Process flow and steam gathering system

Session VI

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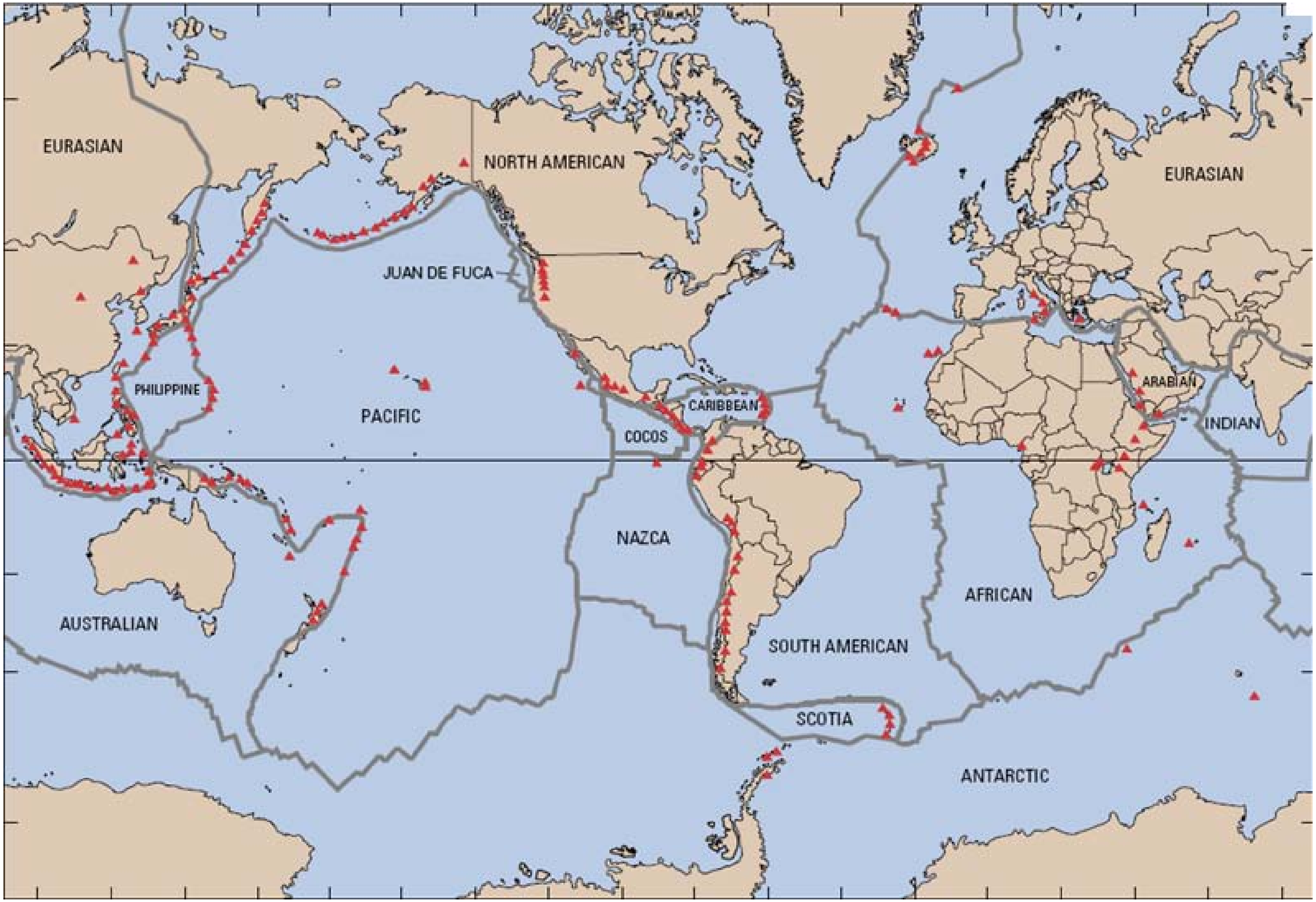
Presentation overview

- Presentations reviewing different cycles and design process
- Demonstration of thermodynamic models for different working cycles
- Calculated example showing methods used within geothermal steam gathering system design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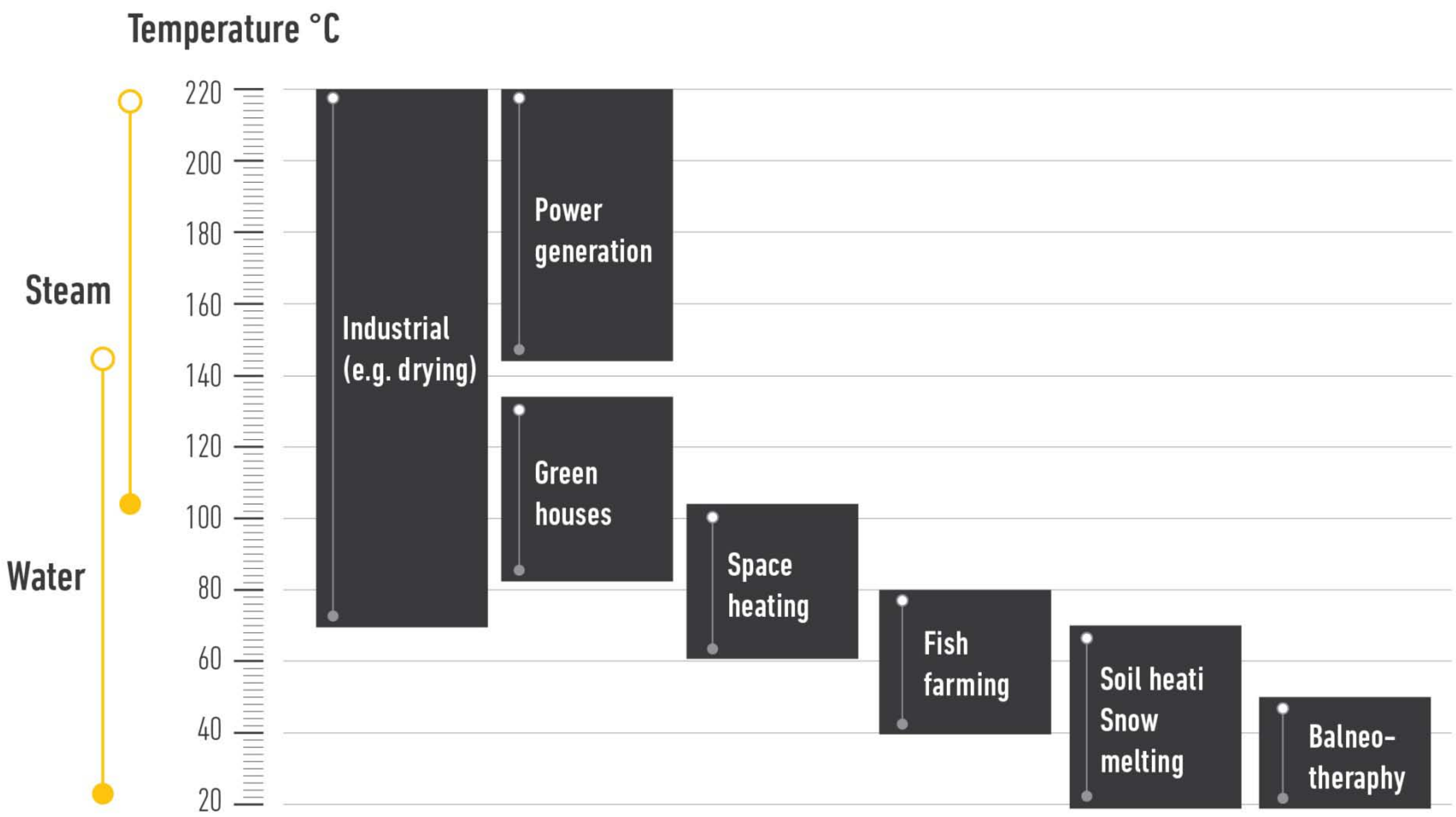

Lindal diagram

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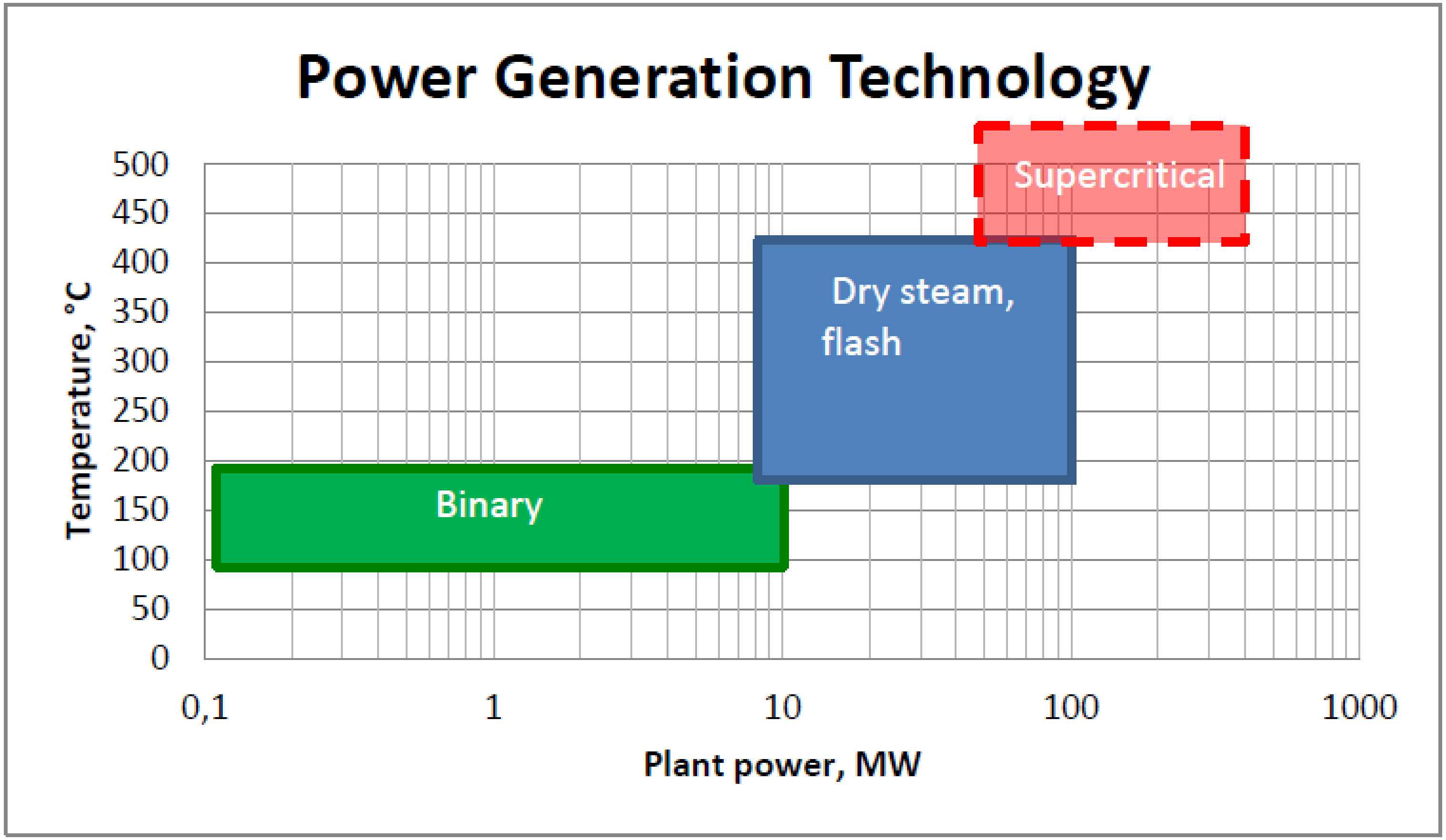
Geothermal power generation



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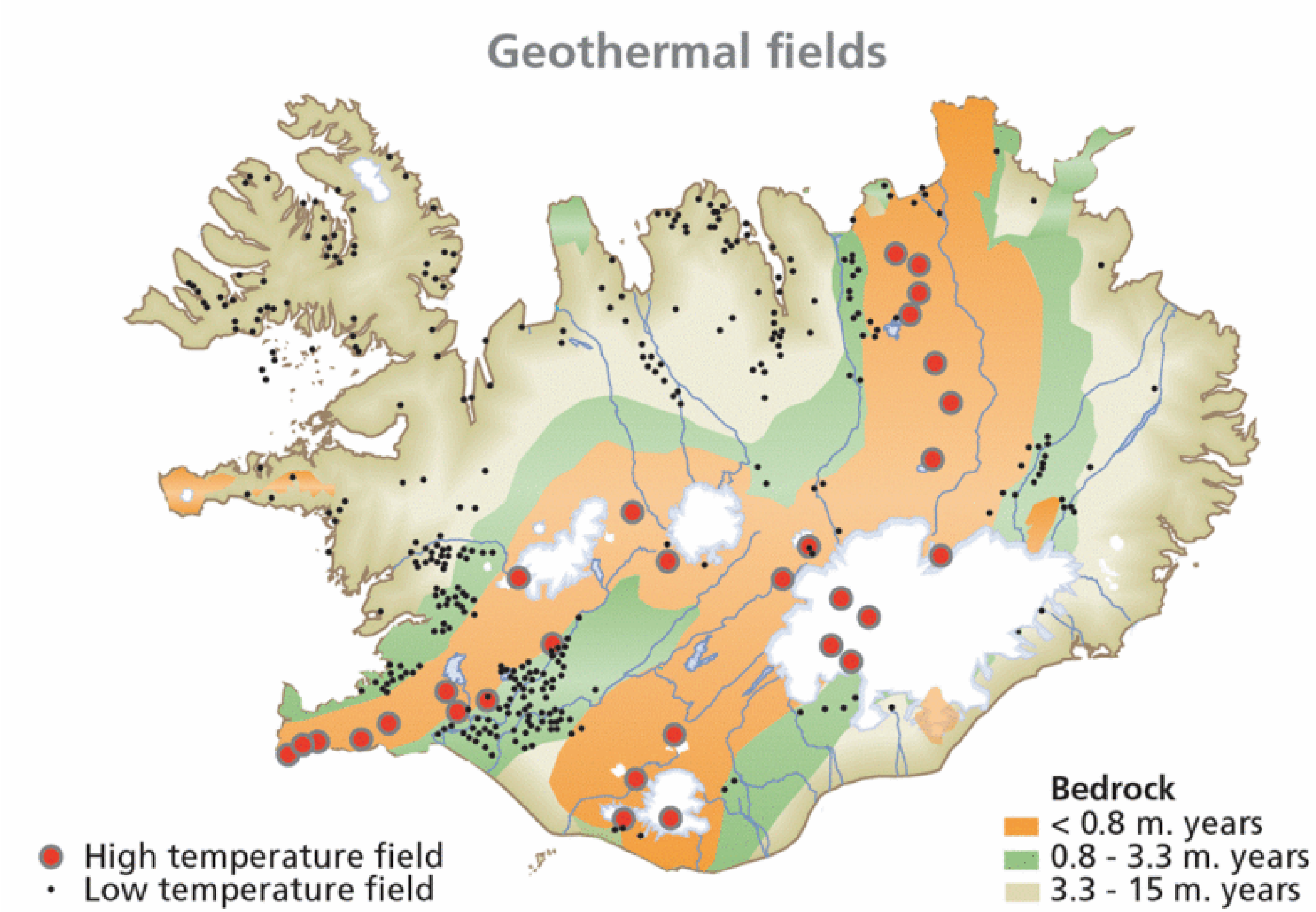
Geothermal in Iceland



