# What Does the Future Hold for Geothermal Energy?

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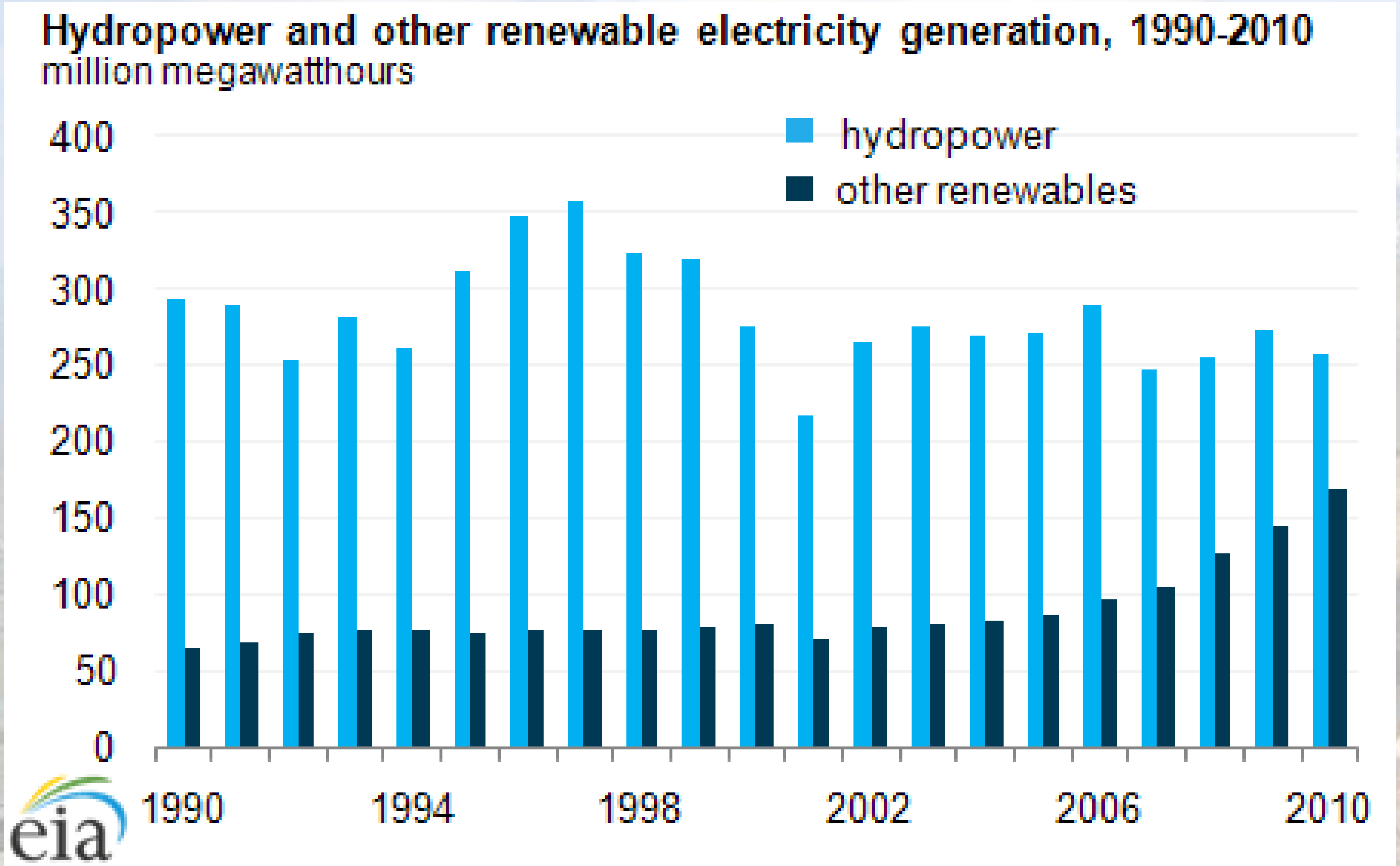
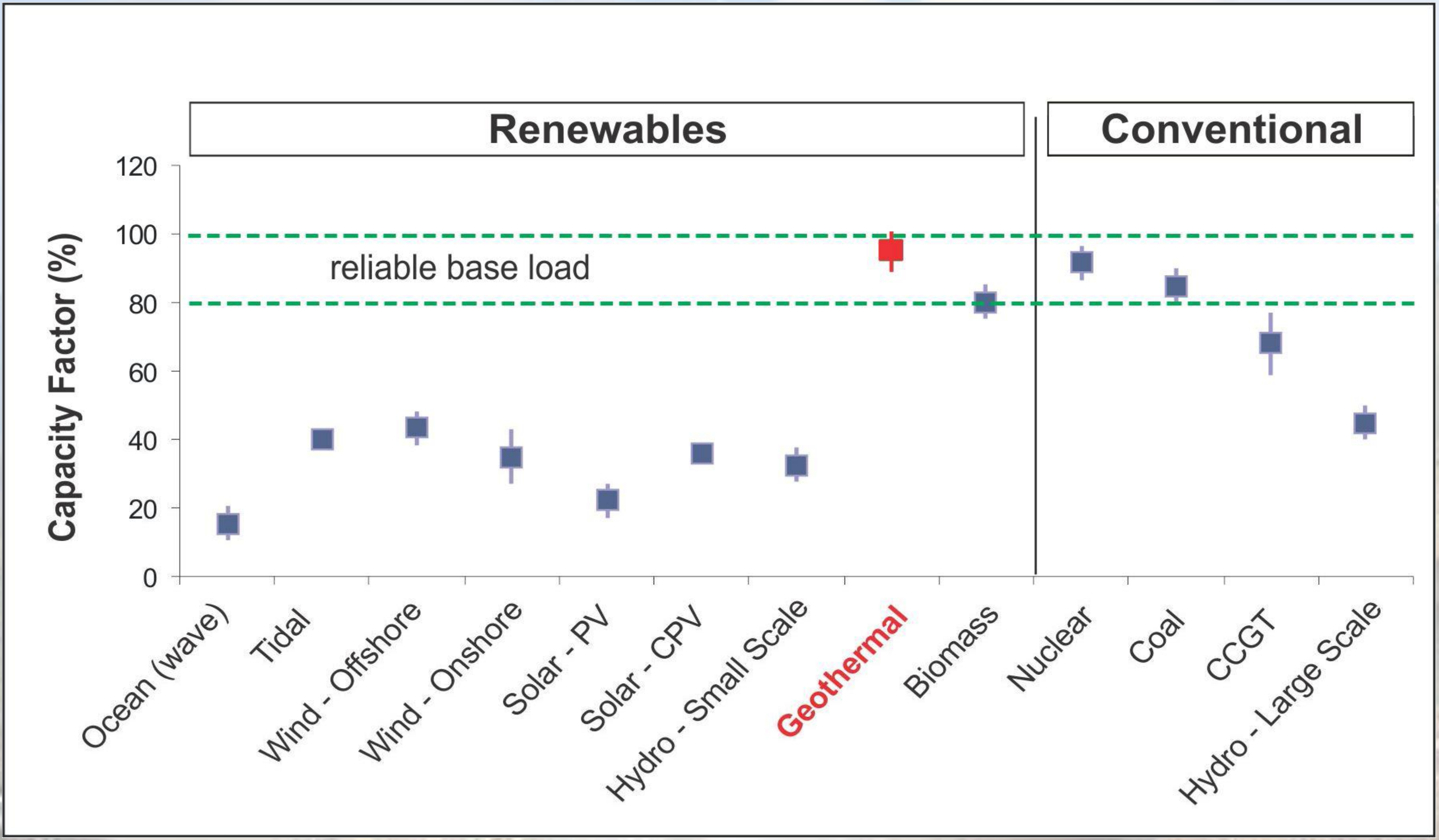
# The Future of Geothermal Energy

1. Where are we now?
2. Innovations in plant design.
3. Use of lower temperature resources.
4. Reservoir enhancement.

# 1. Strong Growth in Renewables

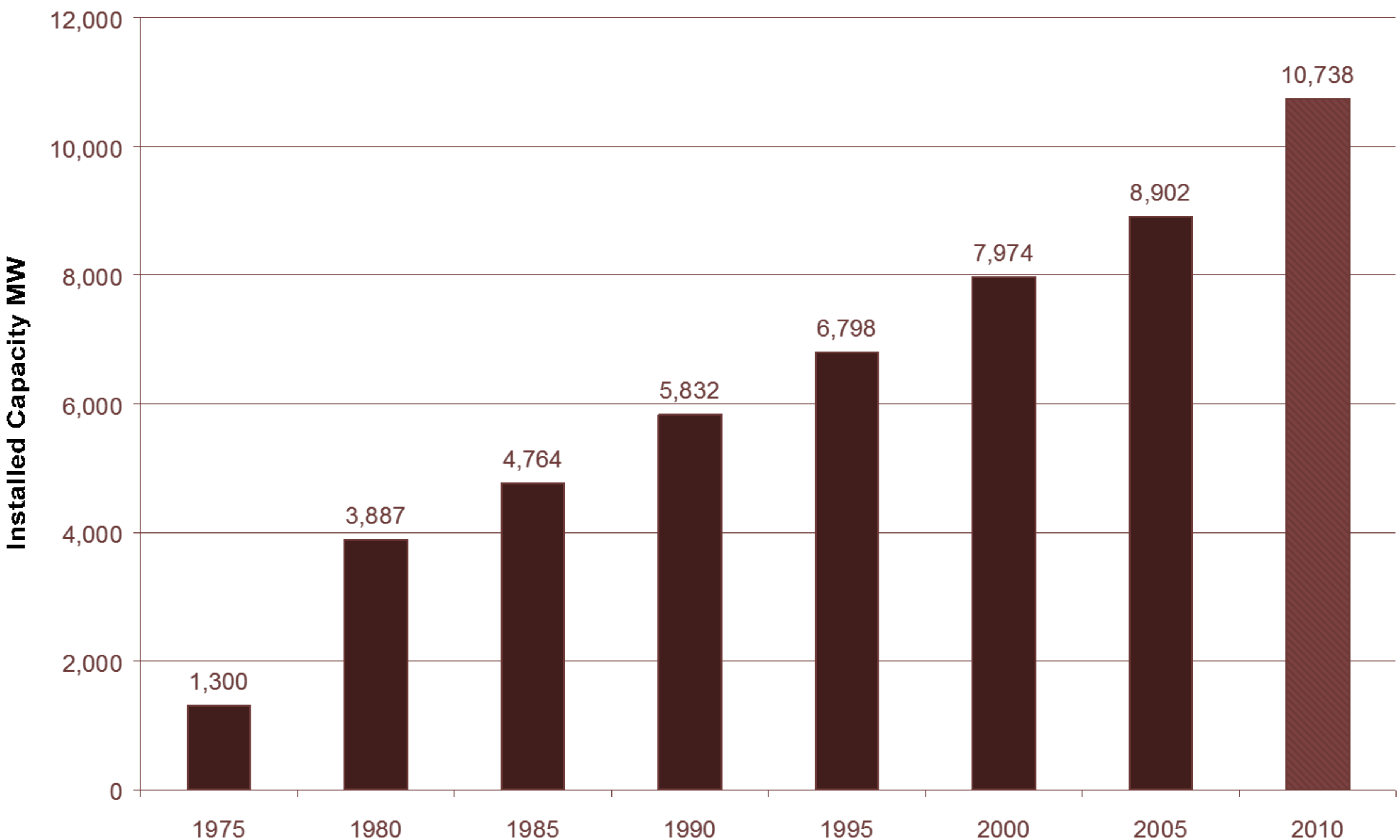


# Not All Renewables are Alike




Source: Emerging Energy Research (2009)

