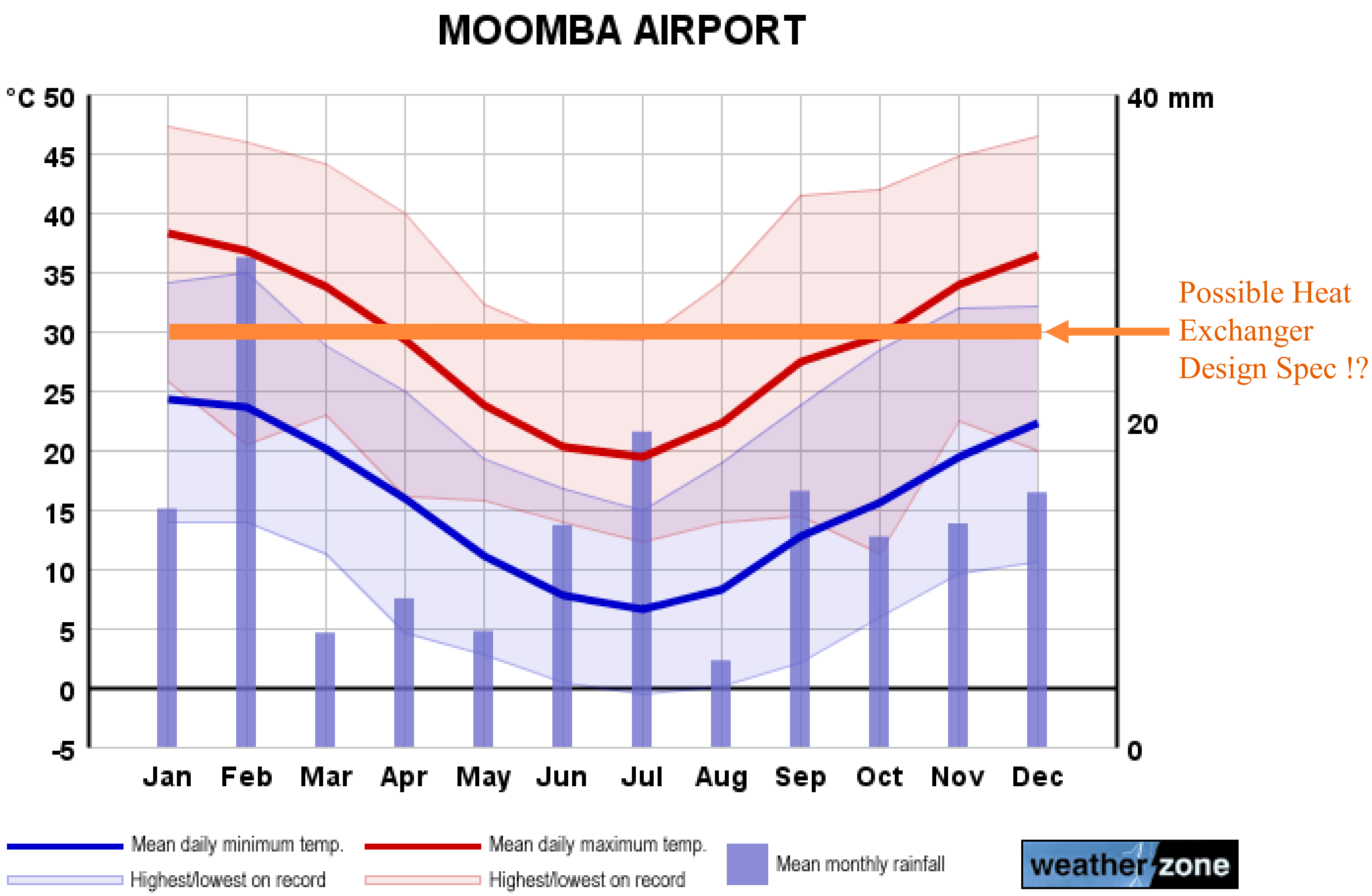
EFFECT OF AIR TEMPERATURE ON PLANT OUTPUT



This chart was created by NREL by running ASPEN simulations on the 1-MW binary plant at Empire, Nevada. The baseline system consists of 15 induced-draft fans drawing air through 10 tube bundles 18-m long each. The geothermal inlet fluid temperature was assumed to be 118 °C.

Assessment of Evaporative Cooling Enhancement Methods for Air-Cooled Geothermal Power Plants, Kutscher and Costenaro (2002)

MOOMBA AIRPORT TEMPERATURES



http://www.weatherzone.com.au/climate/station.jsp?lt=site&lc=17123

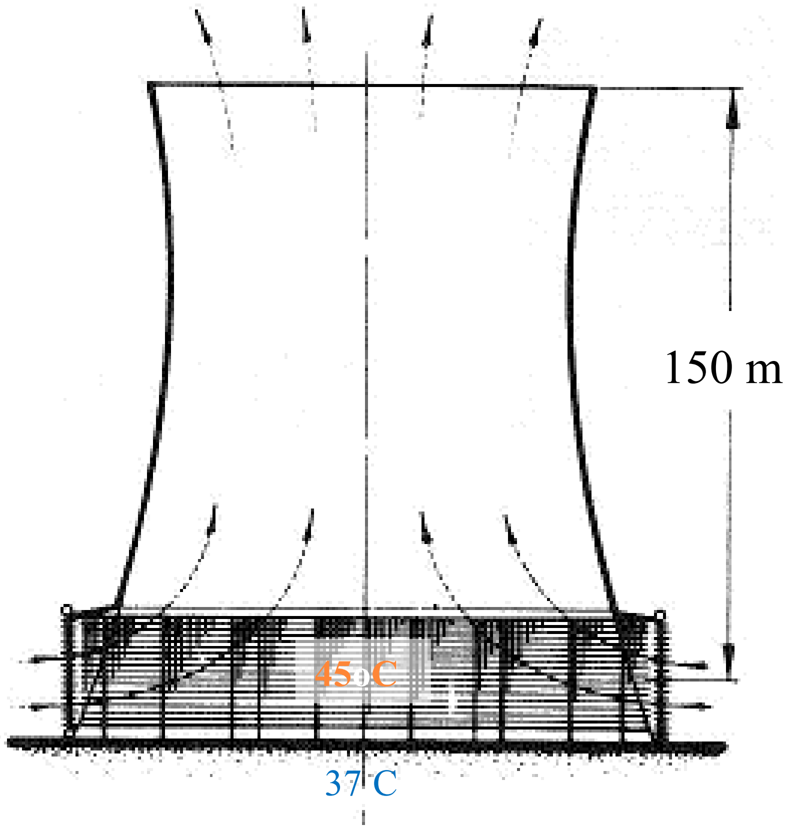
CURRENT BEST PRACTICE IN DRY COOLING TOWERS

