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Geothermal Binary Power Plants

Þóra Hlín Þórisdóttir

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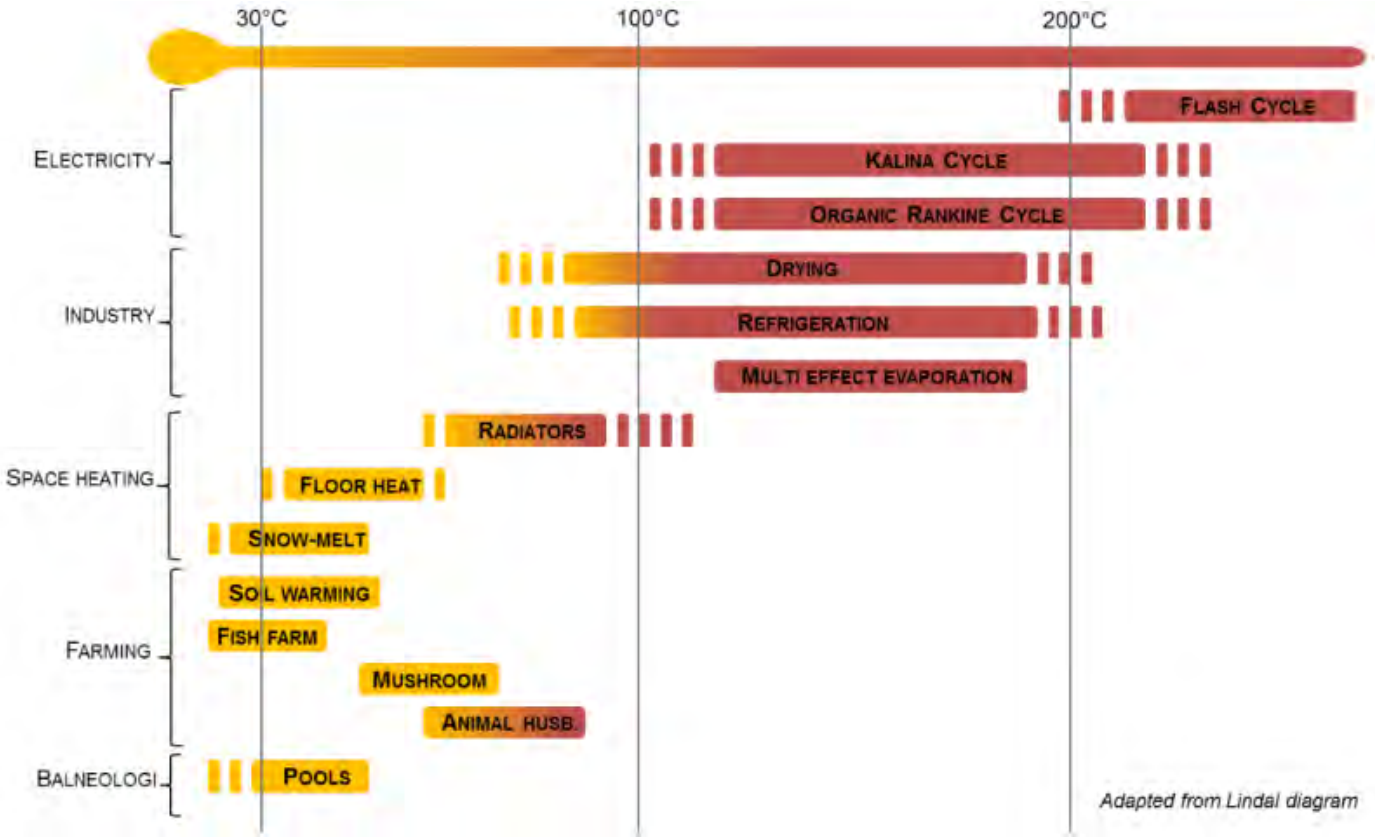
Lindal Diagram



