GEOTHERMAL ENERGY

Dry steam power plants at The Geysers in California.

Geothermal energy

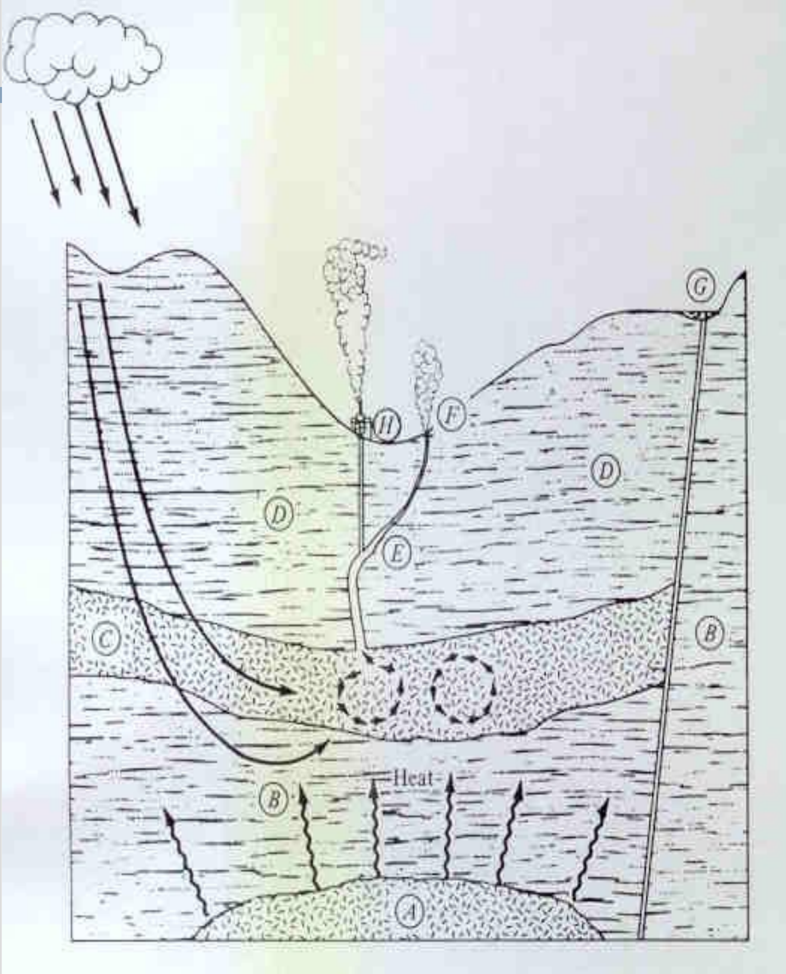
- heat (**thermal**) from the earth (**geo**)
- thermal energy in the rock and fluid that fills fractures and pores within the rock in the earth's crust.

The earth's initial energy from its molten state is sustained thru energy input from the sun and radioactive decay deep within the earth.

Topics – Geothermal Energy

- Geothermal Energy, Its Origin and History
- Geothermal Resources, Hydrothermal Sources
- Geothermal Technologies (Vapor, Flash, Binary, Hybrid)
- Emissions and Availability of Geothermal Plants
- Cost of Geothermal Power
- Geothermal Plants in the Philippines and US
- Operational & Environmental Problems
- Mitigating Measures being Implemented
- Benefits from Geothermal Plants
- Risks with Geothermal Plants

Origin of Geothermal Energy



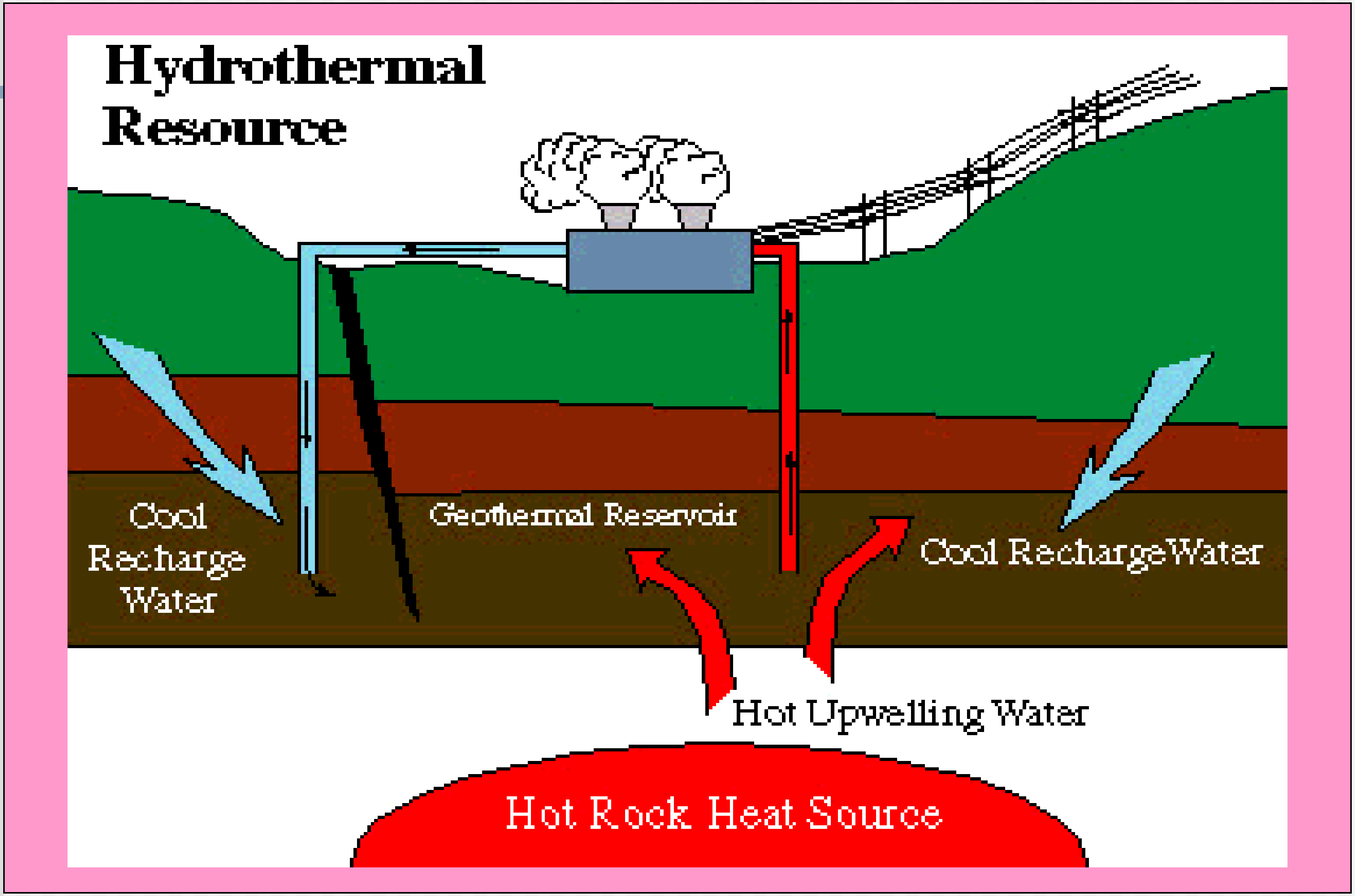
Typical Geothermal Field

Hot magma (A) solidifies into igneous rock (B). Heat of magma is conducted upward to this igneous rock. Ground water from rainfall finds its way down to this rock thru fissures, heated by the rock or hot gases and steam from the magma. Heated water rise convectively into porous or permeable reservoir (C). Layer is capped by impermeable solid rock (D) that traps the hot water in the reservoir. Fissures (E) acts as vents of the giant underground boiler. Vents shows up at surface as geysers (F) or hot springs (G). Well (H) taps steam from a fissure for use in a geothermal power plant.