# World Geothermal Electricity (2005)




source: Bertani (2005) WGC2005

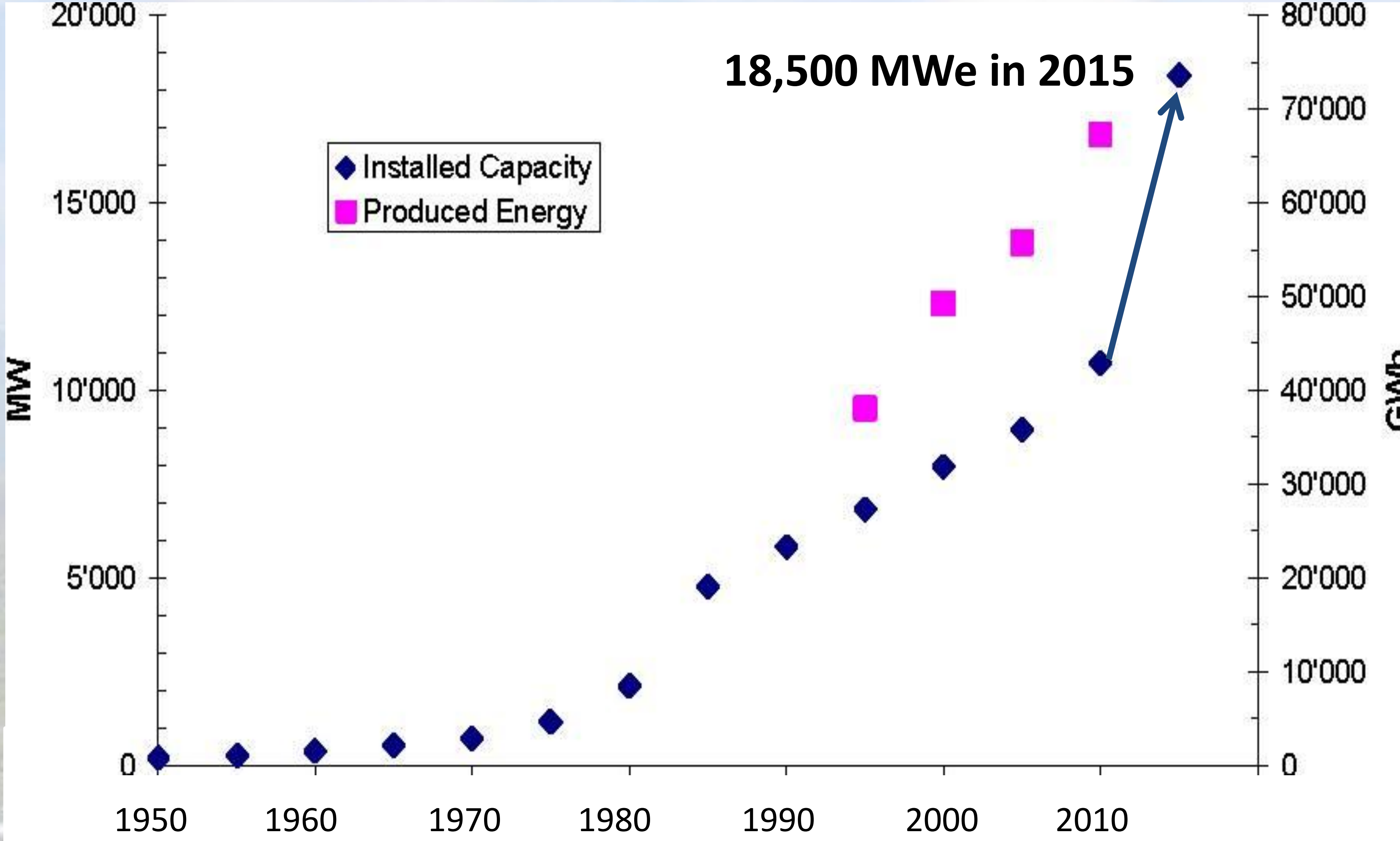
# 2010 Capacity and Use

| Use | Installed Power (MW) | Energy Use (GWh/yr) | Capacity Factor |
|---|---|---|---|
| Electric | 10,715 | 67,246 | 0.72 |
| Direct-use | 48,483 | 117,778 | 0.28 |

**Geothermal energy kept its promises!**

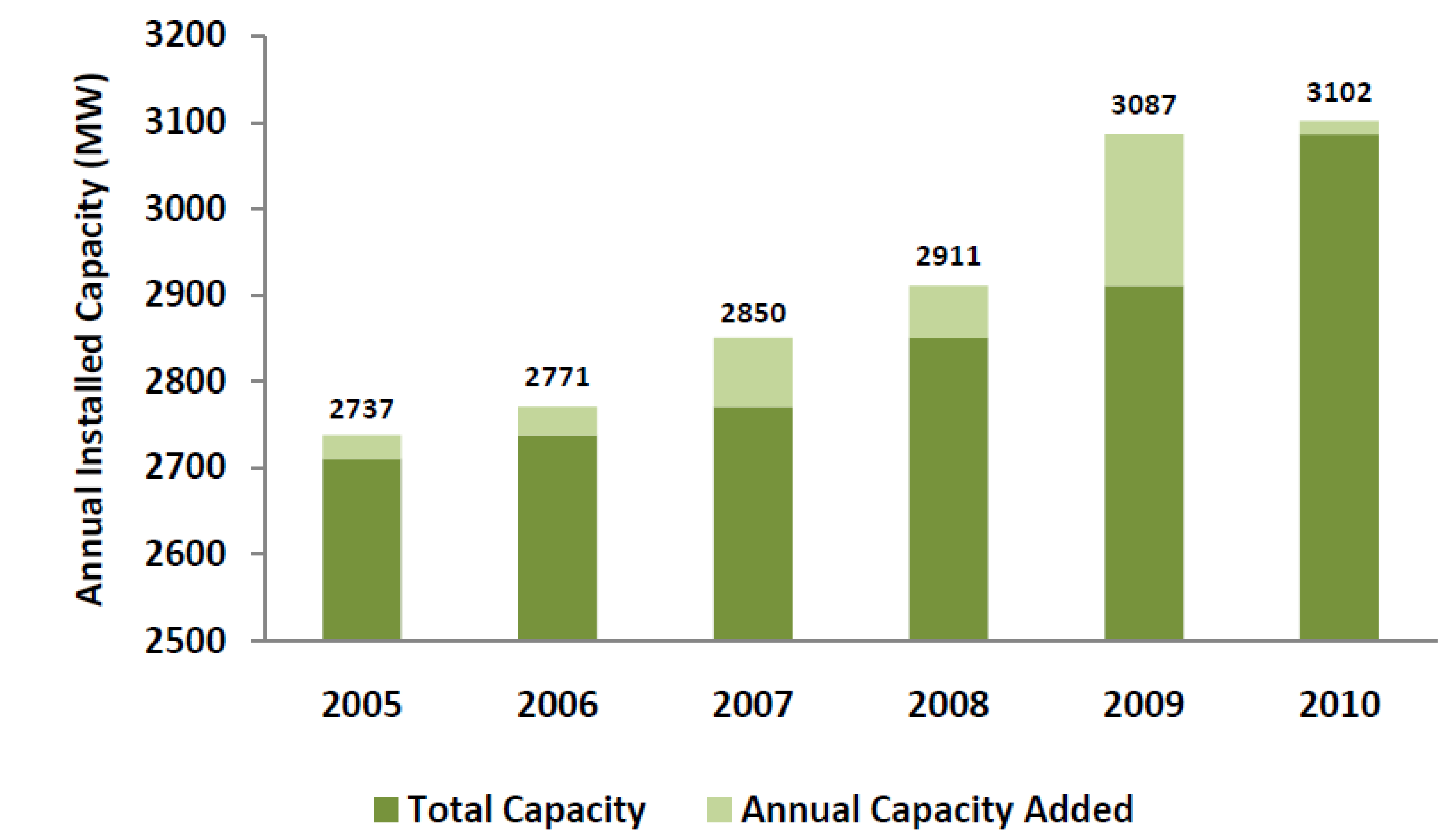
Lund and Bertani, 2010, WGC and GRC

# World Geothermal Electricity (2010)



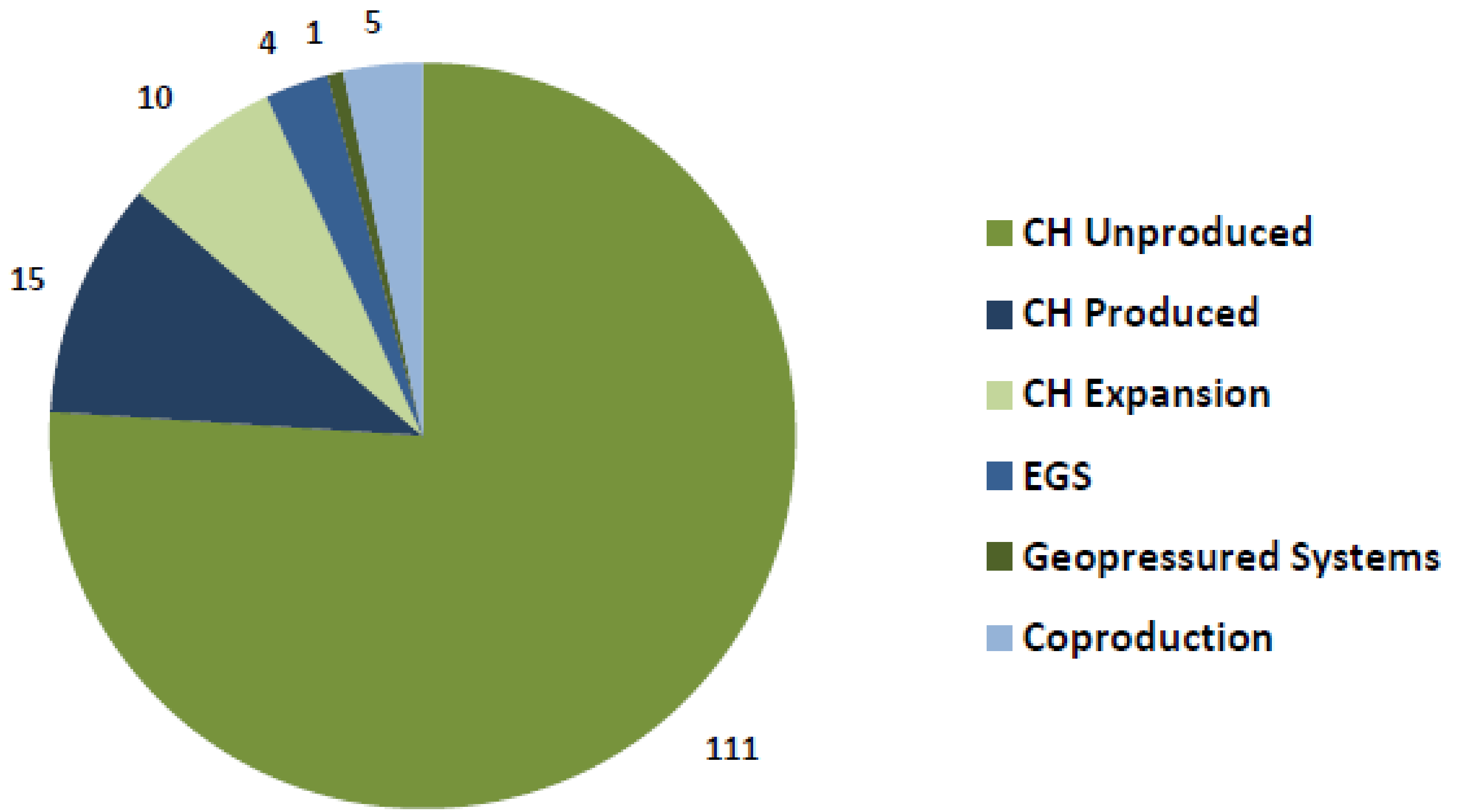

Bertani, 2010, WGC

# Installed Capacity in USA

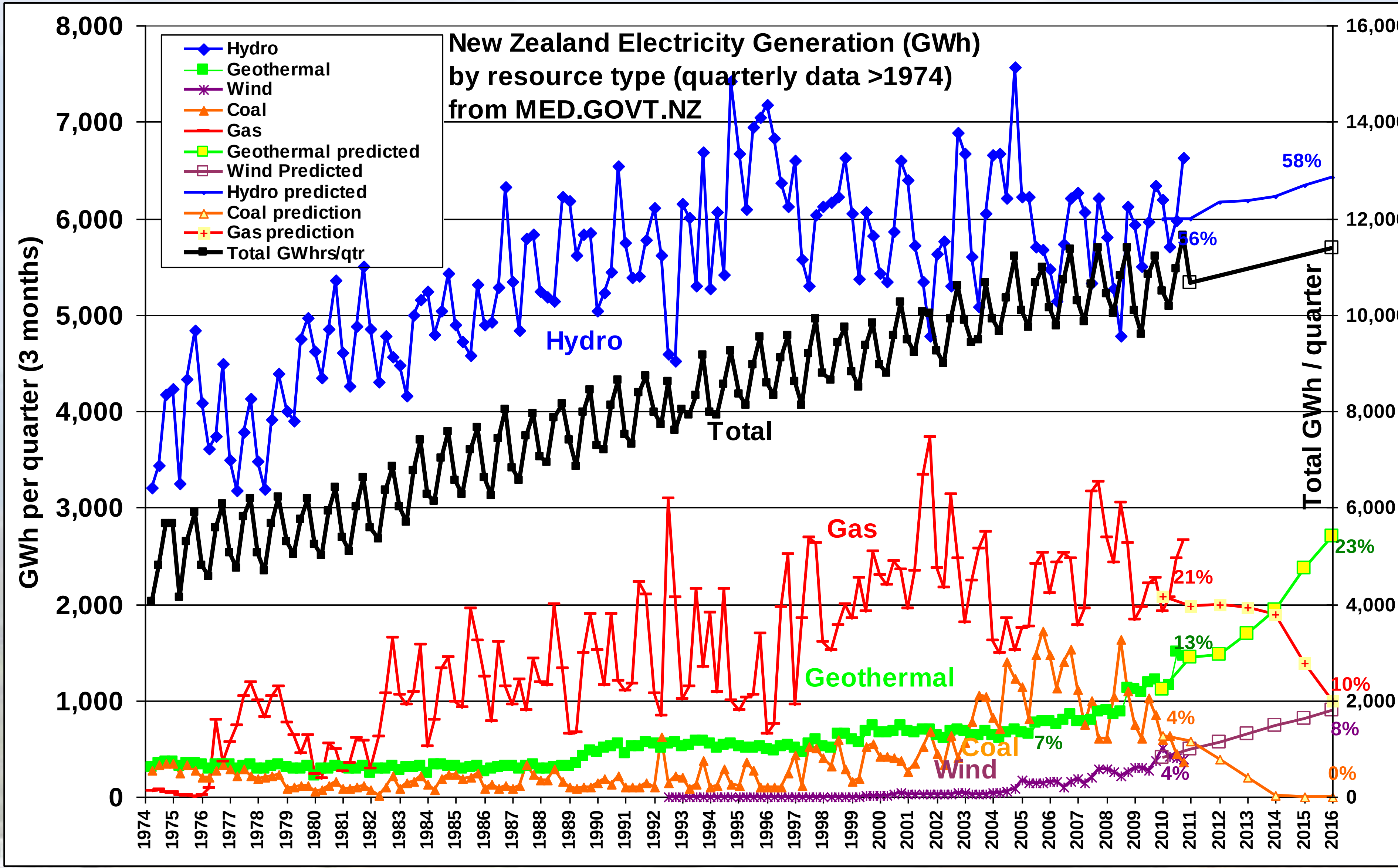



Source: GEA April 2011

# 146 Projects Under Development




**Source: GEA** April 2011




Bromley, 2011

# 2. Innovation in Plant Design

- 1970-2000 “Standard”:
  - – 55 MWe single-flash plant
  - – Inlet pressure ~600 kPa
  - – Steam consumption 8-10 kg/kWh
- 2000+ plants:
  - – Combined cycle plants
  - – Hybrids
  - – Inlet pressure up to 2550 kPa
  - – Steam consumption as low as 5 kg/kWh


