Introduction of the geothermal energy (Week2, 7 & 9 Sept)

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Last time

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- Assessment
  - Homework : 30 %, ~1 homeworks /2 weeks,
  - Mid/Final exam : 30 %
  - Term project : 30 % (Very Important!)
  - Participation : 10 % (attendance + eTL discussion & FAQ + α)

- Textbooks
  - DiPippo R, 2008, Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact, Elsevier, 2nd Ed.
  - Gupta H, Roy H, 2007, Geothermal Energy - An alternative resource for the 21st century, Elsevier
  - MIT, 2006, The future of geothermal energy - Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st century, US Department of Energy, http://www1.eere.energy.gov/geothermal/future_geothermal.html
  - Tester JW et al., 2005, Sustainable Energy - Choosing among options, The MIT Press, (chapter 11)
  - Zoback MD, 2007, Reservoir Geomechanics, Cambridge University Press
  - Scanned copy and handouts will be distributed as needed

Expected self-study for this course: ? hours/week

Introduction
Term Project

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- An enjoyable learning experience - become familiar with the technical, economic, political, and environmental issues associated with the topic that they are exploring.
  - Both report and presentation should be in English
  - Make a group of 3
  - Select (or suggest) a topic of your own interest
  - Timeline
    - 14 Sept Finalization of instruction
    - 25 Sept Submission of proposal (~1 page)
    - 30 Oct Submission of progress report (~5 pages)
    - 4 Dec Submission of final report (~20 pages)
    - 7 Dec, 9 Dec Presentation of term project

Useful courses for taking courses in English

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- 1. 공과대학(3주 12시간)
  - 글쓰기
  - http://eng.snu.ac.kr/bbs/notice_list.php
- 2. 교수학습개발센터 (9월29일-30일, 총8시간)
  - 글쓰기 및 발표
  - http://ctl.snu.ac.kr/news/

Homework #1

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- Watch the 45 minutes-video on geothermal energy by Dr Carol Bruton at the Lawrence Livermore National Laboratory in the US
- http://www.youtube.com/watch?v=pA27aEamWzY
- And submit a report (1-2 pages) on the video. The report should contain the summary of the video and your own views on her lectures.
- Note that the content of her lecture is also part of this course.
- Due date: 12pm on 13 Sept, and 12pm 15 Sept(with 20% penalty)

Content of the lecture

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- What is Geothermal Energy? And the origin.
- Types – indirect/direct uses
- The elements – what is needed
- History and Status
- Types of Geothermal Power Plants
- Advantages/disadvantages
- Environmental Impacts

What is Geothermal Energy

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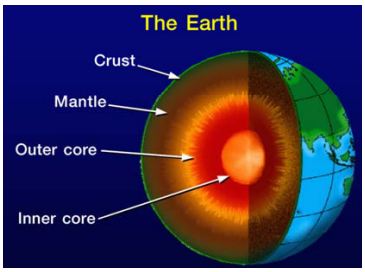
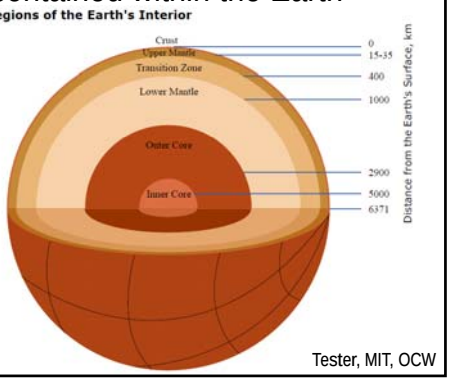
- Geo: Earth
- Thermal: Heat
- Geothermal Energy is the heat contained within the Earth



http://geothermal.marin.org



Tester, MIT, OCW

The origin of geothermal energy

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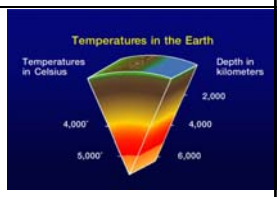
- Two mechanism:
  - The interior is hot (the center is ~6000°C);
  - Decay of long-lived radioactive isotopes:
    - Th (Thorium 232), U (Uranium 238), K (potassium 40).
    - Concentrated in upper crystal rock.
    - Account for about 80% of the surface heat flow
- Geothermal Gradient: the rate at which earth temperature increases with depth, typically: 25 – 30 °C/km
- Surface heat flow
  - Global means: 87 mW/m^2 (Pollack et al., 1993), In boundaries between plates: 300 mW/m^2



http://geothermal.marin.org

Types of geothermal resources

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- Indirect use (Electricity)
  - Hydrothermal field
  - Enhanced Geothermal System (EGS)
  - Geopressurized
  - Magma Energy
- Direct use of heat (non-electric)
  - Various usage of heat
  - Geothermal Heat Pump (GHP)