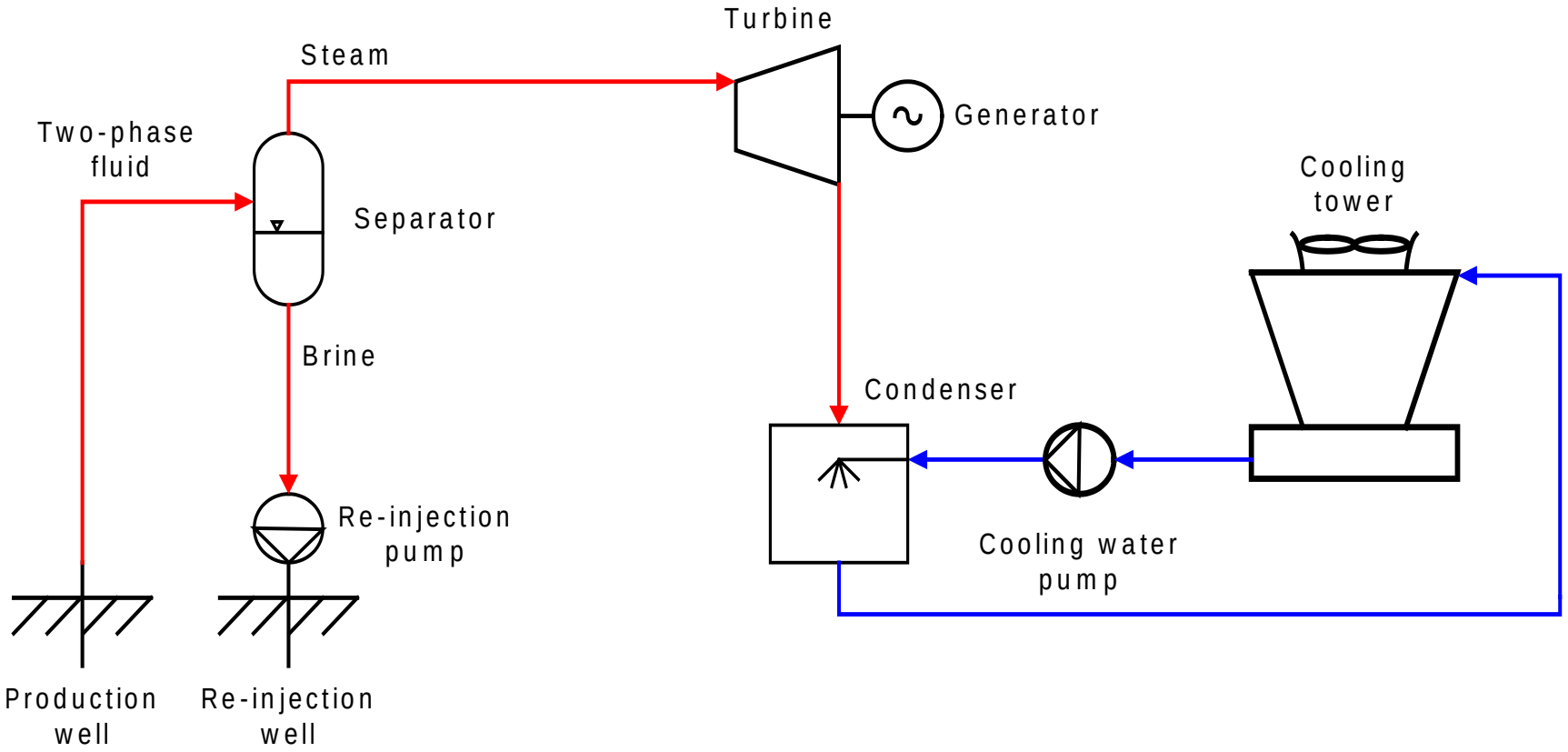
- This study focused on low-temperature resources (90-150°C)