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Process flow

- A review of thermodynamic cycles used in geothermal energy production. Flash steam cycles with single flash and double flash as well as different binary cycles as ORC and Kalina Cycle are introduced and compared

Binary technology

Main features:

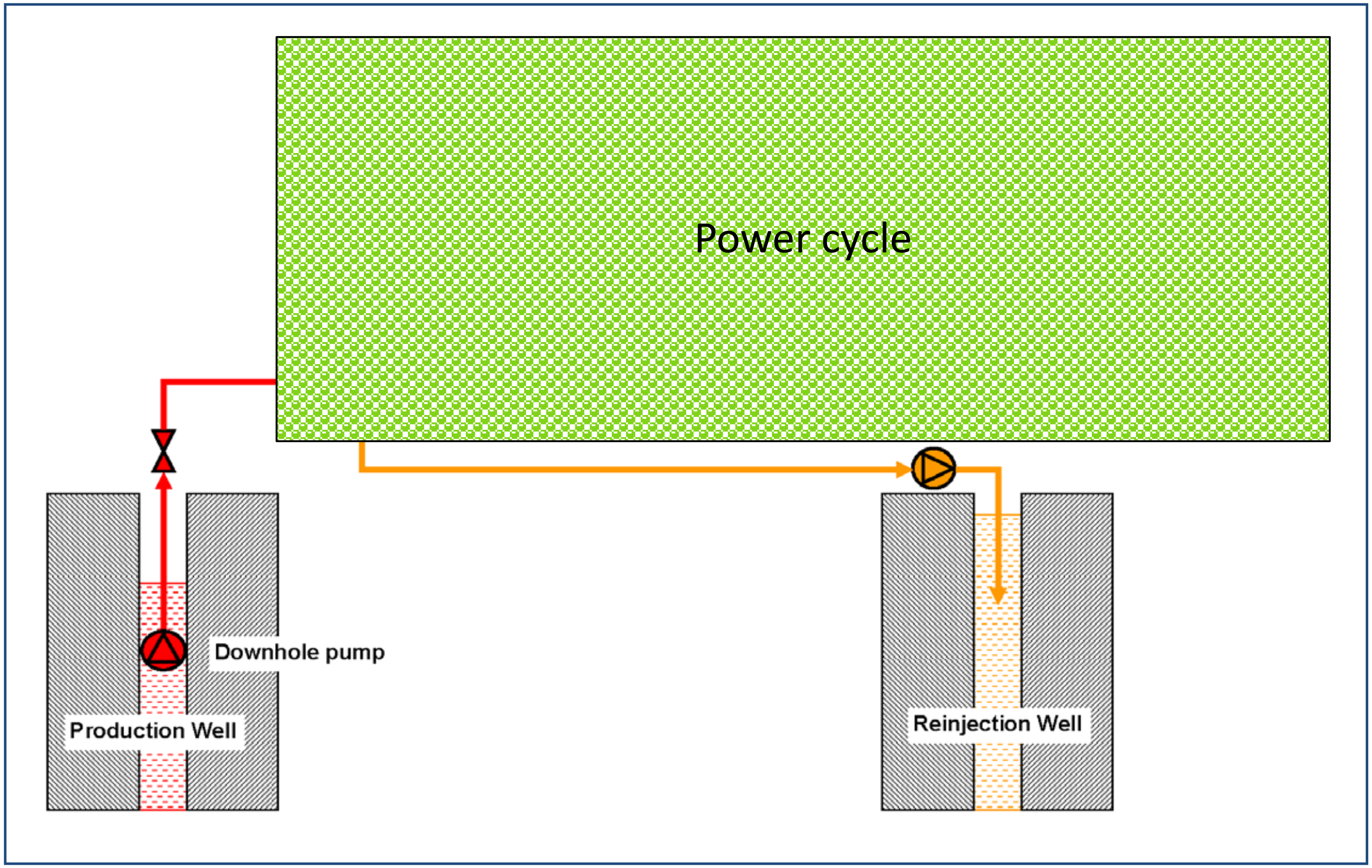
- Power generation by means of closed thermodynamic cycle
- Geothermal fluid loop and power cycle are completely separated
- Nearly zero emission plant
- Suitable for integration with other energy sources (solar, biomass, waste....)

Low enthalpy fluid gathering

- Doublet: (1 production well, 1 injection well) is the typical layout
- Triplet is also used

- Multi-well, with several modules is being discussed

The geothermal fluid loop



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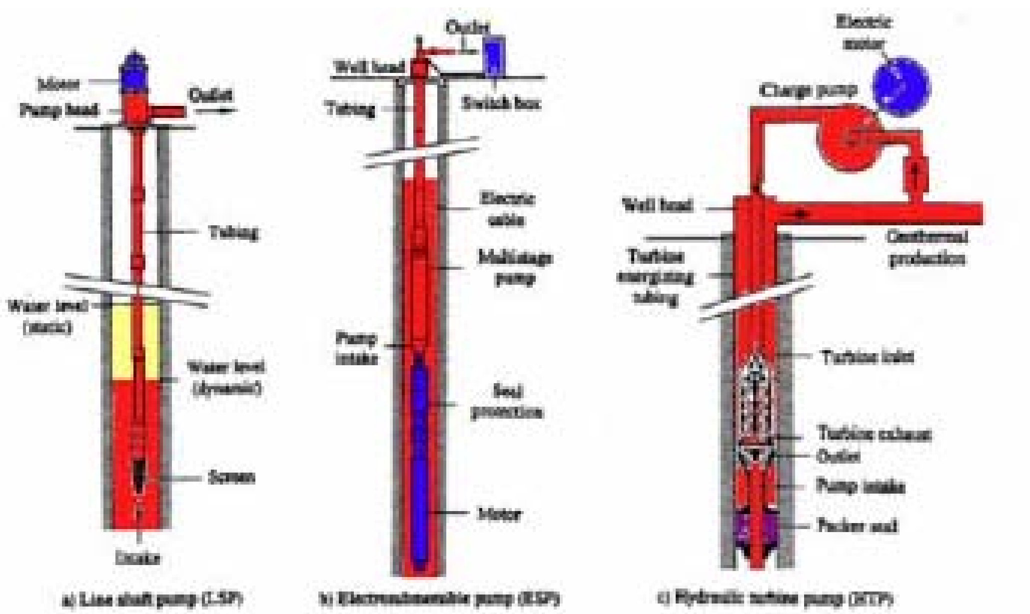
The downhole pump:

lineshaft (LSP), submersible (ESP), hydraulically driven (HTP)

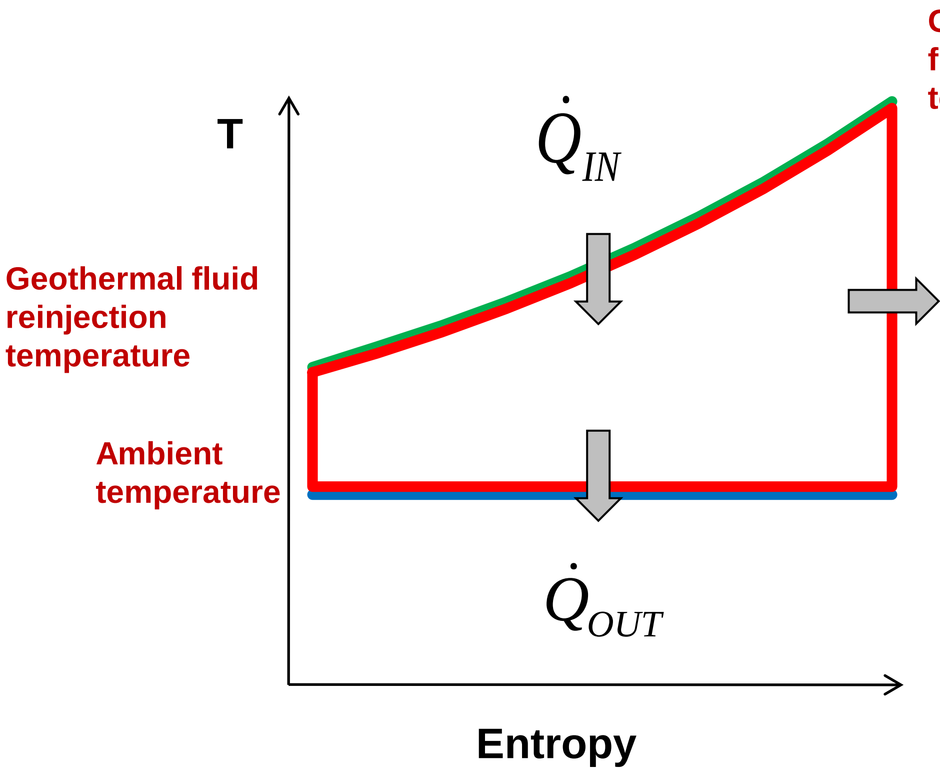


Source: TP-Geoelec) "Strategic Research Priorities for Geothermal Electricity»

Main issues: depth, pumping head, temperature, reliability and availability

Power cycle: the reference ideal cycle

for all liquid heat source, with constant heat capacity



$$P = \dot{Q}_{IN} \cdot \eta$$

REMIND: the cycle efficiency depends only on the geothermal source and ambient temperatures

$$\eta = 1 - \frac{T_{amb}}{\dfrac{\left(T_{geoth,source} - T_{reinjection}\right)}{\ln\left(\dfrac{T_{geoth,source}}{T_{renijection}}\right)}}$$

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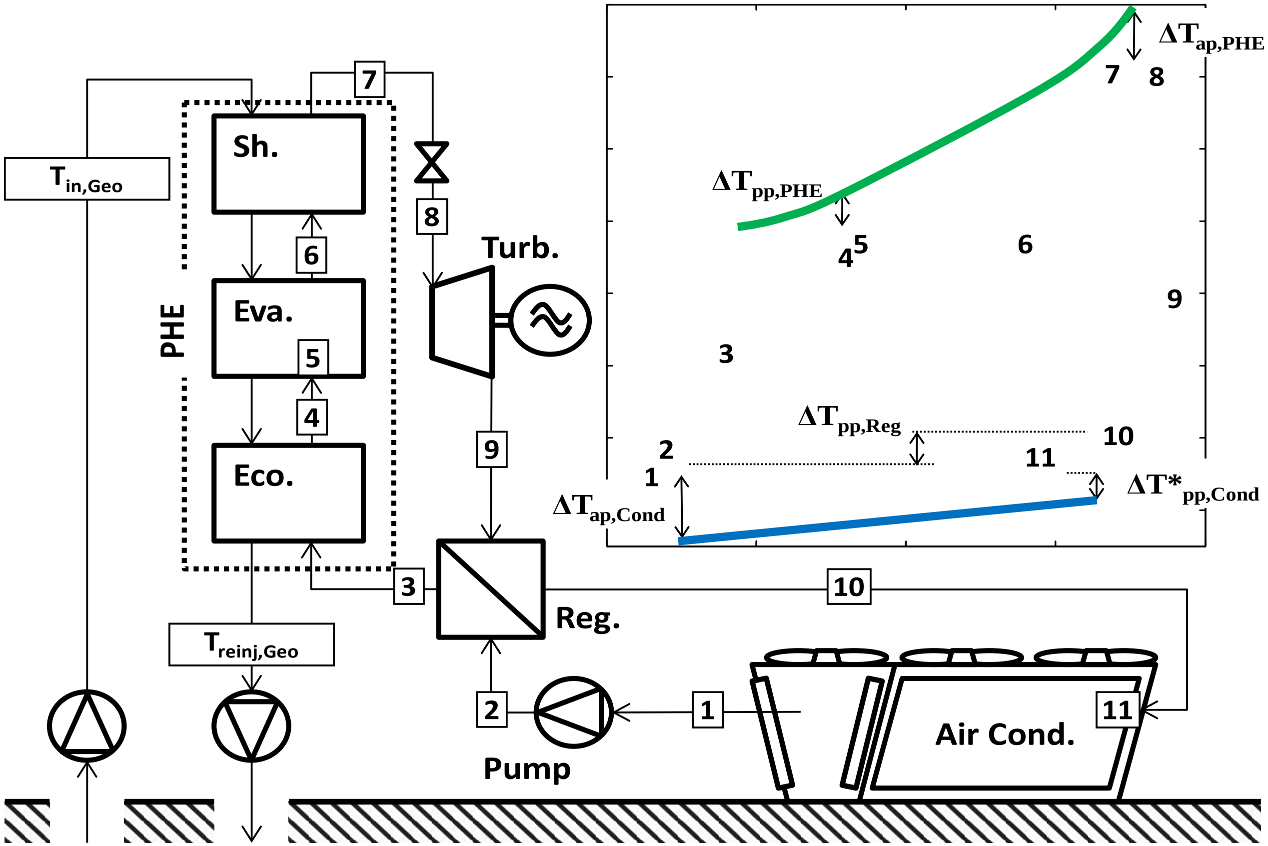
Power cycle: the real cycle



Concepts for binary cycle design

- <u>Objectives:</u>

- high efficiency
- => second law analisys: minimize second law losses

- low cost, €/kW
- => optimize component design

- Critical choice: the cycle working fluid

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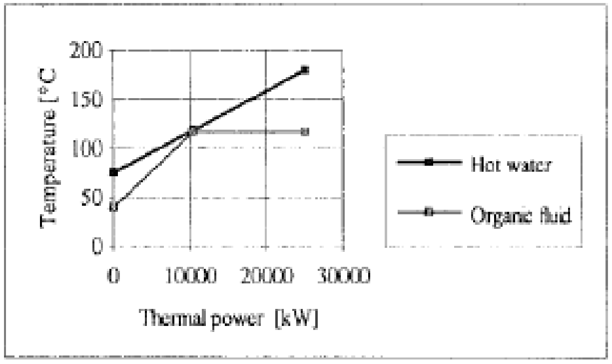
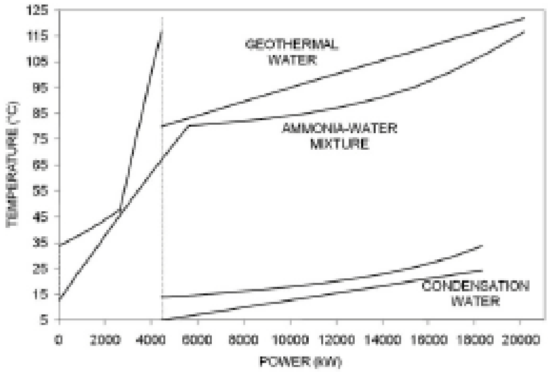
Concepts for binary cycle design

