THE BASICS OF GEOTHERMAL POWER CONVERSION

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SUMMARY OF WORLD GEOTHERMAL POWER UTILIZATION

- 23 countries produce electricity from geothermal energy
- Total of 8,700 MWe of installed capacity
- Generating 54 billion kWh/year
- Operating with a capacity factor of 71%

TYPES OF UTILIZATION

- Non-condensing plants (DS and F)
- Dry steam plants (DS)
- Wet steam or flash plants (F)
- Binary or organic Rankine cycle plants
- Combined cycle plants
- Hybrid plants
- Total flow plants

WORLD PLANT TYPES

	DS	1F	2F	3F	Binary	Other
% Units (~500)	17	29	10	0.2	39	5
% MWe (8700)	23	45	24	0.1	4	4
Ave. MWe/unit	22	25	38	10	2	14

NON-CONDENSING PLANTS

- **Atmosphere exhaust plants**
- **Eliminates the cost of a cooling tower - cheaper**
- **Monobloks modules have been used – Indonesia - 250 kWe & 2.0 MWe – easy installation/operation**

NON-CONDENSING PLANTS

- Lose 50% of power compared to condensing plants as they use 2x steam for same power output
- Non-condensable gases released to atmosphere – used where high percentage of NCG are present and allowed (>10 to 15% by weight of steam)
- Used to get power on-line fast on a temporary basis

NON-CONDENSIBLE GASES

- **Examples (by weight of steam):**
  - **Wairakei: 0.35 to 0.5%**
  - **The Geysers: 0.6 to 1.0%**
  - **Cerro Prieto: ~ 1.25%**
  - **Larderello: 4.5 to 5%**
  - **Matsukawa: ~ 1.1%**
- **At Mt. Amiata, Italy – wells initially have high NCG content (25%) – used atmospheric exhaust plant until gas content declined – then condensing plant added after about 3 years**

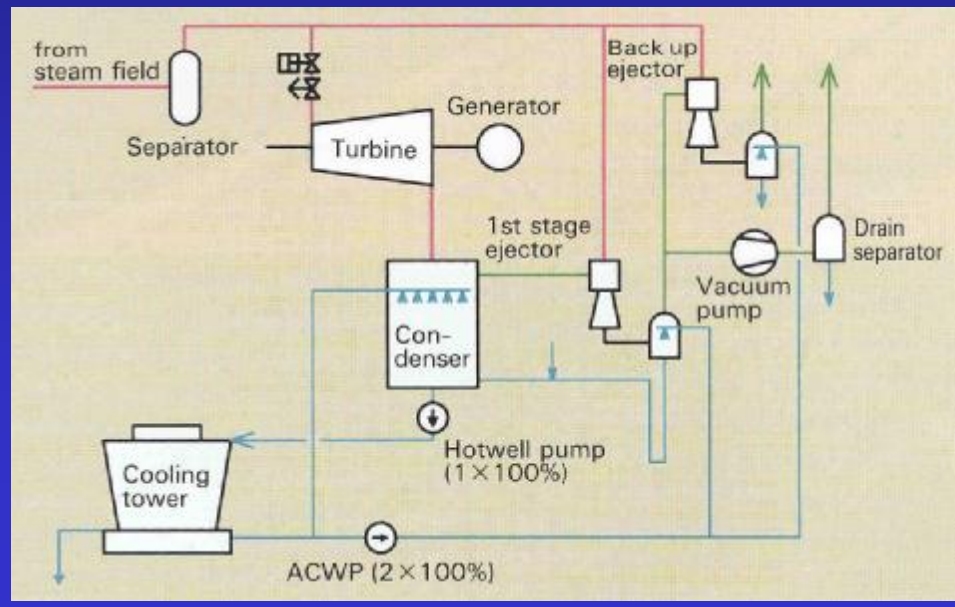
CONDENSING PLANTS

- A condenser is normally used on all geothermal plants to increase the power – by maximizing pressure drop across turbine
- Condensing the steam at the turbine exhaust, creates a vacuum (0.15 atm), thus maximizing the pressure drop and power output

CONDENSERS PLANTS II

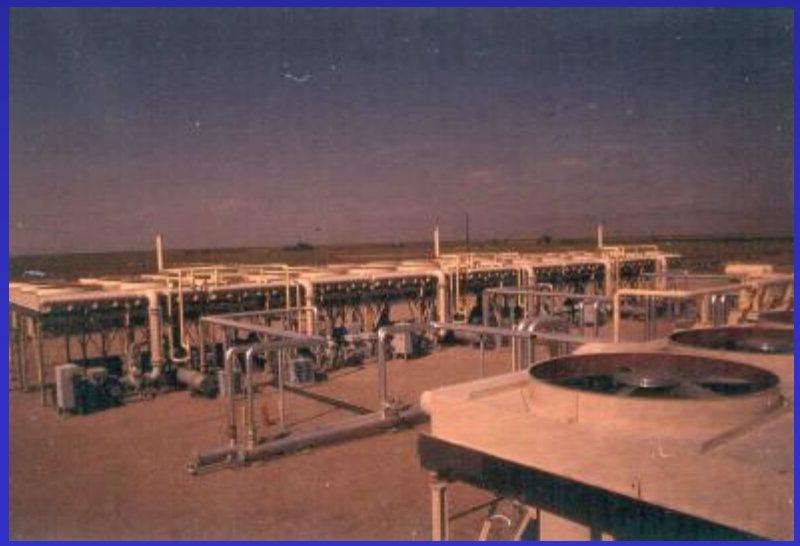
- **Surface and direct-contact types used**
- **Surface type – the cooling water and exhaust steam do not come in contact – heat exchanger used -- necessary if non-condensable gases are treated to limit emission of H_2S and SO_2**