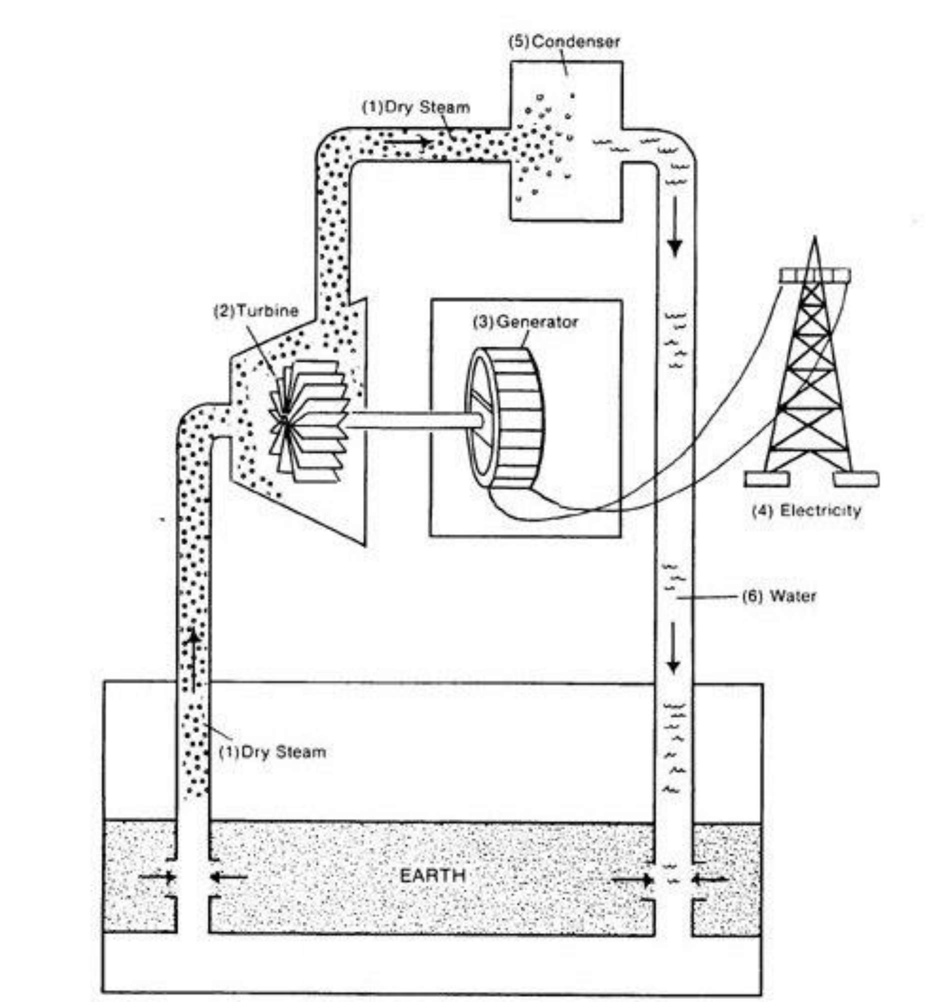
Geothermal Resources

- **Hydrothermal** systems – water sources heated by contact with hot rock; classified into vapor-dominated and liquid-dominated (flashed-steam, binary-cycle and total flow concept) systems; high temperature (>150 C) used mainly for power generation, as in Makban, Tiwi, etc.
- **Geopressured** systems – water or "brine" sources heated like hydrothermal water but trapped and pressurized in deeper underground aquifers; saturated with natural gas or methane CH_4.
- **Petrothermal** systems – hot, dry rock heated by the earth's magma at 150-290 C; 85% of total geothermal resources in the US; requires water to be pumped into the resource and back out to the surface to extract its thermal energy.