Scope of the Study

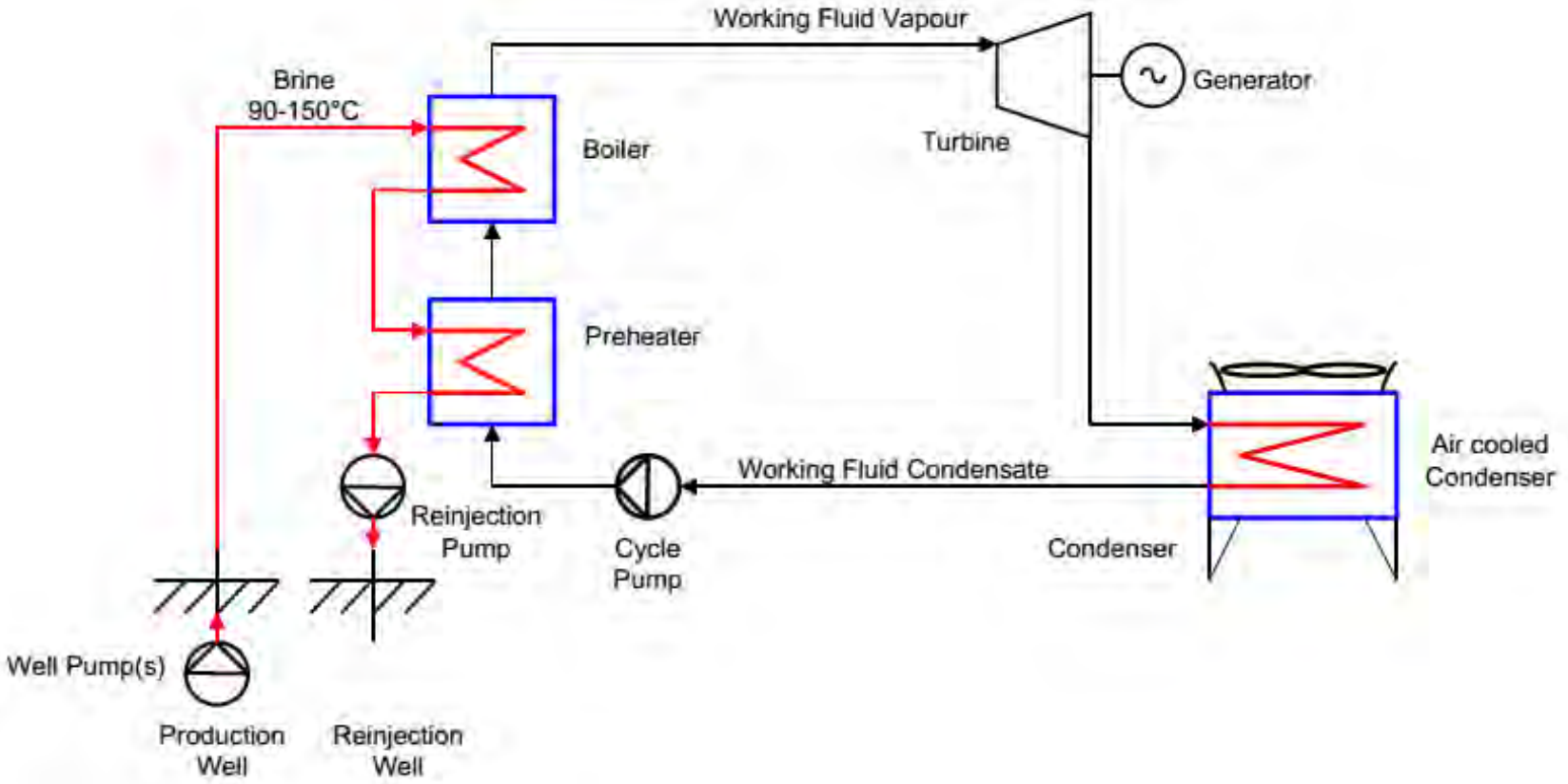
- Geothermal fluid temperature 90-150°C
- Generator outputs 250 kW – 10MW

- Funded by ICEIDA
- Prepared by Verkís Consulting Engineers in cooperation with ISOR