Map of earth's lithospheric plates

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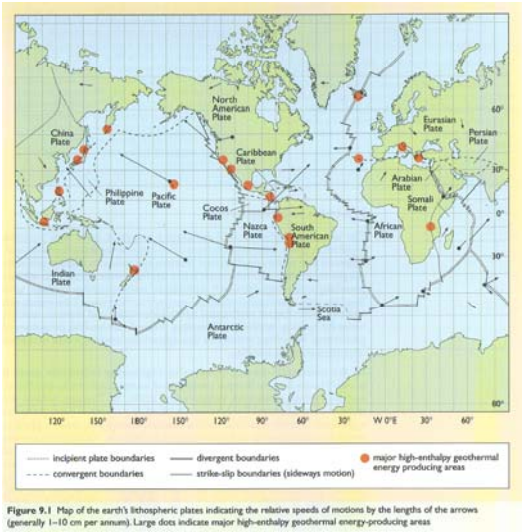

Figure 9.1 Map of the earth's lithospheric plates indicating the relative speeds of motions by the lengths of the arrows (generally 1–10 cm per annum). Large dots indicate major high-enthalpy geothermal energy-producing areas

Boyle, 2004, Renewable Energy

The elements of geothermal resources

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- Three important elements;
  - A large heat source (must be natural)
  - A supply of water (can be artificial)
  - A permeable reservoir (can be artificial)
- Other elements
  - An overlying layer of impervious rock (cap rock)
  - A reliable recharge mechanism
  - stability of rock formations
  - economic factors (well drilling/completion costs, surface plant costs)

The elements of geothermal resources

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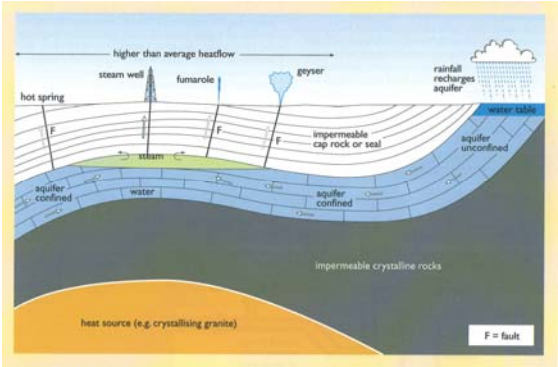
- The intent of a geothermal development project is; to locate such systems and produce them by strategically drilled wells.



Boyle, 2004, Renewable Energy

The physics of geothermal resources

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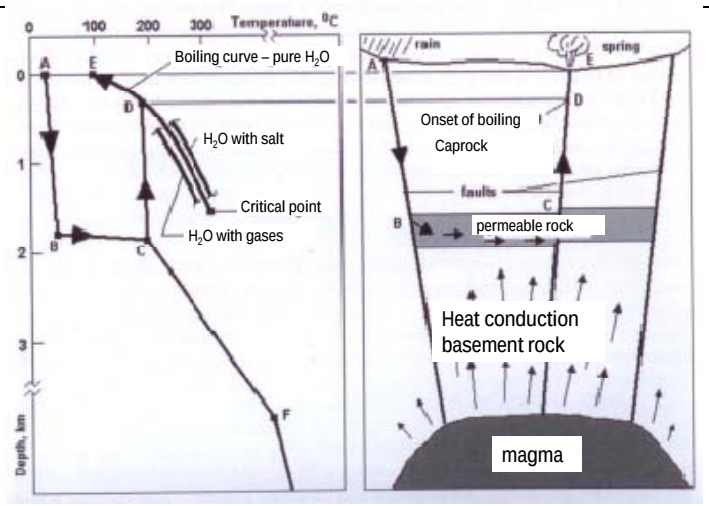

Schematic model of a hydrothermal geothermal system (DiPippo, 2008, Fig.1.4)

Geothermal Power Generation analogy
Can steam spin a turbine?

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http://pathstoknowledge.files.wordpress.com/2009/07/boiling1.jpg

Cookingfor.us

Unit of Power and Energy
W vs. Wh

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- W: unit of Power (1W = 1 J/sec)
  - rate at which energy is converted from one form to another
  - Conventional coal- or oil-fired station : a few hundred MW
  - Geothermal station : 30-50 MW
- Wh: unit of Energy
  - 1 kWh = 1000 (W) x 1 hour = 1000 x 3600 (sec) = 3.6 MJ
- TOE: Tonne of Oil Equivalent
  - Energy produced by burning one tonne of crude oil
  - 1 TOE = 42 GJ = 12,000 kWh

Unit of Power and Energy
How big is big?