- New 1000-MW plant with air cooling every fortnight
- All new coal-fired power plants built in Northern China are required by government regulations to use dry cooling towers

Dots show recent air-cooled condensers installed by only one company

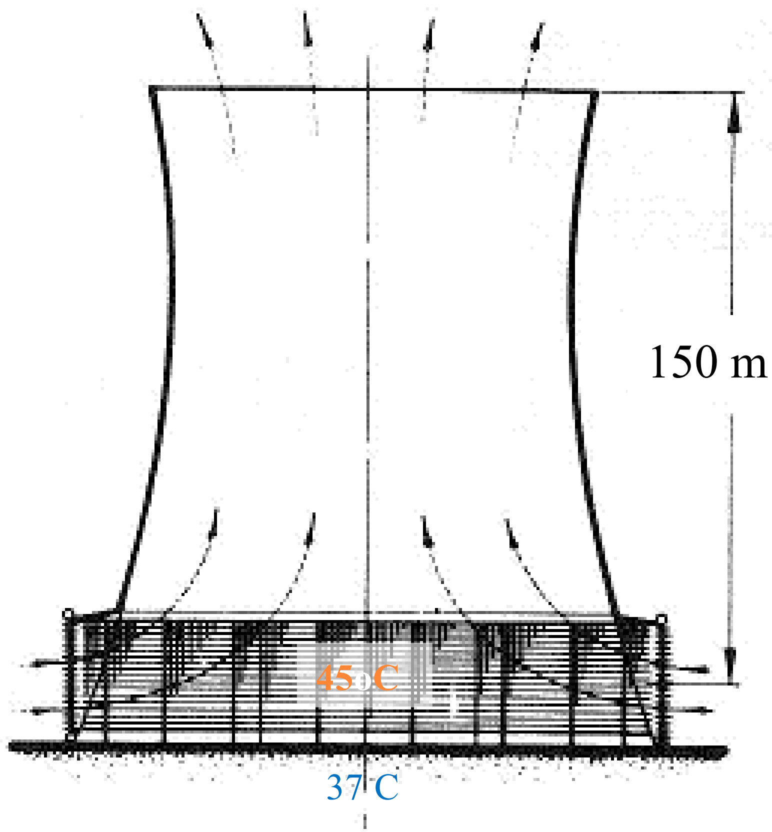
COST OF THE CURRENT BEST PRACTICE

- Coal-fired power plants
  - A$100/kWe
    - 65% heat exchanger
    - 35% structural and others
- Geothermal plants
  - A$250/kWe
- Cost Breakdown
    - 65% heat exchanger
    - 35% structural and others

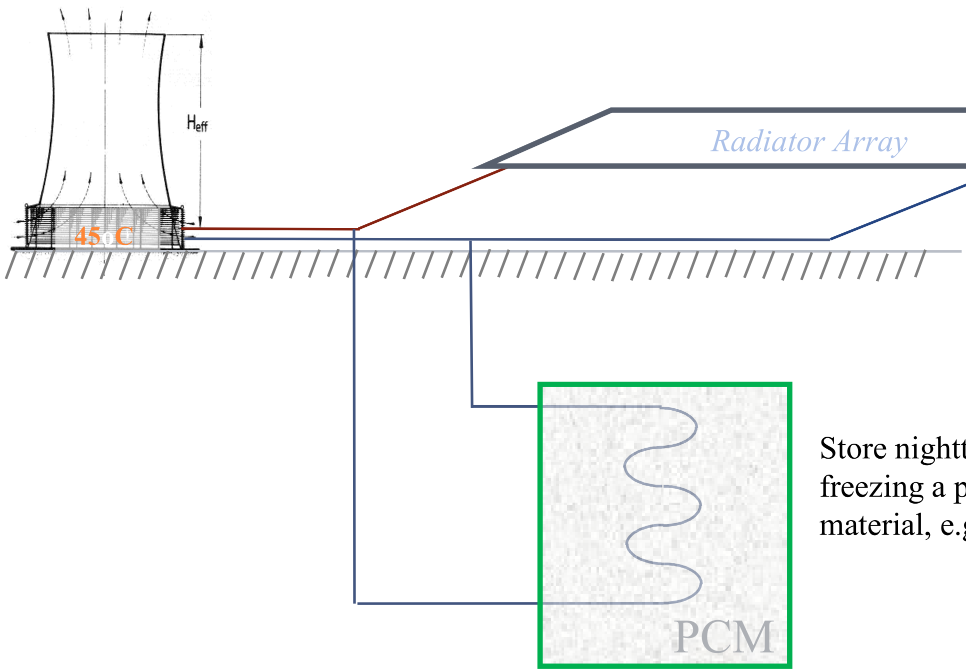


IMPROVING THE CURRENT BEST PRACTICE

- Buoyancy drives a cooling tower
- The trade-off between the heat exchange area and the pressure drop is important
- Local terrain and wind conditions may have a significant effect
- Research avenues
  - Advanced heat exchanger technology
    - Porous matrix heat exchangers
    - Printed circuit heat exchangers
    - Nanotechnology
      - Heat exchange fluids
      - Surface augmentation
  - System optimisation
    - CFD studies
    - Experimental studies
  - System innovations
    - Nocturnal cooling
    - Partial evaporative cooling
    - Supercritical cycles