•Direct-contact type less expensive – no HX



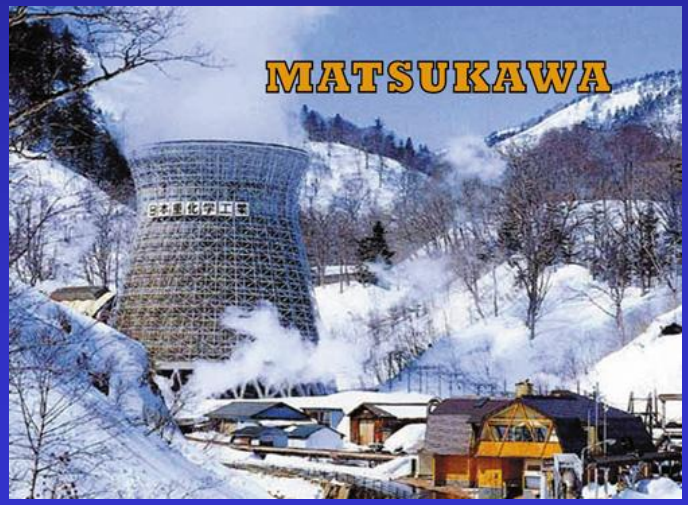
COOLING TOWERS

- **Water-cooled using fluid from a cooling tower – from steam condensate**
- **Air-cooled – used where water is scarce (desert climates) – efficiency up to 30% lower in summer due to high dry-bulb temperature**



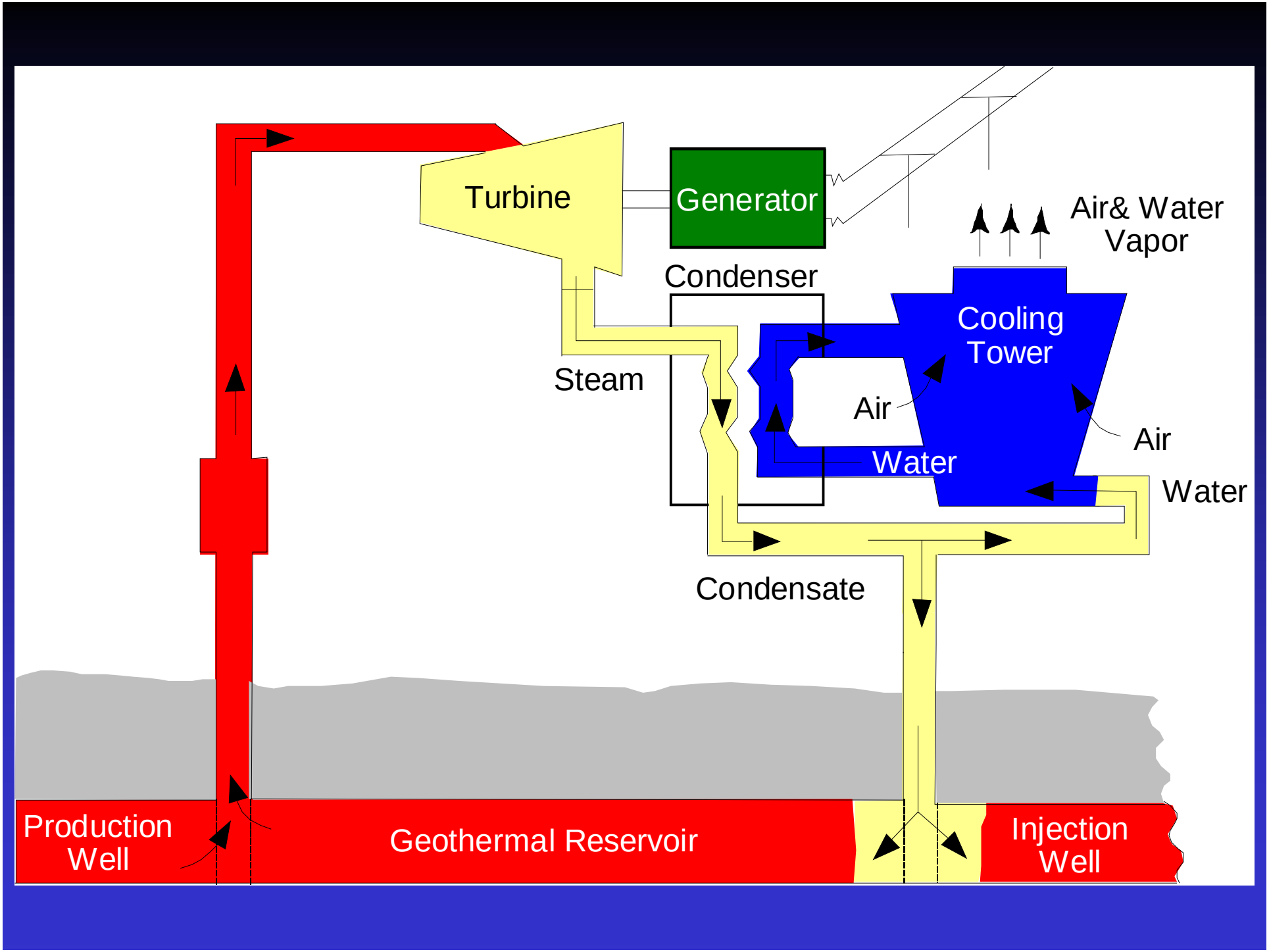
COOLING TOWERS II

- Natural draft cooling towers used at some plants such as Larderello, Matsukawa, and Ohaaki, NZ
- These have lower operating costs and reliable, continuous operations as compared to mechanical draft
- However, they have a high profile



DRY STEAM PLANTS

- Energy from vapor dominated reservoirs
- Reservoir permeability low – so all fluid entering is flashed to steam
- Resource around 240ºC
- Dry, saturated or slightly superheated steam produced from wells
- Steam used directly in turbines
- Only dust/rock separators and drain pots needed to remove condensation prior to entering turbine