Photo: Mighty River Power

Rotokawa:
Combined cycle flash/binary plant
Flash turbine inlet pressure 2550 kPa
Steam consumption 5 kg/kWh

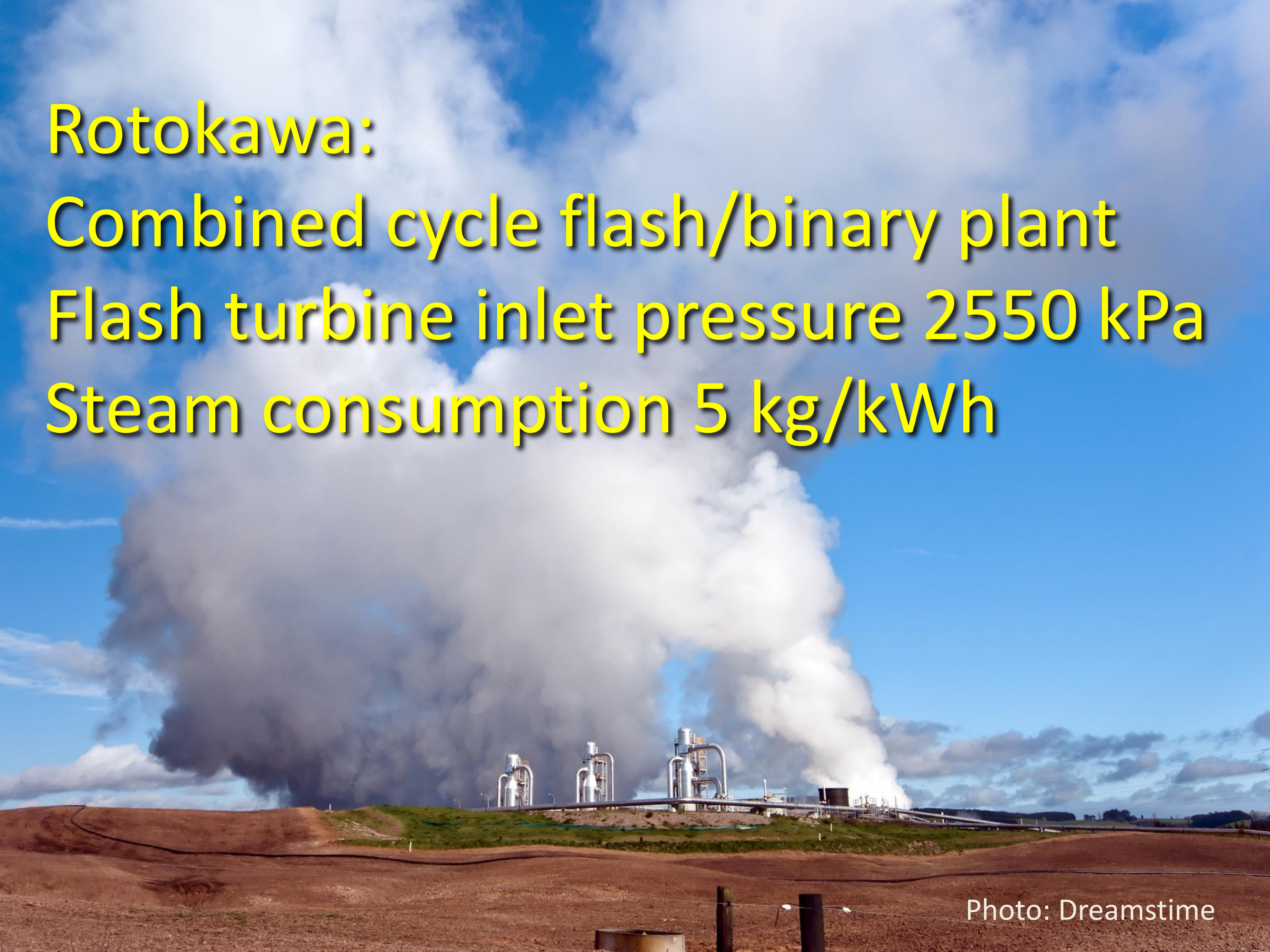


Photo: Dreamstime

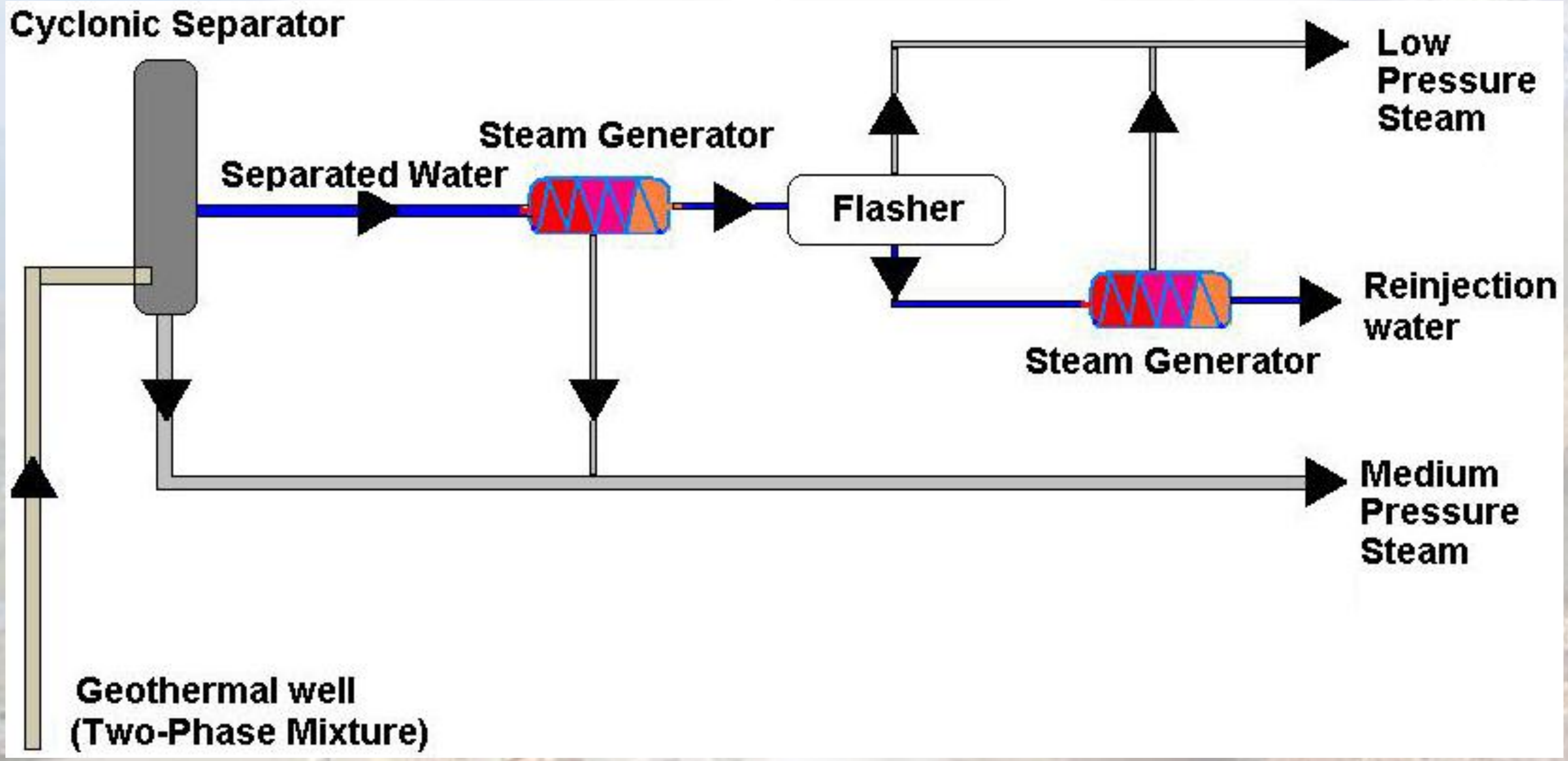
# Geothermal and Solar Thermal Hybrids

- Ahuachapán, El Salvador, well AH-6.

Handal et al., 2007

# Geothermal and Solar Thermal Hybrids

- Ahuachapán, El Salvador, well AH-6.




Alvarenga et al., 2008

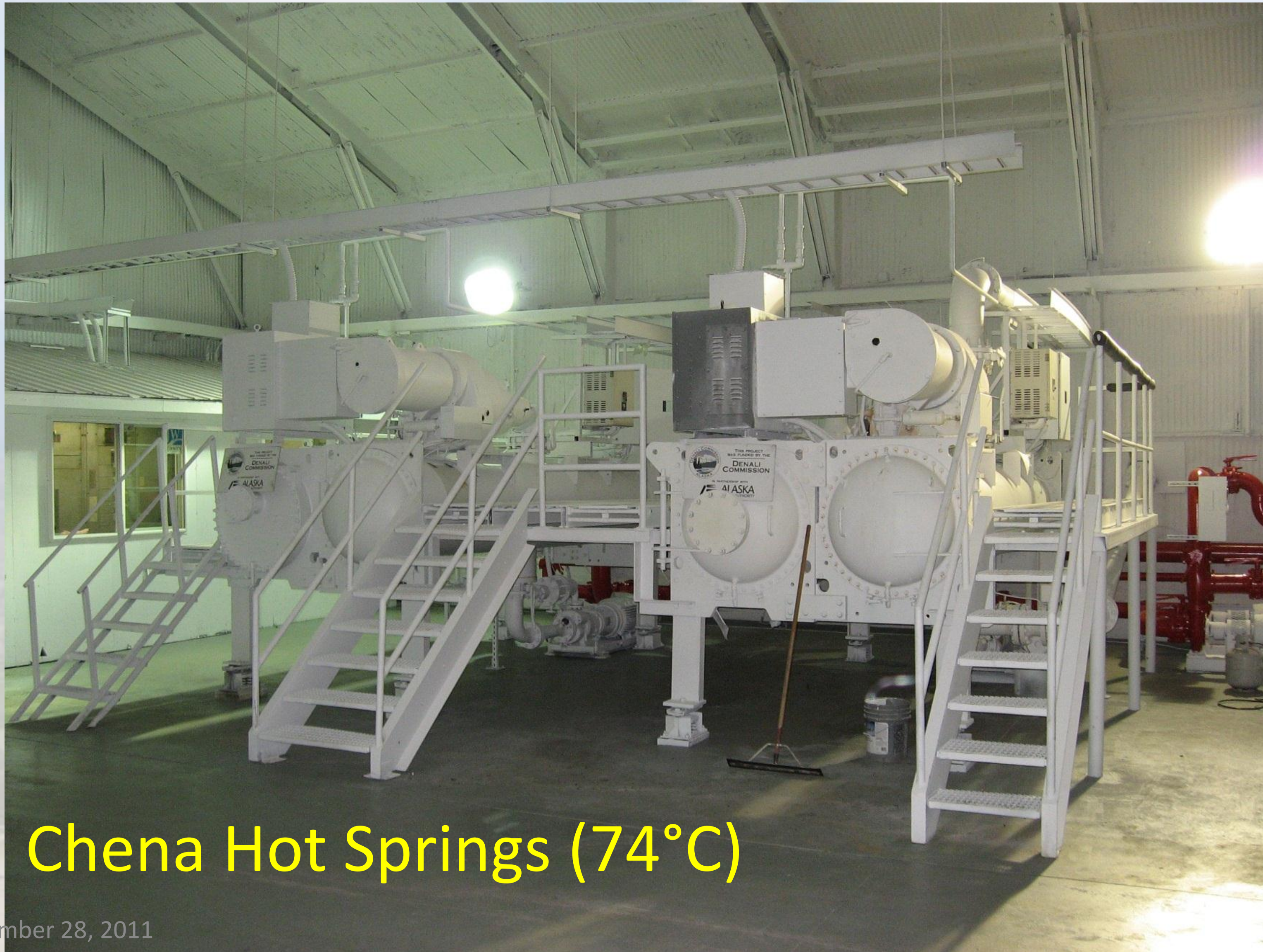
# Geothermal and Solar PV Hybrid

- 24-megawatt solar installation at Stillwater Geothermal Plant in Churchill County, Nevada, for peak addition to the 47 MW geothermal plant.