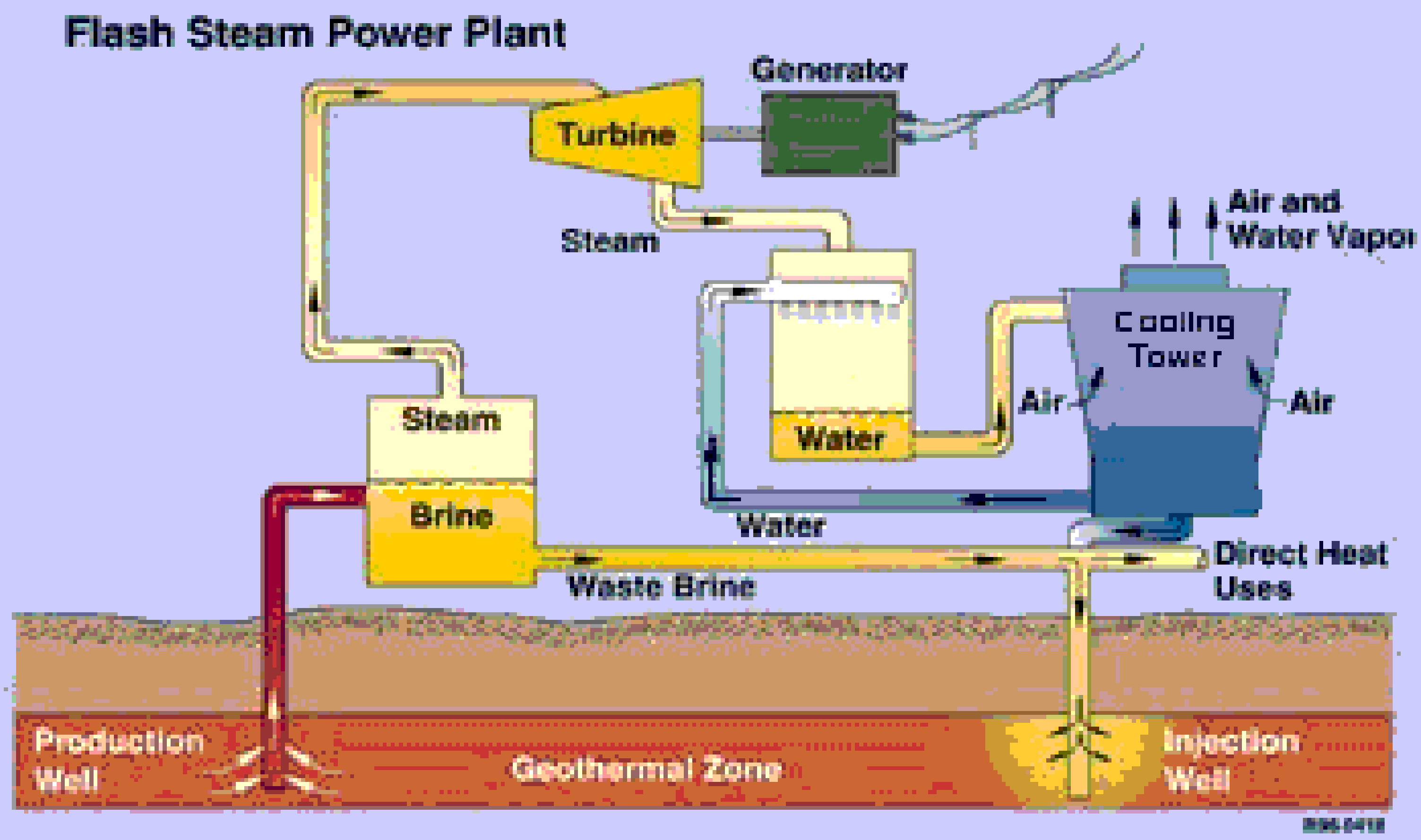
Hydrothermal Resource



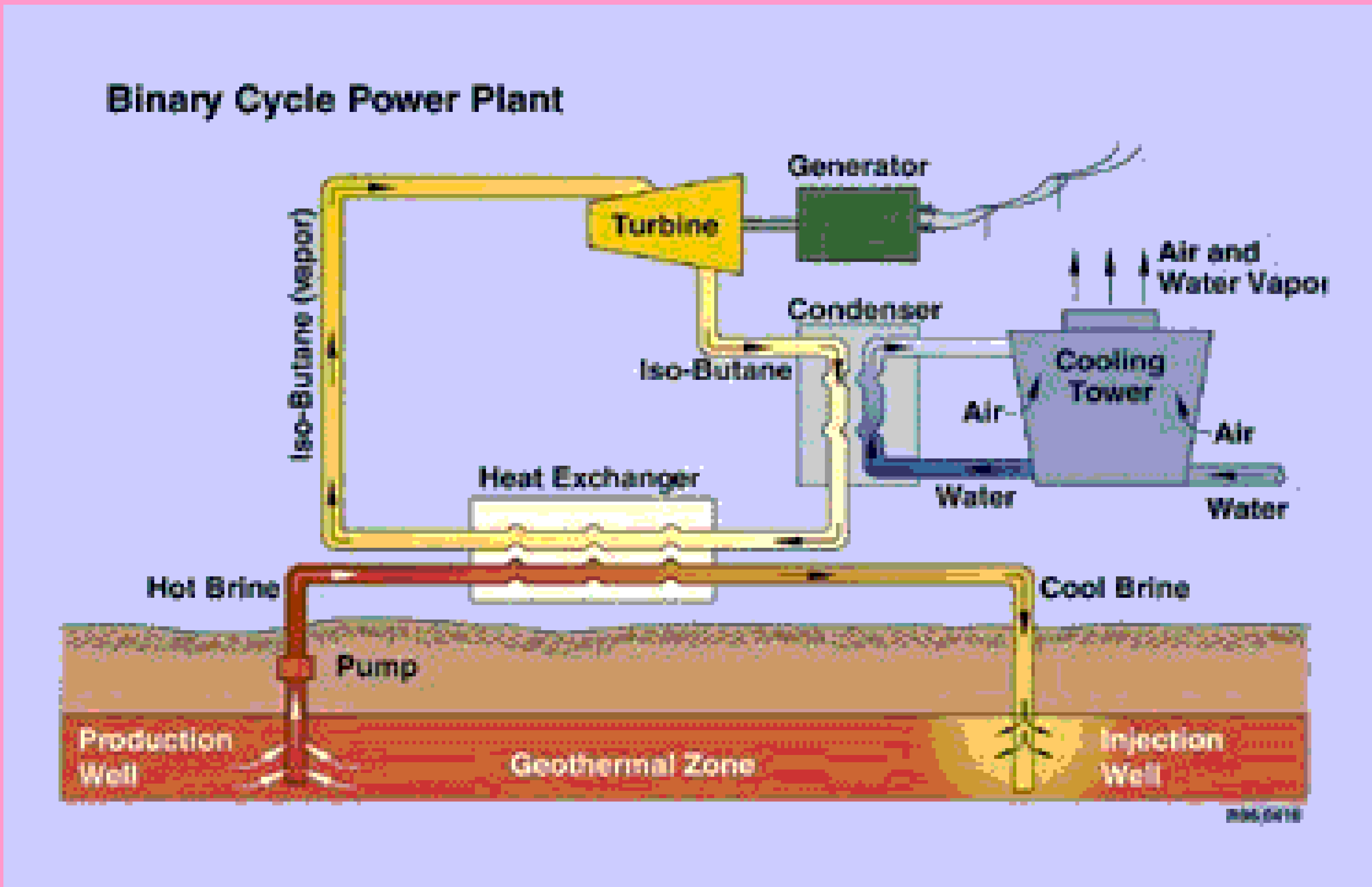
Dry Steam Power Plant Diagram



Flash Steam Power Plant



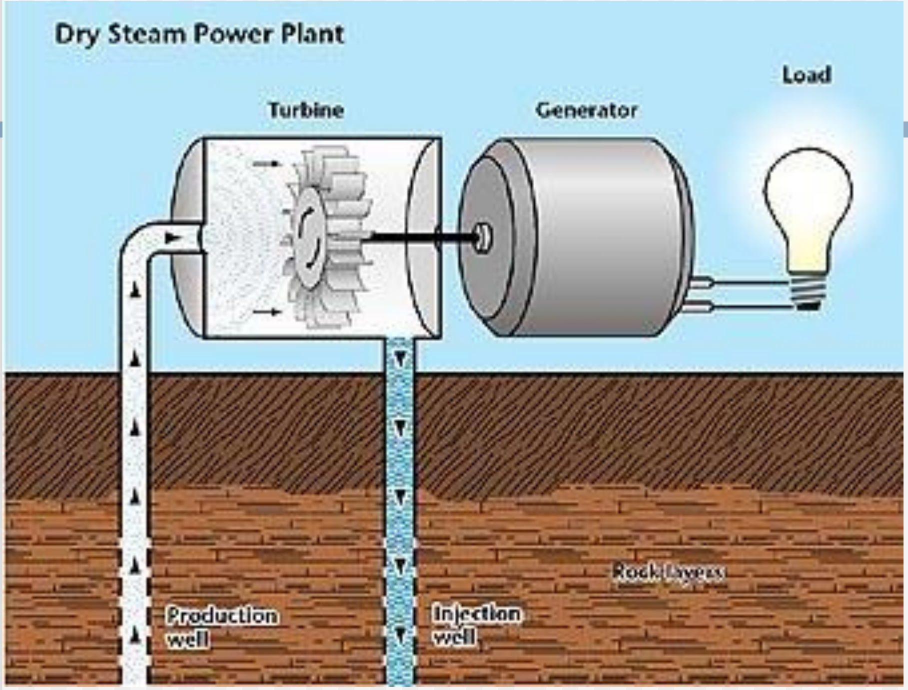
Binary Cycle Power Plant



Geothermal Technology

- **Dry Steam (or Vapor)** power plants – use hydrothermal fluids, primarily dry steam or vapor; oldest geothermal plant, first used at Larderello in Italy in 1904
- **Flash Steam** power plants – use hydrothermal fluids above 200 C under high pressure and sprayed into a flash tank at lower pressure to rapidly vaporize the steam; used in MakBan
- **Binary-Cycle** power plants –use fluids below 200 C by using a heat exchanger to heat a second fluid with a much lower boiling point than water, causing the binary fluid to flash into vapor; used in Ormat