Turbine
Generator
Air& Water
Vapor
Condenser
Cooling
Tower
Steam
Air
Air
Water
Water
Condensate
Production
Well
Geothermal Reservoir
Injection
Well

Drilling – The Geysers

Steam turbine - generator

Turbine blades

DRY STEAM PLANTS II

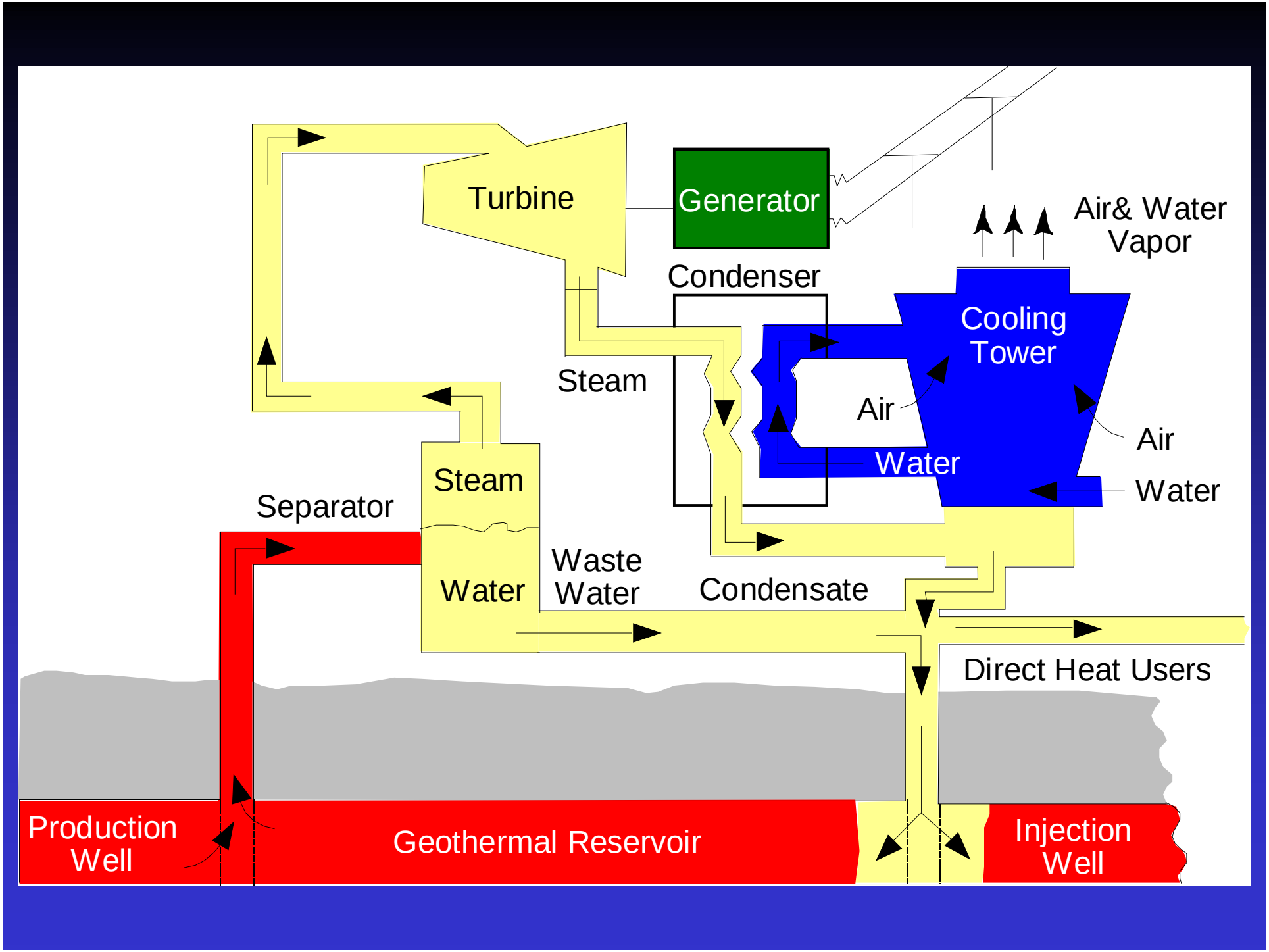
- Dry steam fields are rare – most notable are:
  - Larderello in Tuscany, Italy
  - Matsukawa on Honshu, Japan
  - The Geysers in northern California, USA
  - Kamojang on Java in Indonesia
- Plant least expensive to install - <$1,000/kW
- <$2,000/kW with well field
- Non-condensable gases must be removed – typically 2-10% by weight of steam