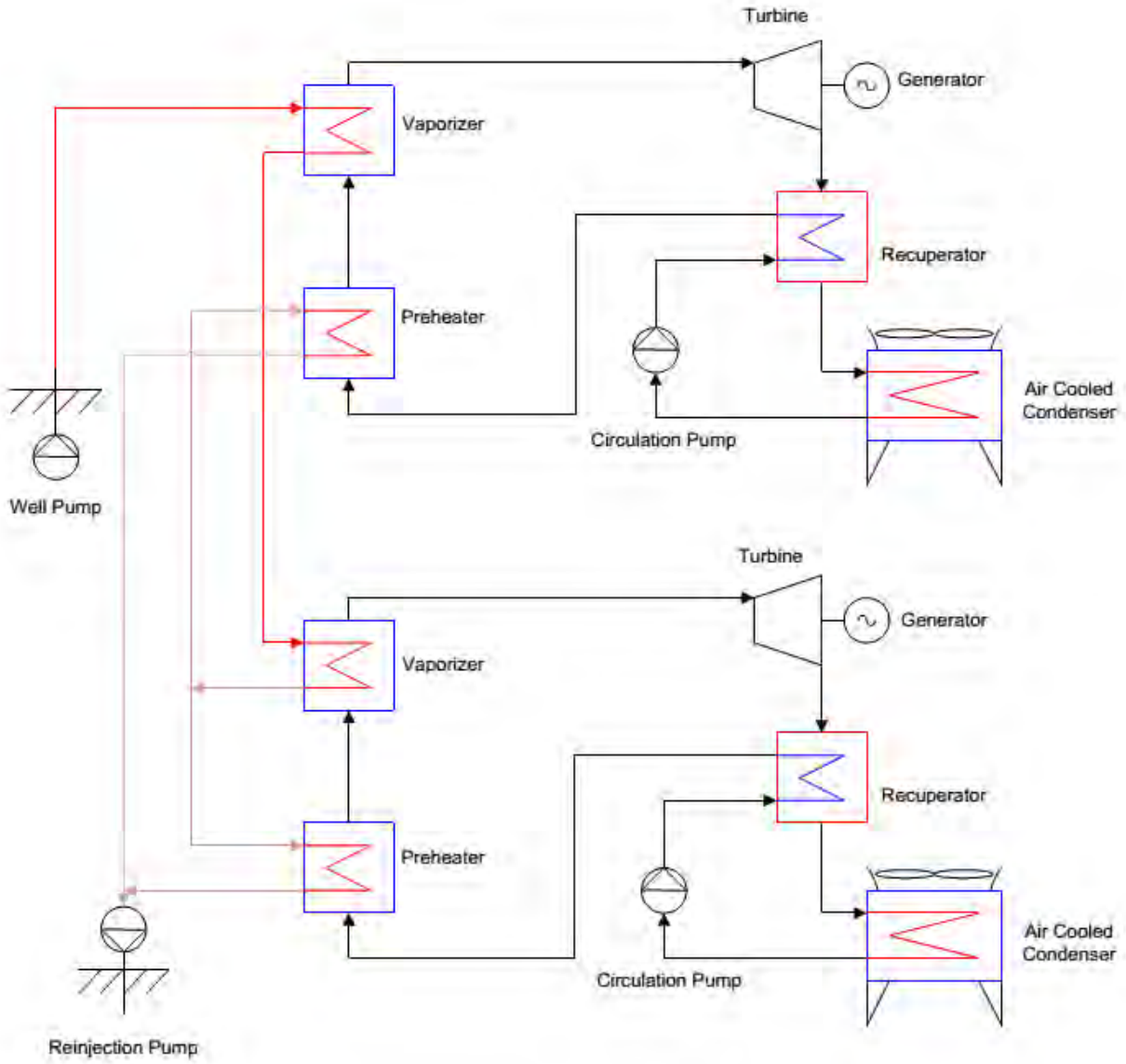
Single Flash



Binary – Organic Rankine Cycle (ORC)