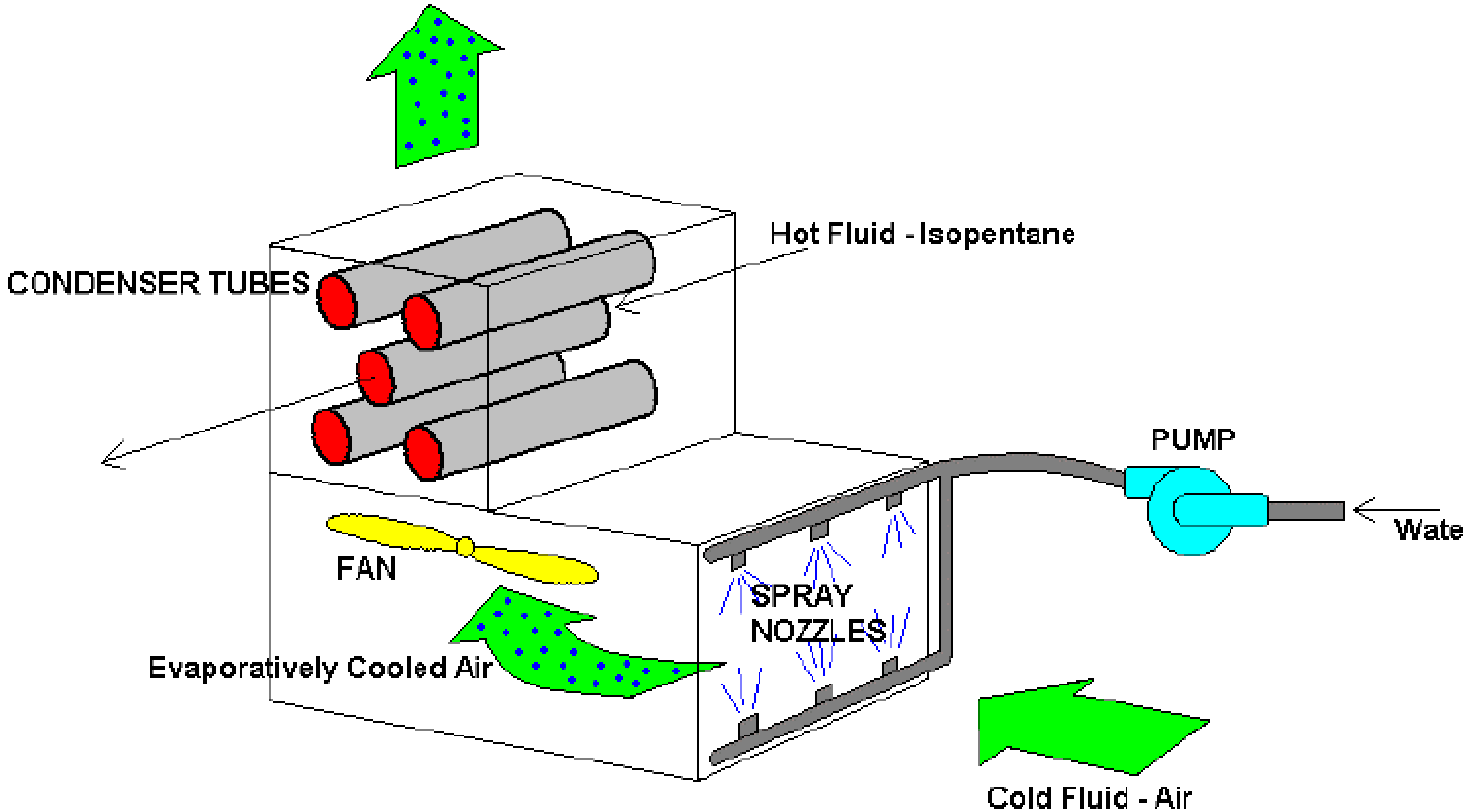
AIR COOLING OPTION #1 – NOCTURNAL COOLING



Radiate heat to nighttime sky

Store nighttime “coolth” by freezing a phase-change storage material, e.g. Glauber’s salt

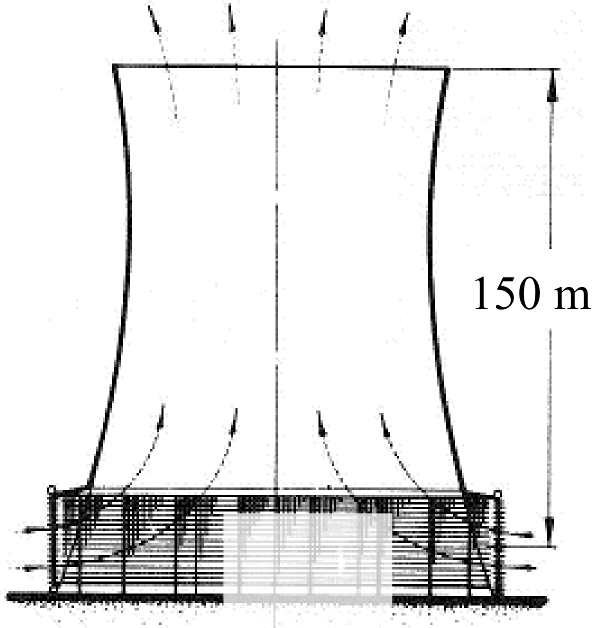
AIR COOLING OPTION #2 – (PARTIAL) EVAPORATIVE COOLING



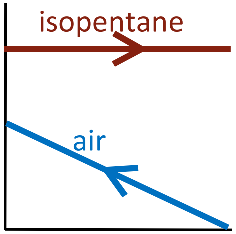
Assessment of Evaporative Cooling Enhancement Methods for Air-Cooled Geothermal Power Plants, Kutscher and Costenaro (2002)

OPTION #3 – COOL THE CYCLE FLUID DIRECTLY NOT AIR

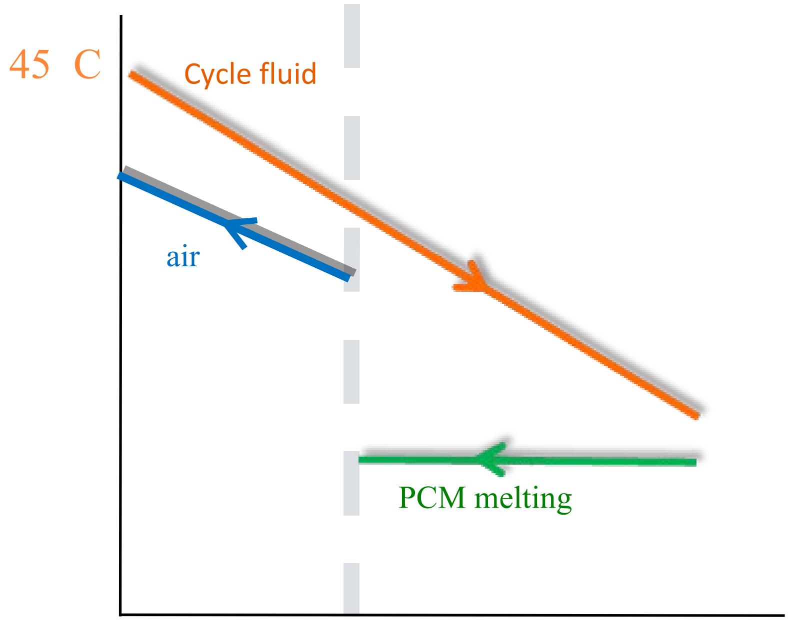
- If we have extra cooling capacity, it is better to use it directly
- Why not cool isopentane by
  - Using air for the first stage of cooling
  - Using additional means for extra cooling
- Unfortunately, this is not possible with condensation at a fixed temperature