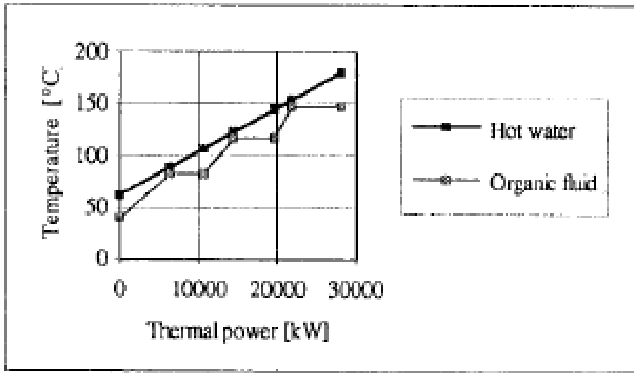
The heat introduction process



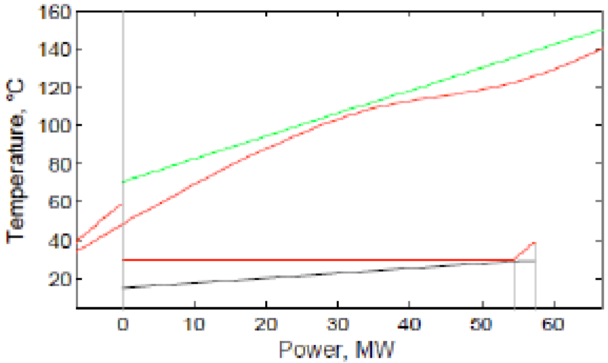
Single evaporation pressure



Kalina cycle



Multiple evaporation pressures



Supercritical cycle

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ORC Cycle working fluid selection

- *The fluid must be suitable for the selected geothermal source and plant size (Fluid critical temperature and pressure, molecular complexity are relevant*)
- Hydrocarbons
- Refrigerants
- Others

Important issues: environmental, toxicity, flammability

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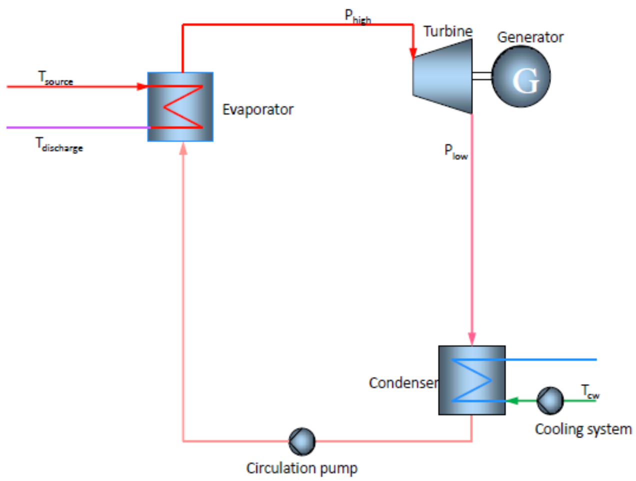
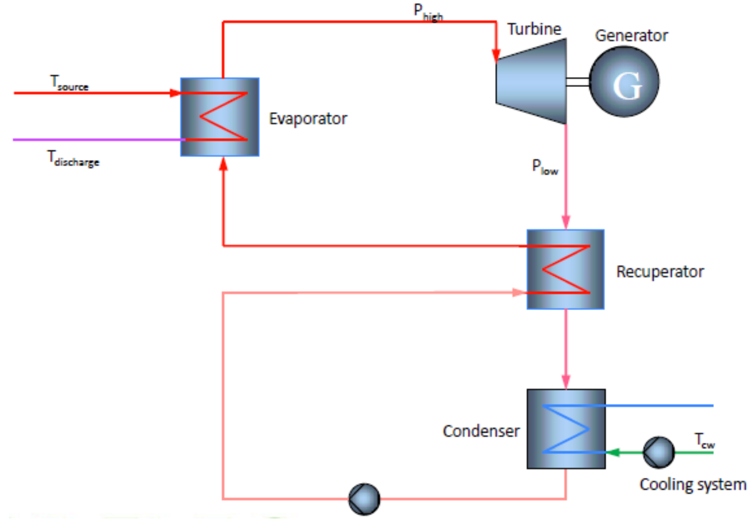
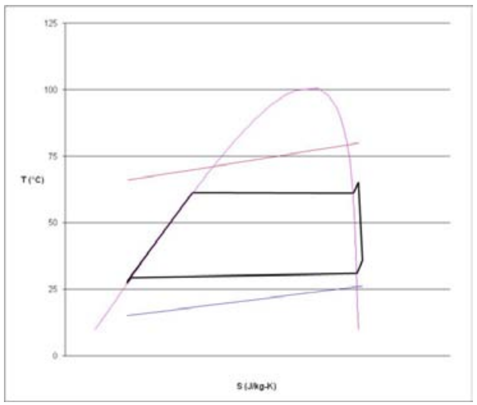
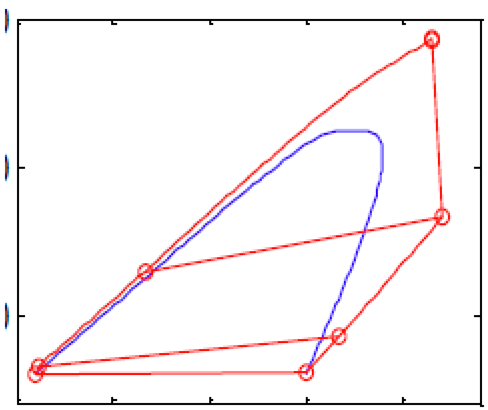
Cycle selection: simple or recuperative

subcritical or supercritical

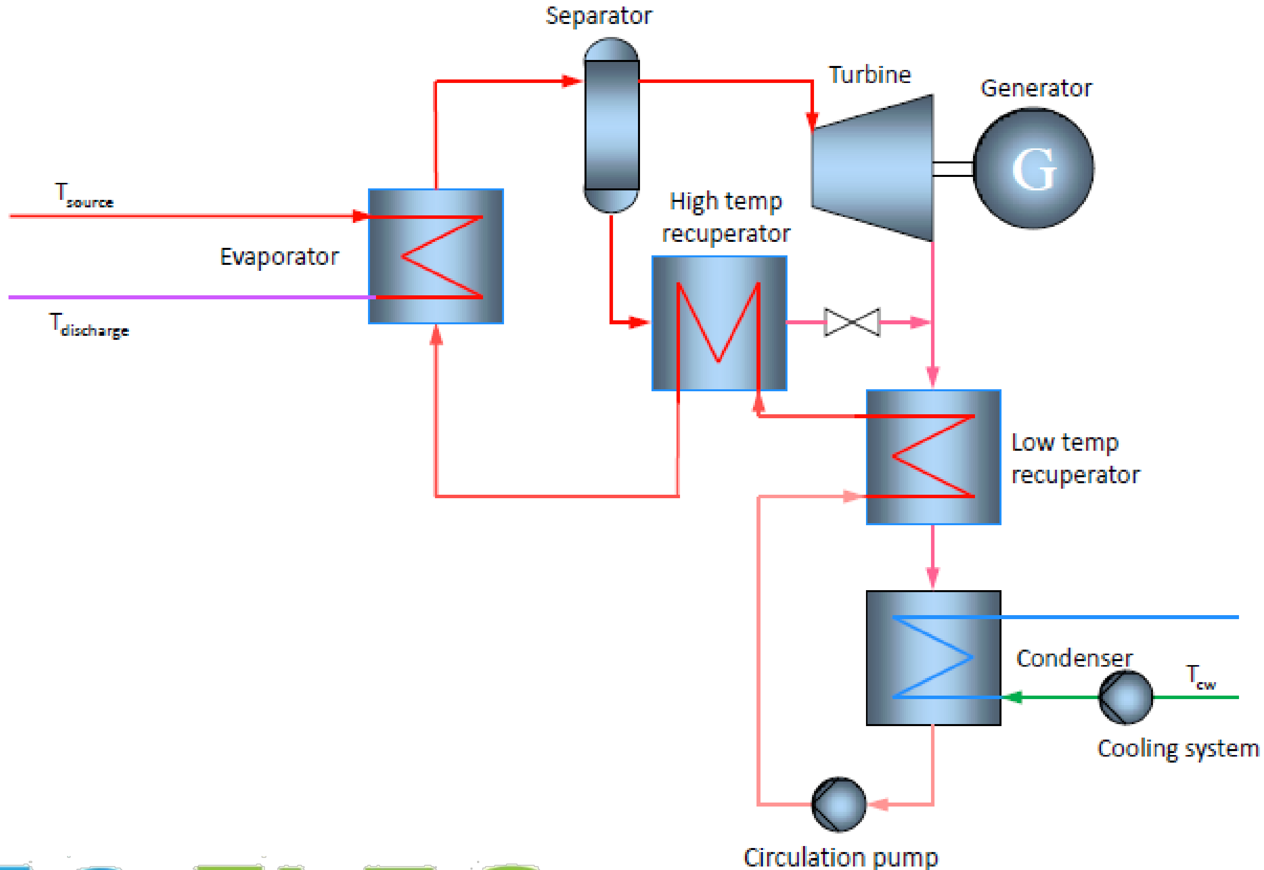








Kalina plant
working fluid: ammonia-water mixture



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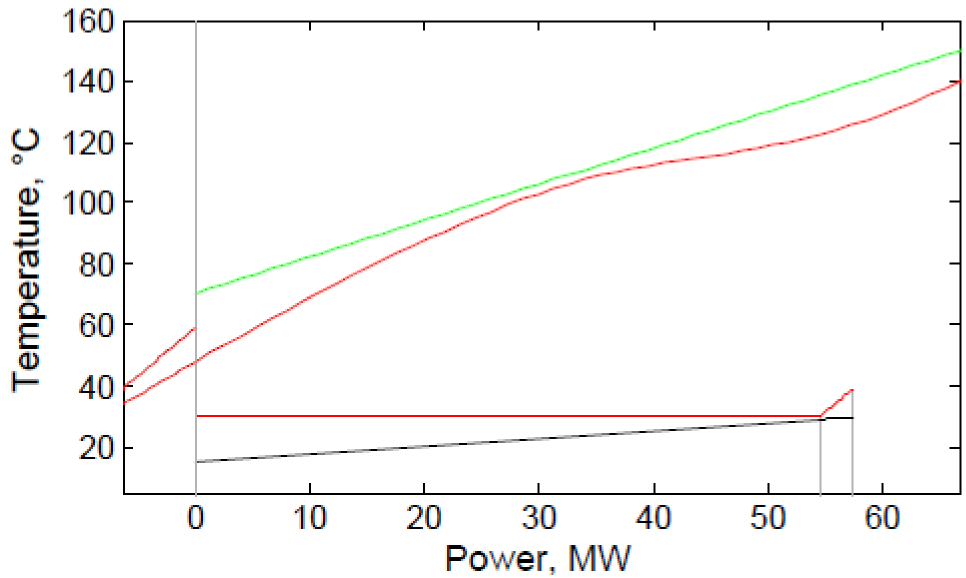
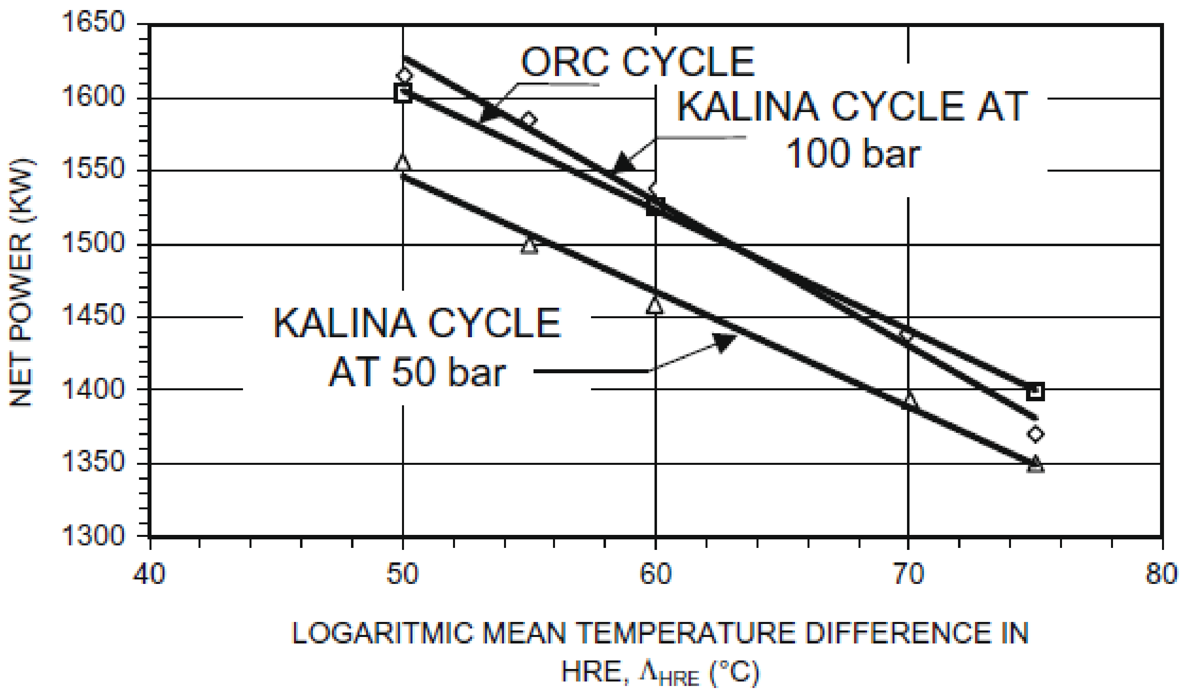
Cost & component sizing

- Turbine sizing
- Selection of $\Delta T_{pinch\ point}$ for the heat exchangers: *the smaller the $\Delta T_{pinch\ point}$, the higher the efficiency but also the heat exchanger cost*



Component sizing and performance

Example for heat recovery case (Diesel engine)