The Geysers

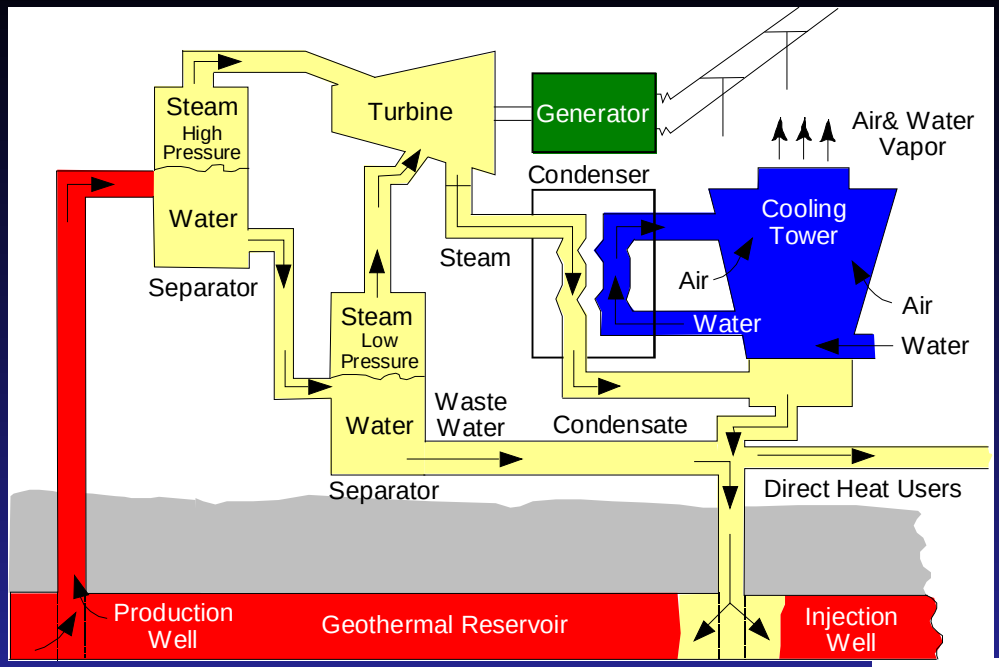
Larderello

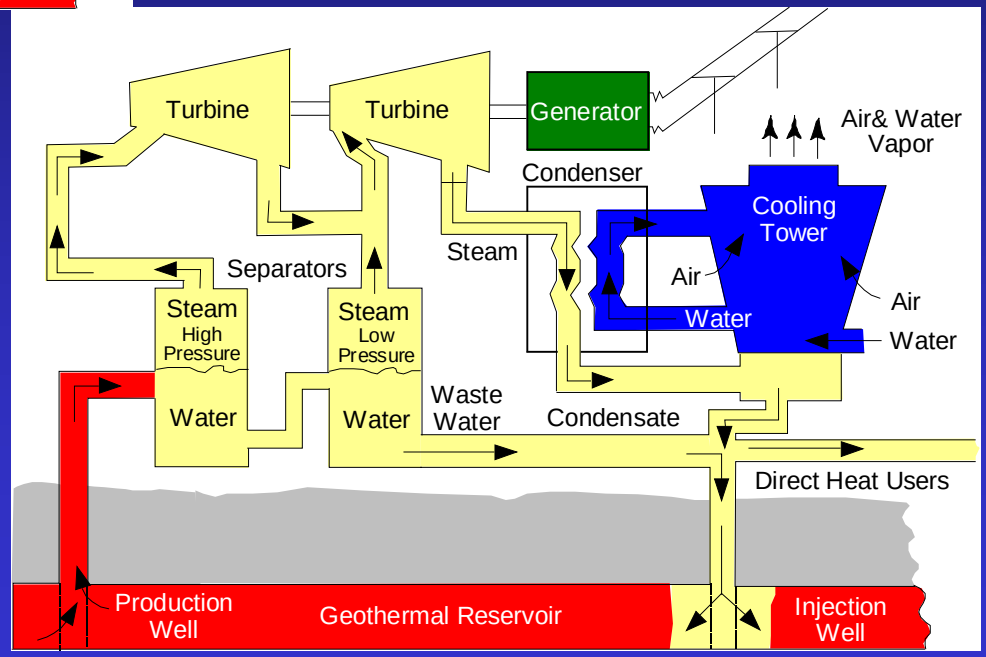
WET STEAM PLANTS

- Most common type of fields – superheated hot water under pressure – artesian flow
- Single flash plants – most common
- Double flash plants – 15 to 20% more output – more common in the USA
- Triple flash plants – 5 to 10% more output – very uncommon due to cost – Wairakei, NZ
- Combined cycle plants used instead of 3F
- US$2,000 – 3,000/kW with well field


Turbine
Generator
Air& Water
Vapor
Condenser
Cooling
Tower
Steam
Air
Air
Water
Water
Steam
Separator
Water
Waste
Water
Condensate
Direct Heat Users
Production
Well
Geothermal Reservoir
Injection
Well

Types of double flash plants





Flash steam power plants

SEPARATOR

- **Two-phase flow from well is directed horizontally and tangentially into a vertical cylindrical pressure vessel – THE CYCLONE SEPARATOR**
- **Liquid flow circumferentially along the inner wall and flows out thru the bottom**
- **Vapor moves to top and is removed thru a vertical standpipe**