No condensation if



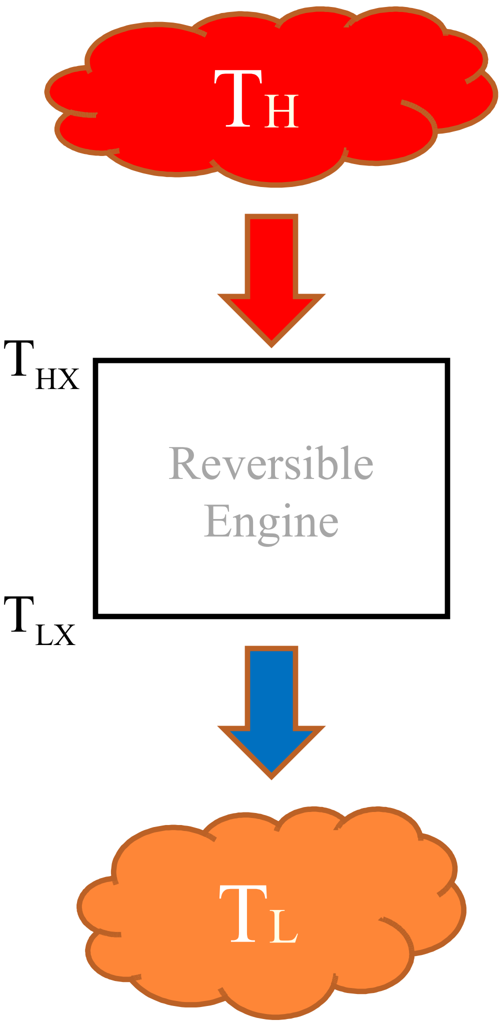
VARIABLE TEMPERATURE CONDENSATION



With a variable condensation temperature, we can contemplate systems where high-temperature cooling is done by the ambient air and the low-temperature cooling is provided by other means, e.g. boost by nocturnal cooling.

- The following cycles offer variable-temperature cooling
  - Kalina cycle
  - Mixed hydrocarbons
  - Supercritical cycles
- Variable temperature applies during boiling as well with a further boost to the cycle efficiency
- Supercritical CO_2 is a suitable option but there are others

REVERSIBLE HEAT ENGINE



Ideal heat exchange between the two reservoirs

$$\eta_o = 1 - \frac{T_L}{T_H}$$

The actual heat engine will work between T_{LC} and T_{HC} because of the heat exchanger temperature differences:

$$\eta_x = 1 - \frac{T_{LX}}{T_{HX}}$$

The efficiency loss

$$\eta_o - \eta_x = 1 - \frac{T_L}{T_H} - \left(1 - \frac{T_{LX}}{T_{HX}}\right) = \frac{T_H \Delta T_L + T_L \Delta T_H}{T_H \left(T_H - \Delta T_H\right)} \cong \frac{\Delta T_L}{T_H} + \left(1 - \eta_o\right)\frac{\Delta T_H}{T_H}$$

- It is important to minimise the heat exchanger temperature differences
- The importance of the high temperature differential is higher at low efficiencies

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HEAT EXCHANGE TEMPERATURE DIFFERENCES

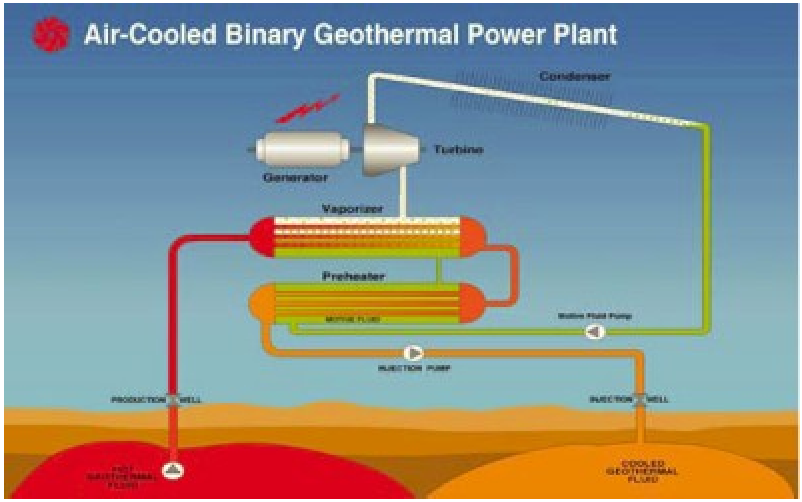
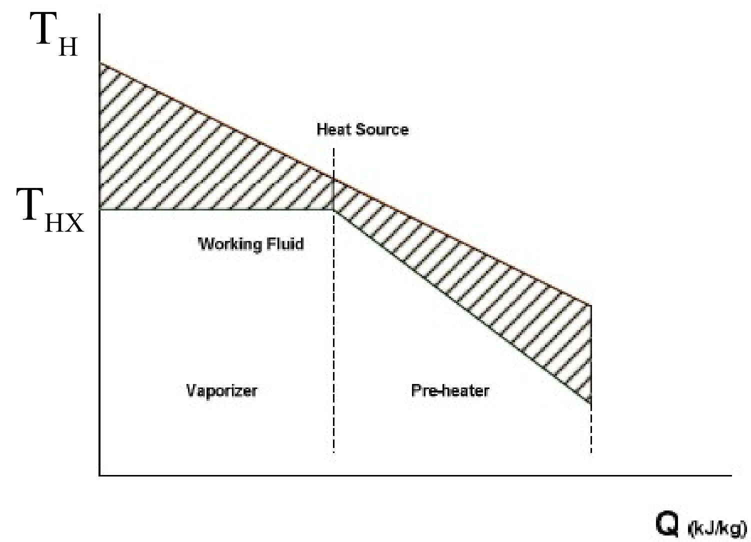
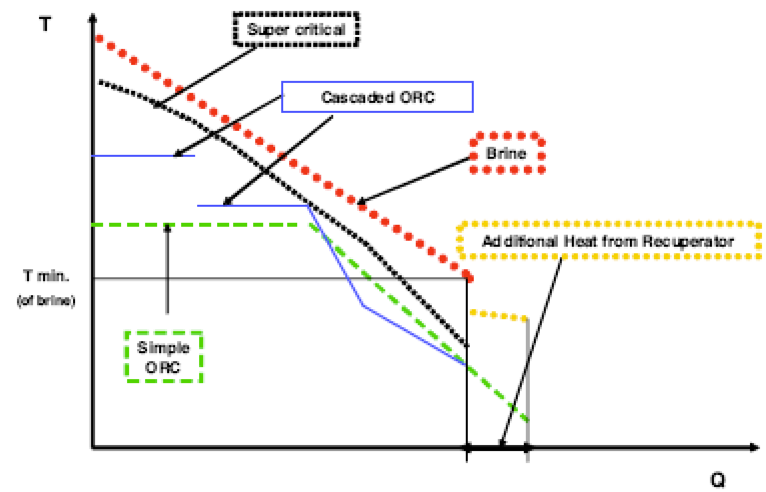