Source: C. Pietra et al. 2010

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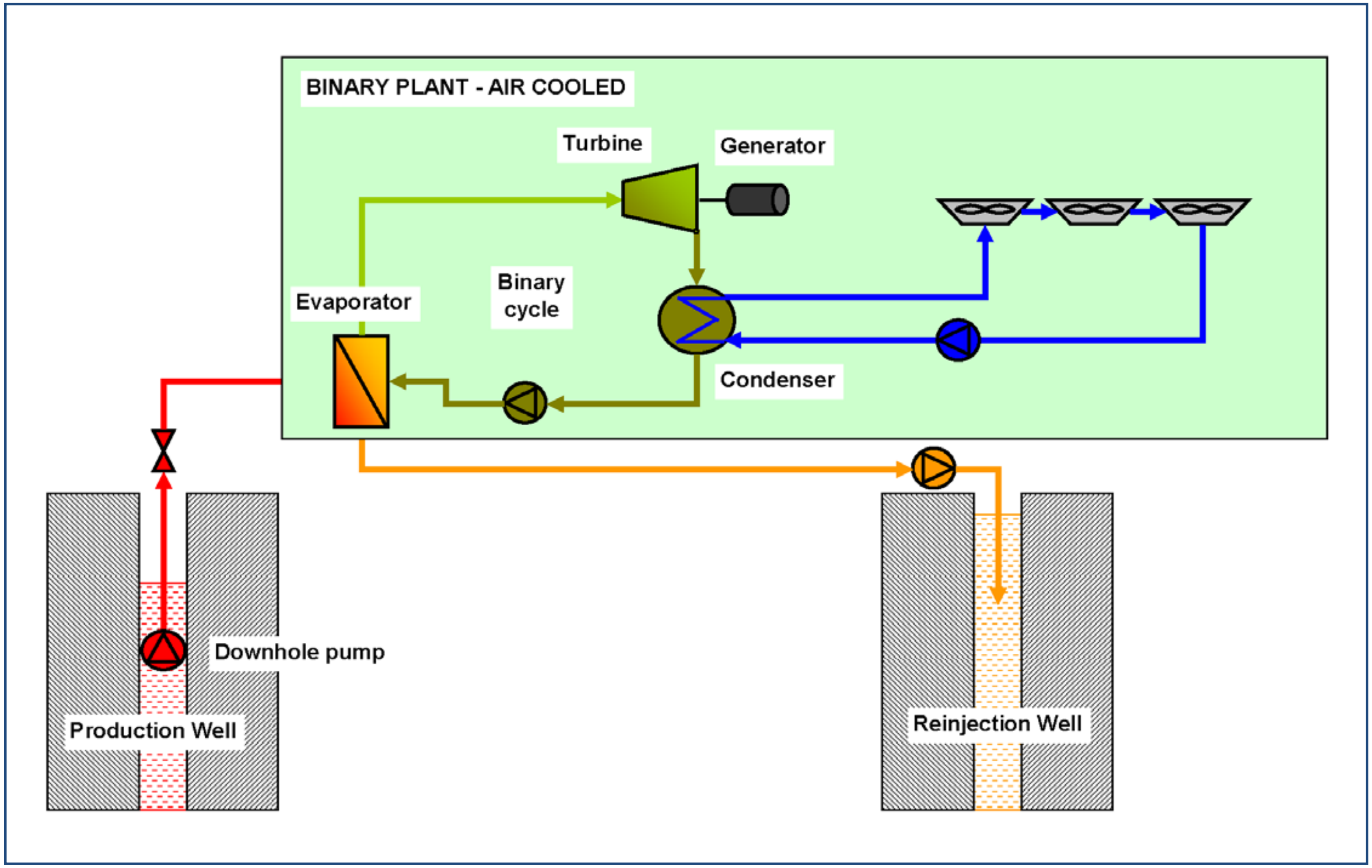
Demonstration of model

- ORC preliminary evaluation http://www.turboden.eu/en/rankine/rankine-calculator.php

The plant power balance

Net plant power = (turbine power – pump power) -auxiliaries power consumption



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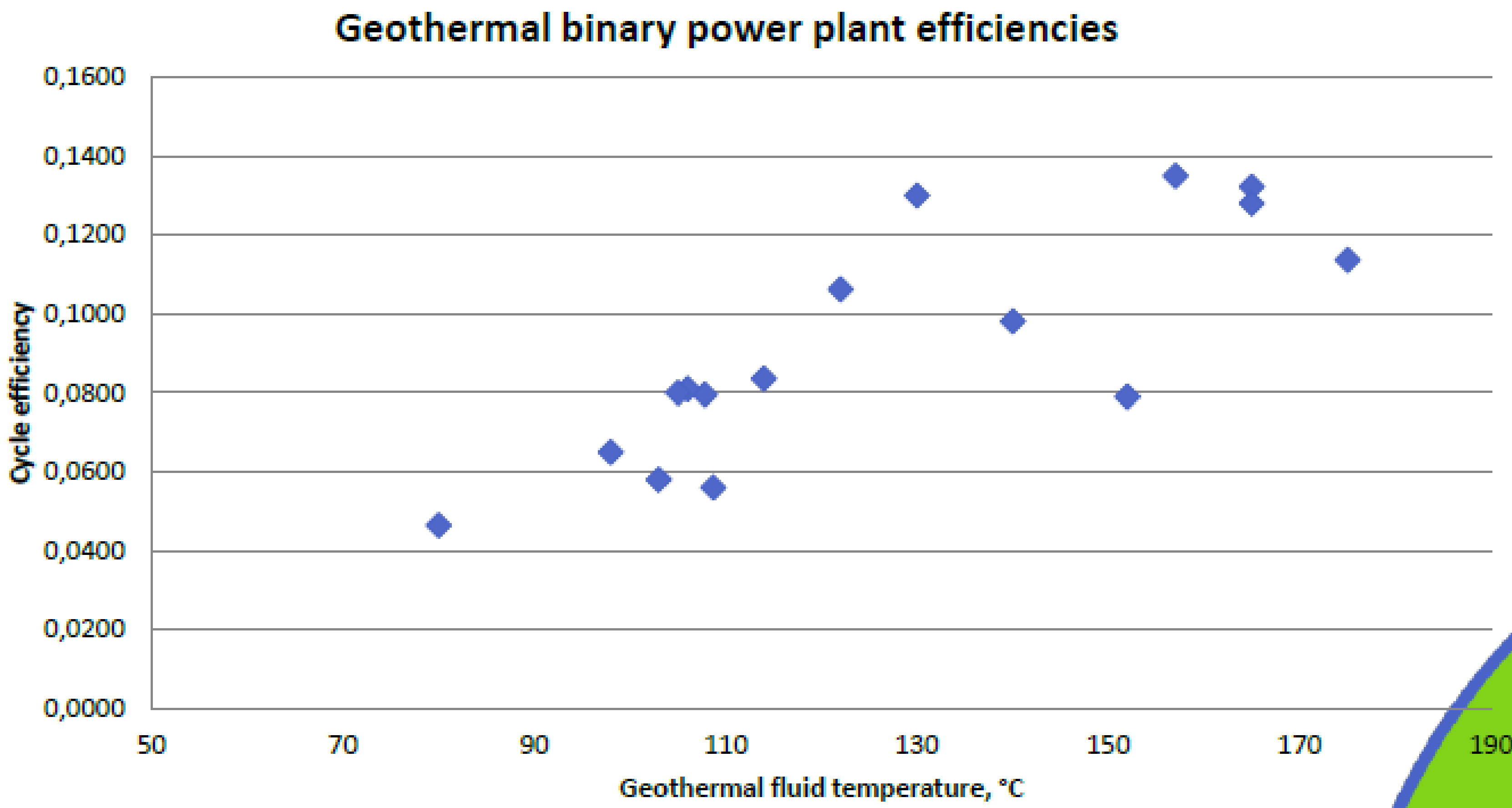
Binary plant performance



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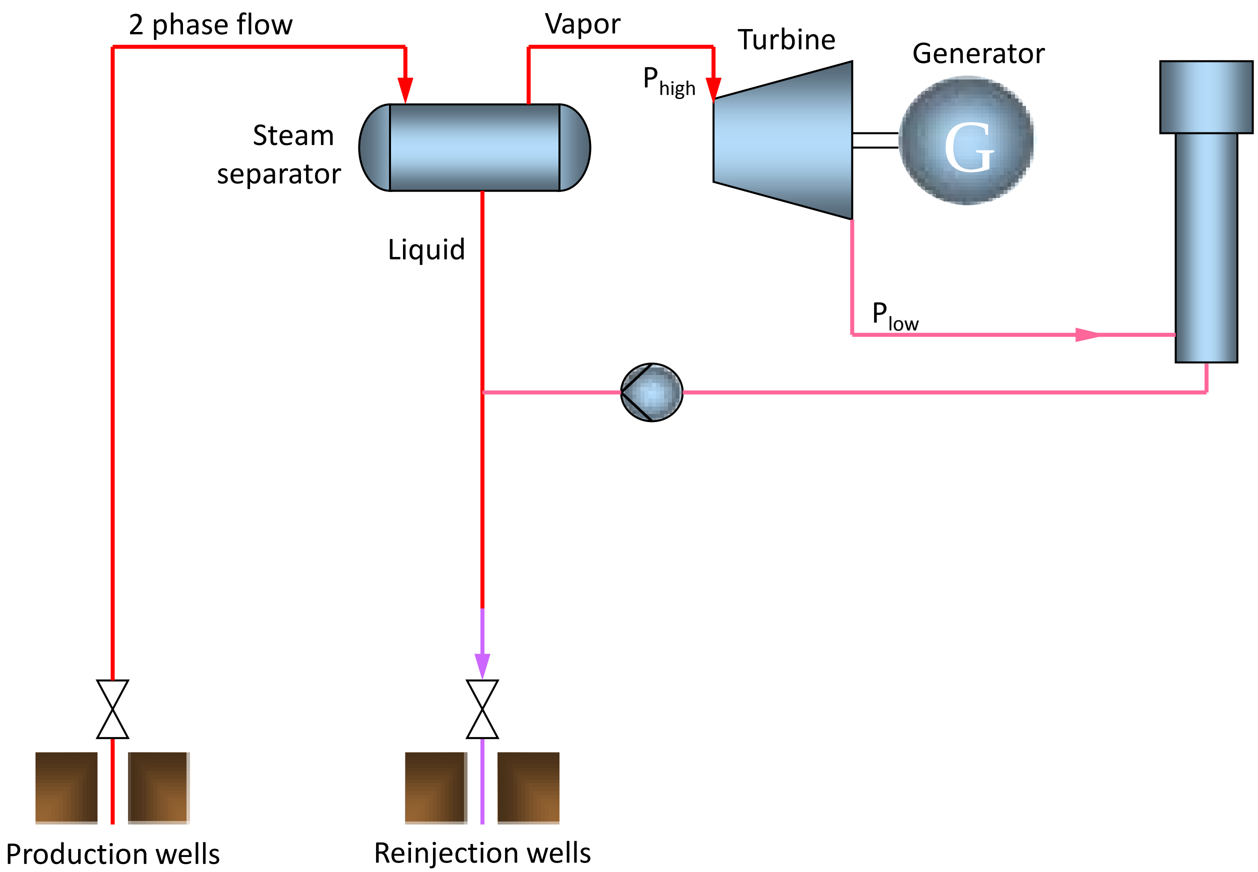
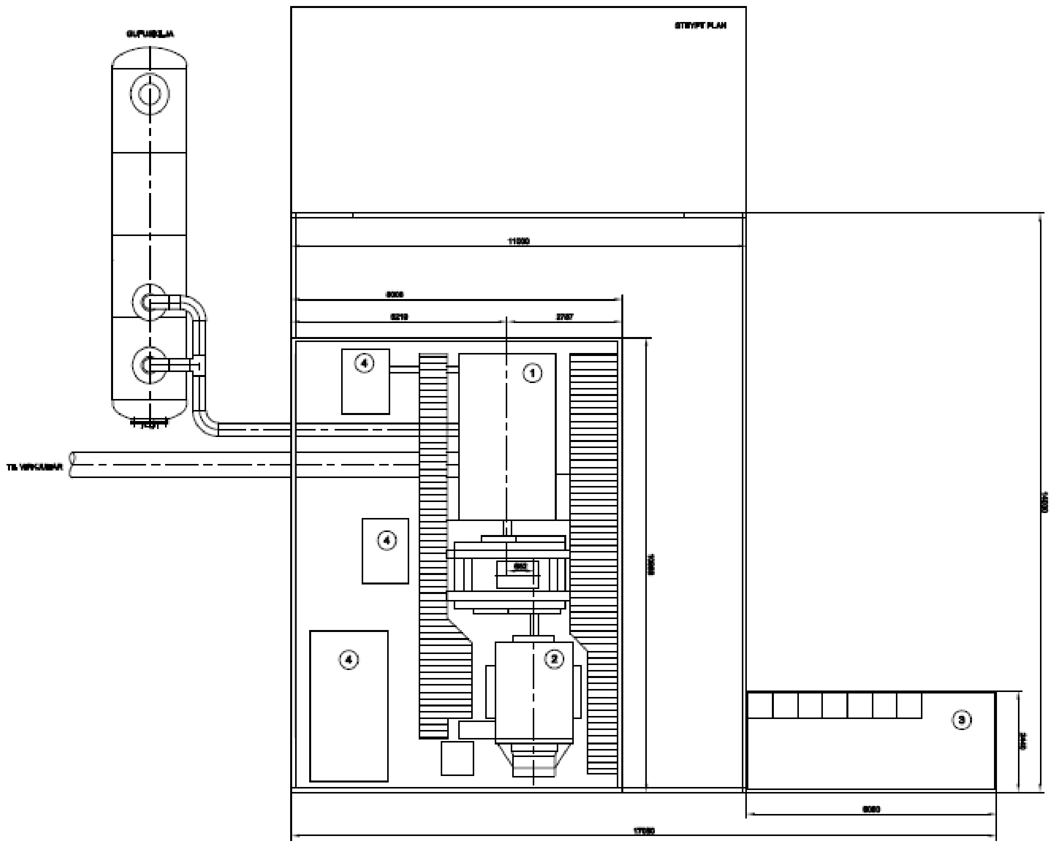
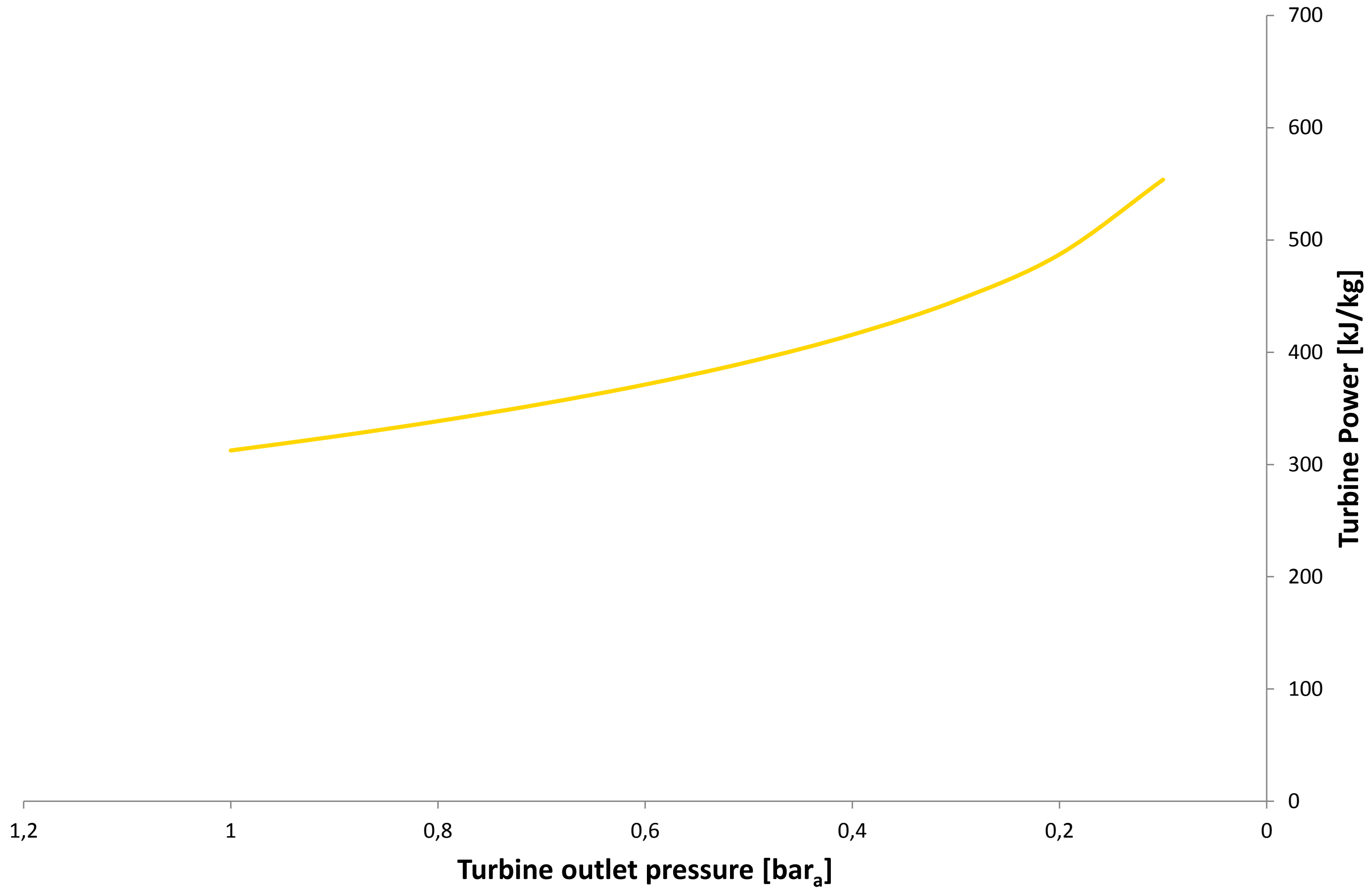
Back Pressure Steam Power Plant



