Organic Rankine Cycles and Geothermal systems

Workshop for inspectors – Method and Techniques in Geothermal Power Plant inspection

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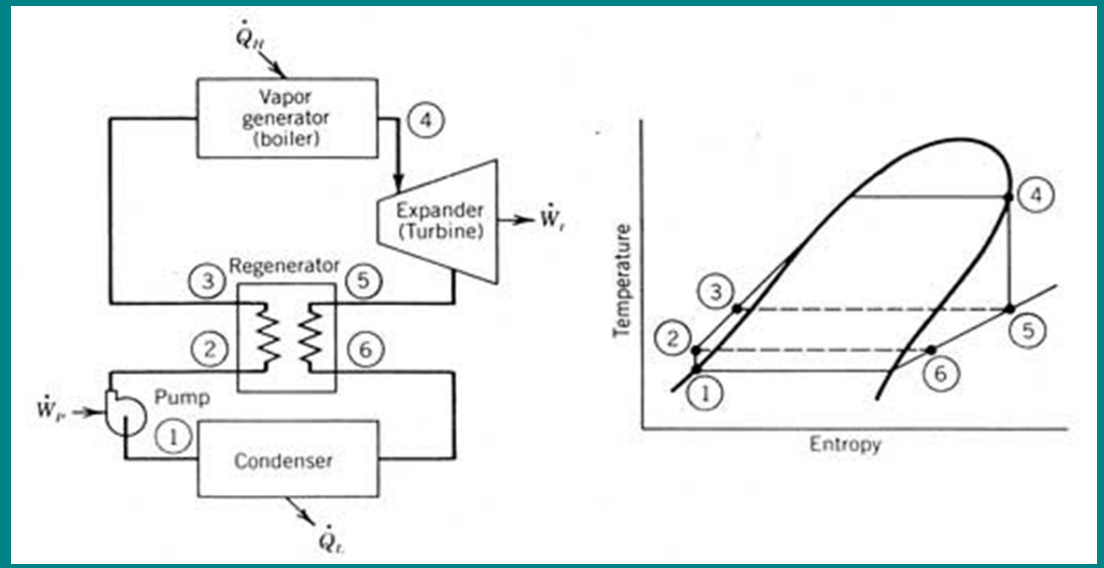
Organic Rankine Cycle (ORC)