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〈표 1-11〉 에너지원별 발전전력량 (단위 : 10억kWh)

구 분	수력	무연탄	유연탄	석유	가스	원자력	기타*	발전량
2007	5.0	4.5	150.2	17.8	78.4	142.9	4.2	403.1

〈표 1-12〉 발전량 비중 추이 (단위 : %)

	수력	무연탄	유연탄	석유	가스	원자력	기타*	발전량
2007	1.3	1.1	37.3	4.4	19.5	35.5	1.1	100.0

* 석유에서 기타 분리('04 부터), 기타 : 집단에너지, 풍력, 매립가스, 태양광 등

신재생 에너지백서, 2007

- 403 x 10^9 (kWh) / 365 (days) / 24 (hours) = 46x10^6 kW = 46 GW
- 1 GW ~ for 1 million people (for Korea), 1MW ~ 1,000 peple.

worthwhile to remember!

History of Geothermal Energy
Larderello, Italy

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- Greek & Roman times
  - Hot water from the earth used for medicinal, domestic and leisure applications.
- 1904 - First Power Generation
  - Larderello, Italy, 250 kW (1913)

Figure 9.2 The Larderello field prior to development for geothermal power production

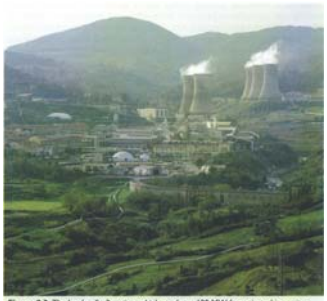

Figure 9.3 The Larderello 3 station, which produces 120 MW from six turbine units. The geothermal pipeline network consists of an inner steel pipe lagged with asbestos fibre and covered with aluminium plate

Boyle, 2004, Renewable Energy

History of Geothermal Energy

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- 1958, Wairakei, New Zealand
  - Currently ~180 MW
- 1960, The Geysers (name of a location*), USA
  - Currently largest in the world
  - ~100 km north of San Francisco
  - ~750 MW with 22 power plants

*geyser: 간헐온천, a hot spring characterized by intermittent discharge of water ejected turbulently and accompanied by a vapour phase (steam).

**Fumarole: 분기공, an opening in Earth's crust, often in the neighborhood of volcanoes which emits steam and gases

Status of geothermal energy production (1)

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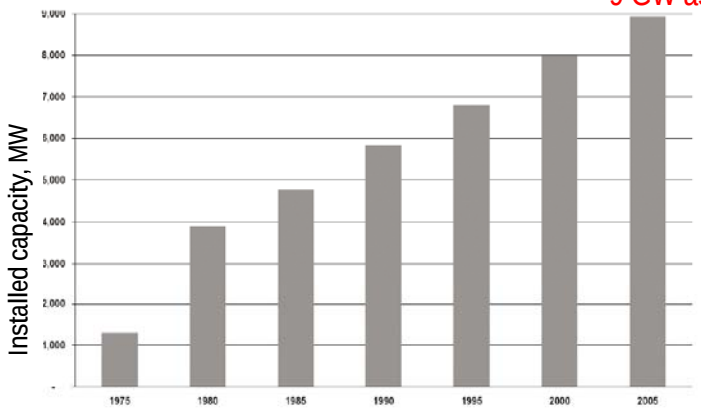
~9 GW as of 2005



[그림 3] 세계 지열발전 설치 용량(ABS Energy Research, 2007)

나상민, 2008, 지열, 4권, 2호

Status of geothermal energy production (2)

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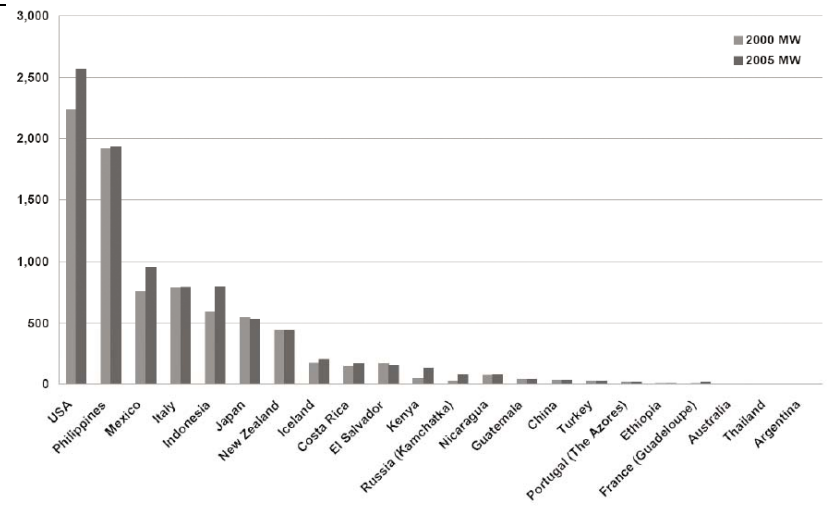