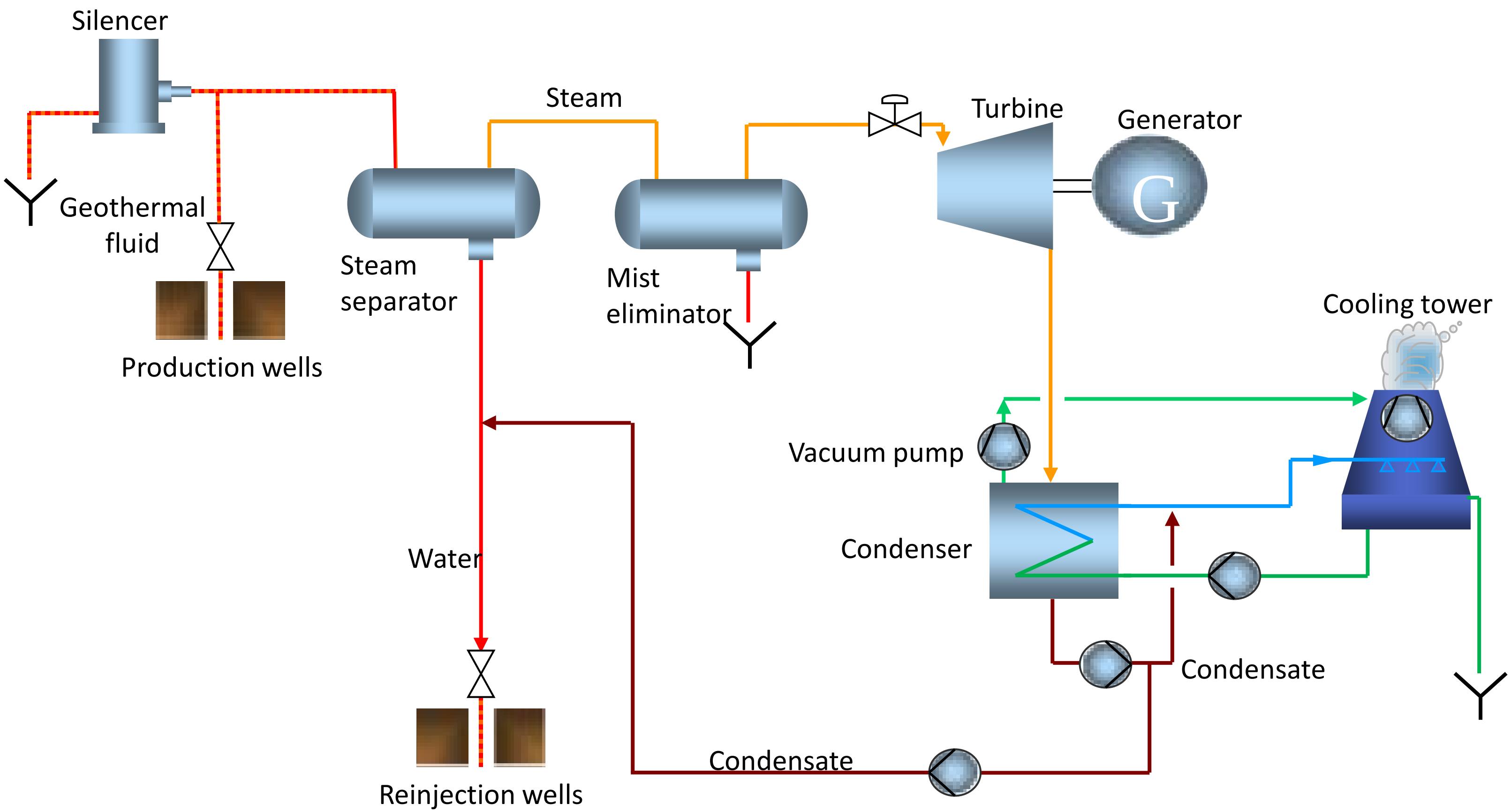
Back pressure unit - layout





700
600
500
400
300
200
100
0
Turbine Power [kJ/kg]
1,2
1
0,8
0,6
0,4
0,2
0
Turbine outlet pressure [bar_a]

Steam Power Plant with Condenser



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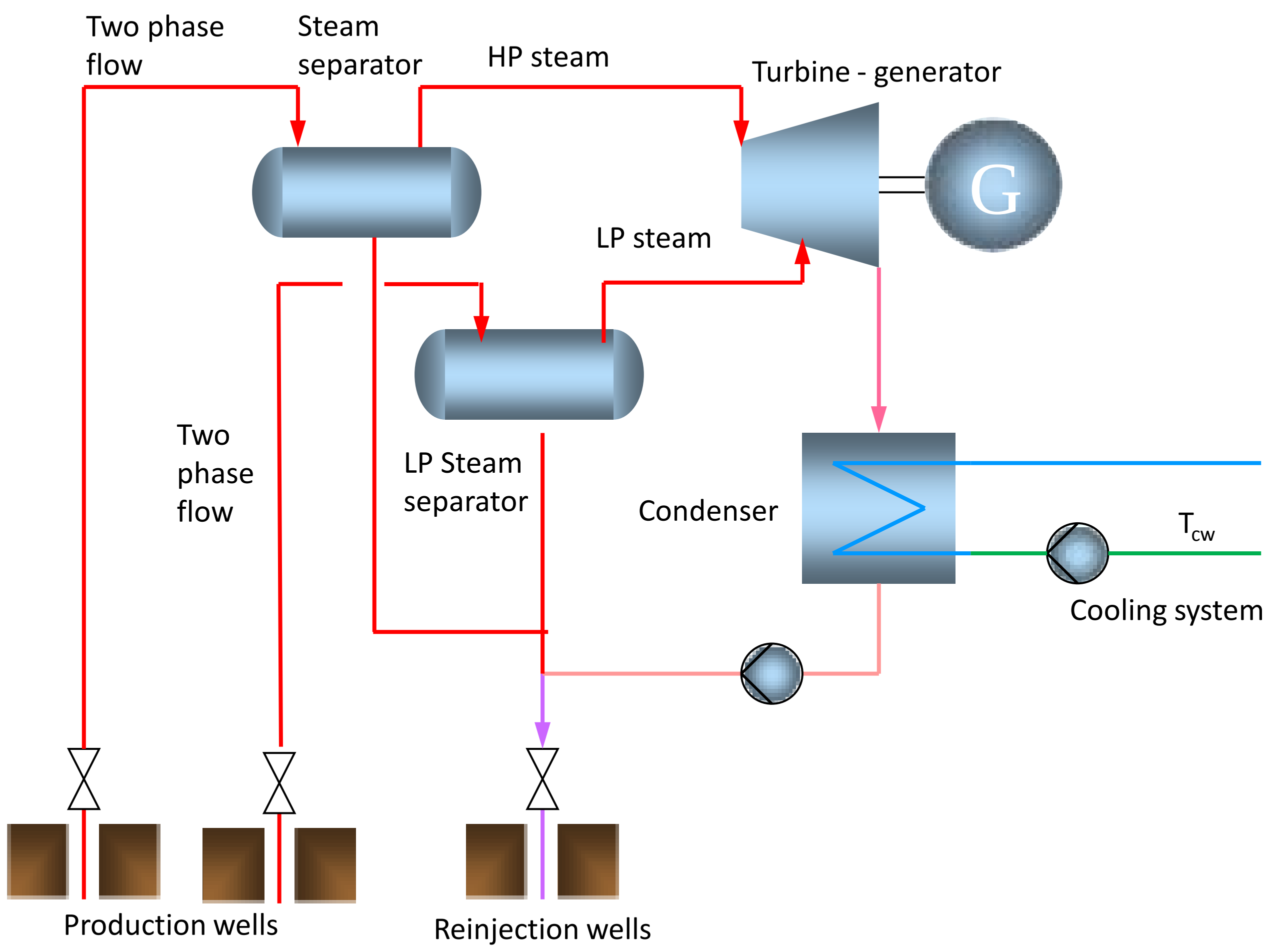
Hellisheiði-Single flash

Hellisheiði power plant

Steam Power Plant – Double Pressure



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Svartsengi – the“Octopus”

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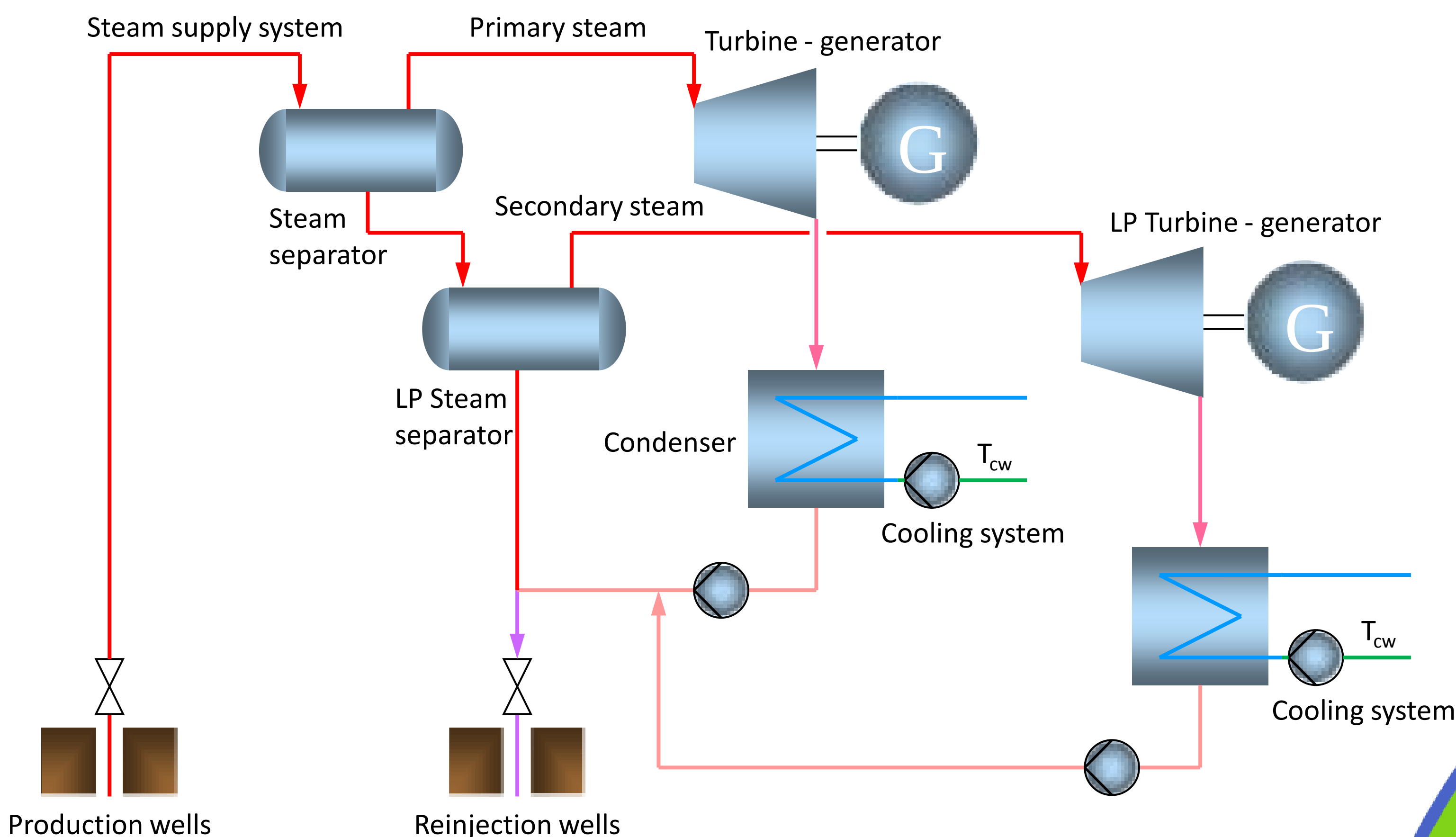
Steam Power Plant – Double Flash



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Hellisheiði – low pressure unit