http://www.arthurdomagala.com/blog/2011/10/stillwater-solar-power-plant-construction/

# 3. Lower Resource Temperatures



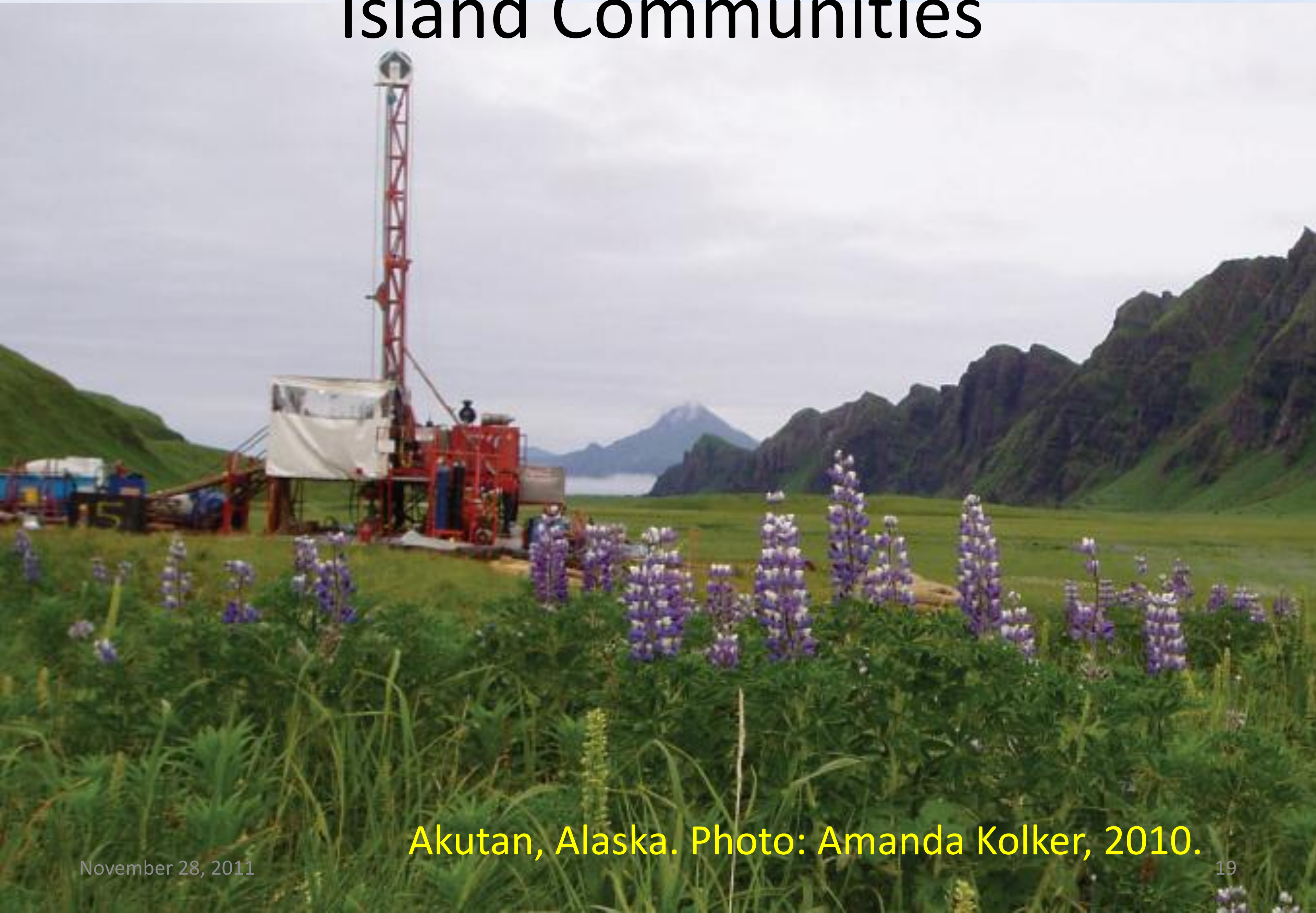
Chena Hot Springs (74°C)

Photo: Roland Horne, 2007

# Lower Resource Temperatures

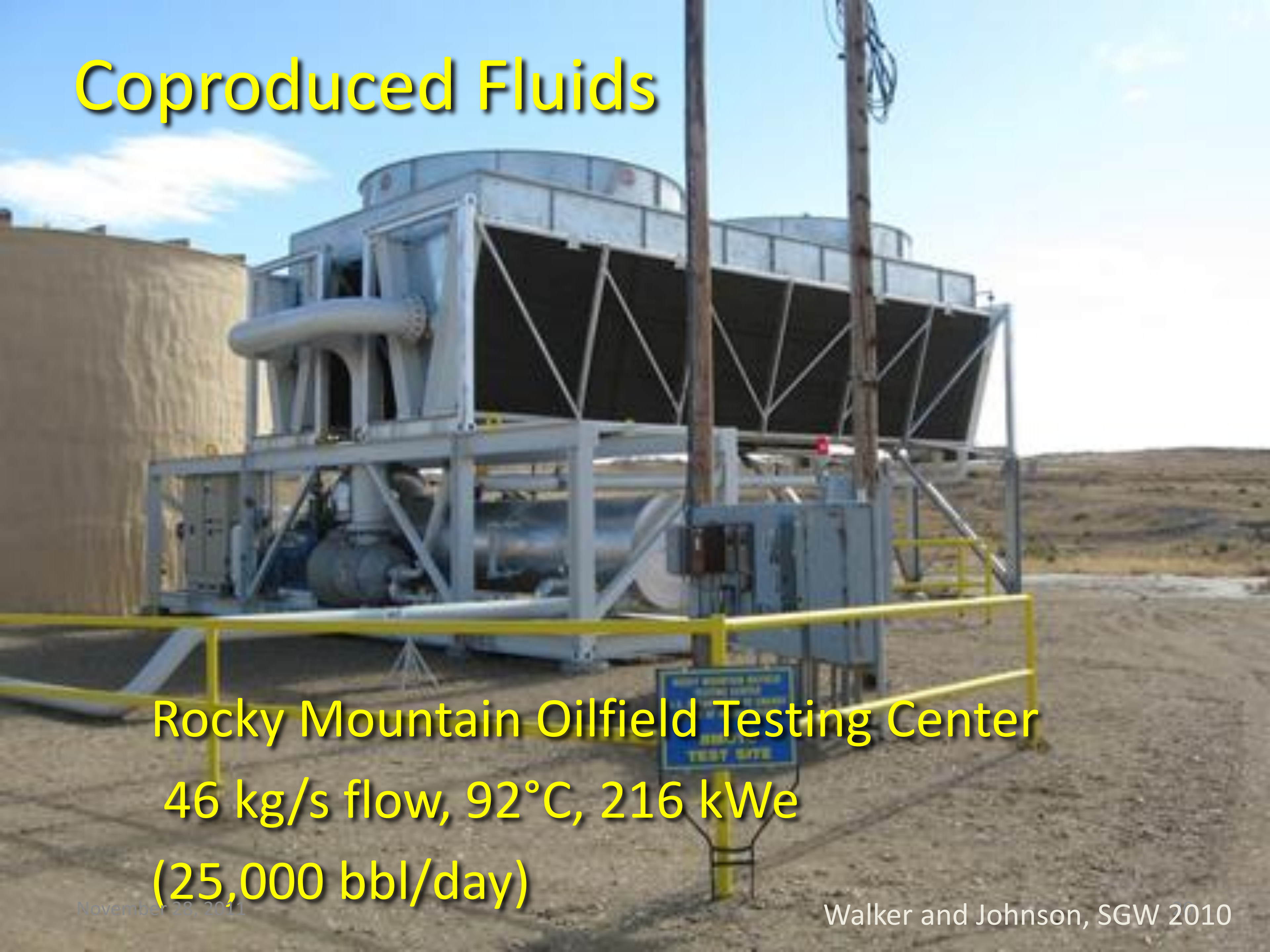
- Isolated, off-grid communities, e.g. Alaska.
- Island grids, e.g. Caribbean.
- Resort power for spas, e.g. Japan onsens.
- Coproduced fluids, e.g. RMOTC, Huabei.

# Island Communities



Akutan, Alaska. Photo: Amanda Kolker, 2010.

# Coproduced Fluids



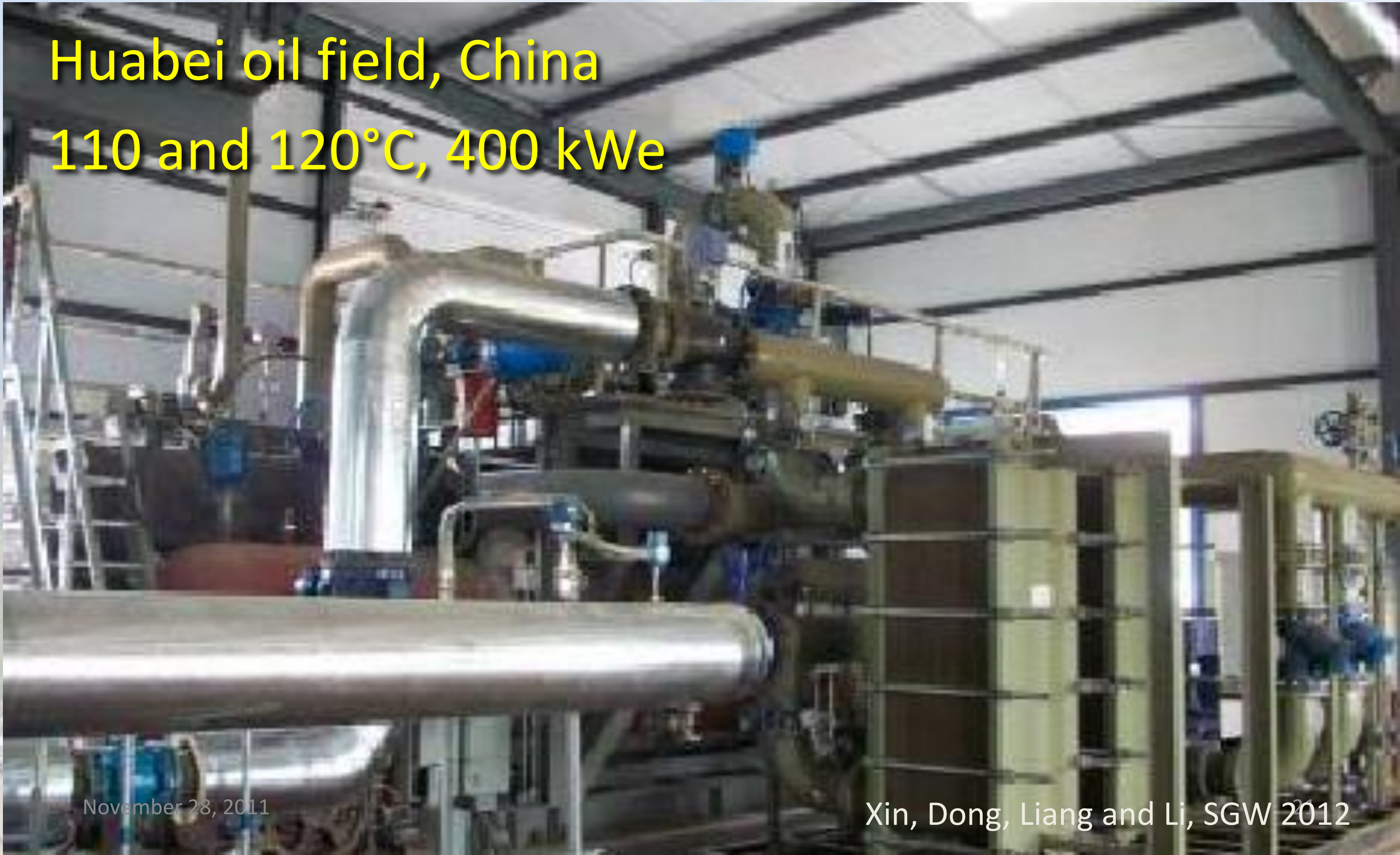
Rocky Mountain Oilfield Testing Center

46 kg/s flow, 92°C, 216 kWe

(25,000 bbl/day)