Fig. 3. Single-phase 2.2 MW Hatchobaru Plant in Japan





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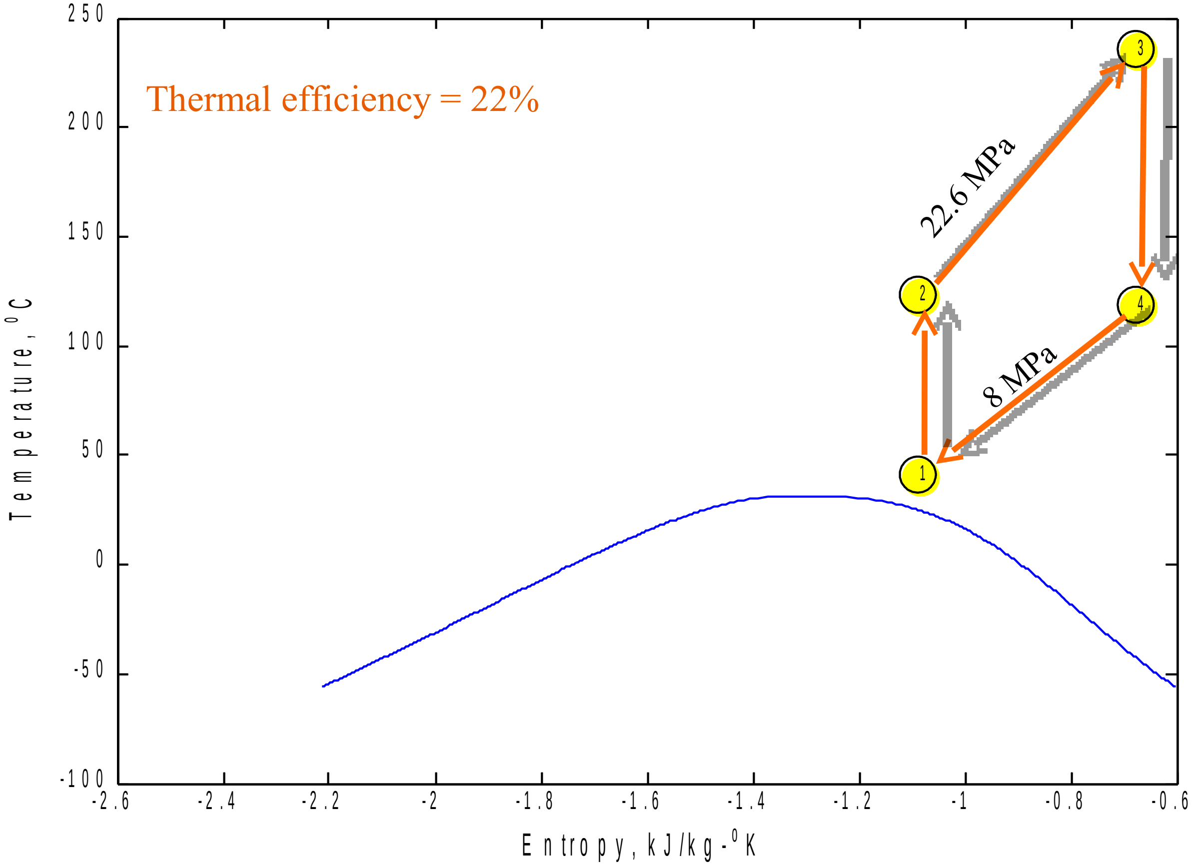
SUPERCRITICAL CO_2 CYCLE



DRY COOLING TOWER RESEARCH PROGRAM STRATEGY

- Seek research and manufacturing partner to catch the best practice
- Experimental and analytical studies to explore
  - Nocturnal cooling
  - Hybrid systems
  - Supercritical cycles
- Landmark project to test a small-scale prototype
- Scale up to a 50-MW geothermal power plant
- Do all this in the next three years

H Gurgenci (h.gurgenci@uq.edu.au)

POWER CONVERSION PROGRAM

- System Studies
  - Accurate cost estimates for geothermal electricity
  - Start from fundamentals and draw on the global and the national experience
  - Use data from related industries
  - Thermodynamic data accessed through a fluid property database, e.g. `refprop`
  - Outcomes publicly available in 2009
- Power Cycle Fluids
  - Newcastle University is trialling different fluids. We will monitor the work.
- Expander/Turbine
  - Research on off-design and part-load efficiencies of expanders and turbines on different power cycle fluids. This will help planning optimum extraction schedules for geothermal reservoirs. Access will be sought to the Geodynamics 1-MW pilot plant, which is using a steam turbine in a binary plant.
  - QGECE turbine testing laboratory will have the capability to test small turbines (<5kW). Simulation tools will be developed to predict the same for larger industrial turbines.
  - Develop and test a supercritical CO_2 turbine
    - 5-kWe laboratory prototype tested in 2011
    - Manufacturing alliance to build a 500-kWe turbine in 2012
  - Continue exploring different expander options. In addition to generation of in-house alternatives, third-party inventions can be tested and evaluated in the QGEC turbine laboratory

RESERVOIR PROGRAM

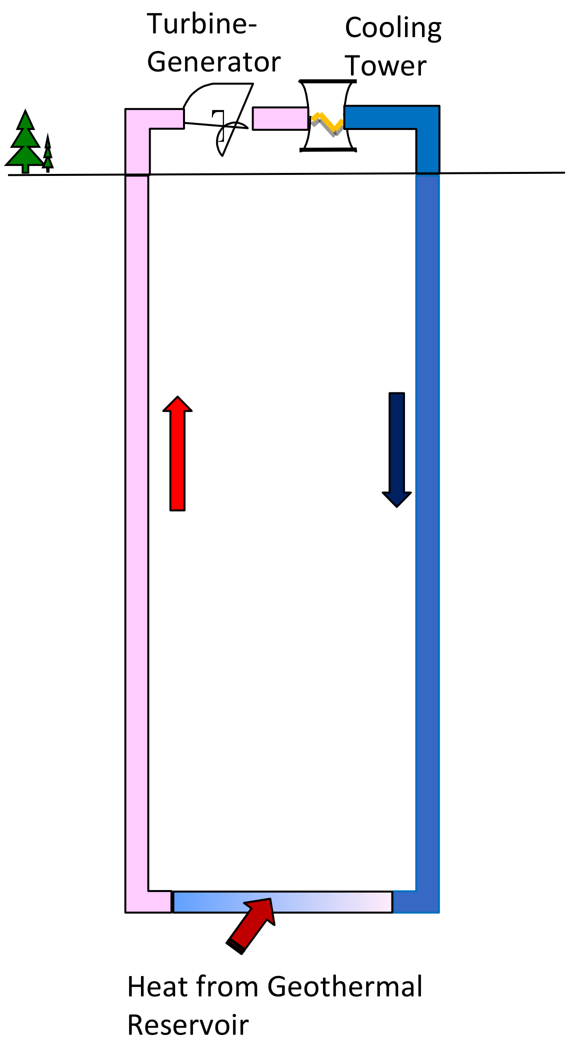
- Improve the existing knowledge and develop new innovative scientific approaches for the identification of geothermal resources in Queensland
- Provide an understanding of long-term effects of water-rock interaction on geothermal reservoir
- Specifically,
  - PhD 1 : New petrological, geochemical and geochronological approaches to characterisation and identification of heat-producing granites in Queensland
  - PhD 2 : Geochemistry and timing of fluid flow events as fingerprints in determining geothermal heat anomalies and their sources
  - PhD 3: Detailed geochemical studies of water and gas samples to represent geothermal targets with high potential
  - Honours/MPhil: Compiling and interpreting all available geophysical data collected from files of Geoscience Australia and oil/gas company archives