나상민, 2008, 지열, 4권, 2호

[그림 4] 국가별 지열발전 용량(ABS Energy Research, 2007)

Status of geothermal energy production (3) – share of Geothermal in electricity production

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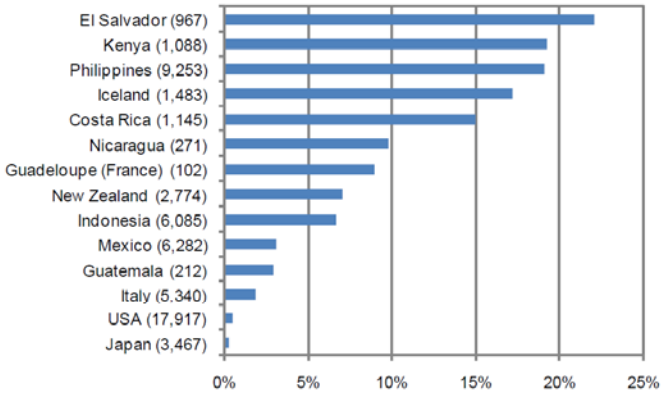

Figure 6. The fourteen countries with the highest % share of geothermal energy in their national electricity production (Fridleifsson, 2007). Numbers in parenthesis give the annual geothermal electricity production in GWh in 2004 (Bertani, 2005).

Fridleifsson, 2008, In: O. Hohmeyer and T. Trittin (Eds.), 59-80

Status of geothermal energy production (4)

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- Geothermal Heat Pump (GHP) utilization in Europe

Table 3. Estimated number of GHP units and total installed capacity in EU countries (Geothermal Energy Barometer, 2007)

Countries	2005		2006	
	Number	Capacity (in MW_{th})	Number	Capacity (in MW_{th})
Sweden	230094	2070.8	270111	2431.0
Germany	61912	681.0	90517	995.7
France	63830	702.1	83856	922.4
Denmark	43252	821.2	43252	821.2
Finland	29106	624.3	33612	721.9
Austria	32916	570.2	40151	664.5
Netherlands	1600	253.5	1600	253.5
Italy	6000	120.0	7500	150.0
Poland	8100	104.6	8300	106.6
Czech Republic	3727	61.0	5173	83.0
Belgium	6000	64.5	7000	69.0
Estonia	3500	34.0	5000	49.0
Ireland	1500	19.6	1500	19.6
Hungary	230	6.5	350	15.0
United Kingdom	550	10.2	550	10.2
Greece	400	5.0	400	5.0
Slovenia	300	3.4	420	4.6
Lithuania	200	4.3	200	4.3
Slovakia	8	1.4	8	1.4
Latvia	10	0.2	10	0.2
Portugal	1	0.2	1	0.2
Total EU 25	**493236**	**6158.0**	**599511**	**7328.3**

Source: EurObserv'ER 2007

Types of geothermal resources
Indirect use

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- Indirect use (Electricity)
  - Hydrothermal field
    - Vapor dominated – The Geysers (USA), Larderello (Italy)
    - Liquid-dominated – except above two major fields
  - Enhanced Geothermal Systems (EGS) or Hot Dry Rock (HDR) or Hot Fractured Rock (HFR)
  - Geopressured geothermal resources
    - geofluid found in near-offshore petroleum deposits, containing significant amounts of dissolved natural gas at very high pressure and high temperature
    - Uses thermal (hot brine), chemical (natural gas), mechanical (hydraulic)
  - Magma energy

Types of geothermal resources
direct use (non-electric)

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- Direct using
  - Aquaculture
  - Greenhouses
  - Industrial and agricultural processes
  - Resorts and spas
  - Space and district heating/cooling
  - Geothermal Heat Pump (GHP) also known as Ground Source Heat Pump (GSHP)

Content of last lecture

- What is Geothermal Energy? And the origin.
- Types – indirect/direct uses
- The elements – what is needed
- History and status
- Types of Geothermal Power Plants
- Enhanced Geothermal System (EGS)
- Geothermal Heat Pump
- Advantages/disadvantages
- Environmental Impacts

Types of power generation

- Dry steam power plant
- Flash steam power plant
  - Single flash
  - Double flash
- Binary cycle power plant

Types of power generation
Dry steam power plant (건조증기방식)