- **Hybrid geothermal-fossil systems (future) –** utilize low temperature heat of geothermal resource to pre-heat feedwater in a conventional steam cycle or use fossil fuel to superheat the flashed steam to improve thermal efficiency. (**geothermal preheat** and **fossil superheat**)

Dry Steam (Vapor-Dominated)

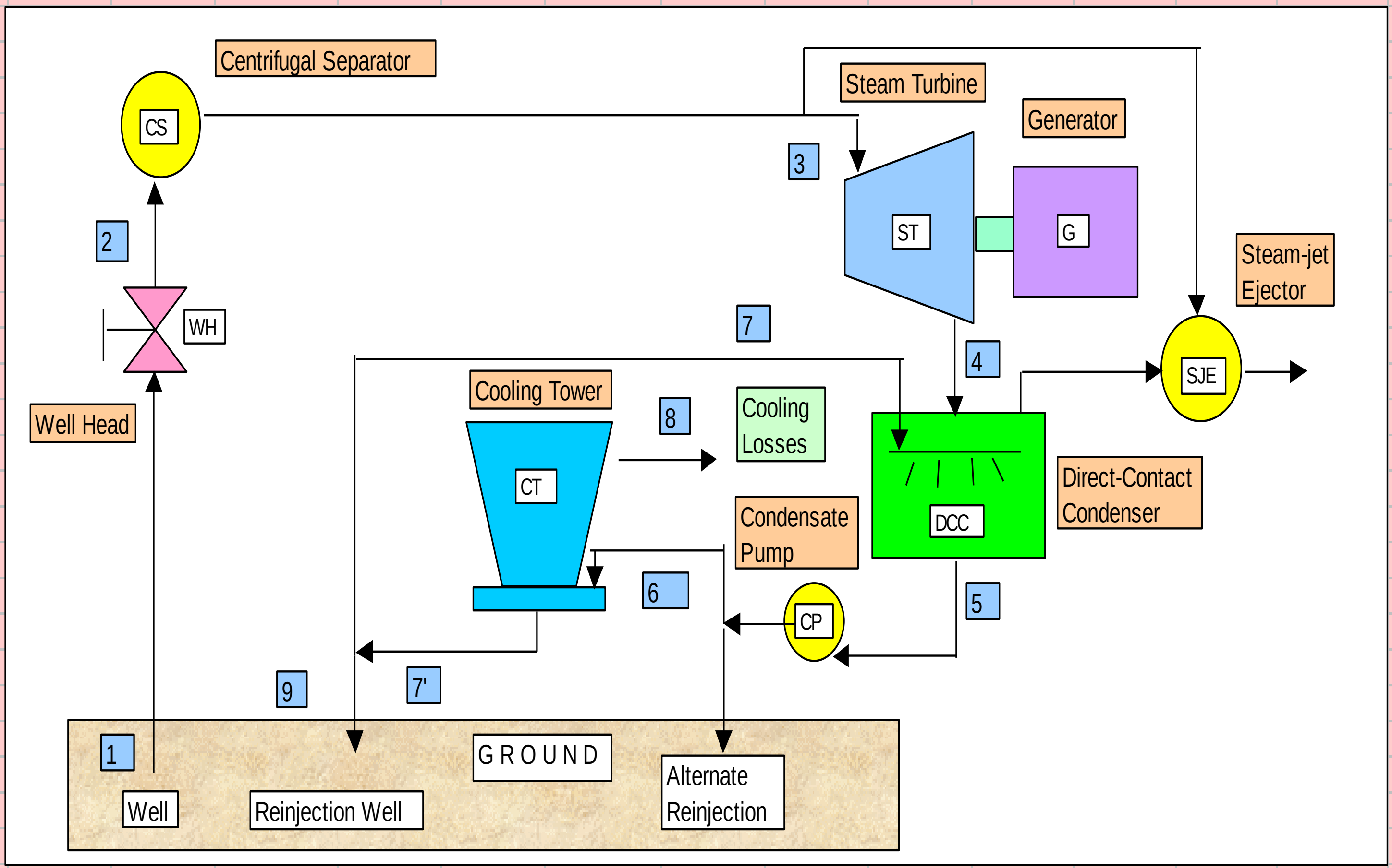


A geothermal power plant at The Geysers.

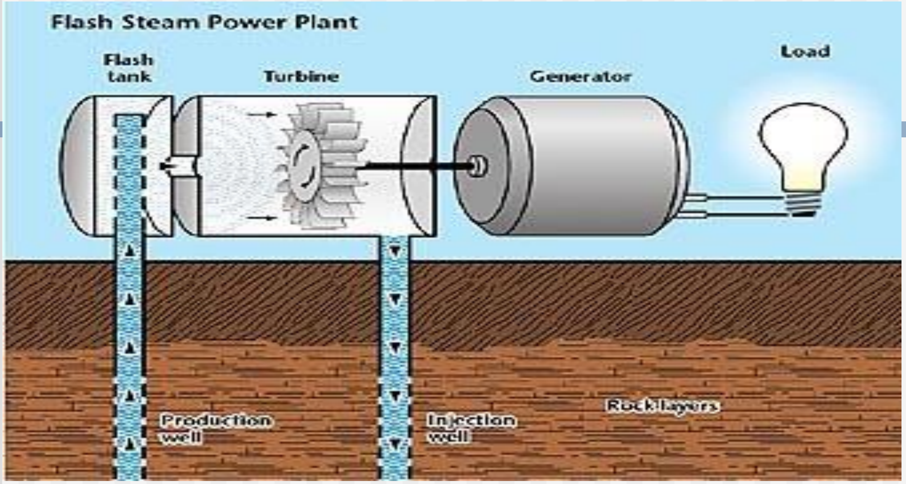
Vapor systems – 5 known sites in the world; accounts for only 5% of all US geothermal resources; The Geysers in California and Larderello in Italy are both vapor-dominated systems, where steam is above 205 C and 8 bar.