1F separator - USA

2F separators - Iceland

3F separators – New Zealand

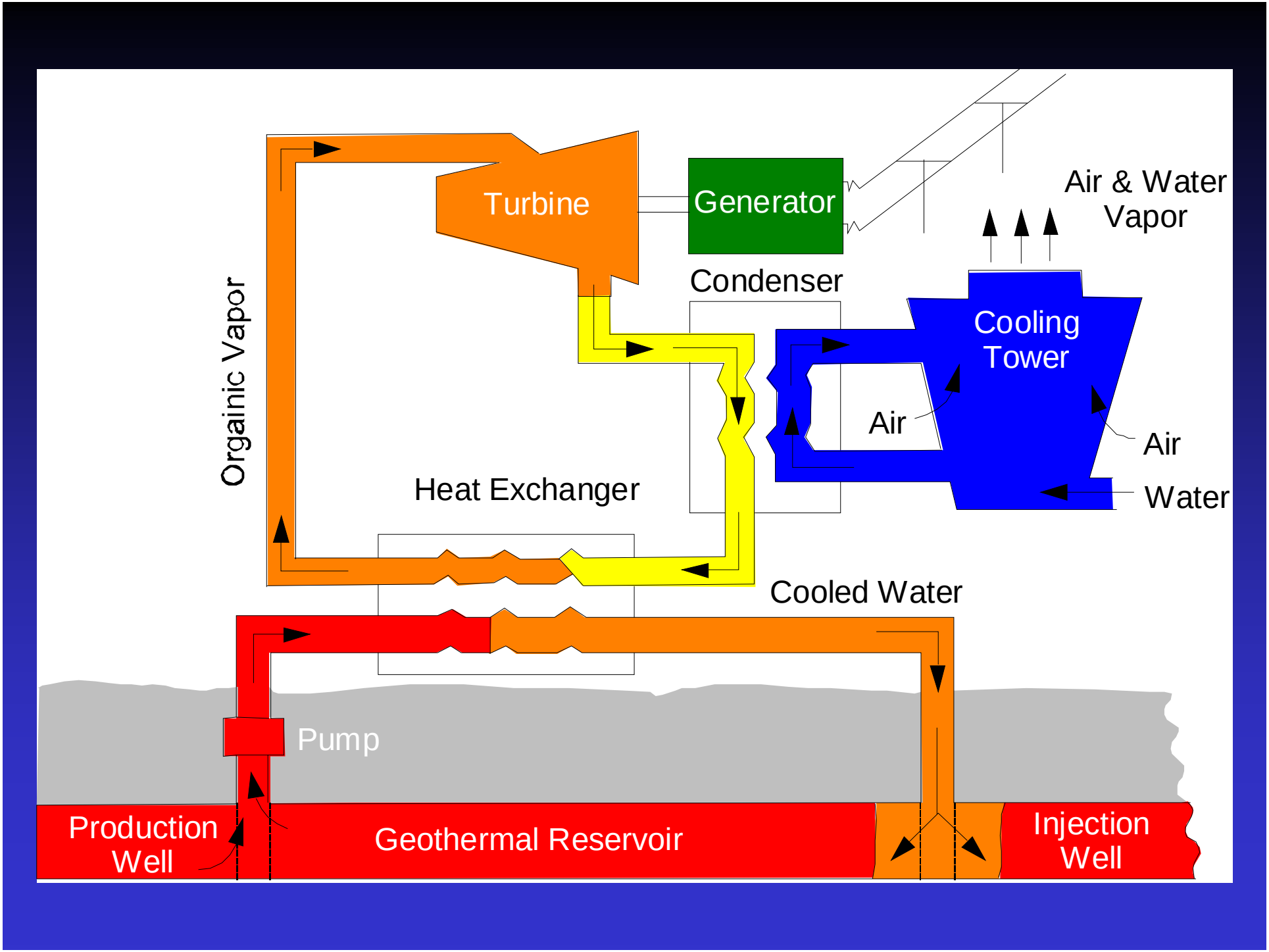
BINARY PLANTS

- Conventional organic Rankine cycle
- Energy from geothermal fluid transferred thru a heat exchanger to a secondary working fluid - hydrocarbon
- Geothermal fluid does not come in contact with the moving parts of the power plant, thus eliminating corrosion/scaling problems

Wabuska, Nevada

750 kWe

104ºC – 54 L/s


Turbine
Generator
Air & Water
Vapor
Condenser
Cooling
Tower
Orgainic Vapor
Air
Air
Water
Heat Exchanger
Cooled Water
Pump
Production
Well
Geothermal Reservoir
Injection
Well

BINARY PLANTS II

- **Main advantages:**
  - **Reduced corrosion or scaling potential**
  - **Can use lower temperature fluids (<150ºC)**
  - **Reduced problems with dissolved gases**
- **Usually requires downhole pump in well, which provides pressure to keep fluid liquid -- preventing flashing in the well, heat exchangers, piping and injection wells**

BINARY PLANTS III

- **Wet cooling is more efficient – however, if no condensate available – makeup water must come from other sources**
- **Dry cooling often used in arid climates – with some loss of efficiency – due to high dry bulb temperature**

Nagqu, Tibet

4,526 m elev.

1.3 MWe

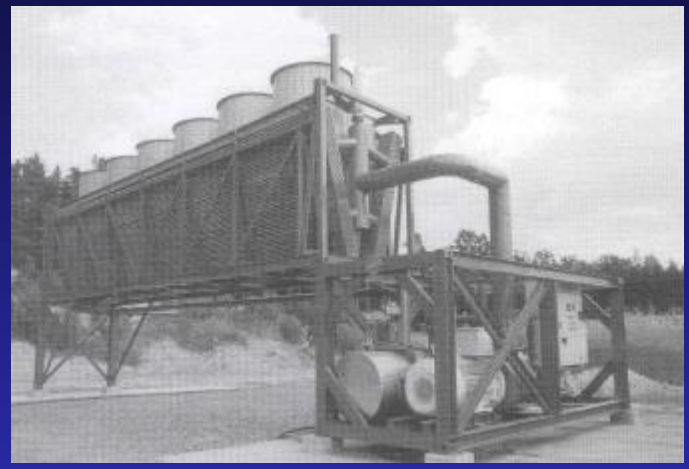
110ºC – 69 L/s

BINARY PLANTS IV

- Working fluid is a hydrocarbon such as isobutane, isopentane and propane – matched to geothermal fluid temperature
- These are all low boiling point fluids
- Plant cost about US$1,800 to 2,500/kWe
- US$2,500 to 3,500/kWe with well field
- Package modules available: 100 kW – 6 MW