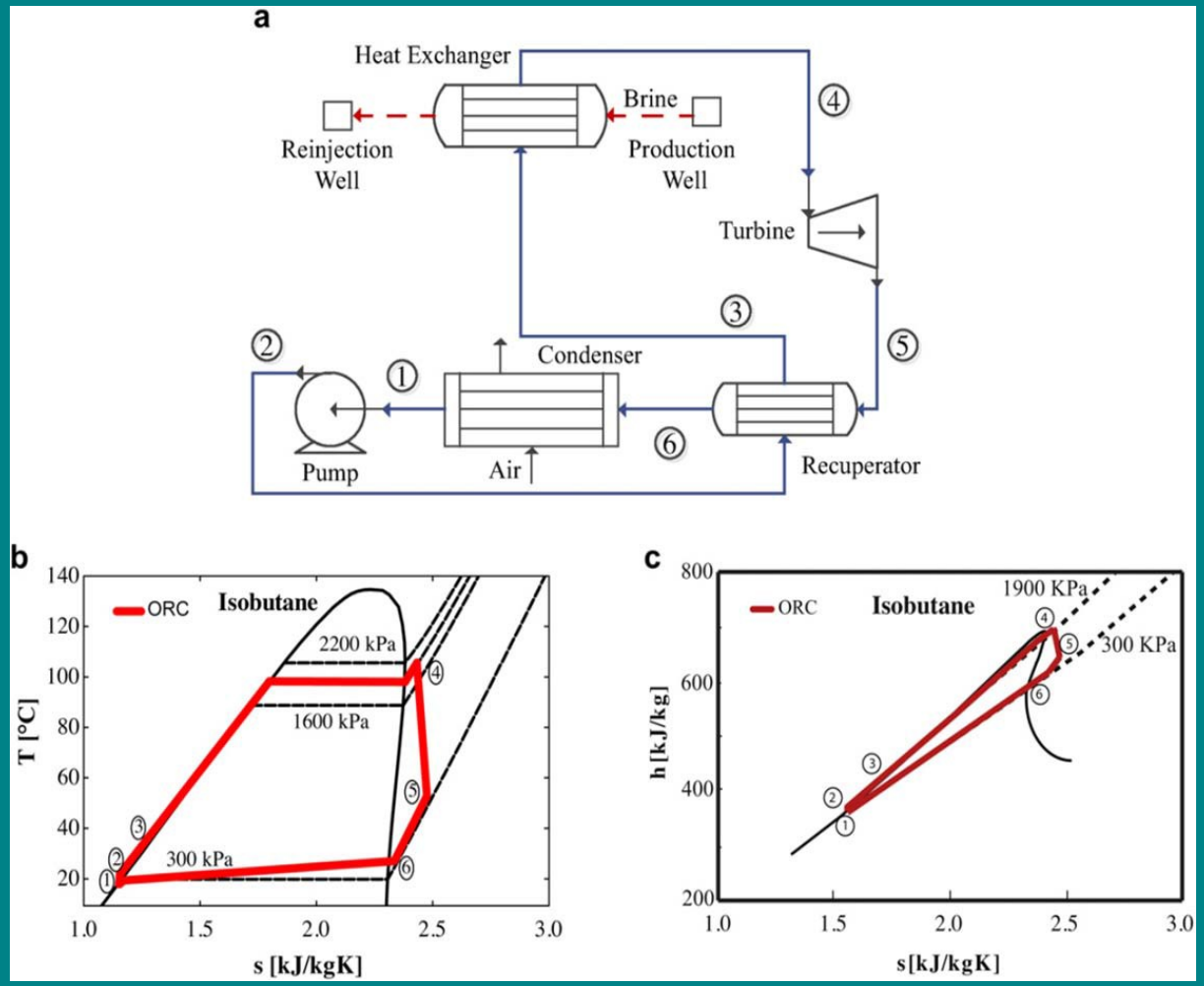
- Organic liquid instead of water
- Typical operational range from few kW up to 3-4 MW
- High efficiency turbine
- No corrosion and erosion problems
- Long lifetime

Organic Rankine cycle (ORC)

- For low temperature sources (solar/geothermal/waste heat) the conventional (water) Rankine cycle has very low efficiency. To improve that an organic Rankine cycle was introduced
- Main difference is in working liquid which for ORC is an organic, high molecular mass liquid with boiling point at lower temperature (octane, isopentane, toluene etc.).
- Organic liquids have also different (from water) liquid-vapor dome, which promotes them to application for ORC systems with regenerator



Organic Rankine cycle (ORC)



Ghasemi et al., Modeling and optimization of a binary geothermal power plant, Energy (2013), 412-428

Lets' set the stage for the ORC

'External' thermal energy source (no internal combustion)

- Geothermal reservoir
- Solar radiation
- ("Dirty") biomass combustion/gasification, landfill gas, waste incineration
- Thermal power recovery: recip engines, gas turbines, industrial waste heat