Dry Steam System Components

Figure 12-5 Schematic of Vapor-Dominated Geothermal Plant



Flashed Steam (Liquid-Dominated)



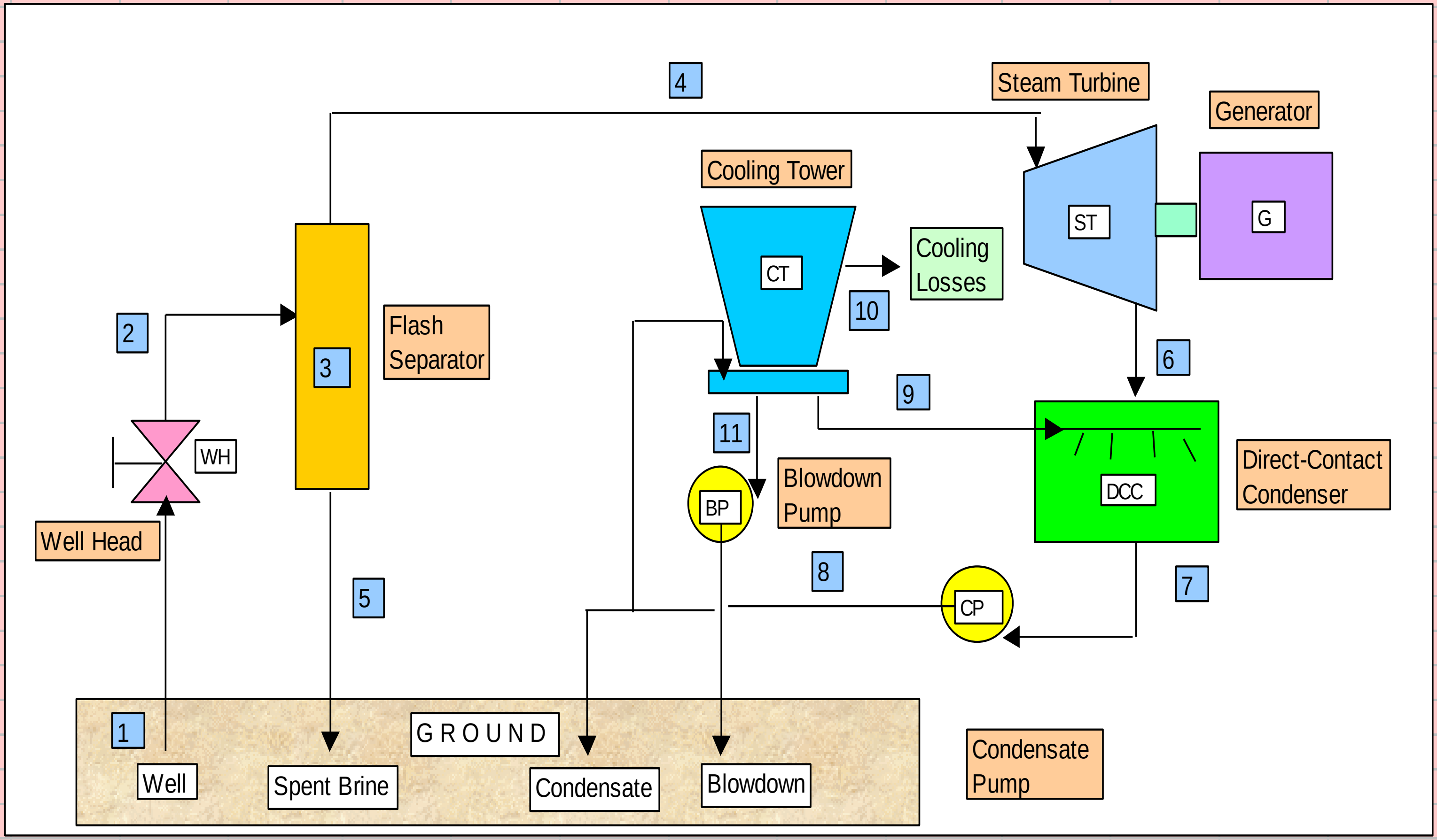
(Also used in Makban)

Dual-Flash Power Plant in Imperial Valley, California

Liquid-dominated systems – more common commercial systems in operation today; require the least extension of technology; hot water at 174-315 C and 10 bar enters a flash tank below 8 bar, causing it to partially flash to a two-phase mixture of low quality steam.