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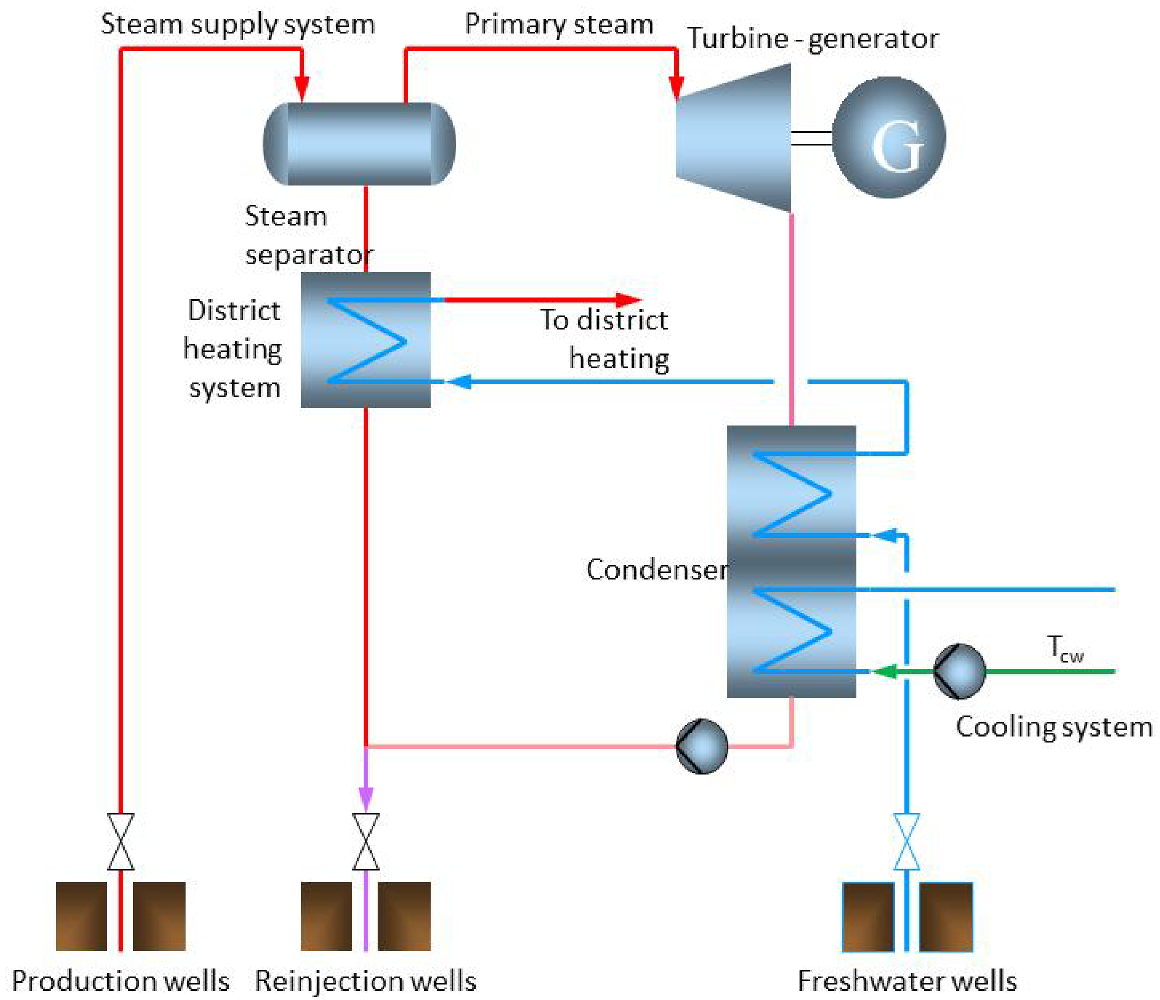
Steam Power Plant w. District Heating



Hellisheiði - Districh heating plant

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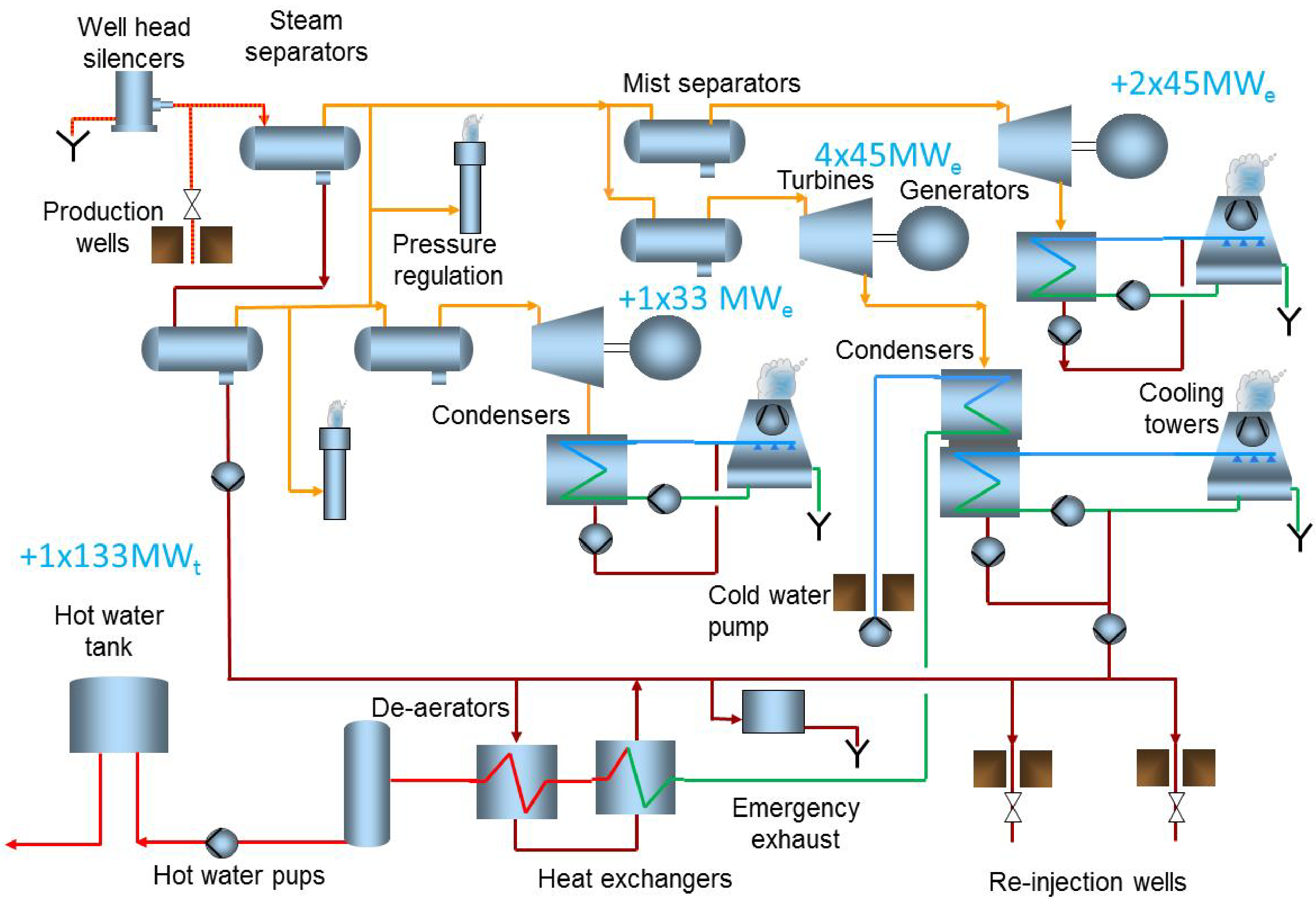

Well head silencers
Steam separators
Mist separators
+2x45MW$_e$
4x45MW$_e$
Turbines
Generators
Production wells
Pressure regulation
+1x33 MW$_e$
Condensers
Condensers
Cooling towers
+1x133MW$_t$
Hot water tank
Cold water pump
De-aerators
Emergency exhaust
Hot water pups
Heat exchangers
Re-injection wells

The Hellisheiði Power Plant

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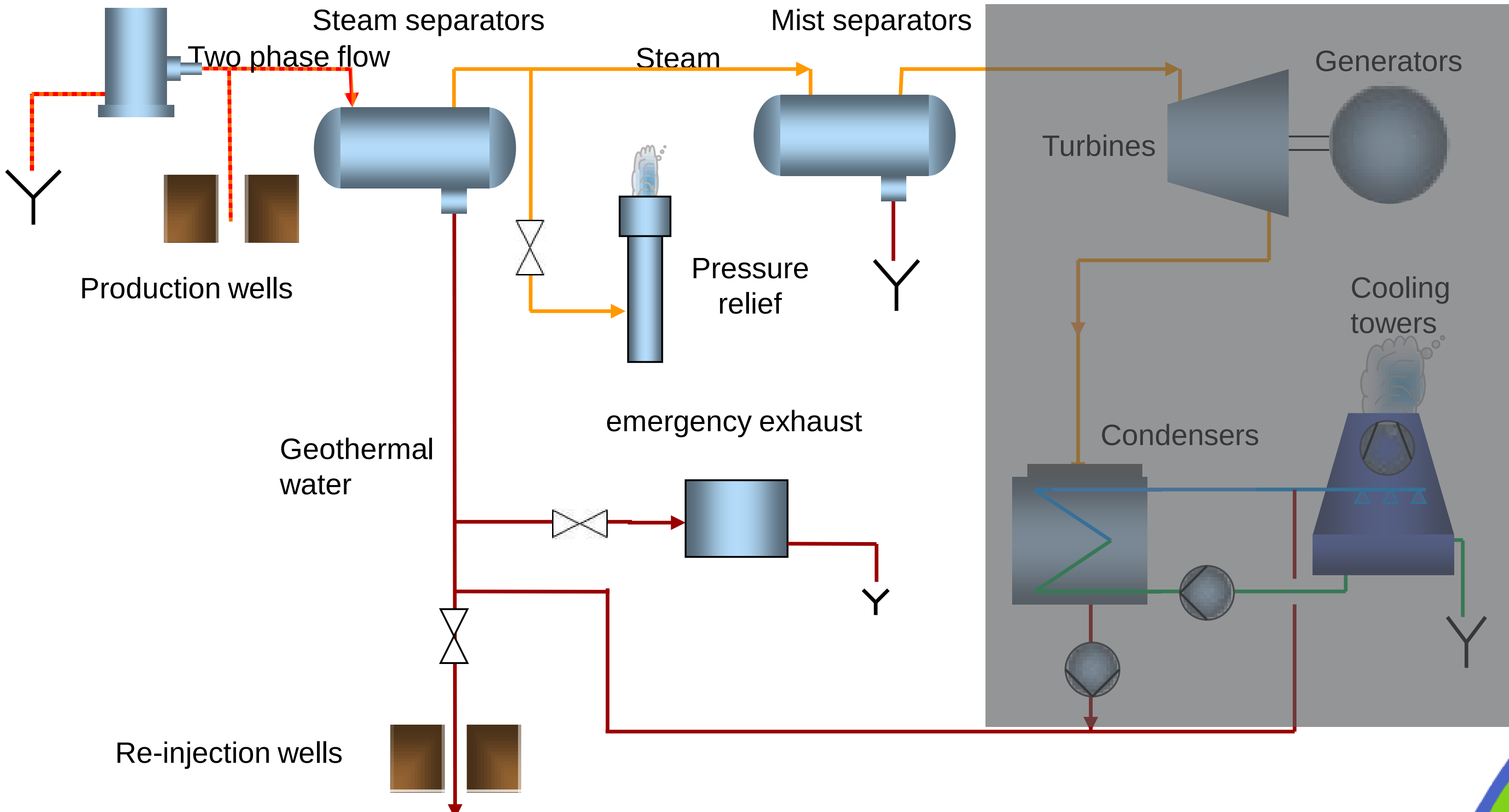
Steam Gathering System

- This session will present an overview of the design process of a geothermal steam gathering system with emphasis on particularities of the geothermal fluid.

Steam Supply - Preliminary P&ID



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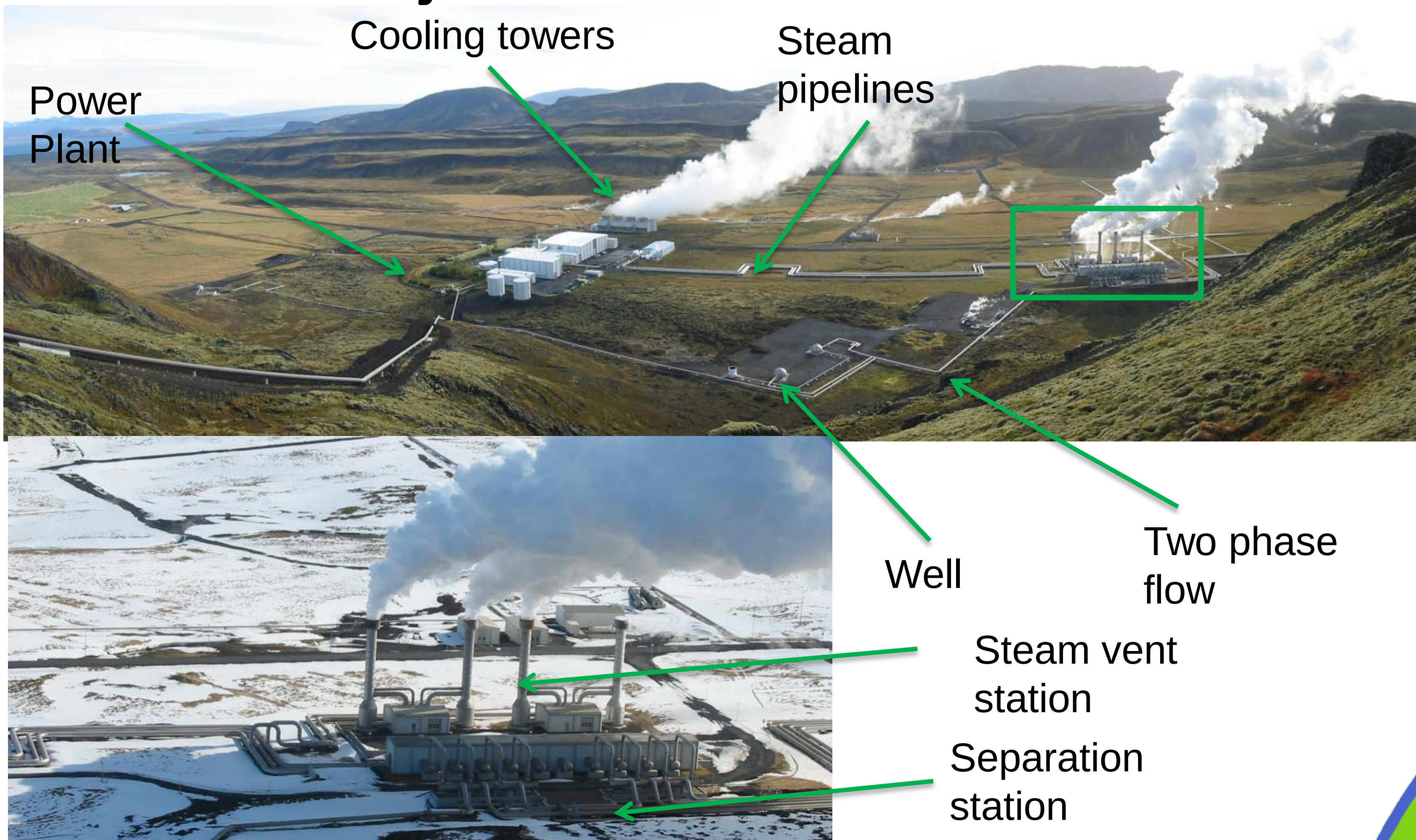
Nesjavellir Power Plant