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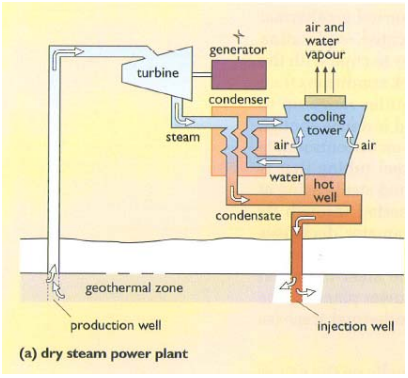
- Dry steam spin the turbine
- The most efficient type
- However, dry steam reservoir is not common



Boyle, 2004, Renewable Energy

Types of power generation
Flash steam power plant (증발증기방식)

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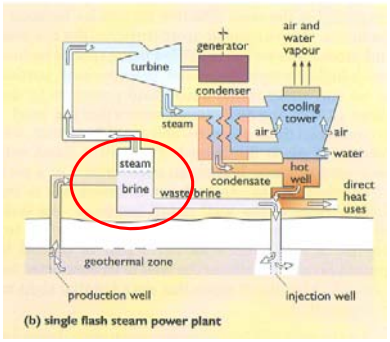
- Use separator to separate into distinct steam and liquid phase
- Mainstay of geothermal power industry
- Single and double flash



Boyle, 2004, Renewable Energy

Types of power generation
Binary cycle power plant

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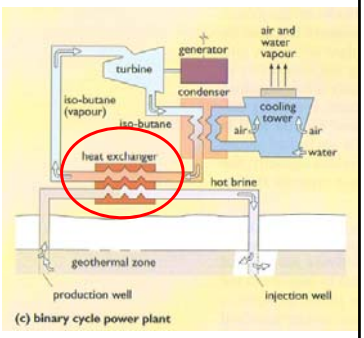
- Uses a secondary working fluid with a lower boiling point than water: pentane, butane
- Also known as Organic Rankine Cycle (ORC) plant
- With geofluid temperature < 150°C
- 162 units in operation which is 32% of all geothermal units (DiPippo, 2008). But this generate only 4% of the total power.



Boyle, 2004, Renewable Energy

Enhanced Geothermal System (EGS)
강화지열시스템

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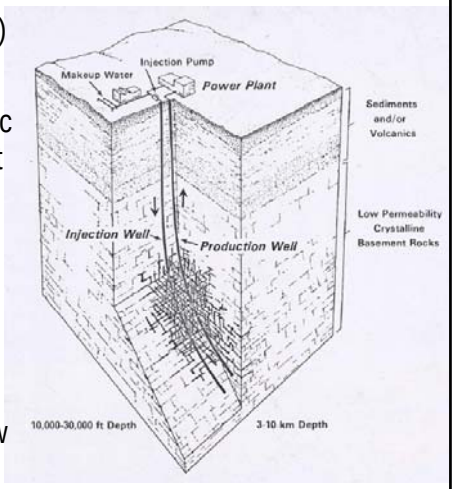
- Also known as Hot Dry Rock (HDR) or Hot Fractured Rock (HFR)
- EGS is a system that uses hydraulic stimulation of a hot (T > 100°C) but comparably impermeable (k < 10^{-16} m^2) rock mass at depth (~3 km) to create an artificial geothermal reservoir (volume ~ 2 km^2).
- Suitable heat exchange surface is then created by opening pre-existing fractures or generating new fractures.



MIT, 2006, Future of Geothermal Energy

The future of EGS

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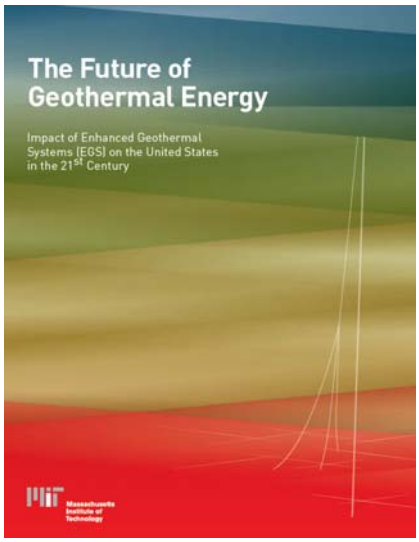

- A study by a panel of experts on EGS in the US (2006).
- Total resource base up to 10 km = 130,000 x annual consumption of energy in the US.
- 100 GW from EGS by 2050 in the US with reasonable investments in R&D.

http://www1.eere.energy.gov/geothermal/future_geothermal.html

History and status (1)