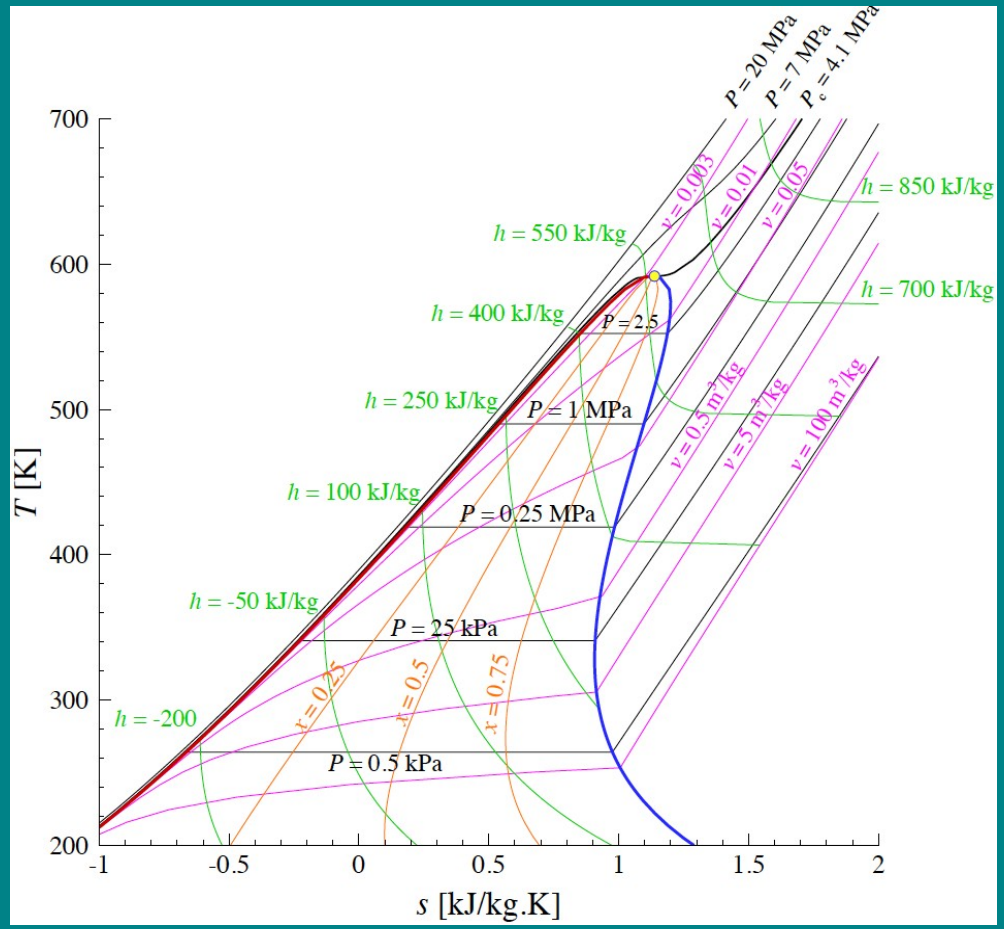
AND

Small-to-medium power capacity (few kW_e to few MW_e per unit)