ELECTRICITY TRANSMISSION PROGRAM

- Develop an electrical grid network model for Eastern and South Australia (this covers the NEMMCO network)
- Develop tools to understand the implications of concentrated geothermal electricity generation at different locations in terms of the following:
  - grid stability, thermal, reactive power and voltage limits
  - inter area frequency oscillation
  - HVAC versus HVDC, regarding cost and network security
  - storage and adequacy, including corridor congestion, dispatch patterns and interaction with trading systems

NOW SOMETHING ENTIRELY DIFFERENT

CO_2 GEOTHERMAL SIPHON



- Supercritical CO2 behaves like a liquid in the injection well and like a gas in when it is hot
- The hot fluid will rise as in a flash geothermal plant
- There is no phase change
- Lower viscosity makes it easier to penetrate the reservoir
- Supercritical CO_2 turbines will be more compact and possibly cheaper
- No need for
  - Boiler
  - Submersible pump

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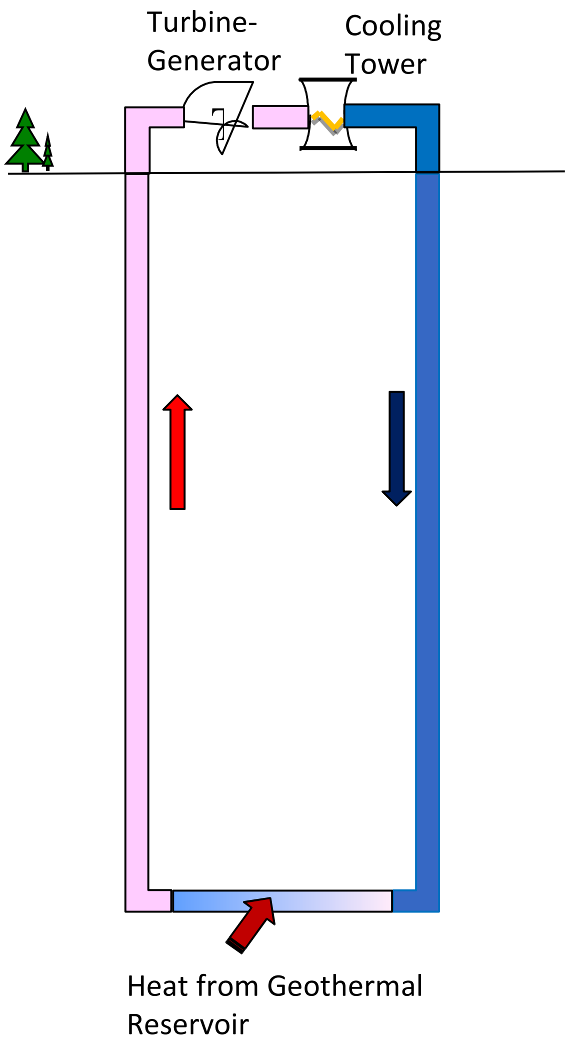
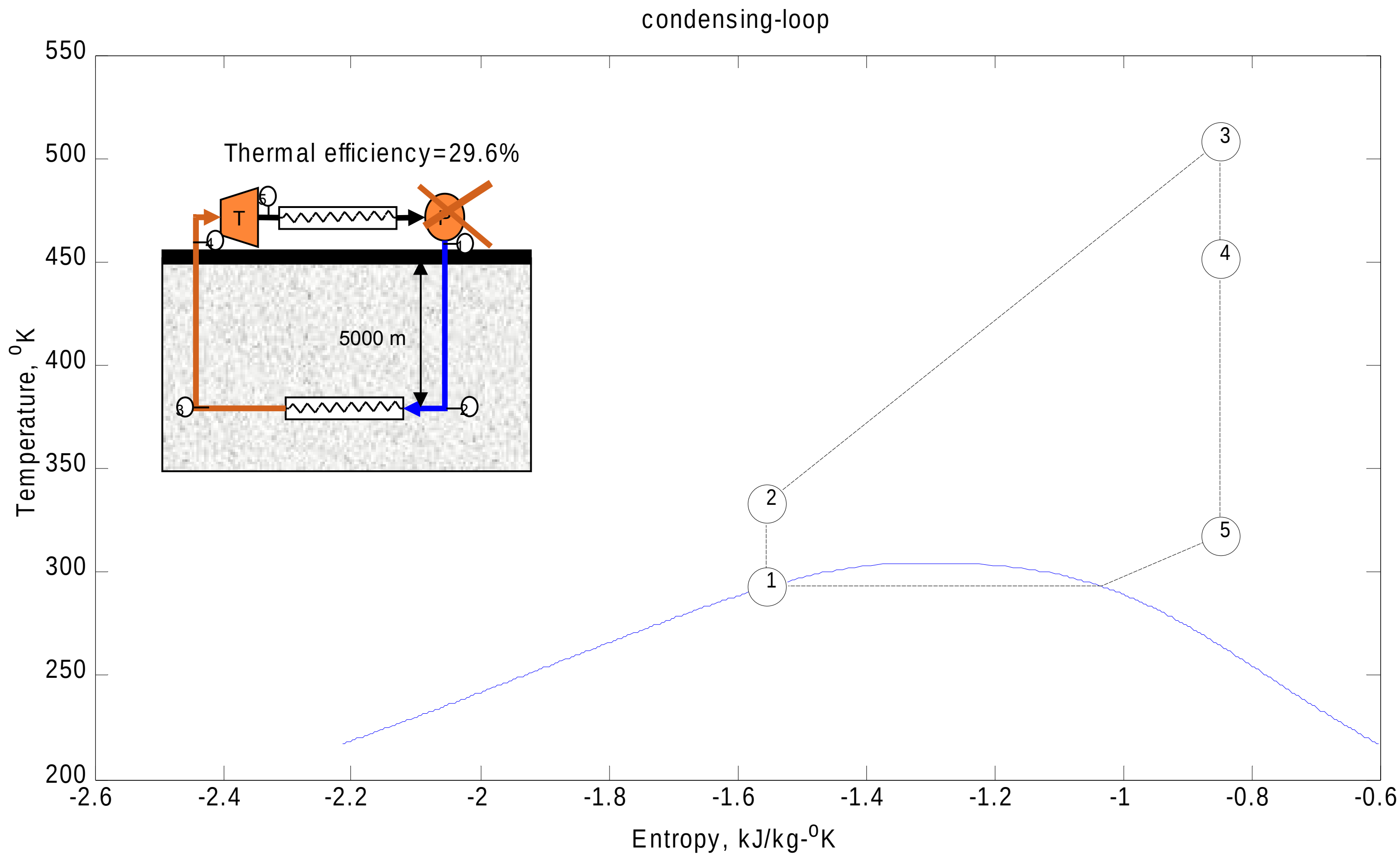
GEOTHERMAL SIPHON VS BINARY PLANT