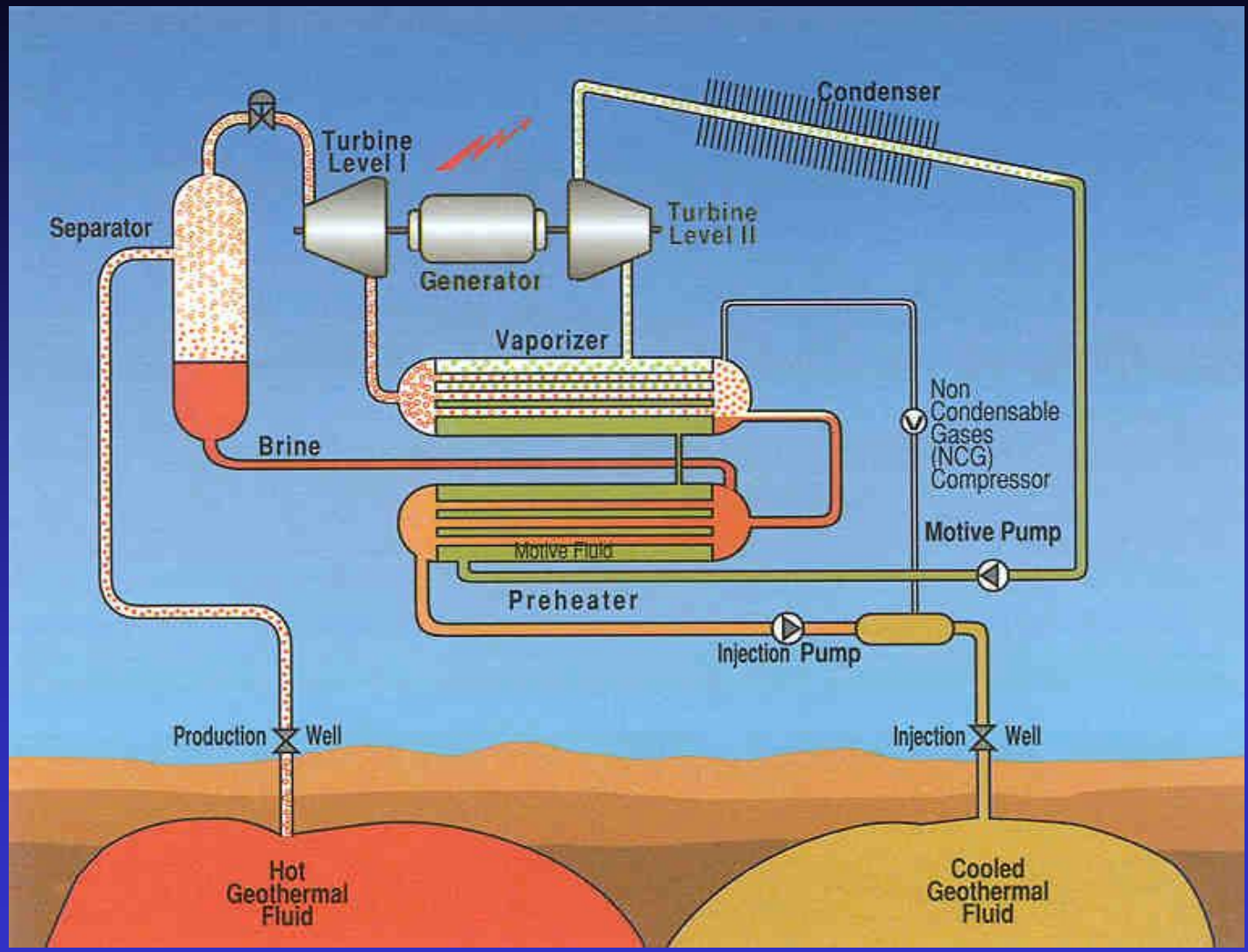
BINARY PLANTS V

- Well suited for modular power packages
- Generally <1 MWe
- Geothermal temperature uses have recently been extended down to 100 to 120ºC
- Efficiencies are 6 to 8% at this range
- Geothermal flows around 80-100 L/s for 1 MWe unit



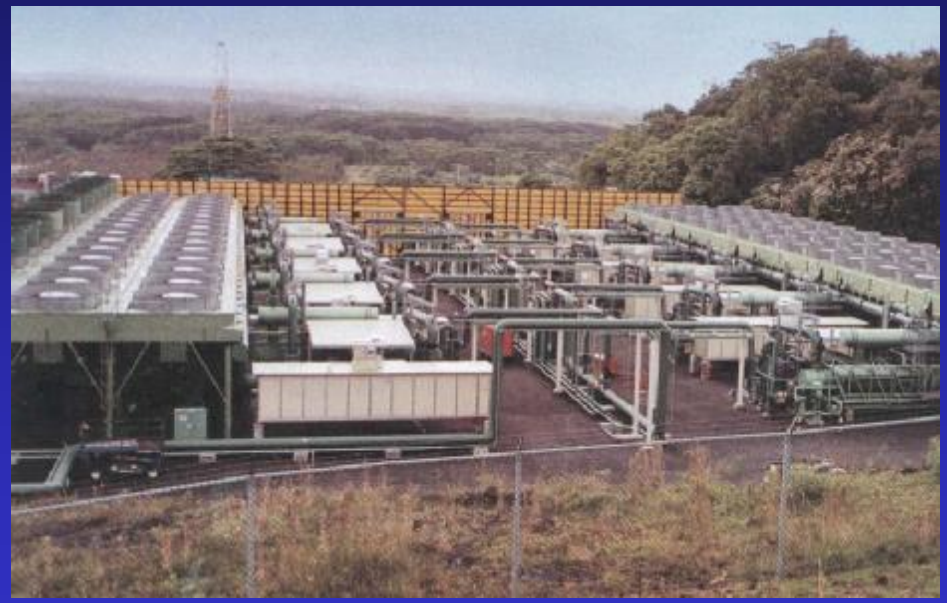
COMBINED CYCLE PLANTS

- To achieve a more effective use of the resource
- Combined plants use
  - Flash plant uses the steam, then
  - Waste water used in binary cycle plant (bottoming cycle)
- Or by recovering excess well head steam pressure (topping cycle) – 2nd flash
- Preferred over triple flash plants


Condenser
Turbine Level I
Turbine Level II
Separator
Generator
Vaporizer
Non Condensable Gases (NCG) Compressor
Brine
Motive Pump
Motive Fluid
Preheater
Injection Pump
Production Well
Injection Well
Hot Geothermal Fluid
Cooled Geothermal Fluid