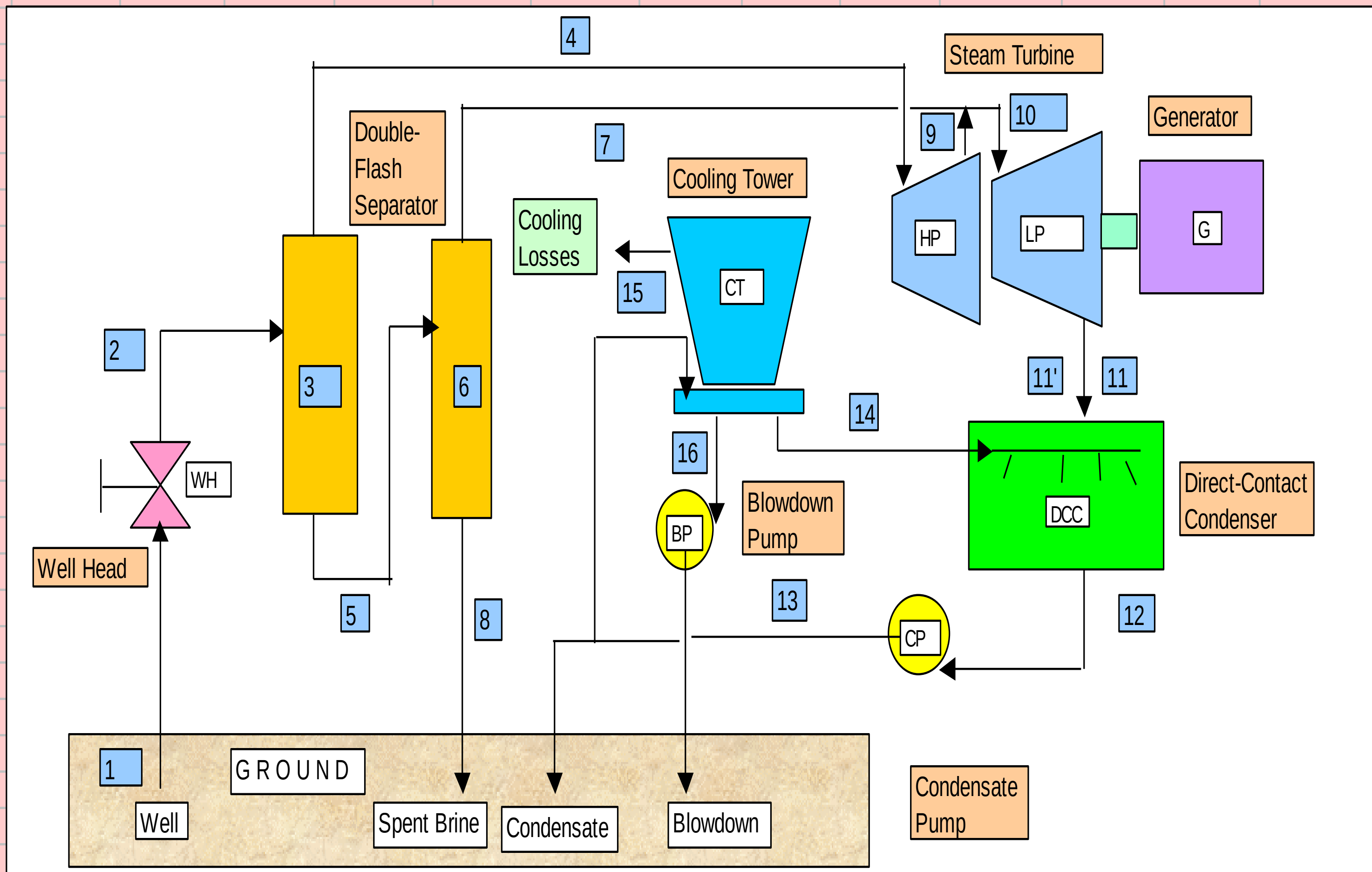
Single-Flash System Components

Figure 12-8 Schematic of Liquid-Dominated, Single-flash Steam System

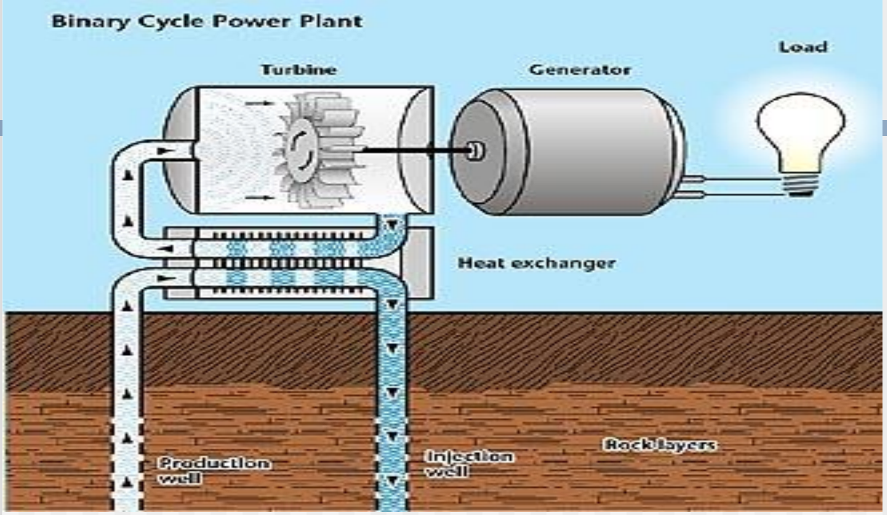


Double-Flash System Components

Figure 12-10 Schematic of Liquid-Dominated, Double-Flash Steam System



Binary-Cycle (Liquid-Dominated)



Geothermal power plant in Nevada.

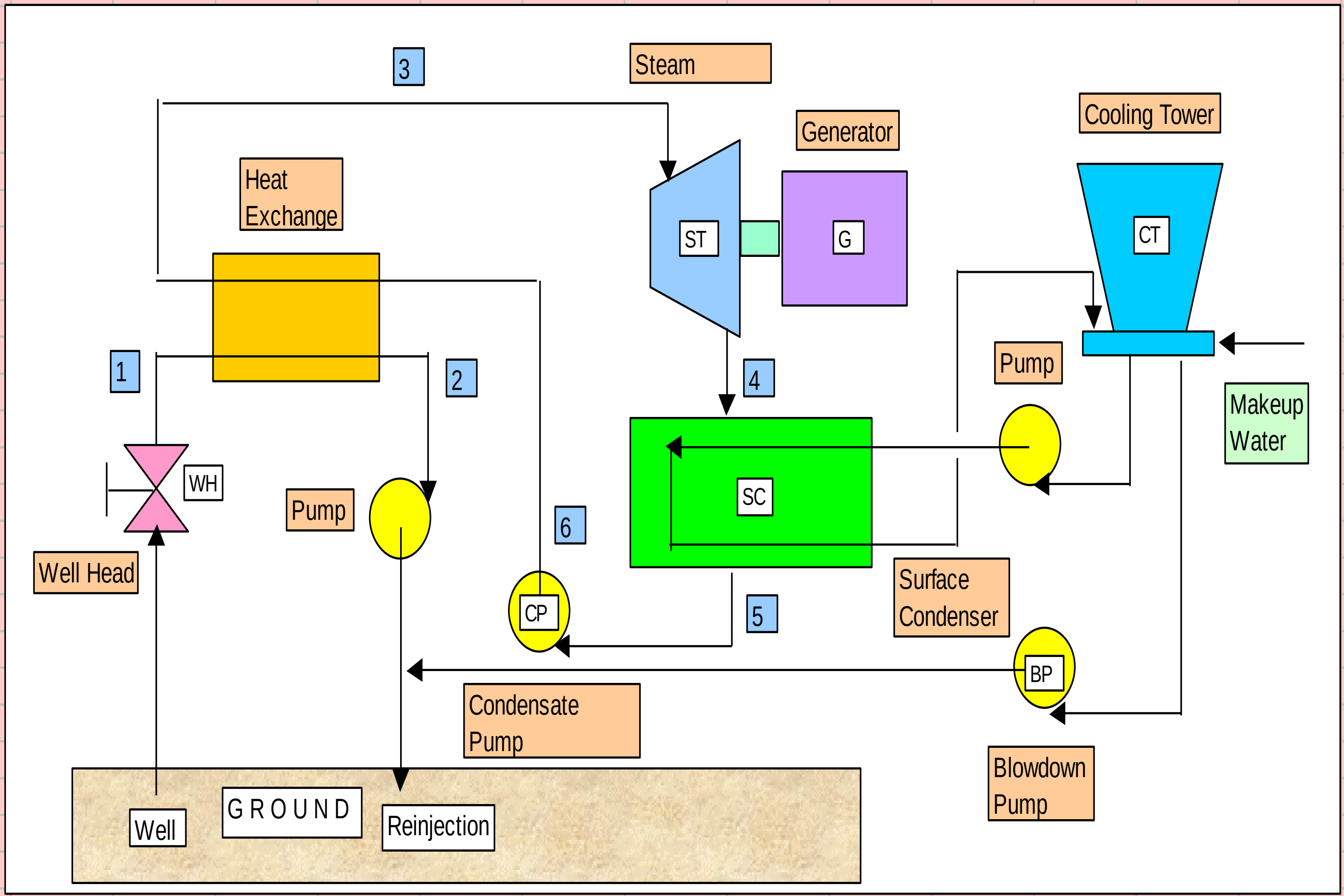
(Also used in Ormat)