- Preserve the EGS Binary Plant Advantages:
  - Access to huge resources around the globe
  - Higher efficiency at low temperatures (compared to steam)
  - Non-corrosive working fluid in turbine
  - Completely dry expansion
  - Condensing temperatures can be lower
- But eliminate all its disadvantages:
  - No extra heat exchanger to boil the cycle fluid
  - No extra costs and efficiency losses
  - No need for a submersible pump to suck the brine



TRANSCRITICAL CO_2 RANKINE CYCLE



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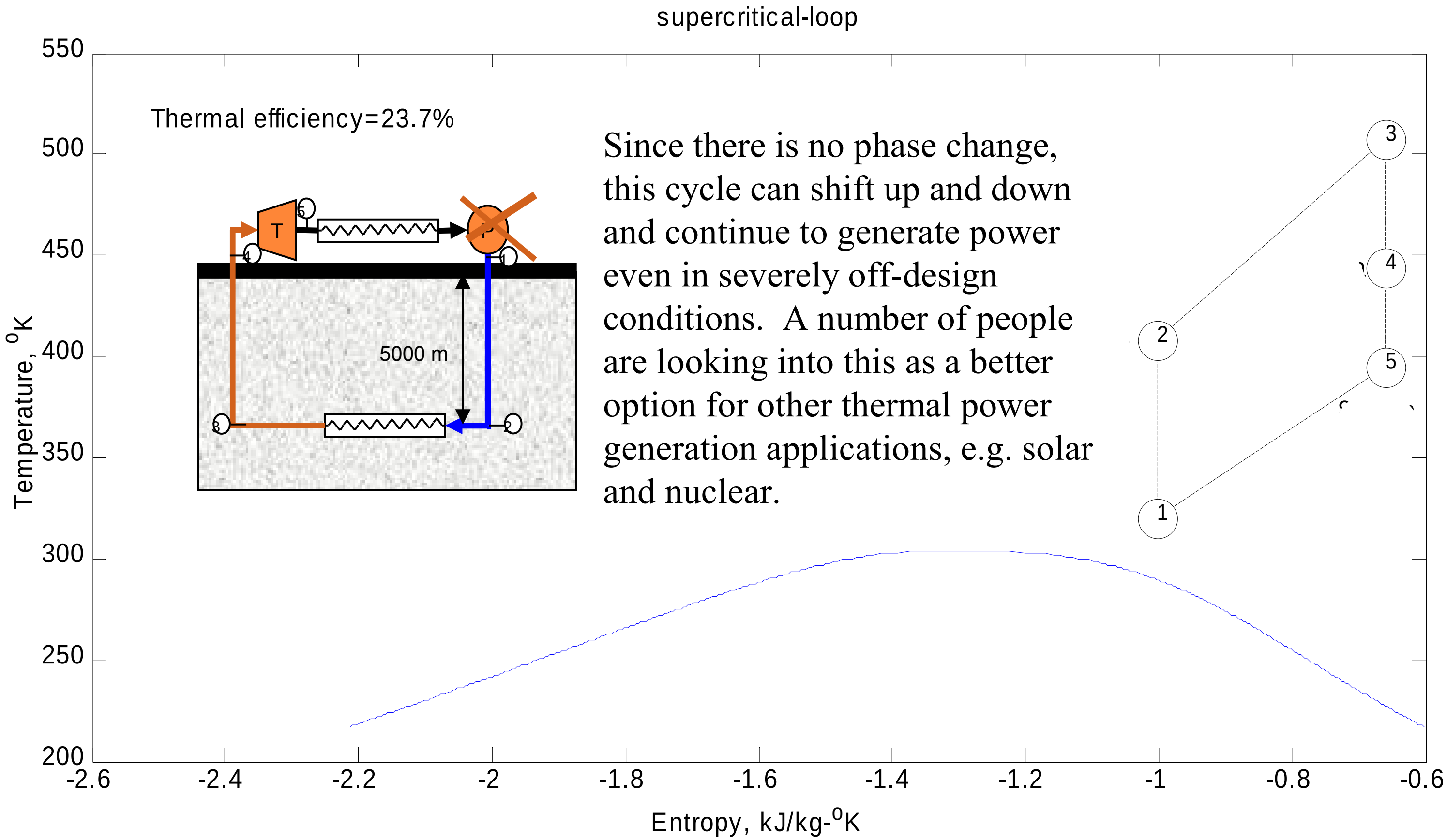
SUPERCRITICAL CO_2 BRAYTON CYCLE



Since there is no phase change, this cycle can shift up and down and continue to generate power even in severely off-design conditions. A number of people are looking into this as a better option for other thermal power generation applications, e.g. solar and nuclear.

WHAT IS THE CATCH?

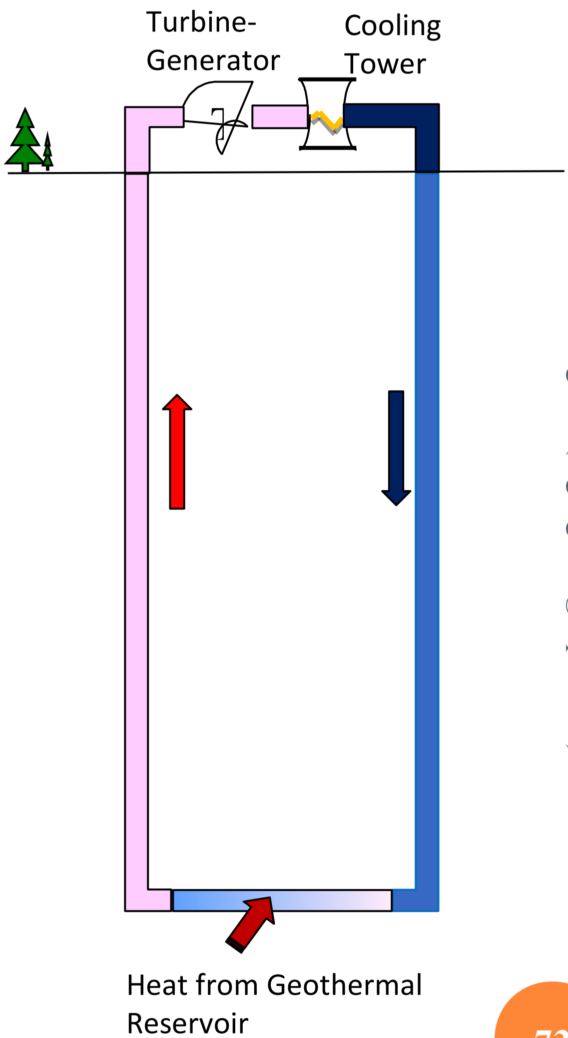
- This is a new concept. There are questions that can only be answered by scientific investigation.
- Large quantities of CO_2 needed to get the geothermal siphon running