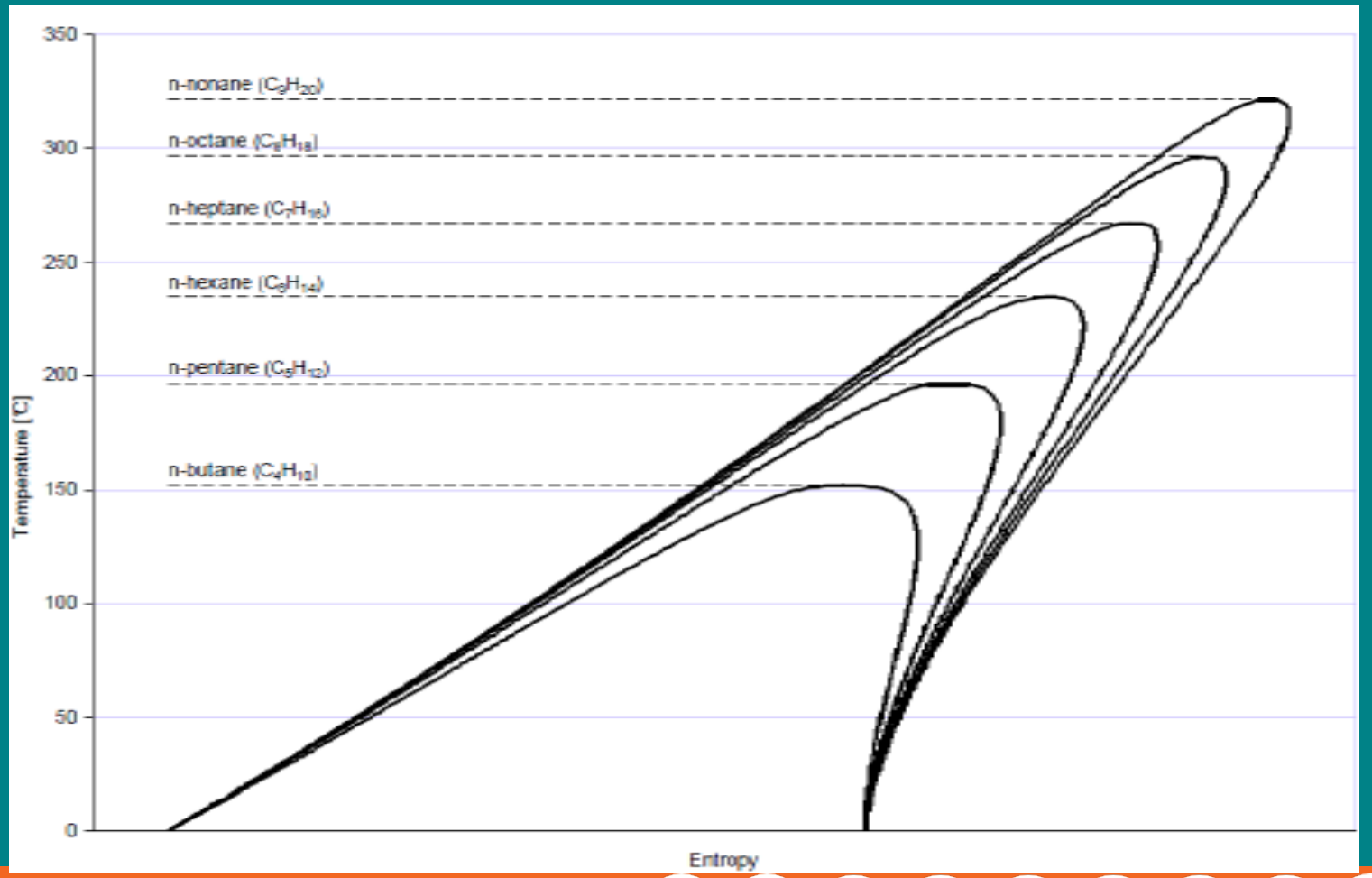
Rankine cycle but… WATER

Why an organic fluid?

- Fluid -> T_c, P_c, Δh, β, volume flow, (condenser P)
- P and T level of the cycle
- Cycle configurations: saturated, superheated, supercritical (at low P)
- Simple layout even for high TIT/T_{cond}
- Non-extractive regeneration
- Dry expansion
- Working fluid can be used as lubricant



Some ORC Working Fluids



Working fluids

Not only cycle thermodynamics and turbine design...

Thermal stability

Toxicity Availability

(cost)

Flammability

ODP

GWP

Options:

- Linear and aromatic hydrocarbons
- Fluorocarbons (Refrigerants)
- Perfluorocarbons
- Linear and cyclic Siloxanes

Status

Geothermal: ~1500 MW_e installed

Biomass combustion:
in Europe impressive growth (several hundreds of plants)

Solar: pilot plants, large potential

Heat recovery: few plants and quickly increasing (process and oil industry)

Ideas and early developments: automotive heat, Domestic μCHP, recovery, ship and train engines HR

Geothermal power systems

- The Earth's heat content is about 10^{31} J. This heat naturally flows to the surface by conduction at a rate of 44.2 TW.
- Most of this power is very diffuse (approximately 0.1 W/m^2 on average) to be recoverable.
- Geothermal gradient is approx. 25–30 °C/km in most of the world, and wells would have to be several kilometers deep to permit electricity generation.
- The quantity and quality of recoverable resources improves with drilling depth and proximity to tectonic plate boundaries
- At present, geothermal wells are