Binary-Cycle Power Plant in Nevada

Binary-Cycle systems – use the remaining 50% of hydro-thermal water in the moderate temperature range of 150-205 C; this water is used to heat another working fluid with low boiling point, e.g. isobutane, freon-12, ammonia or propane while the spent water is pumped back to the ground; condenser is cooled by water from a natural source or a cooling-tower circulation system.

Binary-Cycle System Components

Figure 12-12 Schematic of Liquid-Dominated, Binary-Cycle System

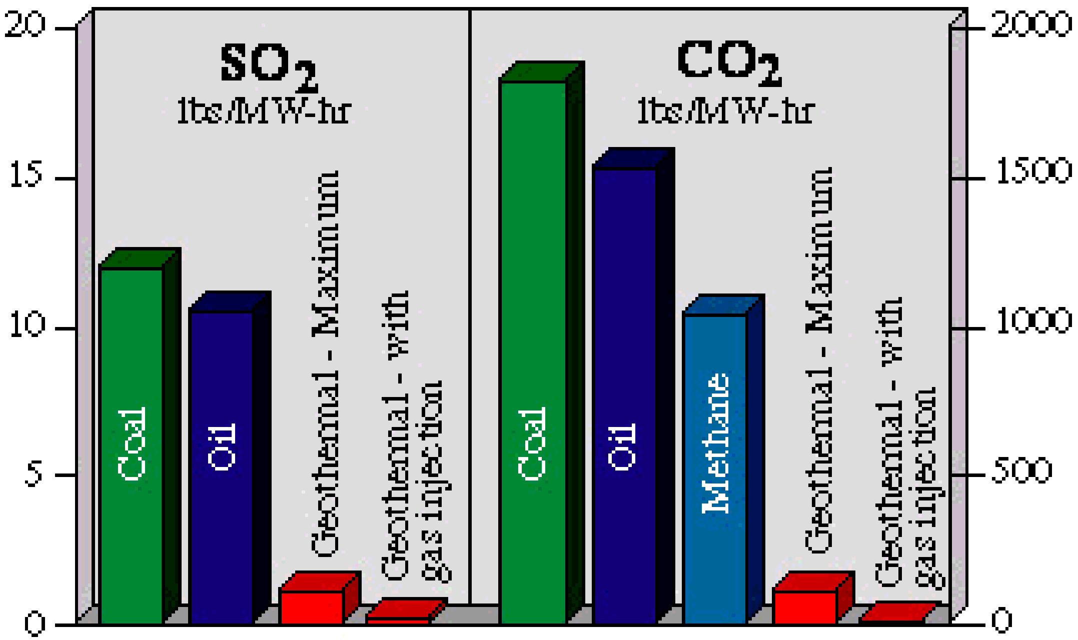


Future Geothermal Technologies

Hybrid Geothermal-fossil-fuel systems utilize the low-temperature heat of geothermal sources in the low end of a conventional cycle and the high-temperature heat from the fossil-fuel combustion in the high end of cycle to increase thermal efficiency and reduce fossil fuel consumption. The two possible arrangements are:

- **Geothermal preheat -** uses geothermal heat to preheat to its saturation point the feedwater of a conventional fossil-fueled plant. No steam is bled from the LP turbines to preheat the water, thus increasing power output.
- **Fossil superheat -** uses fossil fuel to superheat the vapor obtained from a flash separator to raise temperature and efficiency of the steam cycle.

Emissions from Geothermal Plants

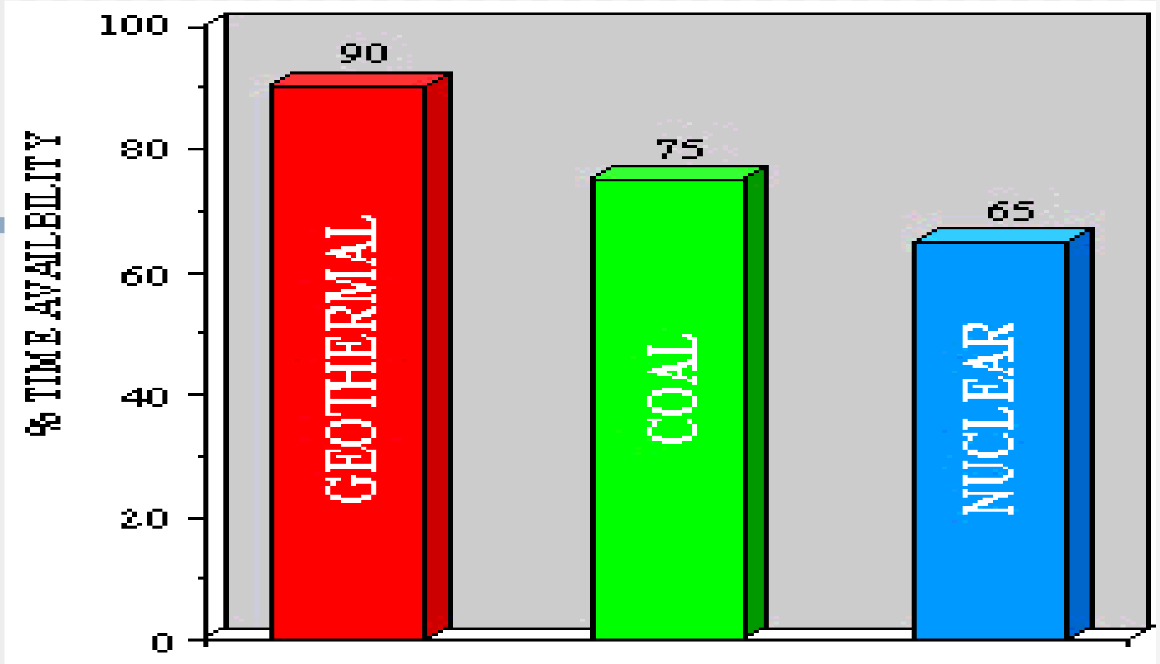


After Goddard & Goddard, GRC Transactions, 14, 643-649 (1 lb = 0.4536 kg)

Emissions are low.