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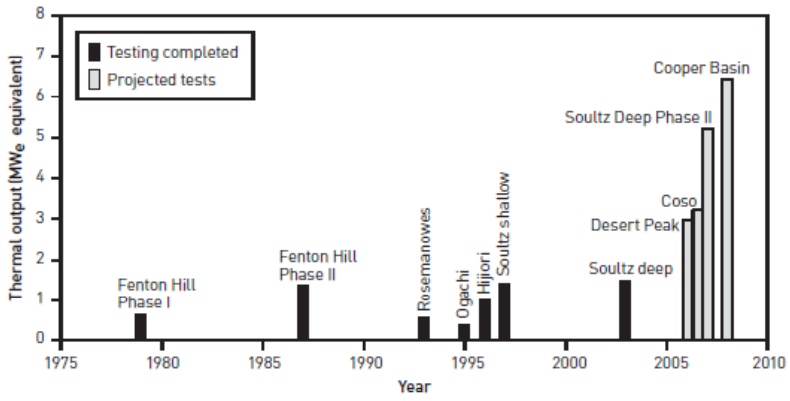

Figure 4.16 Evolution of estimated electrical power output per production well, with time from EGS projects. The Fenton Hill, Coso, and Desert Peak projects received, or are receiving, major funding from the U.S. DOE.

MIT, 2006, Future of Geothermal Energy

History and Status (2)
Australia

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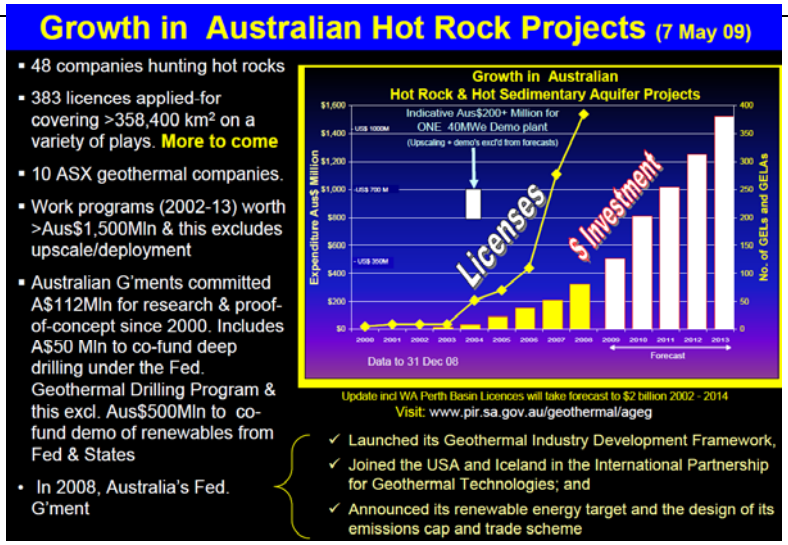

Goldstein BA, 2009, http://www.geothermal.pir.sa.gov.au

Enhanced Geothermal System (EGS)
Challenges

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- Flow short circuiting – too rapid temperature drop, especially the distance between two borehole is small
- High injection pressure - > min. in situ stress at a point of injection
- Water losses
- Instrumentation at high pressure & temperature
- Rock-fluid interaction (Geochemical impacts)
- Induced seismicity – can be felt in the surface
- Inherent issues for geological engineering:
  - Fracture design model – no credible model available for hydraulic fracturing in discrete fracture network
  - Fracture mapping & rock property quantification

Drilling Cost

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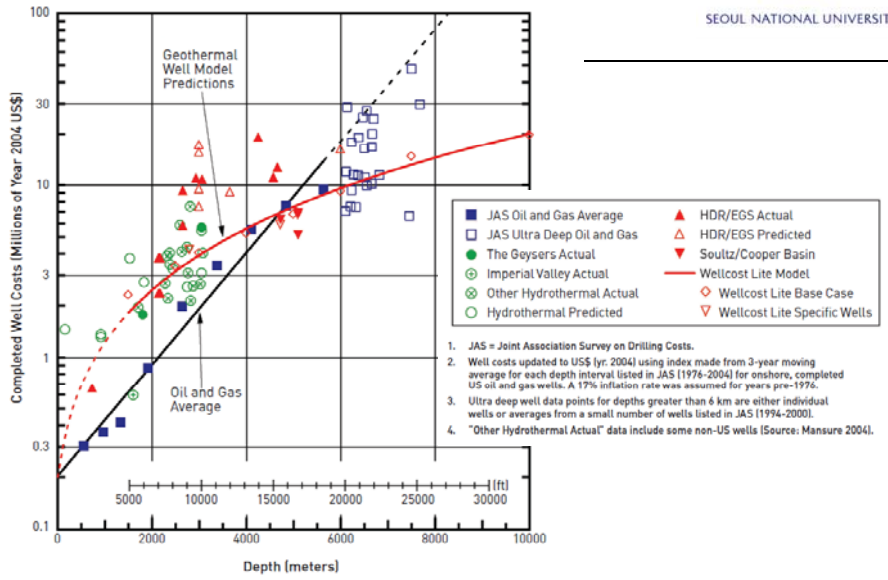

Figure 6.1 Completed geothermal and oil and gas well costs as a function of depth in year 2004 U.S. $, including estimated costs from Wellcost Lite model.