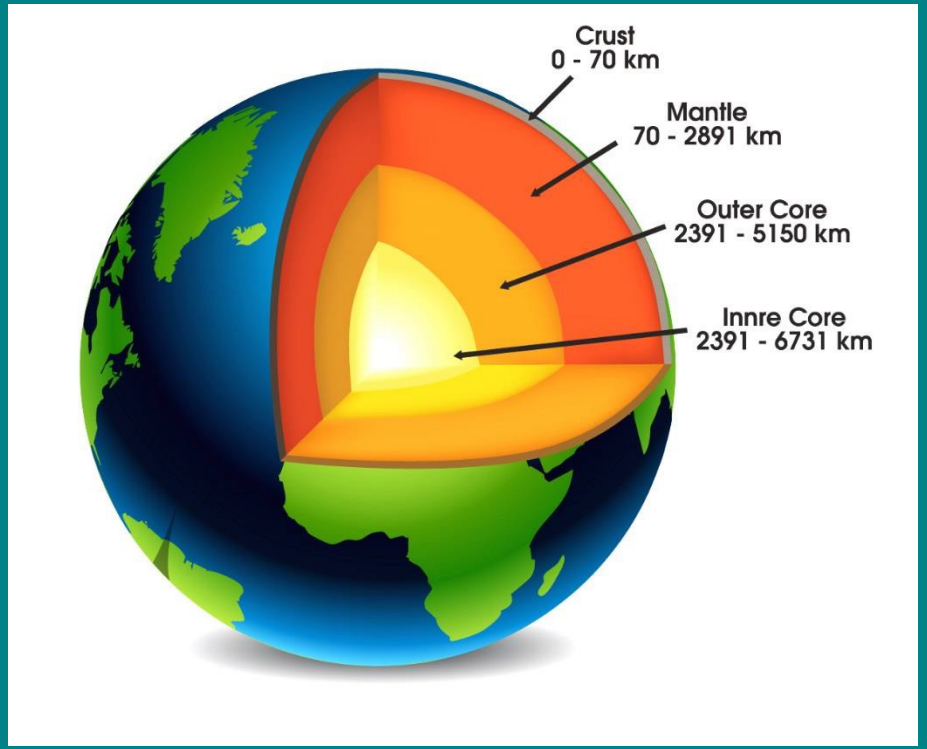
  rarely more than 3 km deep

Geothermal power systems

- Oil companies are already drilling down to 5-10 km where temperatures can reach up to 300°C. However, drilling becomes a challenge due to the high temperatures and pressures. Wells drilled to depths greater than 4 km generally incur drilling costs in the tens of millions of dollars.
- The deepest research well in the world, the Kola superdeep borehole, is 12.3 km deep.
- Typical efficiency of a geothermal power plant is about 15-20%

Geothermal plants

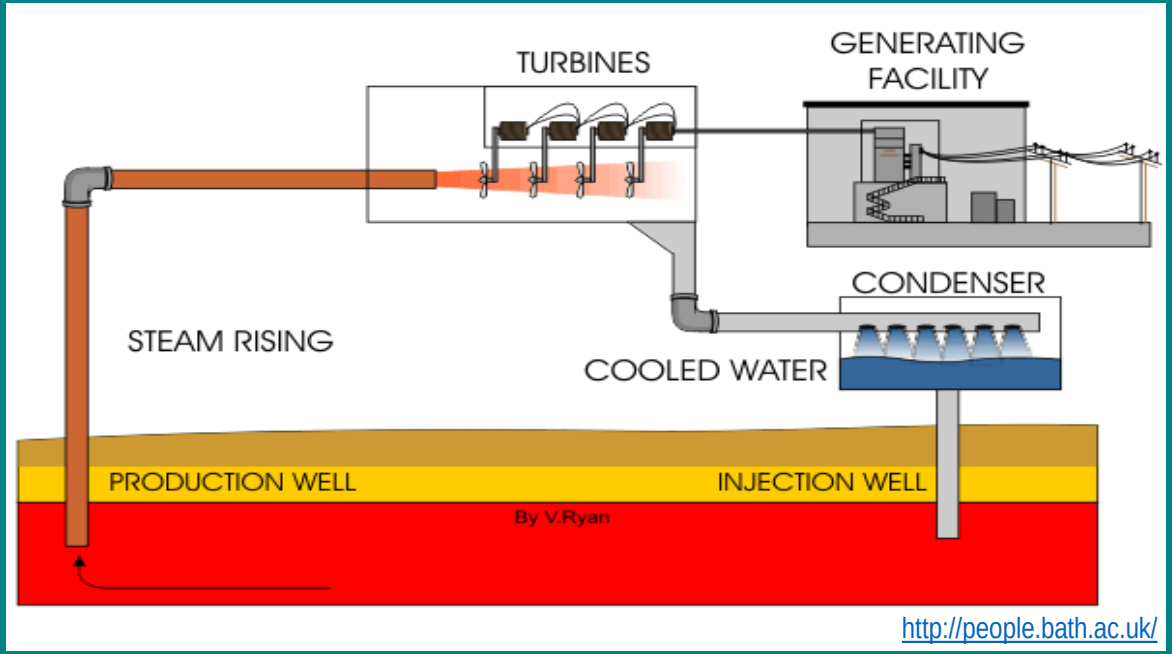
- The following types of geothermal power plants have been used for power generation:
  - Dry steam
  - Flash steam
  - Binary cycle
- Key features of geothermal systems
  - Small land footprint
  - High availability
  - High capacity