- Geothermal flash plants emit only excess steam.
- Binary-cycle plants have no air emissions or liquid wastes
- Salts/dissolved minerals are re-injected with spent brine.
- Some plants produce useful solid materials (Zn and S).

Availability of Geothermal Plants



"Availability" is the percentage of time that a plant can actually produce electricity. Traditional plants like coal and nuclear can only produce electricity at about 65-75% of the time. The average geothermal plant is available 90% of the time. A higher percentage means the plant is available to generate electricity (and revenues) more often.

Cost of Geothermal Power

- Cost of geothermal power (EIA, 1996) for a 50 MW plant:

Resource type	Base load
Capacity factor	90 - 95%
Real levelized cost (1999$)	4.5 – 7 cents / kWh
Construction lead time	1 – 3 years
Overnight capital cost	$2,000 / kW
Annual Fixed O&M	$96 / kW / year
Variable O&M, $/kWh	nil

- Levelized cost of geothermal energy in the US is estimated to be:

2000	5 cents / kWh
2010	4 cents / kWh

- Recent data show the initial cost at $2,000/kW, probably $3,000-5,000/kW for small plant and $1,500-2,500/kW for larger plants, while variable O&M ranges from $0.015 to $0.045/kWh.
- The Geysers energy is sold at $0.03-$0.035/kWh.
- A proposed 40 MW plant in Negros will cost $2,700/kW (40% for developing the steam field and 60% for building the power station).

Geothermal Plants in RP

	Geothermal Power Plants in the Philippines								
Plant Name/ Proponent	Location	Owner	Contract Type	Grid	Region	Year Comm.	No.	Unit Size	Capacity MW
Mak-Ban Plant A	Laguna, Calauan	NPC		Luzon	IV	1979	2	55.0	110.00
Mak-Ban Plant B	Laguna, Calauan	NPC		Luzon	IV	1980	2	55.0	110.00
Mak-Ban Plant C	Laguna, Calauan	NPC		Luzon	IV	1984	2	55.0	110.00
Mak-Ban Plant D	Laguna, Calauan	NPC		Luzon	IV	1995	2	20.0	40.00
Mak-Ban Plant E	Laguna, Calauan	NPC		Luzon	IV	1996	2	20.0	40.00
Ormat-Makban	Laguna, Bay, Bitin	NPC-IPP	BTO	Luzon	IV	1994			15.70
Tiwi Plant A	Albay, Tiwi	NPC		Luzon	V	1979	2	55.0	110.00
Tiwi Plant B	Albay, Tiwi	NPC		Luzon	V	1980	1	55.0	55.00
Tiwi Plant C	Albay, Tiwi	NPC		Luzon	V	1981-84	2	55.0	110.00
Bak-Man I	Sorsogon, Bacon	NPC		Luzon	V	1993	2	55.0	110.00
Bak-Man II	Sorsogon, Bacon	NPC		Luzon	V	1994	1	20.0	20.00
Bak-Man II-2	Sorsogon, Bacon	NPC		Luzon	V	1998	1	20.0	20.00
Palimpinon Geo I	Negros Oriental, Valencia	NPC		Visayas	VII	1983	3	37.5	112.50
Palimpinon II 1 & 2	Negros Oriental, Valencia	NPC		Visayas	VII	1993-94	2	20.0	40.00
Palimpinon II 3 & 4	Negros Oriental, Valencia	NPC		Visayas	VII	1995	2	20.0	40.00
Tongonan I GPP	Leyte, Kananga	NPC		Visayas	VIII	1983	3	37.5	112.50
Leyte A Geo-PNOC	Leyte, Tongonan	IPP	PPA	Visayas	VIII	1996	17		586.00
Mt. Apo GPP 1	N. Cotabato, Kidapawan	IPP	PPA	Mindanao	XII	1996			47.00
Mt. Apo GPP 2	N. Cotabato, Kidapawan	IPP	PPA	Mindanao	XII	1999			48.00
									1,836.70

Operational and Environmental Problems of Geothermal Plants

- **High quantities of dissolved solids** (3000-25000 ppm), **entrained solid particles**, and **non-condensable gases** (0.2 to 4.0 %, mostly carbon dioxide CO_2 [80%] and methane [CH_4], hydrogen [H_2], nitrogen [N_2], ammonia [NH_3], and hydrogen sulfide [H_2S]) **in hydrothermal water and steam**
- **Careful design of gas ejectors** to maintain vacuum in the condenser required due to non-condensable gases
- **Corrosion of wet steam and condensate lines and exposed equipment** due to acid-forming gases under moist conditions
- **Scaling**, which requires turbine nozzles with larger throat areas
- **Bare copper corrosion** (in relays/electrical components) due to H_2S
- **Environmentally undesirable H_2S and NH_3 emissions** when they escape to the atmosphere (acid rain).
- **Land surface subsidence** due to extraction of large amounts of underground fluids
- **Noise pollution**

Mitigating Measures Being Implemented in Geothermal Plants

- Removal of entrained solids usually by centrifugal separators at the well head, before they enter plant equipment, and by strainers, before turbine entry.
- Removal of non-condensable gases in the condenser ejectors and treatment before releasing to the atmosphere.
- Avoiding use of nickel in rotors, replacing bare copper with aluminum in electrical systems and in condensate pipes and valves to minimize corrosion due to H2S
- Use of "clean rooms" under positive gauge pressure to isolate corrosion-sensitive surfaces and equipment.
- Use of static-type exciters instead of copper-commutator or motor-driven exciters
- Use of motor driven, instead of steam driven, auxiliaries
- Re-injection of spent brine, condensate and blowdown to minimize land surface subsidence.
- Installation of silencers to minimize noise from exhausts, blowdowns and centrifugal separators.

Benefits from Geothermal Plants

- **Clean** –emissions are low.
- **Renewable** –source is almost unlimited amount of heat generated by the earth's core; in areas dependent on hot water reservoir, volume taken out can be re-injected, making it a sustainable energy source.
- **High Plant Reliability/Availability** – technology is reliable that geothermal plants have average availabilities of 95 % or higher
- **Indigenous** – reduces dependence on imported and expensive oil.
- **Small footprint** – needs only 400 square meters of land per gigawatt of power over 30 years.

Risks with Geothermal Energy

- **Risks associated with the geothermal resource -** discovered by prospecting; tested to determine the quality of the heat that can be extracted; prospecting involves financial outlay with no certainty of a return; risks may be lower when data exists but needs test drilling.
- **Geothermal fields are not limitless** – will become exhausted in time like in the US and New Zealand; estimates of the rate of decline may be imprecise; best safeguard of investment is not to overexploit the field; watershed has to be managed by protecting the forest cover, reinjecting spent steam, brine, wastewaters.
- **Exploitation is a relatively low-risk venture –** power generation based on underground steam and brine fields are straightforward investment with little risk outside risks normally associated with power sector projects; technology is well established and extensively tested, except for geothermal energy from hot rocks and magma.