Walker and Johnson, SGW 2010

# Coproduced Fluids



Huabei oil field, China

110 and 120°C, 400 kWe

Xin, Dong, Liang and Li, SGW 2012

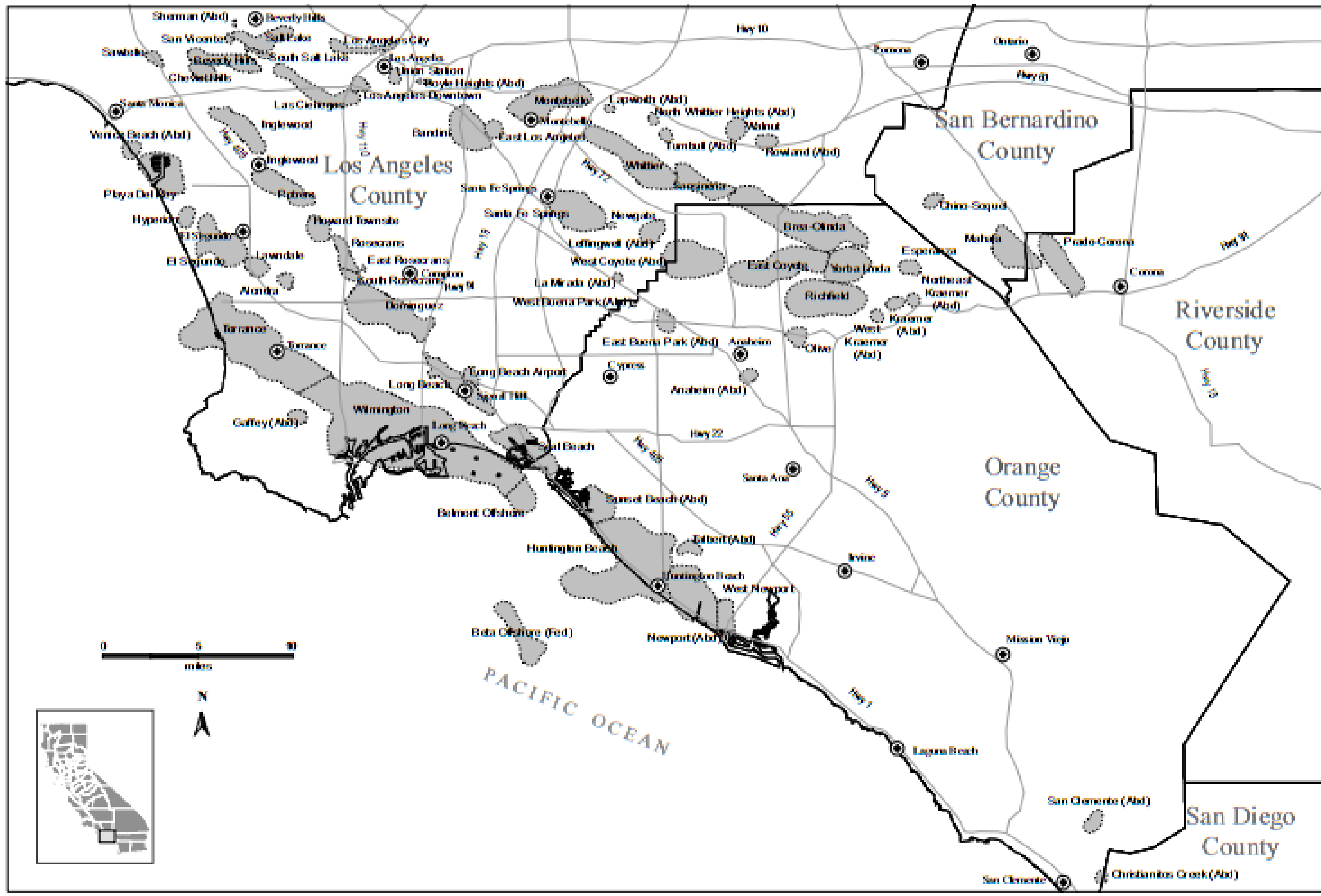
# Los Angeles Basin Oil Fields

http://blog.energytomorrow.org/2009/09/traveling-to-thums.html

# LA Basin Oil Fields

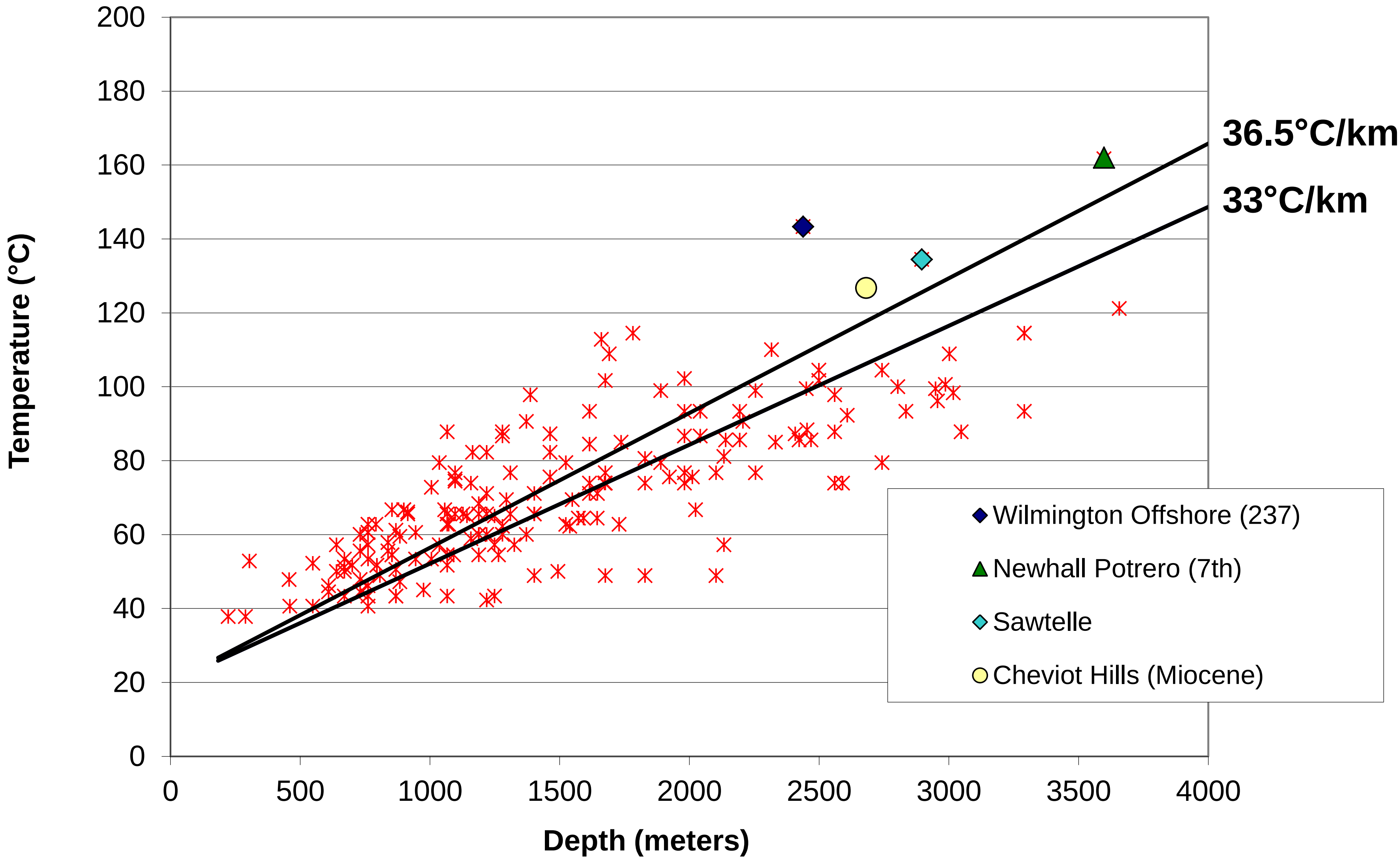
- **49 Oilfields**
- **365 Reservoirs**

- **97% water cut**
- **36°C/km**



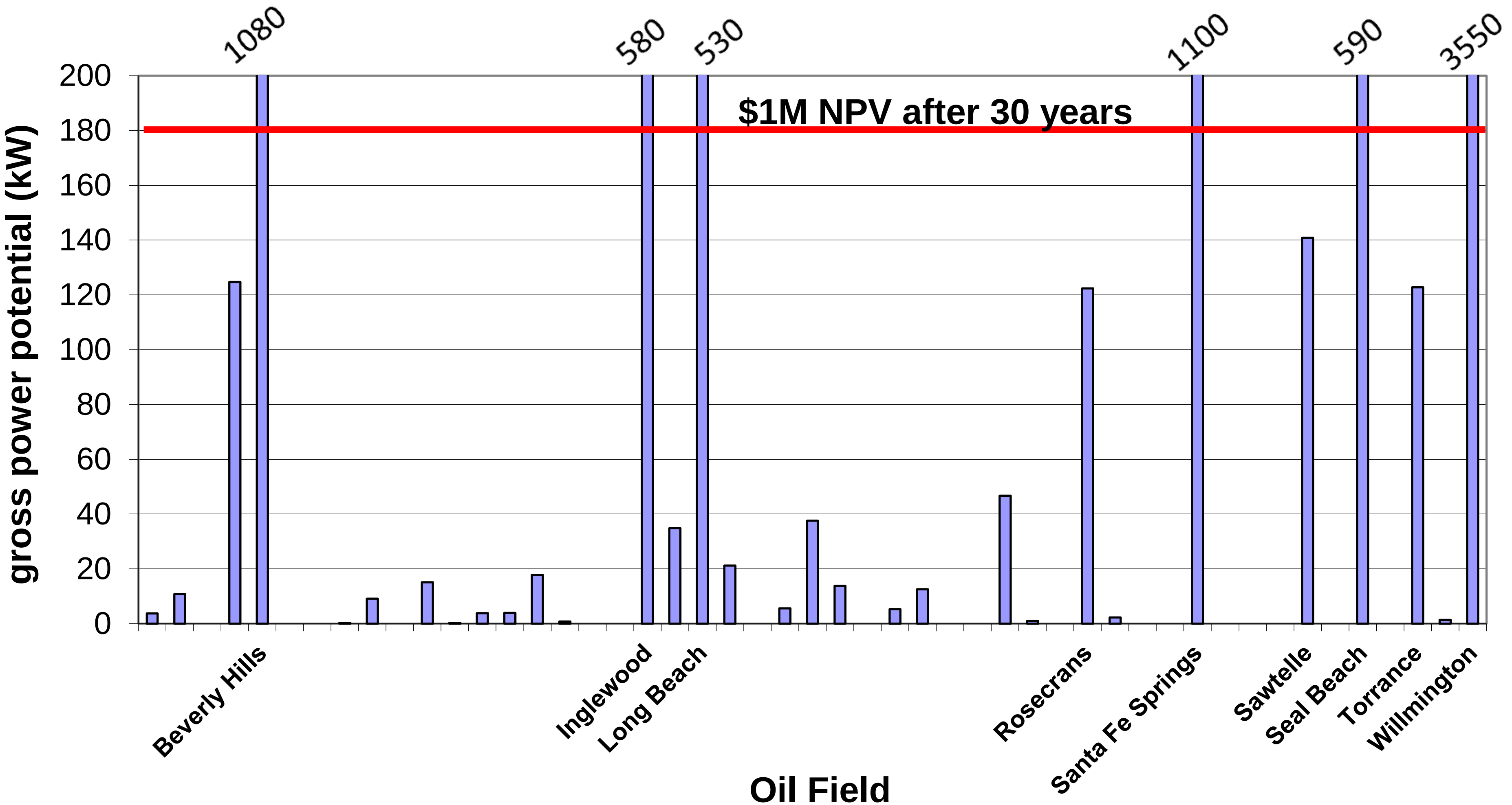

Gamache and Frost, 2003

# Temperature Data




Kara Bennett, 2011

# Power Potential



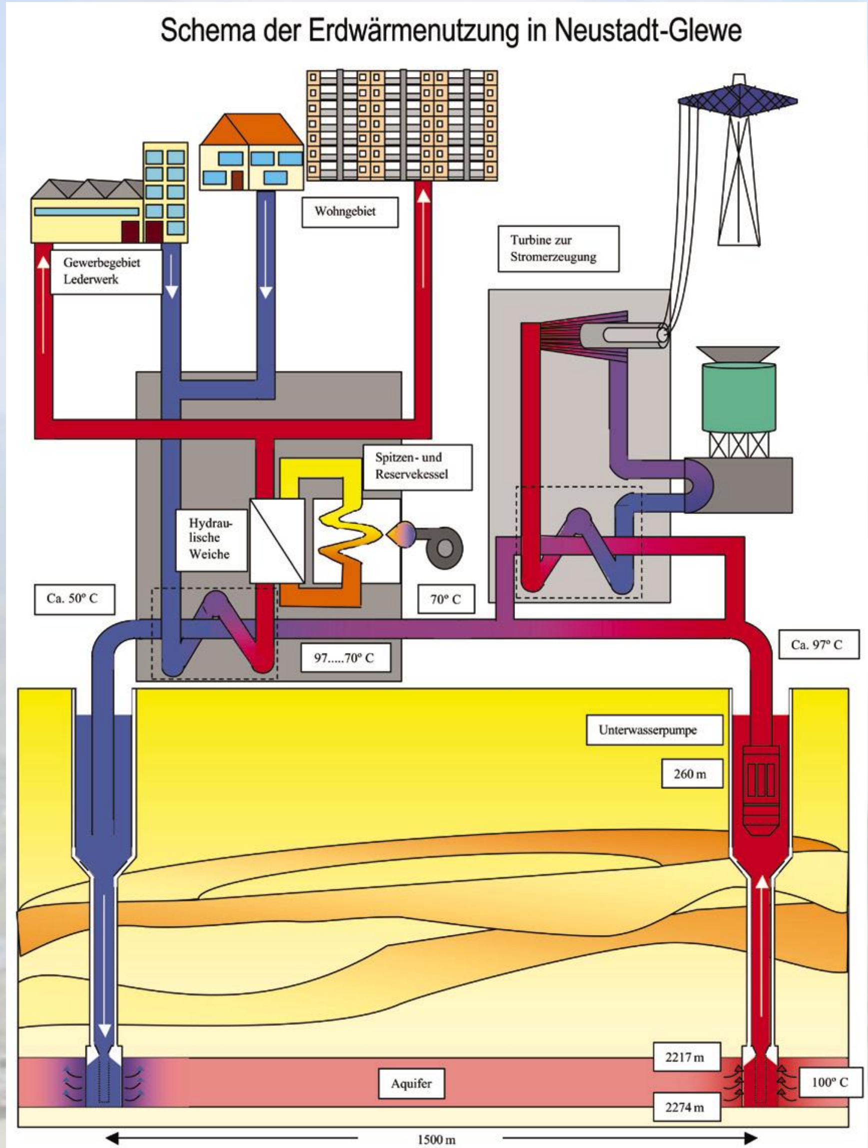

Kara Bennett, 2011

# Net Present Value

| Field | Power Output (kW) | NPV (millions) |
|---|---|---|
| Wilmington (UT, LT, UP, Ford, 237) | 3550 | $19.7 |
| Santa Fe Springs | 1100 | $6.1 |