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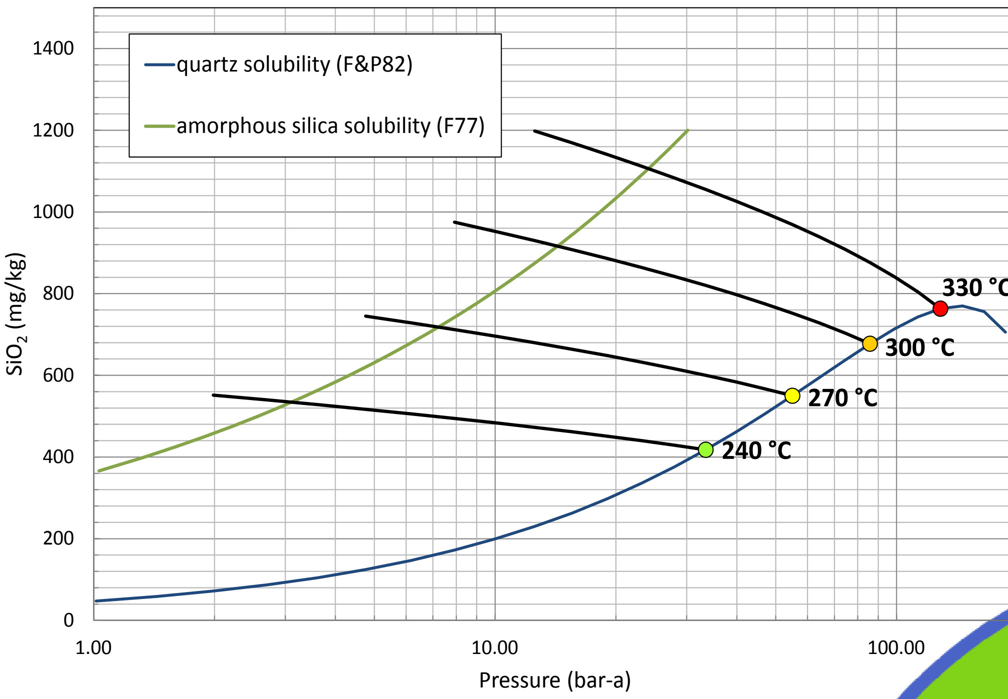
Steam Supply - Design

- Design standards
  - Standards i.e. Pressure directive 97/23/EC
- Pressure selection
  - Chemical constraints
  - Power generation
  - Productivity curves



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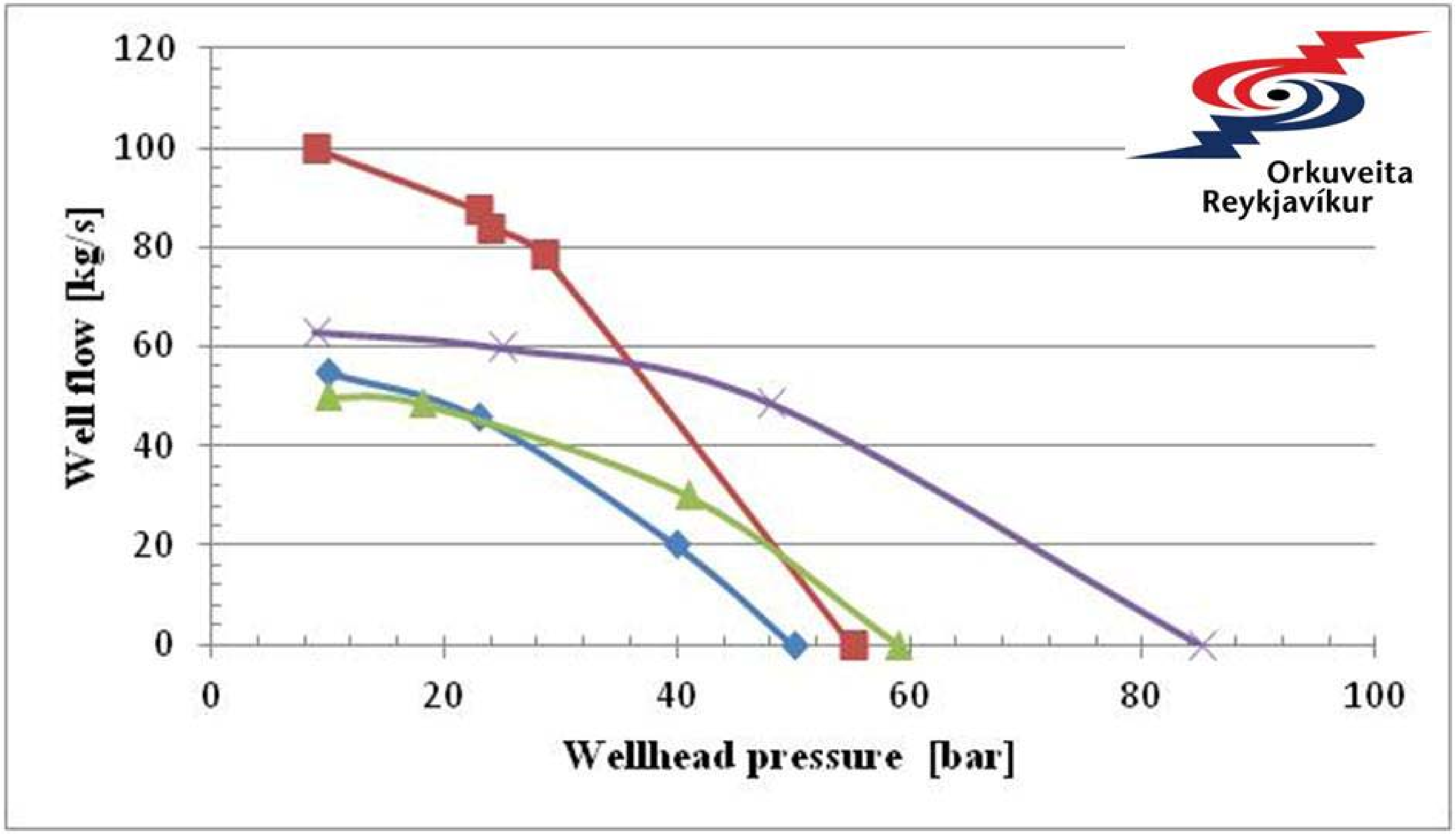
Typical productivity curves



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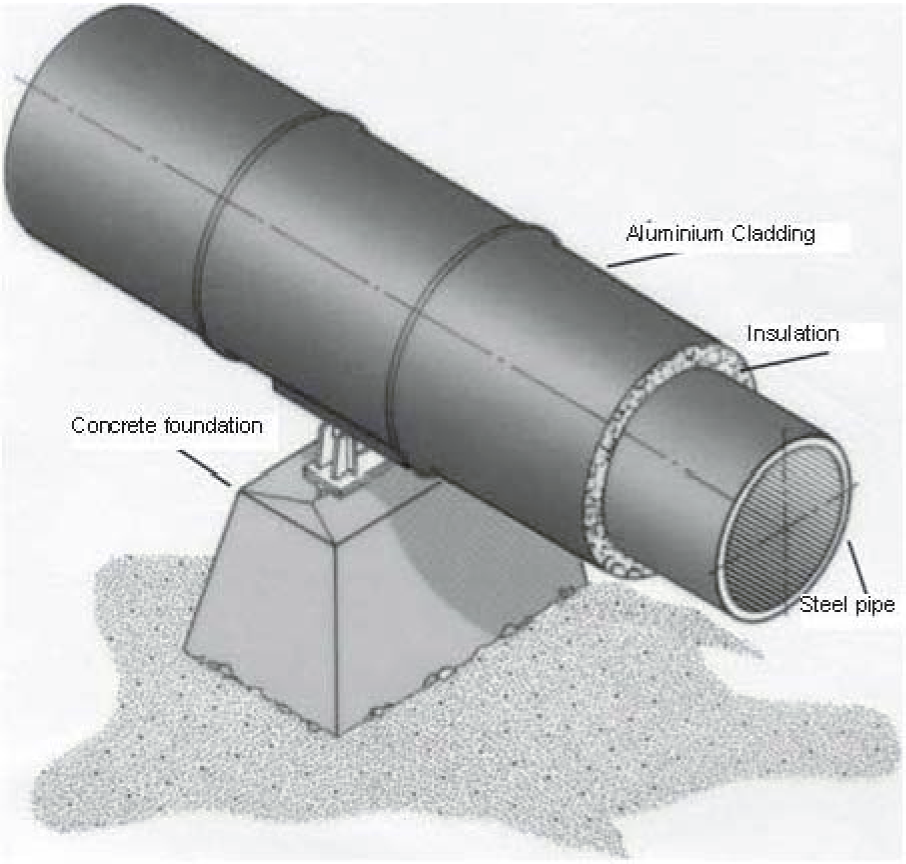
Steam Supply – Design load

- Constant load
  - Weight
  - Pressure
- Variable load (depending on location)
  - Wind
  - Snow
  - Earthquake
  - Ash
- Frictional load
  - Thermal expansion
  - Friction

Steam Gathering System - Pipelines

- Pipe laying
  - Under ground
  - Above ground
- Material selection
- Pipe size
  - Pressure/temperature



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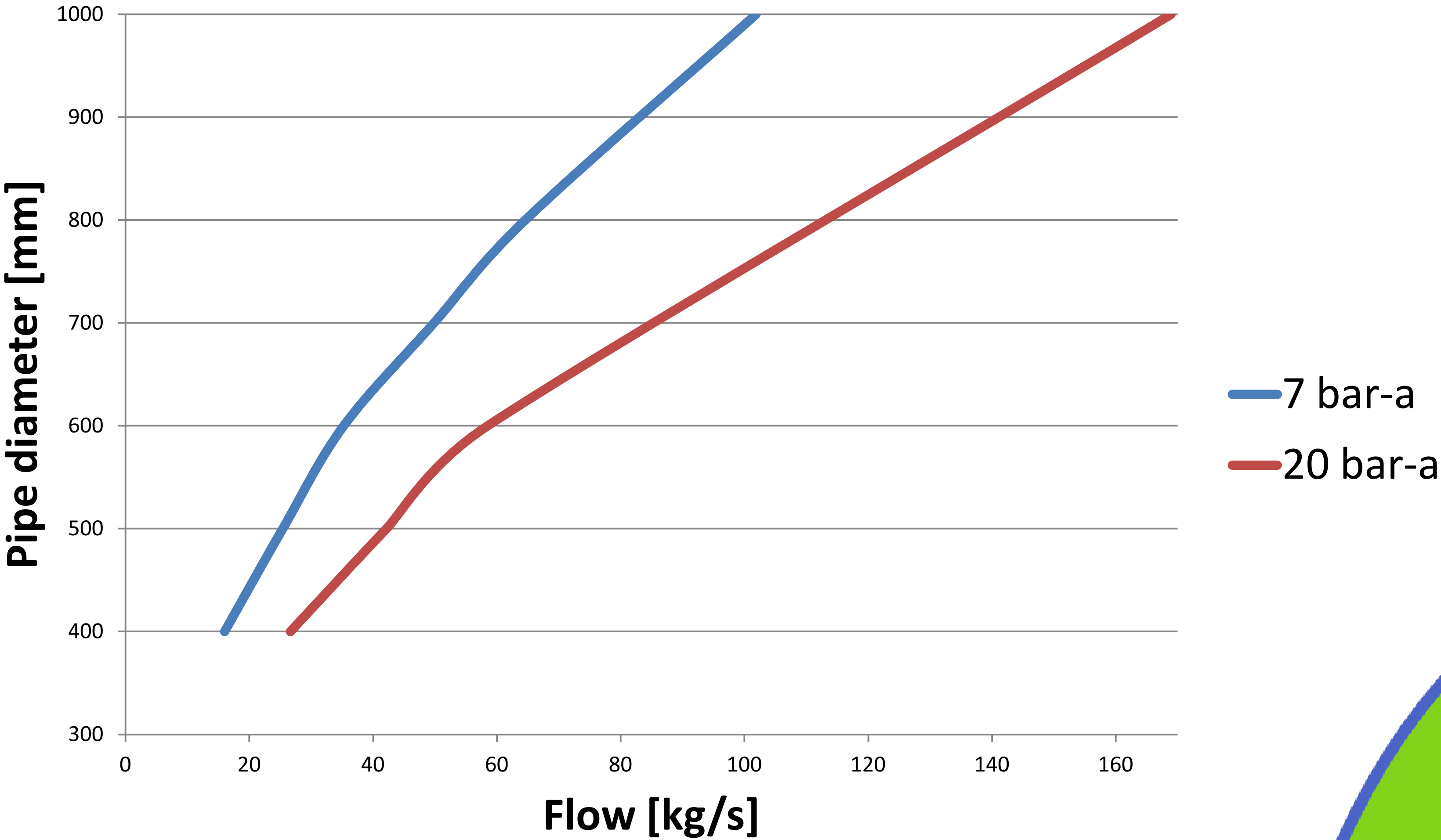
Steam Supply System – Pipelines



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Steam gathering system – route selection

- Public safety
- Environmental impact
- Restriction on land
- Cost efficiency

Steam pipelines

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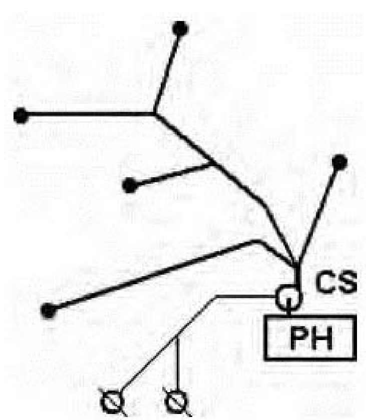
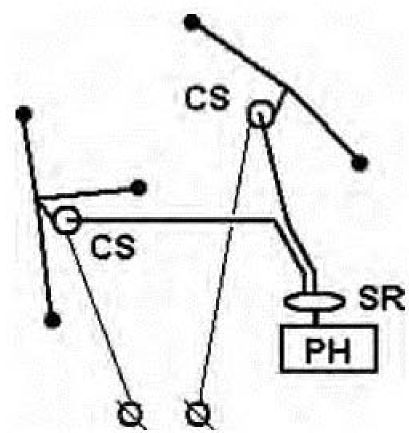
Steam Supply - Layout

- Central separation station
- Satellite separation stations
- Individual separators