Dry steam power plant

- Dry steam power plants operate directly on steam from geothermal reservoir
  - High cost effectiveness
  - High quality/pure steam
  - Steam dominated reservoirs are very rare

What is missing?

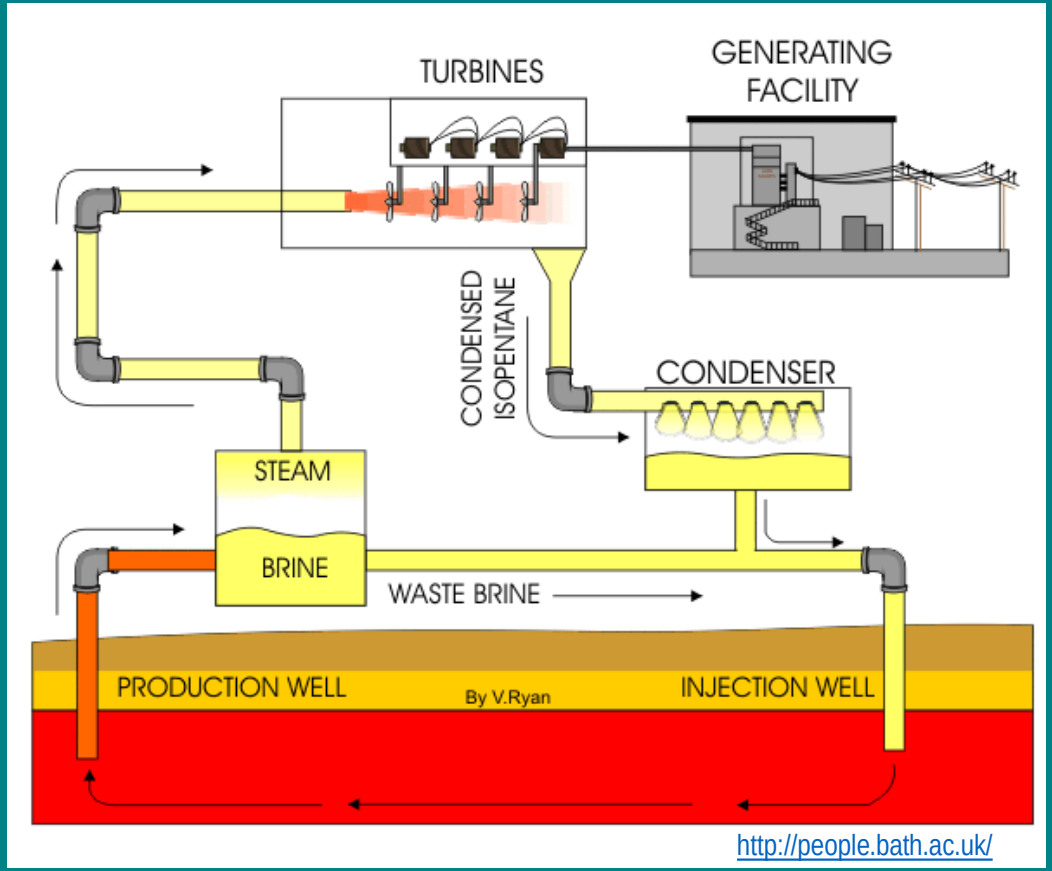


http://people.bath.ac.uk/

Flash steam power plant

- Flash steam power plants operate on steam separated from liquid
- The most common type of geothermal power plants

What is missing?



Binary power plant

- Binary power plants operate on two liquids i.e. geothermal water from the well and organic liquid or steam
- No emissions - working fluid has no contact with atmosphere

What is missing?