| Beverly Hills | 1080 | $6.0 |
| Seal Beach | 590 | $3.3 |
| Inglewood | 580 | $3.2 |
| Long Beach | 530 | $2.9 |
| **Total** | **7430** | **$41** |

Kara Bennett, 2011

# Neustadt-Glewe, Germany: combined heat and power plant




**99°C – 30 kg/s**

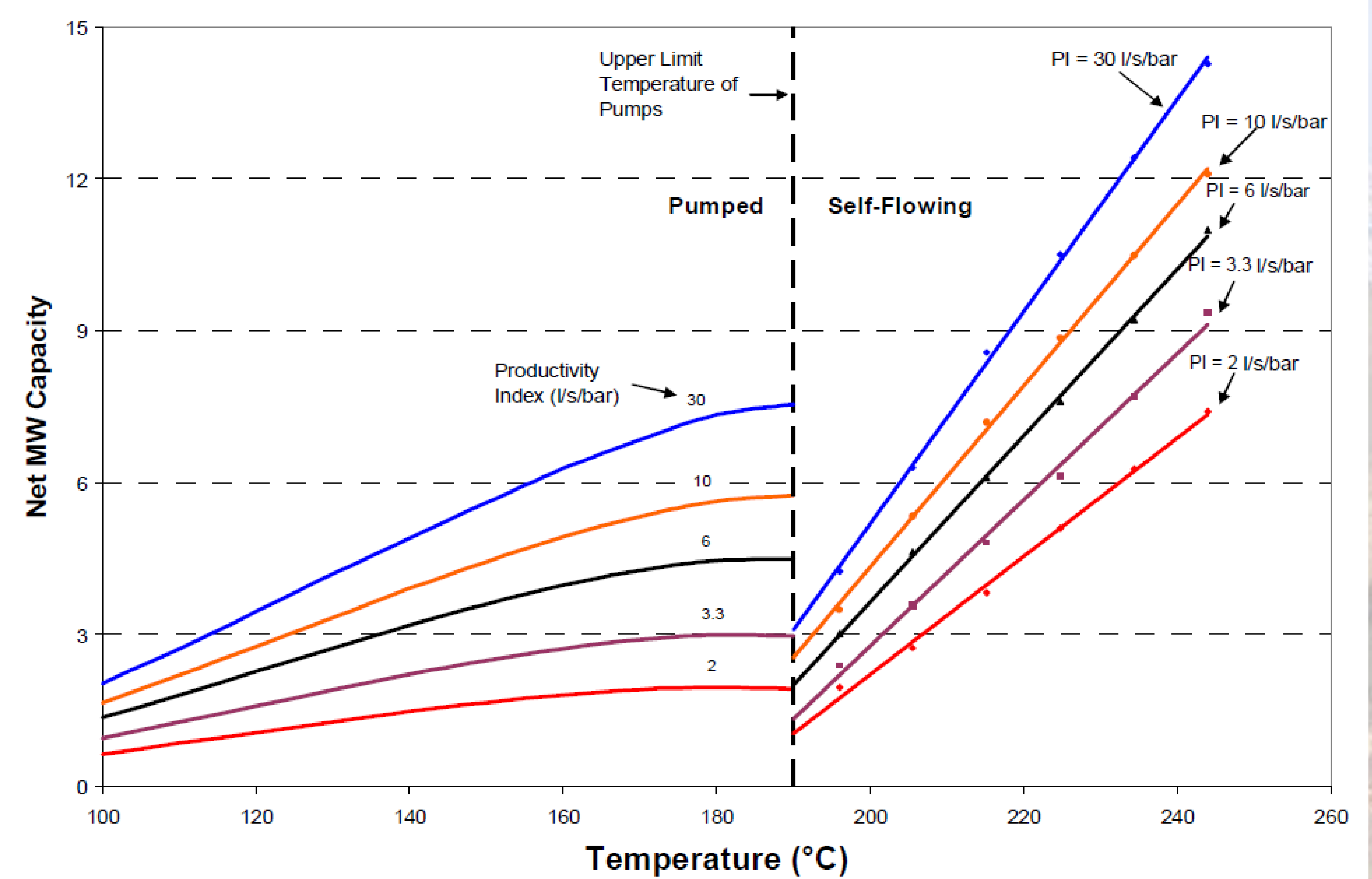
**210 kWe and 6 MWt**





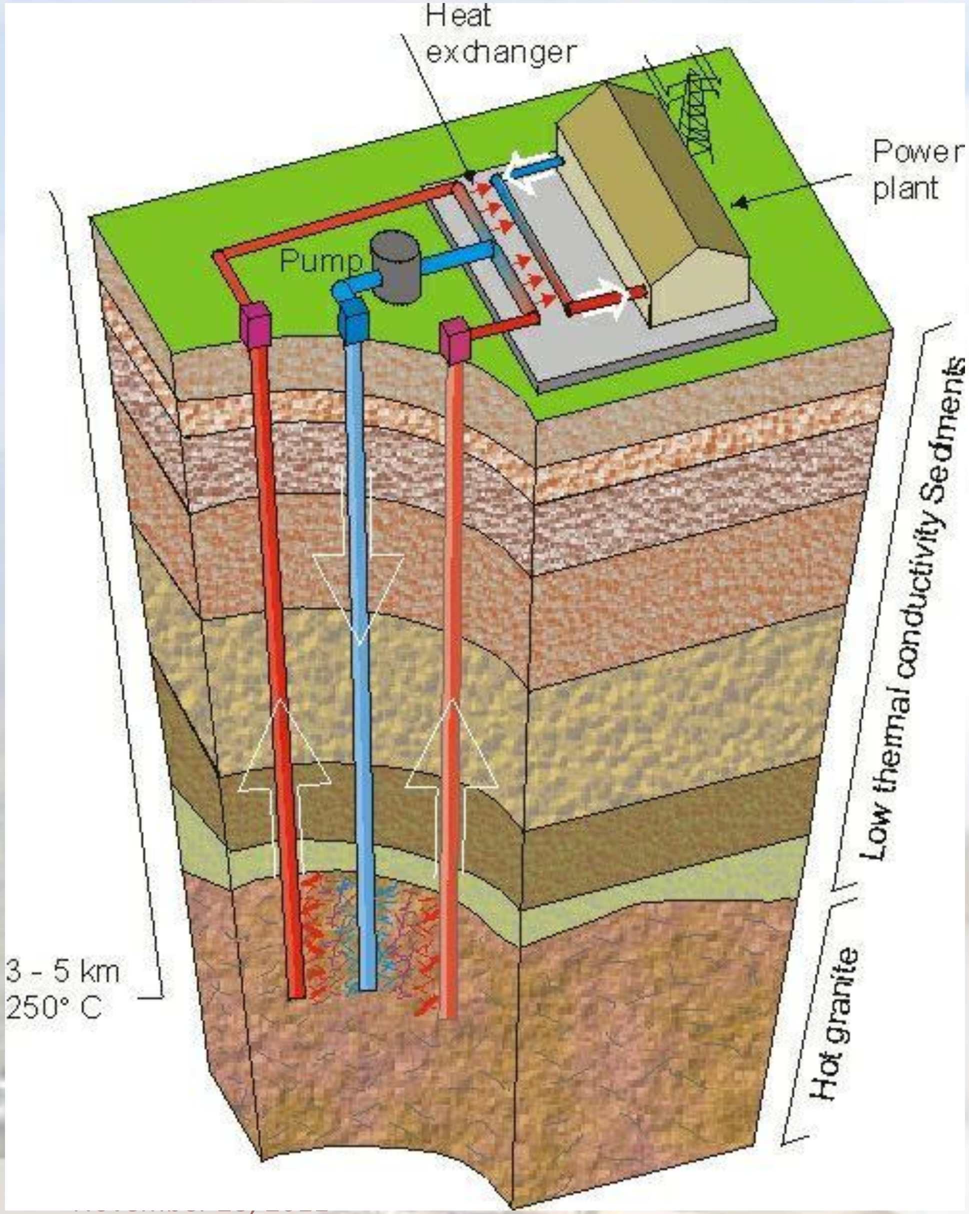
Lund and Bertani, 2010, WGC and GRC

# The Temperature "Hole"




Sanyal et al. (2007)

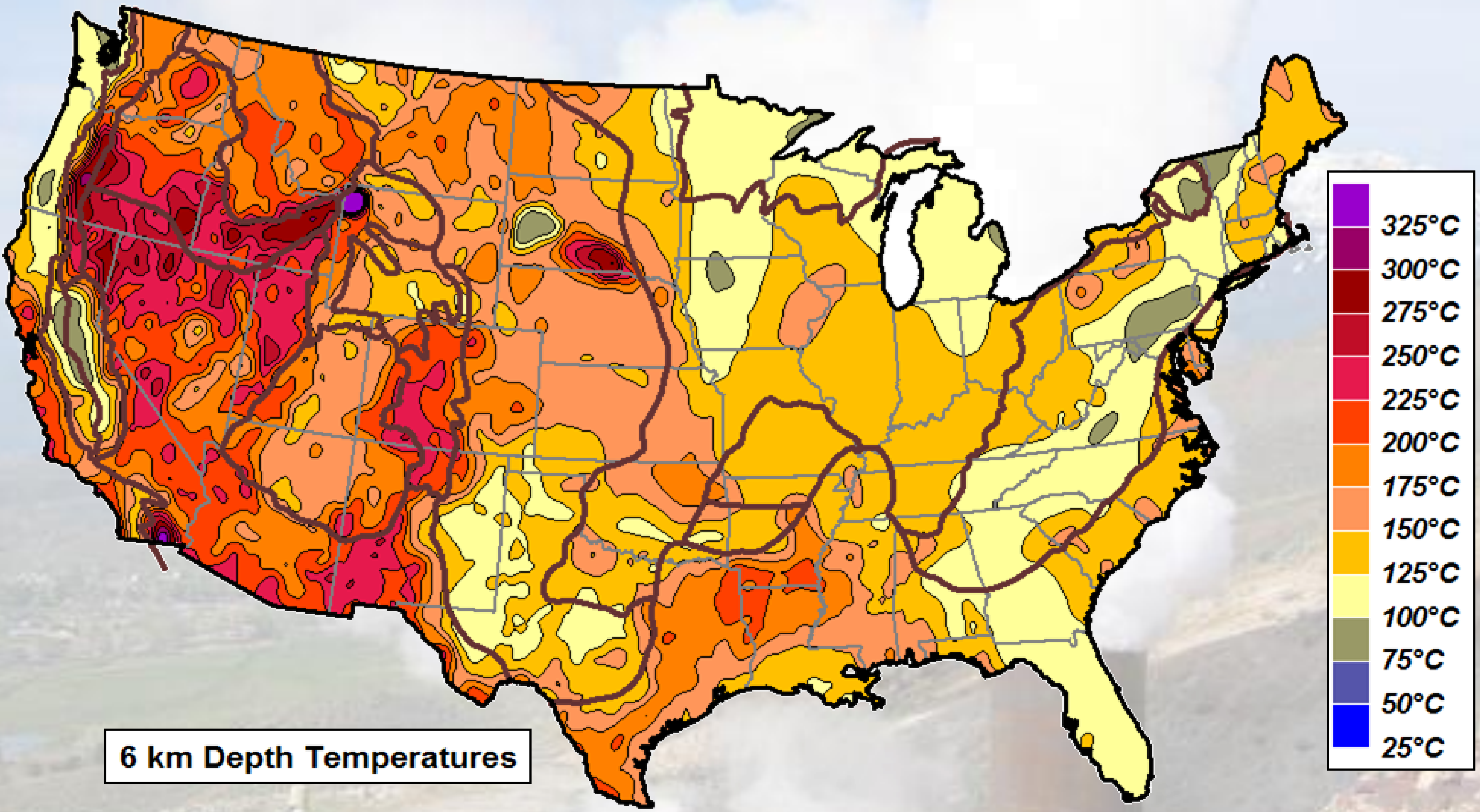
# 4. Enhanced Geothermal Systems EGS




Source: http://hotrock.anu.edu.au

- Most heat is contained in the rock, but:
  - if rock is impermeable how do you circulate water?
  - how do you get injector and producer to communicate?
  - ➔ **fracturing**
- Sometimes known as “Hot, Dry Rock”