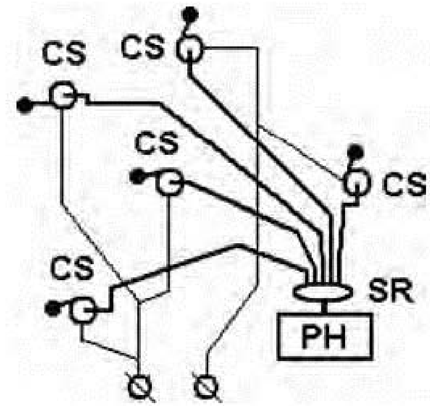
Central



Satellite

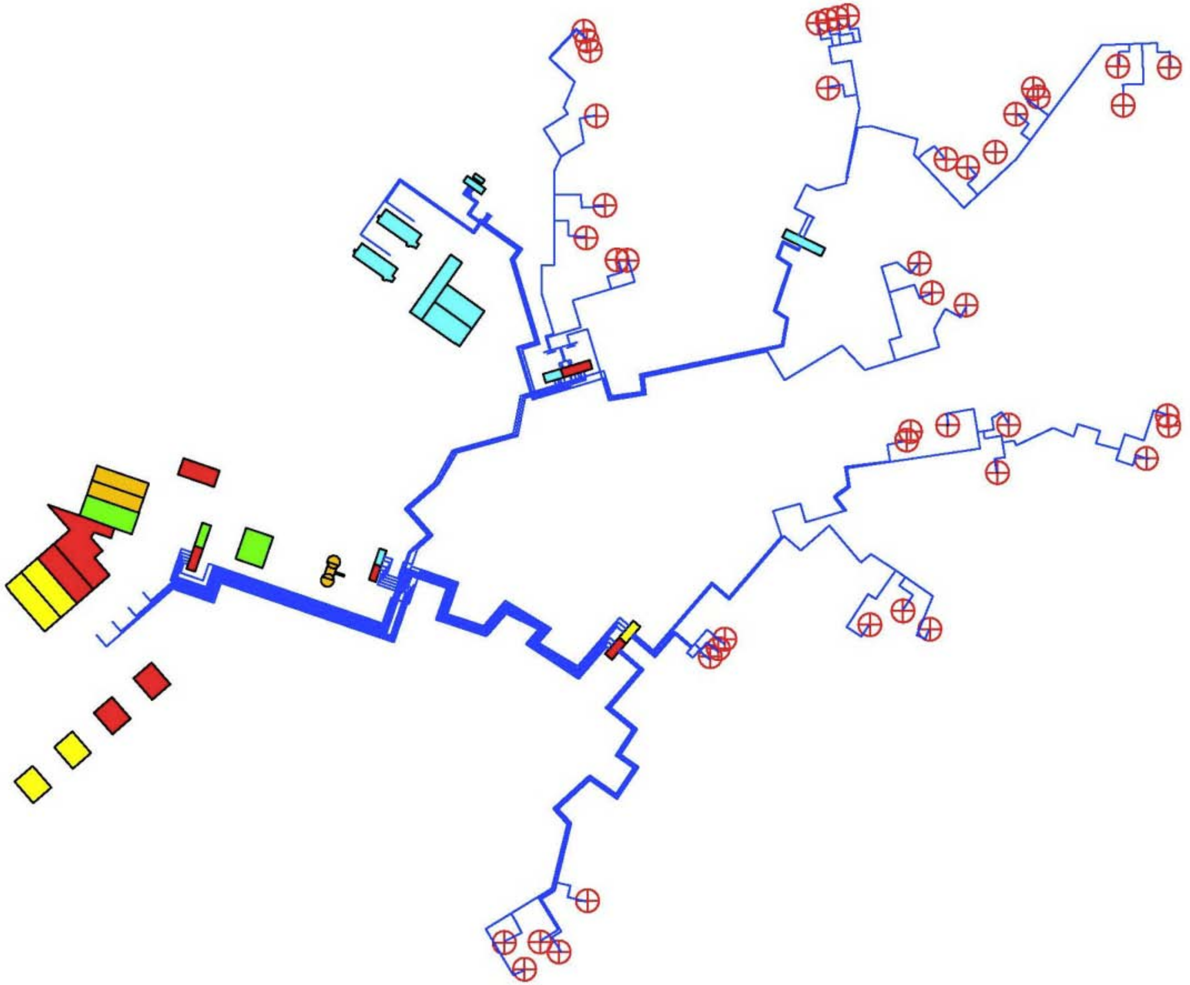


Individual



Source: Di Pippo

Power plant layout



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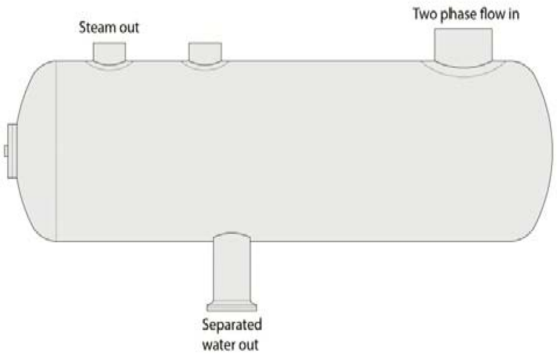
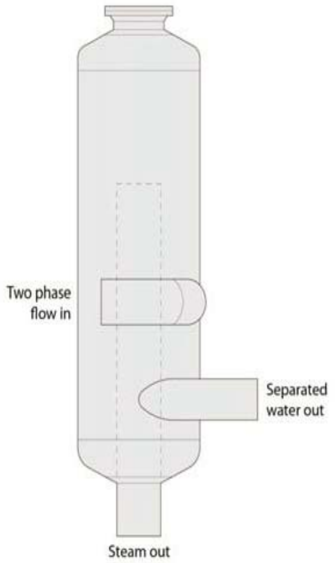
Steam Supply - Separators

- Cyclone separators
- Gravity separators





- Efficiency
  - Steam separator and moisture separator should together achieve 99,99 % bw. liquid removal or better

Calculated example

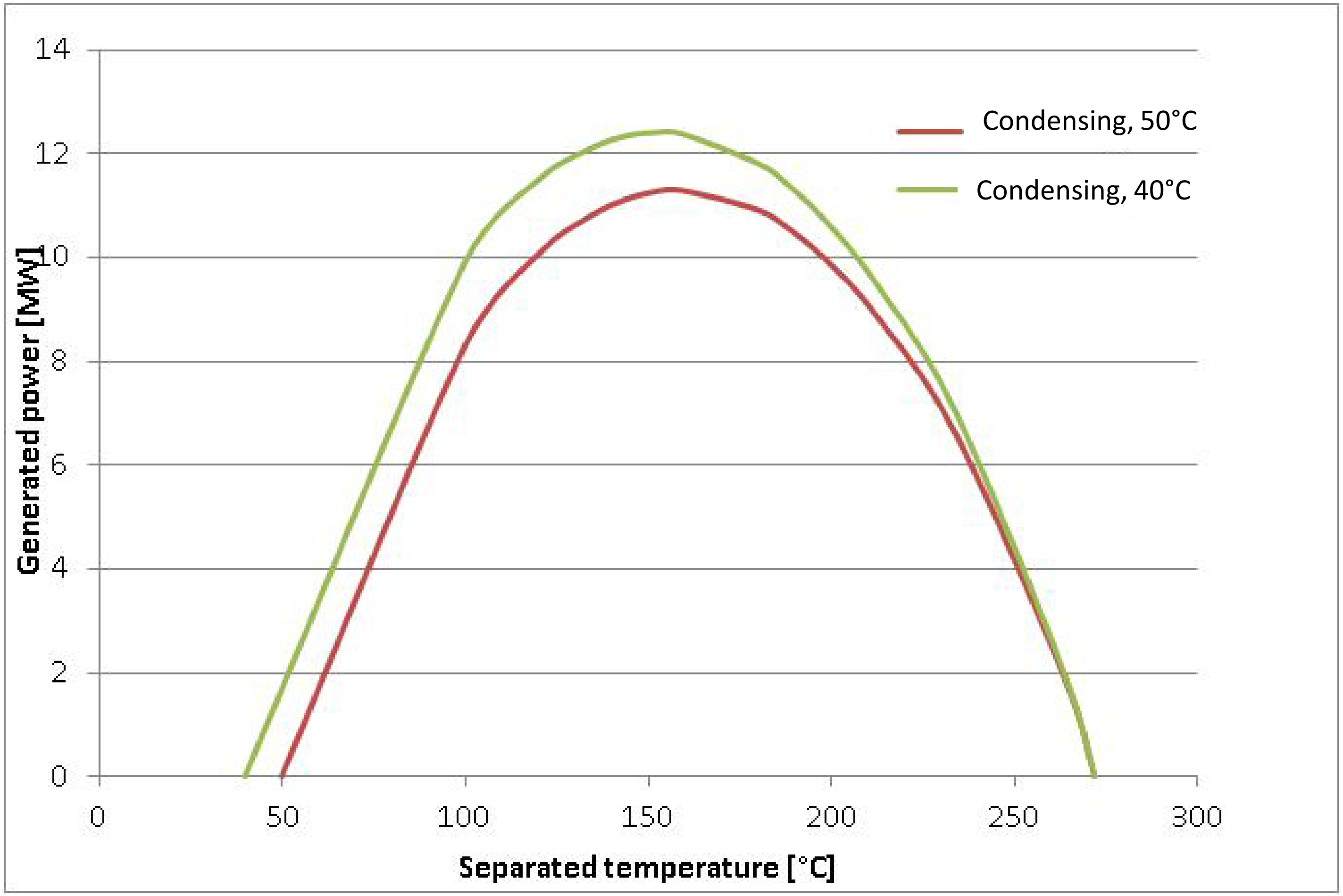
- The presenter will go through a calculated example to show methods used for basic engineering within steam gathering system design. The example taken will be connected to the special conditions encountered in geothermal energy.

Example

- Example for1200 kJ/kg well enthalpy
  - 40-50°C condensing temperature
  - Back pressure
- Objective
  - Maximize the power production

- Assumptions
  - Assume that we know the reservoir enthalpy
  - We know the condenser temperature
  - Assume that separation pressure does not influence the well flow

Example, condensing unit

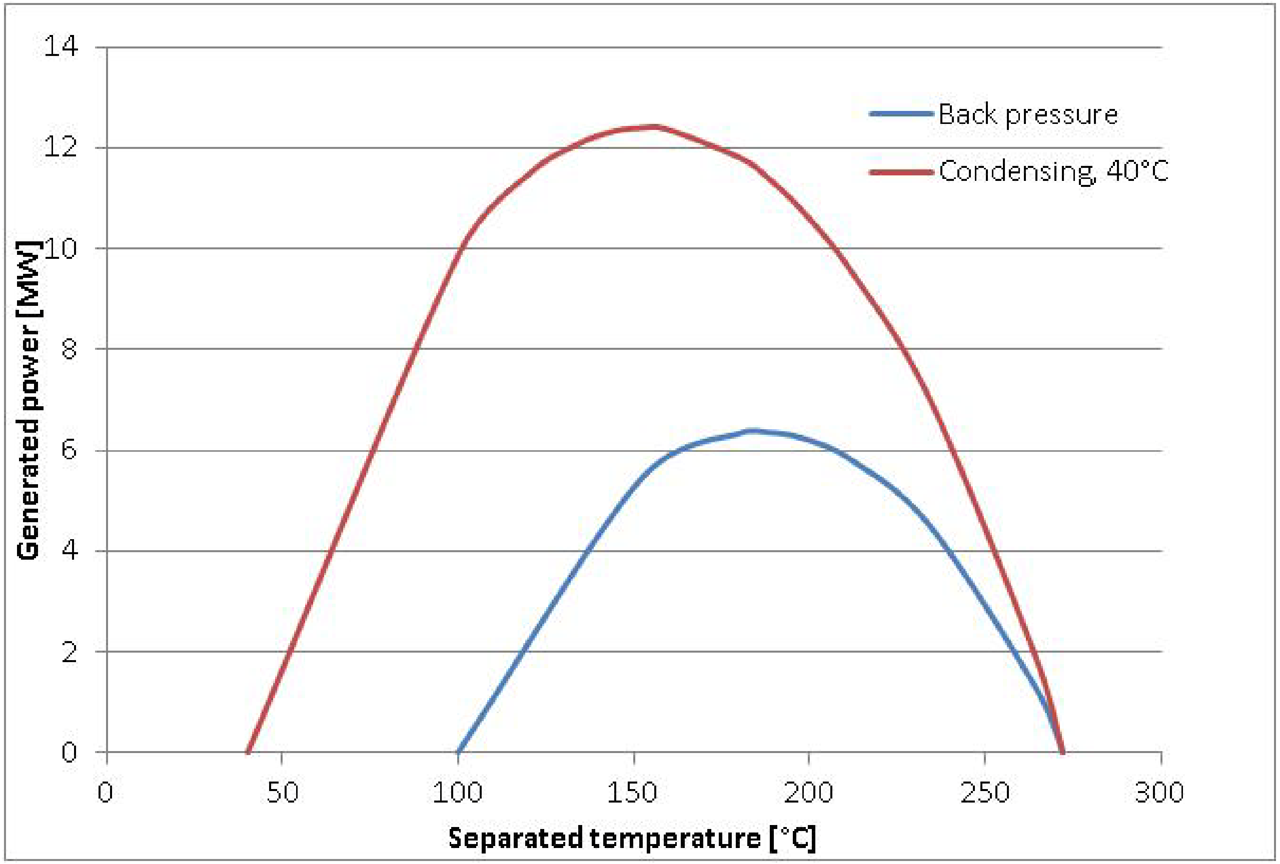


Example, condensing unit

- The maximum power will be 12,4 MW
  - Entalpy = 1200 kJ/kg
  - Condesing pressure 0,075 bara / temperature 40°C
  - Separation pressure 6 bar_a
  - Flow 100 kg/s

- What if we selected backpressure instead?

Example, back pressure



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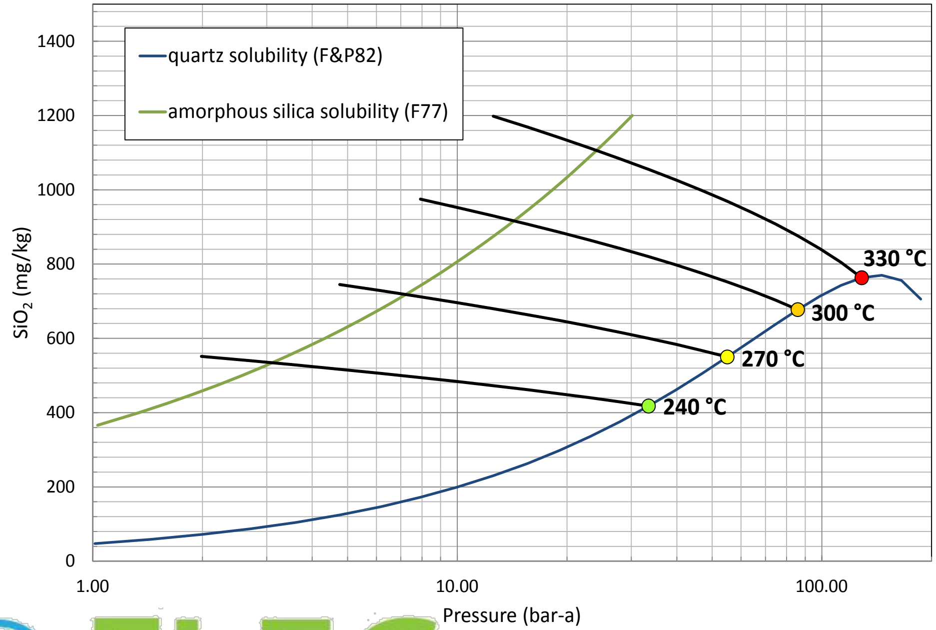
Example, back pressure

- The maximum power will be 6,4 MW
  - Entalpy = 1200 kJ/kg
  - Separation pressure 12 bar_a
  - Flow 100 kg/s

Example

- Optimum separation pressure is 6 bar_a, is that ok?
- Saturation temperature for 1200 kJ/kg is 273°C



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- Technology Roadmap "Geothermal Heat and Power", © OECD/IEA, 2011 International Energy Agency, *www.iea.org*
- Bombarda, P., Invernizzi, C., Pietra C., "Heat recovery from Diesel engines: A thermodynamic comparison between Kalina and ORC cycles" Applied Thermal Engineering 30 (2010) 212–219
- Di Pippo, R.: Second Law assessment of binary plants generating power from low-temperature geothermal fluids, *Geothermics, **33, (2004), 565-586.***

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