COMBINED CYCLE PLANTS II

- **Example:**
  - **Puna, Hawaii, USA: 30 MW from 10 combined cycle plants in parallel – topping steam turbine + binary turbines connected to a common generator - 315ºC at 100 atm**



HYBRID PLANTS

- Use two fuel types where geothermal temperature, production and/or wells limited
- Geothermal + fossil fuel
- Geothermal + biomass (all “green”)
- Example:
  - OEC/HL Power Co. – northern California, USA – 35.5 MWe
  - 34 MW from wood waste + 1.5 MW from geothermal at 118ºC as condensate preheater

TOTAL FLOW MACHINES

- These use the impluse energy of the water mass plus the steam to drive the generator
- Thus, steam and water need not be separated
- Originally tested at Pauzhetka, Russia – 500 kW
- Biphase turbine was used in Nevada, USA – but has since been abandoned
- In theory – eliminates the energy lost in flashing and separation of water-steam

PERFORMANCE

- The geothermal resource utilization efficiency measures how well a plant converts the exergy (available work) into useful output (electricity)
- The difference between gross and net energy output is due to parasitic loads of pumps, motors, etc. required for the units to operate – high with low temp. resource

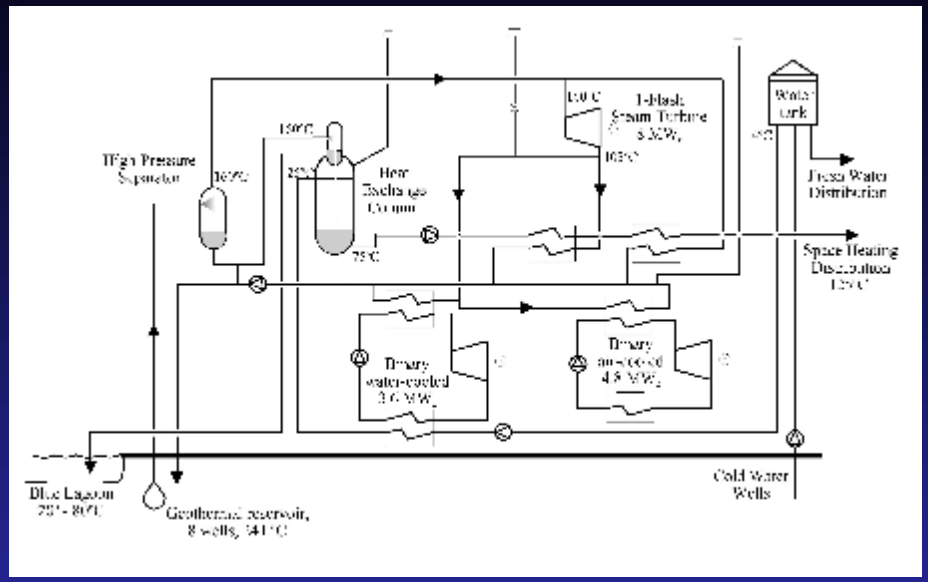
PERFORMANCE II

- **Examples (gross/net%)***
  - **Dry steam (Italy) at 204ºC: 62.9/57.6%**
  - **Single flash (Costa Rica) at 230ºC: 31.2/29.5%**
  - **Double flash (Nevada) at 215ºC: 48.7/46.7%**
  - **Dual pressure binary (CA) at 168ºC: 14.0/13.2%**
  - **Basic binary (CA) at 169ºC: 11.5/8.1%**
  - **Basic binary (CA) at 103ºC: 7.0/5.6%**

*** Ref.: Dr. Ronald DiPippo, GHC Bulletin 20/2, 1999**

CONCLUSION

- **The sustainability of reservoirs and production is important – receiving more attention and understanding today**
- **Fields have been operated for over 50 years, and can be sustained for over 100 years – injection of fluids important**
- **The cost of power is being reduced and in many cases, competitive with fossil fuel – 4 to 5¢/kWh**
- **Combined heat and power plants popular**



Svartsengi, Iceland
combined heat and power plant - 240°C
200 MWt heat and
45 MWe electricity
(8.4 MWe binary)