# EGS target

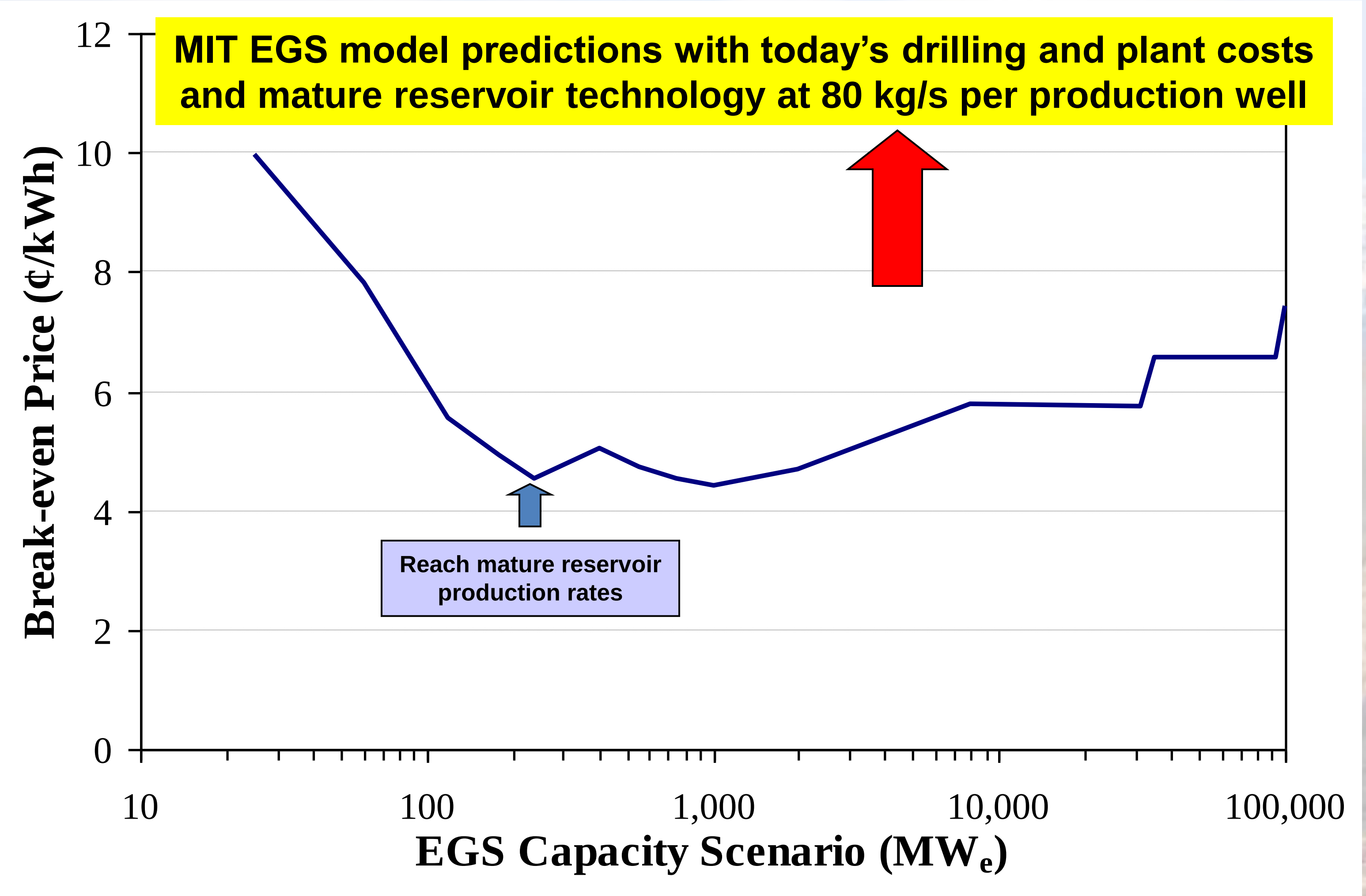



Ref: Blackwell

# Technological Hurdles

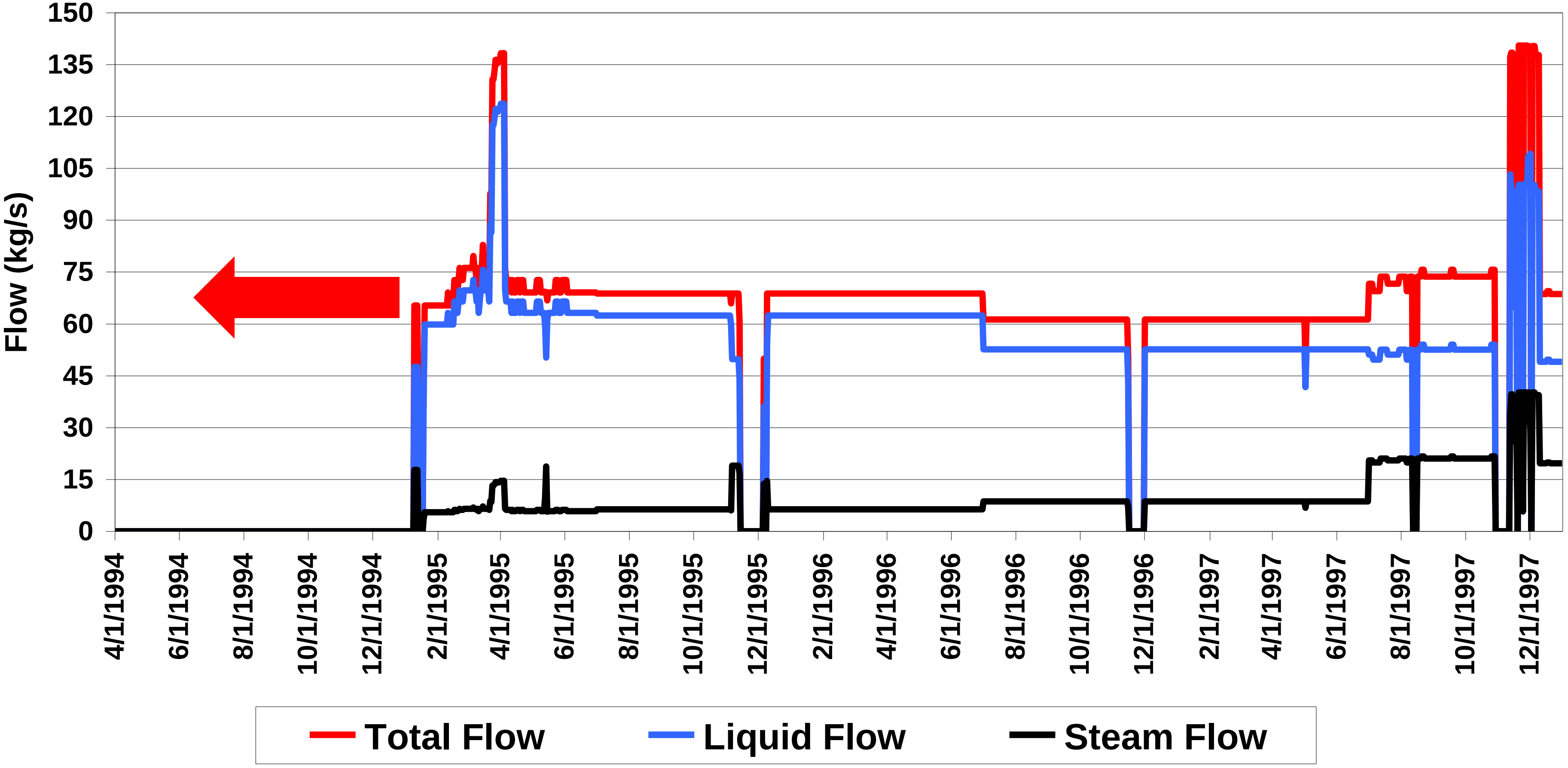
- Surface to volume ratio: stimulating a sufficient body of rock to sustain production for several years.
- Fracture control: placing stimulated fractures to avoid short-circuiting.
- Flow rates: achieving sufficient flow rate (80 kg/sec = ~50,000 bbl/day).
- Induced seismicity (public relations barrier).