KNOWN UNKNOWNS

- Geochemistry of supercritical CO2
- The interaction with pore water
- How are going to dry off a wet reservoir?
- Long-term effects
  - in terms of reservoir connectivity
  - CO_2 leakage (only relevant if carbon credits are used to reduce the cost of obtaining CO_2)
- Supercritical CO_2 turbine and air-cooled heat exchanger needed
  - (will also apply the solar thermal power applications)

CONTINUING FLUID SUPPLY?

- EGS field tests with brine had normal unintended losses from 10% to 40%
- Less viscous CO2 may penetrate further and is more likely to get trapped underground
- We may need large quantities of make-up CO2
  - We do not know exactly how much and for how long but let us assume 10% underground capture
- CO_2 circulation needed to generate 1 MW
  - 12 kg/s
- Make-up fluid required for each MW
  - 1.2 kg/s (based on 10% underground capture)
- Annual make-up required for 50 MW
  - 1.2x3.6x8760=1,900,000 tonnes



Atık CO2 yi yer altında zaptederken ilave elektrik üretimi !?

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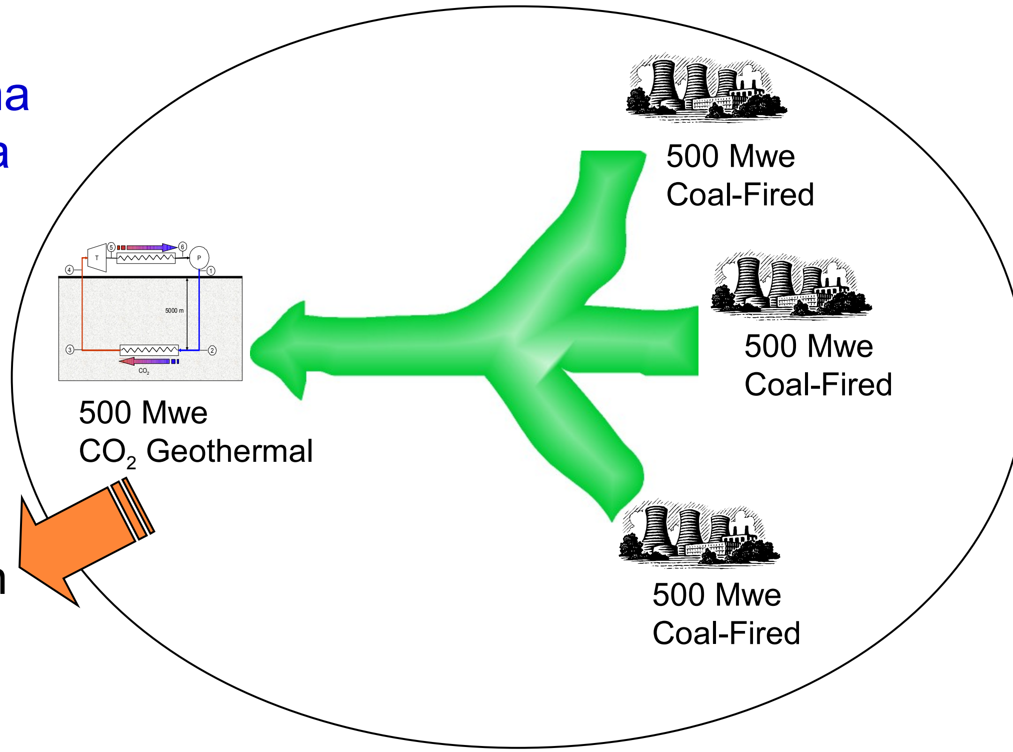
Mümkün mü? Belki.

Zayıf nokta, kömür santrallerinin CO2 yi yakalama maliyeti. Bu maliyet çok fazla olursa, ilave jeotermal enerji vaadi bile kömür santrallerini kurtarmaya yetmeyebilir.



2000 MWe Zero Emission Generation Capacity

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HISTORY

- Brown, D, A hot dry rock geothermal energy concept utilizing supercritical CO_2 instead of water, 25th Stanford Workshop, 2000
  - Introduction of CO_2 as a geothermal heat exchange fluid to transport the reservoir heat to a surface binary plant
- Pruess, K, Enhanced geothermal systems (EGS) using CO2 as working fluid—a novel approach for generating renewable energy with simultaneous sequestration of carbon, Geothermics, 2006
  - Numerical analysis supporting the superior heat exchange properties of CO_2 against water
- Gurgenci, H, Rudolph, V, Saha, T, and Lu, M. Challenges for geothermal energy utilisation, 33rd Stanford Workshop 2008
  - Introducing the single-loop geothermal siphon power generator; demonstrating the adequacy of the geothermal siphon to generate power through a supercritical CO_2 cycle without a binary plant

- USA-Australia-Iceland Collaboration on Geothermal Energy
  - Australian side represented by AGEA/AGEG
- CO_2 geothermal siphon is one of the research priorities identified by the steering committee
  - More work needed to identify research opportunities and priorities in this area.
  - There is interest for national and international (CRIEPI, MIT, DOE) collaboration
  - Establishment of a significant collaborative framework is essential to progress in this area

SUMMARY

- Hot Dry Rocks or Enhanced/Engineered Geothermal Systems (EGS) are defined as underground reservoirs not naturally suitable for geothermal energy extraction but can be made so through economically viable engineering procedures.
- In contrast with the limited availability of conventional geothermal resources, EGS are ubiquitous and abundant.
- They will become cost-competitive in the future when account is taken of the cost of applying greenhouse gas mitigation to conventional power generation through techniques such as carbon dioxide capture and storage (CCS) technology
- To serve the geothermal energy sector, a new manufacturing energy industry will come about with an annual international turnover of $20b. This estimate is based on 10% of the world electricity being provided by geothermal energy.
- The Queensland Geothermal Energy Centre will pursue research in the following areas:
  - Power conversion
  - Efficient air-cooled heat exchangers
  - Electricity transmission and power network modelling
  - Geothermal reservoir management
- The use of CO_2 offers interesting possibilities