Two-Stage ORC



Geothermal Field

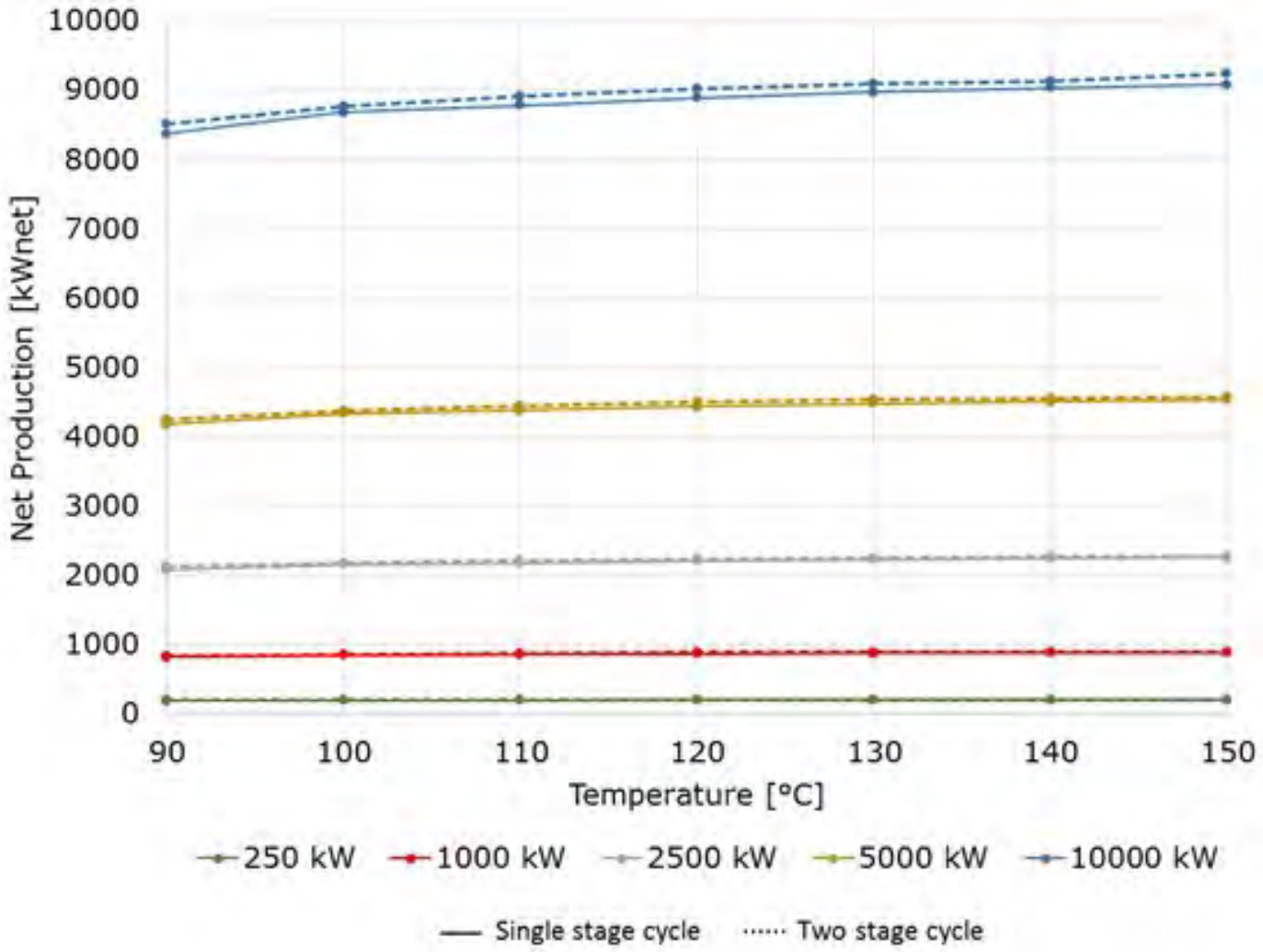
- Field Temperature 90-150°C

- Chemical composition of the geothermal fluid
  - Mineral concentration
  - Gas concentration