# Supply Curve for the US EGS Resource

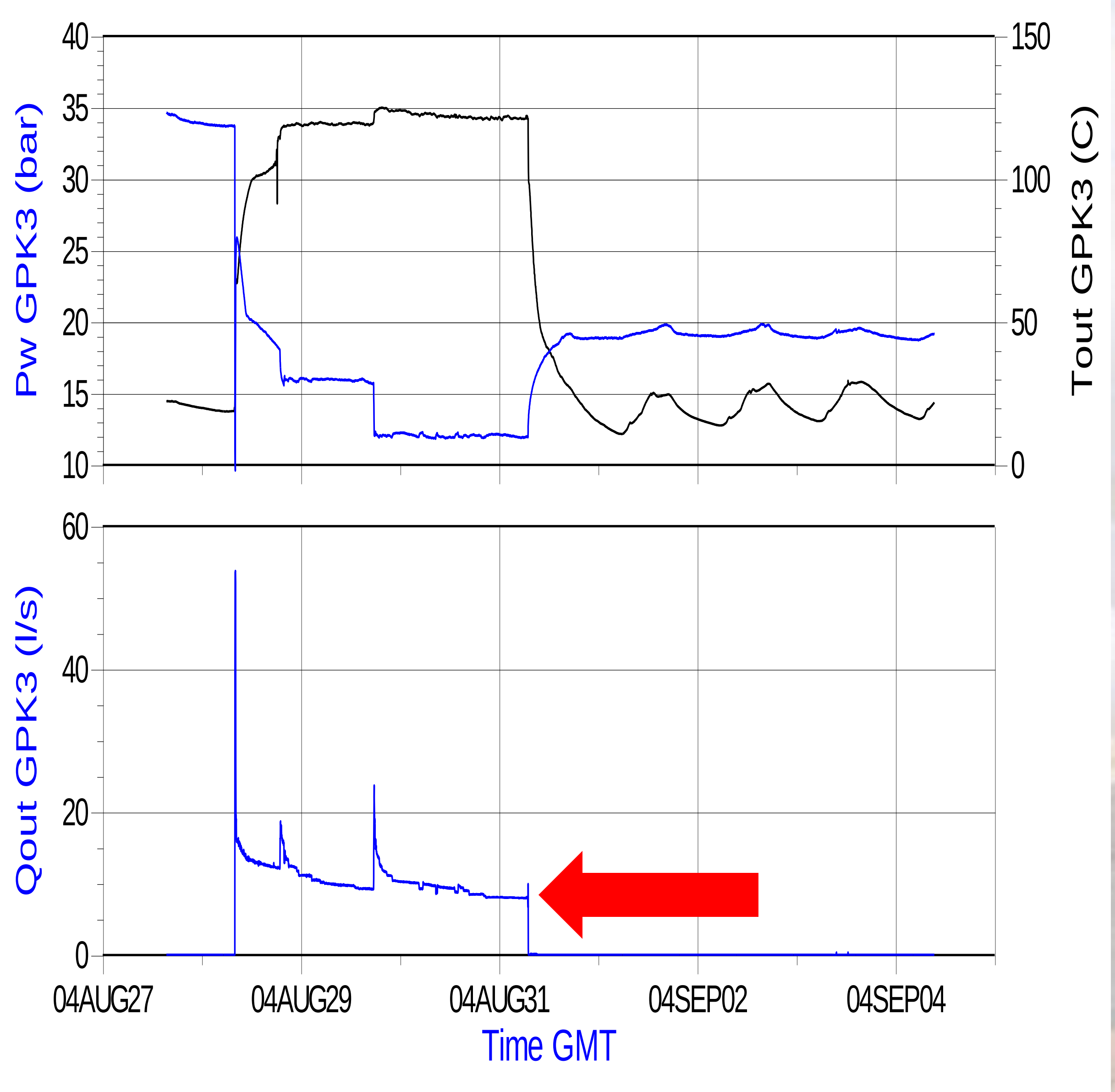



MIT Report, 2007

# Typical Hydrothermal Well



# GPK3 Production test




Baria et al., SGW 2005

# Hijiori, Japan

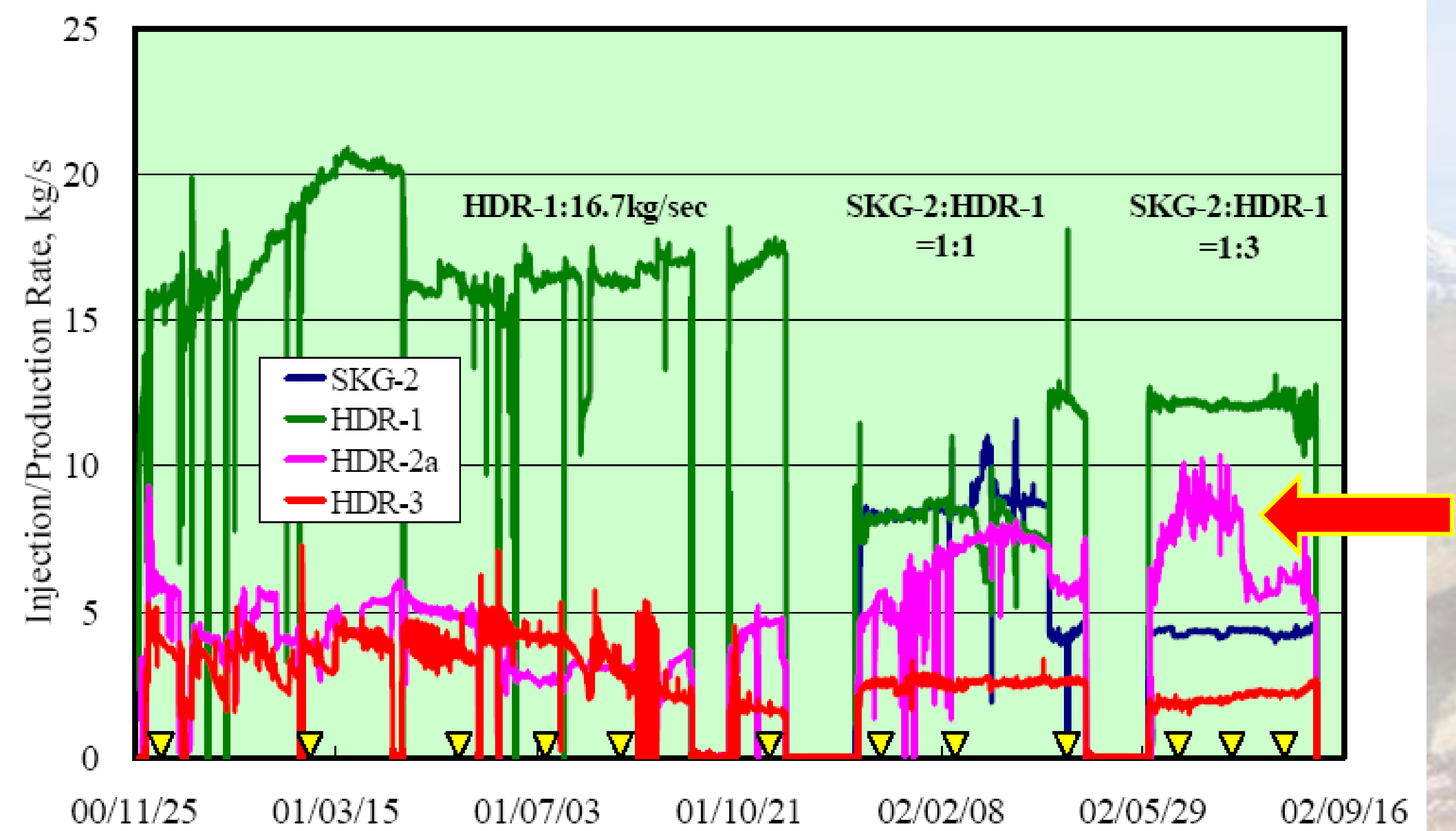



**Figure 1a History of Injection (HDR-1 and SKG-2)/Production (HDR2-a and HDR-3) rate during the LTCT, Term 2 and Term 3.**

Tenma et al. (WGC 2005)

# Hijiori, Japan

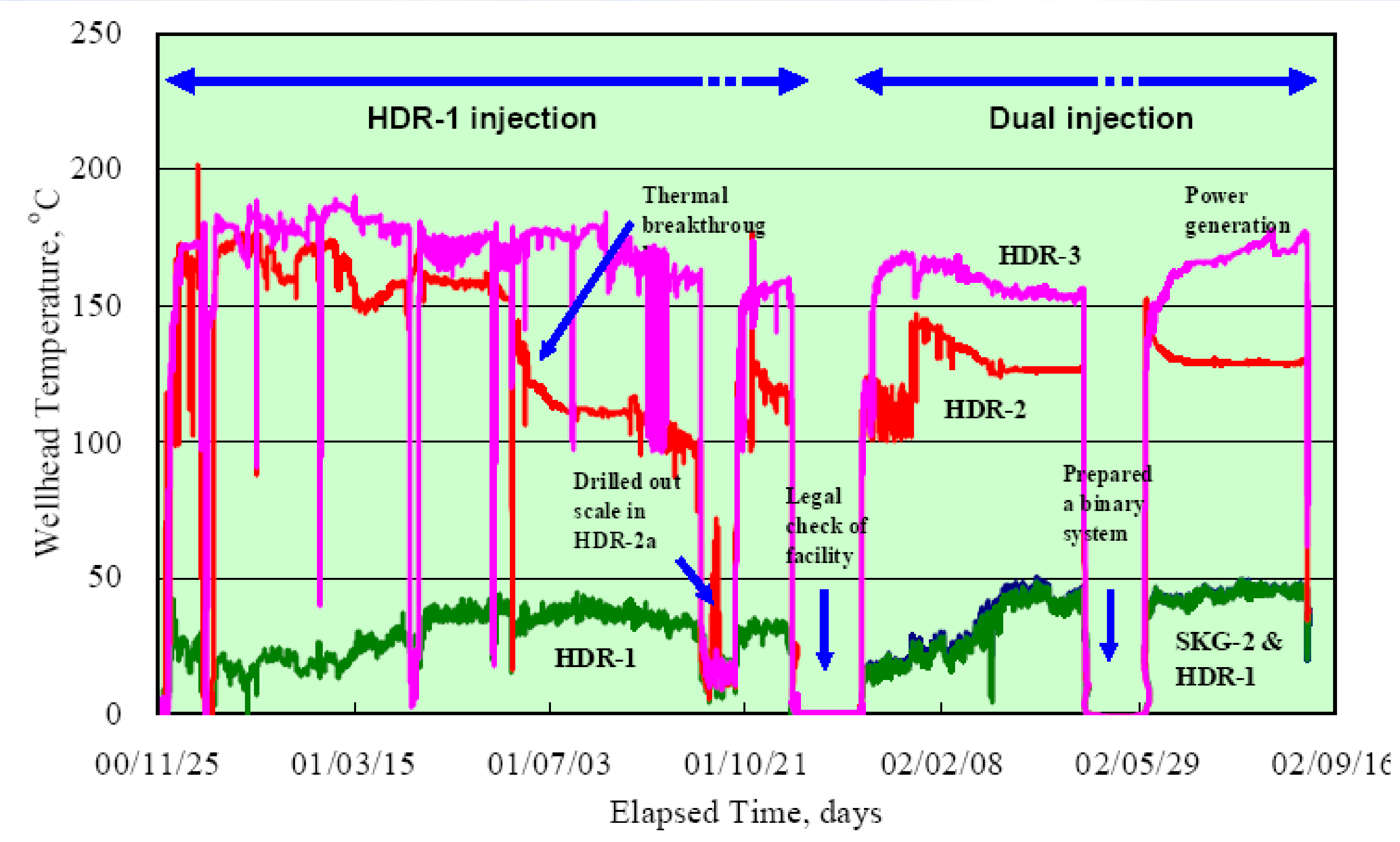



**Figure 2b History of Wellhead temperature for Injection (HDR-1 and SKG-2)/Production(HDR2-a and HDR-3) during the LTCT, Term 2 and Term 3.**

Tenma et al. (WGC 2005)

# Cooper Basin, Australia

- March 2005: two weeks flow above 20 l/s and surface temperatures up to 210$^{o}$C. Estimated 15 MWth.

Habanero #2 well – Cooper Basin
First HFR geothermal steam produced in Australia during clean-up flow test
23 April 2005


Hutchings and Wyborn, NZGW 2006

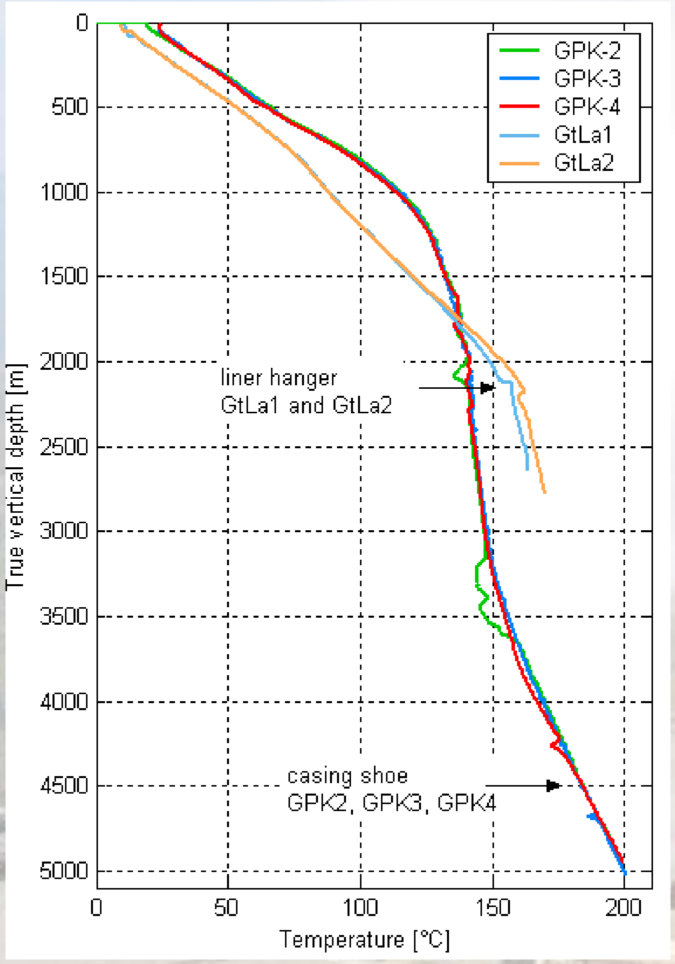
# EGS Project Comparison (1)

| Project | Years | Rock type | Depth (m) | Production Temperature (°C) | Production (l/s) |
|---|---|---|---|---|---|
| Fenton Hill, New Mexico | 72-96 | granodiorite | 3,600 | 191 | 13 |
| Rosemanowes UK | 78-91 | granite | 2,200 | 70 | 16 |
| Le Mayet, France | 84-94 | granite | 800 | 22 | 5.2 |
| Hijiori, Japan | 85-02 | tonalite | 2,200 | 180 | 12.8 |
| Soultz, France | 87-95 | granite | 3,800 | 135 | 21 |
| Soultz | 96-present | granite | 5,000 | 155 | 25 |
| Landau, Germany | 05 - present | granite/faults | 2,600 | 160 | 76 |
| Habanero, South Aust | 03-present | granite | 4,250 | 212 | 30 |

Doone Wyborn, August 2011

# Landau, Germany

- 70 l/s flow, 175ºC, 3MWe (Schellschmidt, Sanner, Pester, Schulz, WGC2010)




www.geox-gmbh.de

# EGS Project Comparison (2)

| Project | Years | Rock type | Depth | Temperature of reservoir |
|---|---|---|---|---|
| Falkenberg Germany | 78-85 | granite | 250 | 13 |
| Hachimantai, Japan | 83-88 | granodiorite | 400 | 60 |
| Fjalbacka, Sweden | 84-89 | granite | 500 | 15 |
| Ogachi, Japan | 89-01 | tonalite | 1000 | 250 |
| Basel, Switzerland | | Granite | 4500 | 180 |
| Bad Urach, Germany | 06-08 | Granite gneiss | 4500 | 180 |
| Jolokia 1 | 09-10 | granite | 4500 | 265 |

Doone Wyborn, August 2011

# Productivity

| Field | Field type | Rock type | Productivity Index kg/(sec.bar) |
|---|---|---|---|
| Soultz | EGS | granite | 0.2 – 0.5 (Nami et al., SGW 2008) |
| Groß Schönebeck | Basin | sandstone/volcanic | 3.6 – 5.3 (Zimmermann et al., 2008) |
| Miravalles | Conventional | volcanic | 11 (PGM-12) (Haukwa et al., 1992) |

# EGS Projects in the USA

1. Newberry, Oregon (AltaRock)
2. Raft River, Idaho (University of Utah)
3. Naknek, Alaska (Naknek Electric Association)
4. New York Canyon, Nevada (Terra-Gen)
5. The Geysers, California (Calpine)
6. St. Johns Dome, Arizona (GreenFire)

# Conclusion

- Since 2005, a geothermal renaissance.
- New countries and new companies have joined the geothermal community.
- New technologies have been implemented.
- Lower resource temperatures are now recoverable.
- EGS widens the accessibility of geothermal energy.