MIT, 2006, Future of Geothermal Energy

Geothermal Heat Pump

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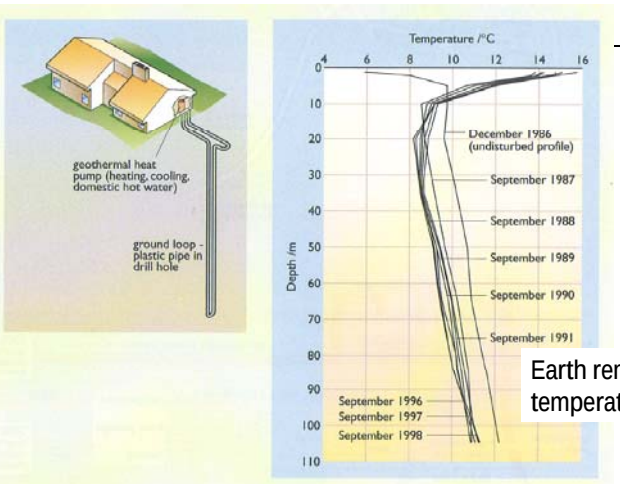

Earth remains at a relatively constant temperature throughout the year

Figure 9.11 (a) The geothermal heat pump (GHP) concept used to extract heat from warm shallow groundwater to supply a single domestic dwelling. In the winter heat is removed from the earth and delivered in a concentrated form via the heat pump. Because electricity is used, in effect, to increase the temperature of the heat, not to produce it, the GHP can deliver three to four times more energy as heat than the energy content of the electricity it consumes; (b) Measured data from a Swiss GSHP installation. After an initial drop, the ground temperature below the solar-dominated surface zone (see Box 9.6) recovers to the same value year after year. This appears to be a truly renewable operation

Boyle, 2004, Renewable Energy

Geothermal Heat Pump

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- Temperature in the underground remain constant regardless of seasons (15±5°C) at ~200 m.
- Uses the earth as a heat source (winter) and a heat sink (summer)
- http://www.youtube.com/watch?v=-ajqiPe_9Ko
- Relies on heat transfer by conduction from the walls of borehole
- Developed independently in Europe and the US

Status of direct use (1) worldwide

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활용 방식별 전 세계 지열 에너지 직접 이용 현황(1995~2005).

	시설용량(capacity), MWt		
	2005	2000	1995
지열 열펌프시스템	15,384	5,275	1,854
지역난방	4,366	3,263	2,579
온실난방	1,404	1,246	1,085
양식업	616	605	1,097
농산물 건조	157	74	67
산업 이용	484	474	544
온천 및 수영	5,401	3,957	1,085
제설	371	114	115
기타	86	137	238
합 계	28,269	15,145	8,664

신재생에너지백서, 2008

Status of direct use (2)
Korea

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- Korea,
  - Total installed capacity 16.9 MW (Song et al., 2005)
  - Drastic increase in the past five years
  - Company installing heat-pump increased to 380 in 2007 from 10 in 2004.

〈표 3-38〉 연도별 지열 냉난방 시스템 보급 용량 (2001~2006).

구 분	2001	2002	2003	2004	2005	2006	합 계
보급 용량(RT)	88	207	670	1,768	2,331	10,007	15,071

*RT(Refrigeration Ton): power required to freeze one short ton (2000 lb) of ice at 0°C in 24 hours. 1RT ~ 3.5 kW

신재생에너지백서, 2008

Four Types of Geothermal Heat Pump(1)
Closed loop

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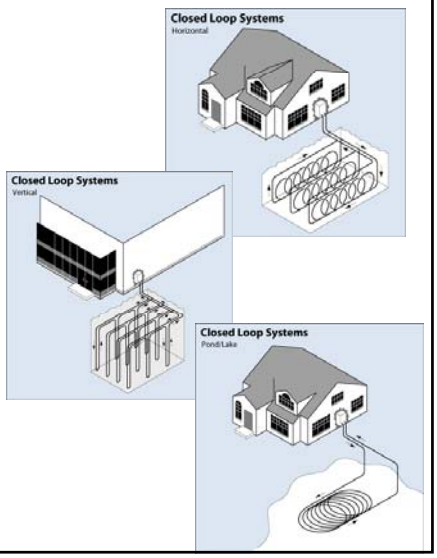
- Horizontal
  - Generally most cost effective
  - Use large land
  - Deeper than about 4 feet
- Vertical
  - For large buildings
  - Up to 200 m deep or more
- Pond/lake
  - When there is water (pond)



Four Types of Geothermal Heat Pump(2)
Open loop

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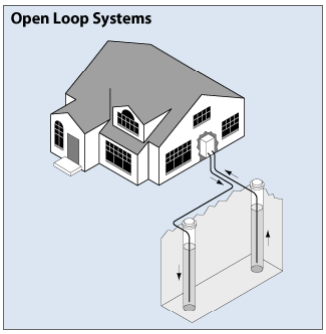
- Open loop
  - Use groundwater as the heat exchange fluid
  - Production/injection well
- Choice of system (open & closed loop) depends on the climate, soil conditions, available land, local installation cost.