CONCLUSIONS II

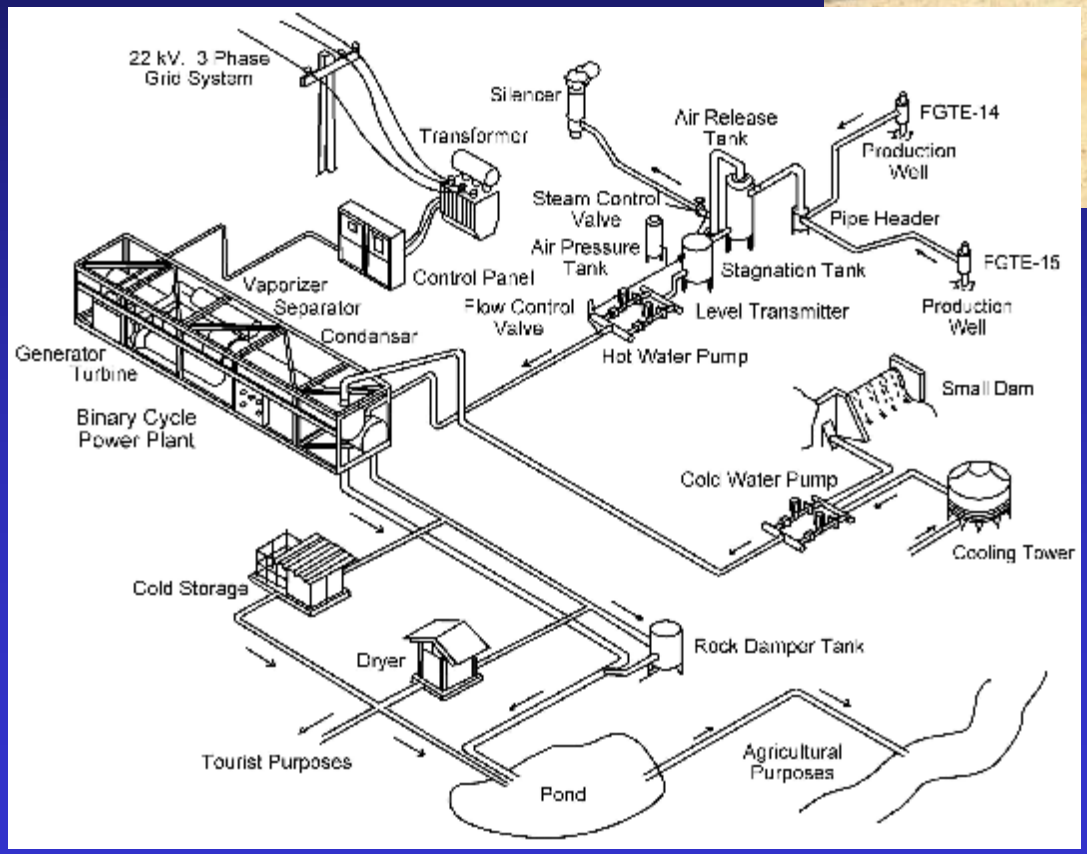
- **Binary cycle plants are becoming more popular – as they can use lower temperatures – down to 100ºC – used in conjunction with direct-use**
- **Most plants use “off-the-shelf” equipment**
- **Modular units are available in both binary and flash steam models = rapid installation**
- **Thus, geothermal electric power will be extended to many “low temperature” countries**

Fang, Thailand

Binary power plant

6.3 – 8.6 ¢/kWh vs.

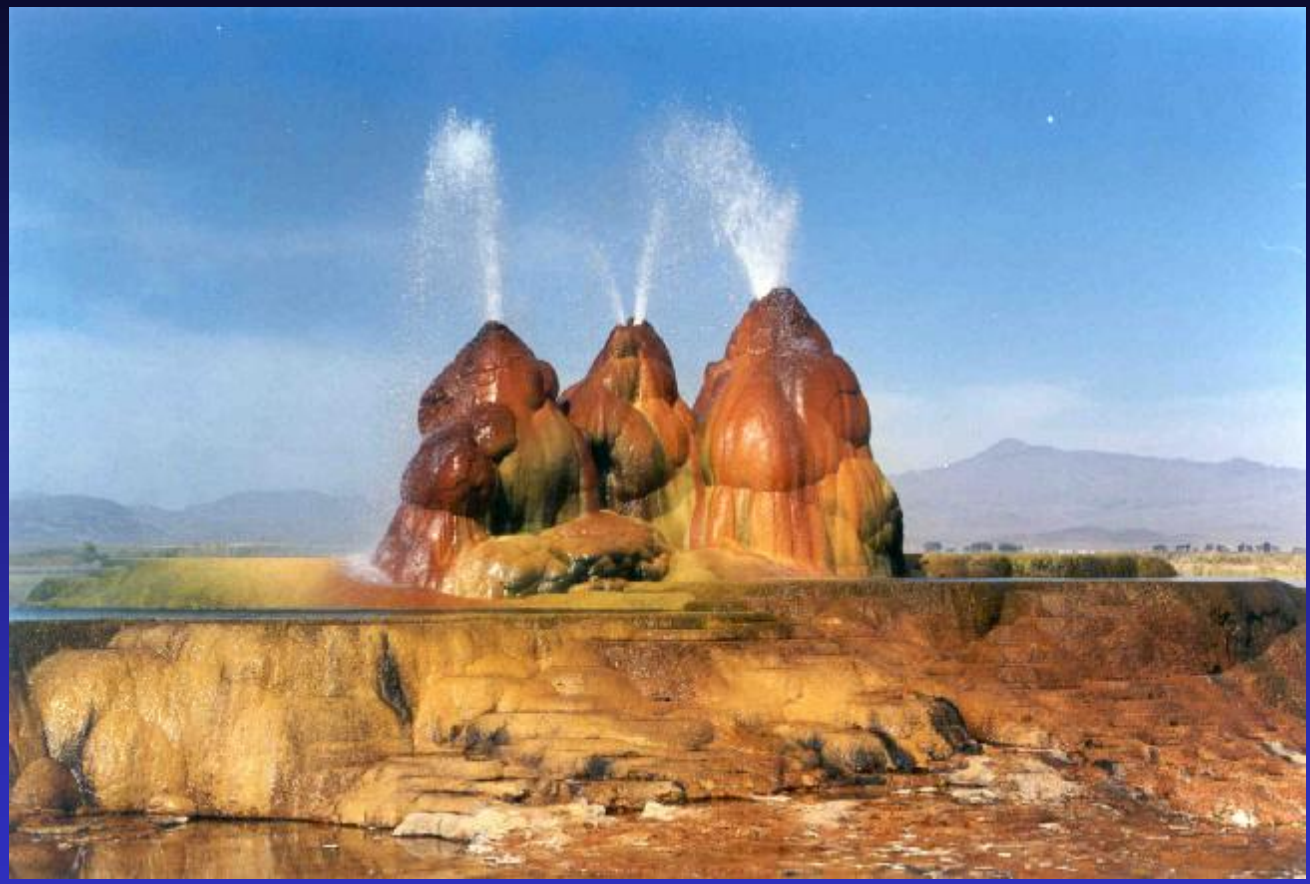
Diesel @ 22 to 25 ¢



Started 1989

300-kWe - 116ºC
– 8.3 L/s
– net 175 kWe

Refrigeration (cold storage), crop drying & spa



THANK YOU