Geothermal Heat Pump
Installation

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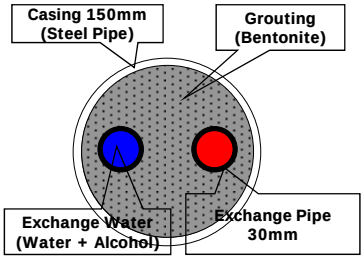

KOTEC Engineering, www. koteceng.net

Geothermal Heat pump
Advantages

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- Do not depend on the presence of water-bearing rocks
- They can be exploited almost anywhere
- Thousands of operations (Switzerland, Germany, Sweden)
- 400,000 units (US)
- Particularly valuable when cooling is required as well as heating.

Advantage of Geothermal Energy (1)

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- Provide base load power (Reliable). Wind and solar energy generate power intermittently
- Electricity at stable prices
- Emit very small amount of CO2 (no mine, no combustion)
- Economic development potential – employment, tax-payer
- Direct use application

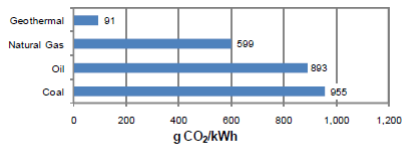

Figure 14. Comparison of CO_2 emission from electricity generation from different energy sources in the USA. Data from Bloomfield et al. (2003).

Fridleifsson, 2008, In: O. Hohmeyer and T. Trittin (Eds.), 59-80

Advantage of Geothermal Energy (2)

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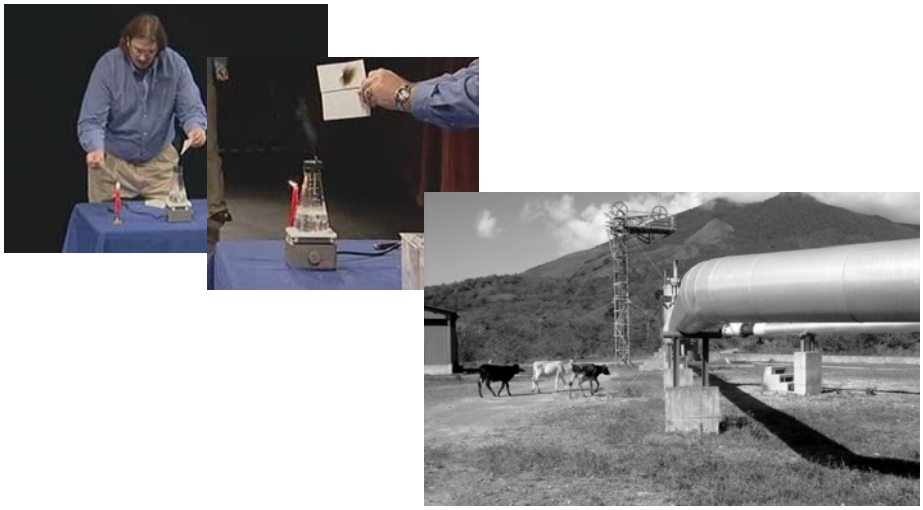

Miravalles geothermal power plant, Costa Rica (DiPippo, 2007)

Disadvantage of Geothermal Energy

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- Not strictly limitless – can be depleted
- Siting processing takes long
- Exploration and drilling remain expensive and risky
  - Drilling alone can account for as much as 1/3 or ½ of the total cost of a project
- Not economic to transport hot water/steam over long distances

Environmental Impact of Geothermal energy

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- Ground subsidence: usually in liquid-dominated fields millimeters ~ centimeters
- Induced seismicity: lubrication and increase of hydraulic pressure, usually associated with reinjection
- Induced landslides
- Noise Pollution, Disposal of drilling fluids
- Disturbance of natural hydrothermal system
- Disturbance of wildlife habitat, vegetation and scenic vistas

Content of this week's lecture - largely qualitative

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- What is Geothermal Energy? And the origin.
- Types – indirect/direct uses
- The elements – what is needed
- History and status
- Types of Geothermal Power Plants
- Enhanced Geothermal System (EGS)
- Geothermal Heat Pump
- Advantages/disadvantages
- Environmental Impacts