Cooling Systems

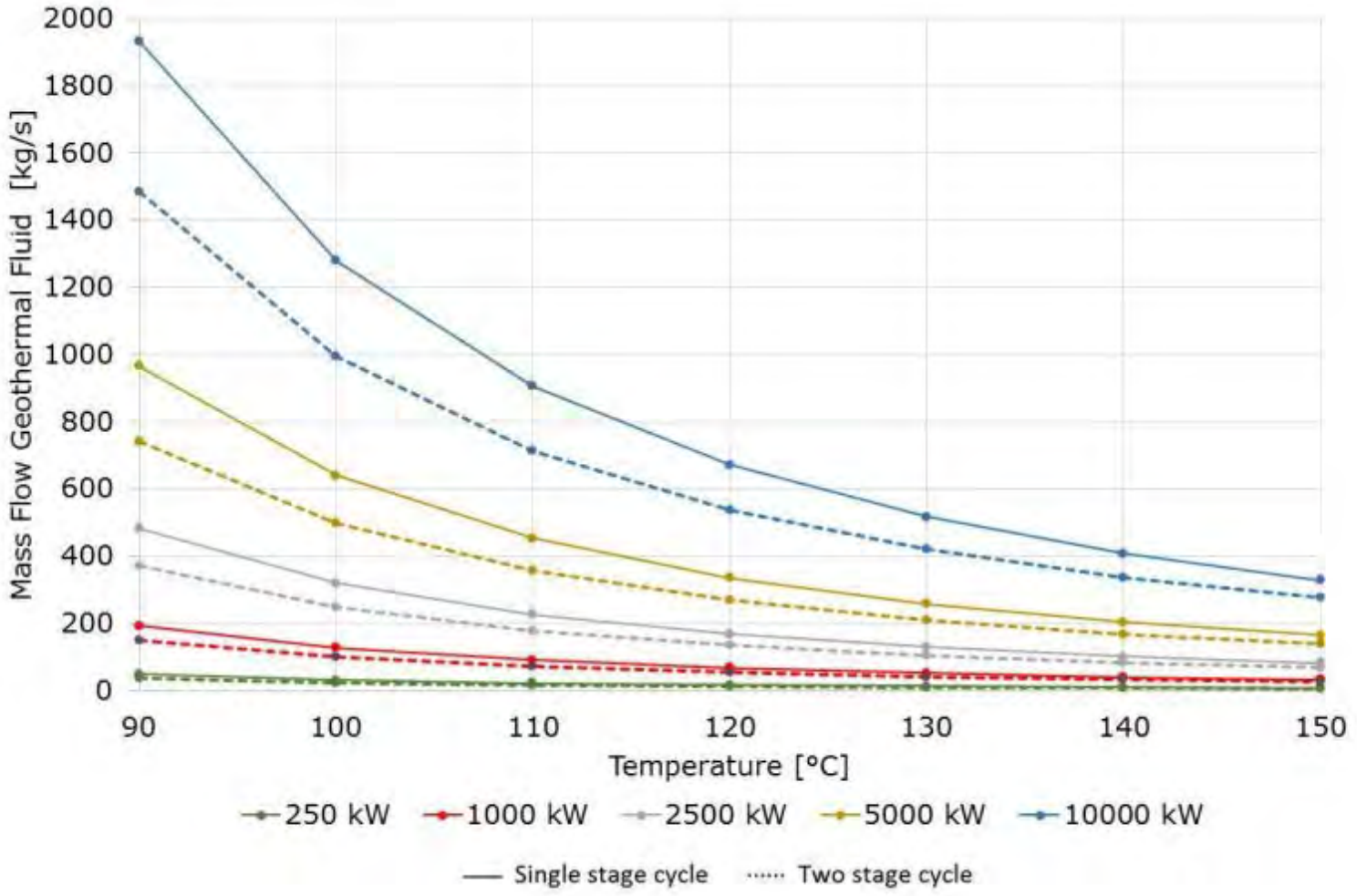
- Direct cooling
- Evaporative cooling tower
- Air cooled condenser

Net Power / Field Temperature



Mass Flow of Geothermal Fluid

Mass flow of geothermal fluid (kg/s) required per each unit



Items which affect net Production

- Turbine and generator efficiency
- Power required for pumping
  - Number of wells
  - Water level
- Air cooled condenser
  - Outdoor temperature
  - Humidity

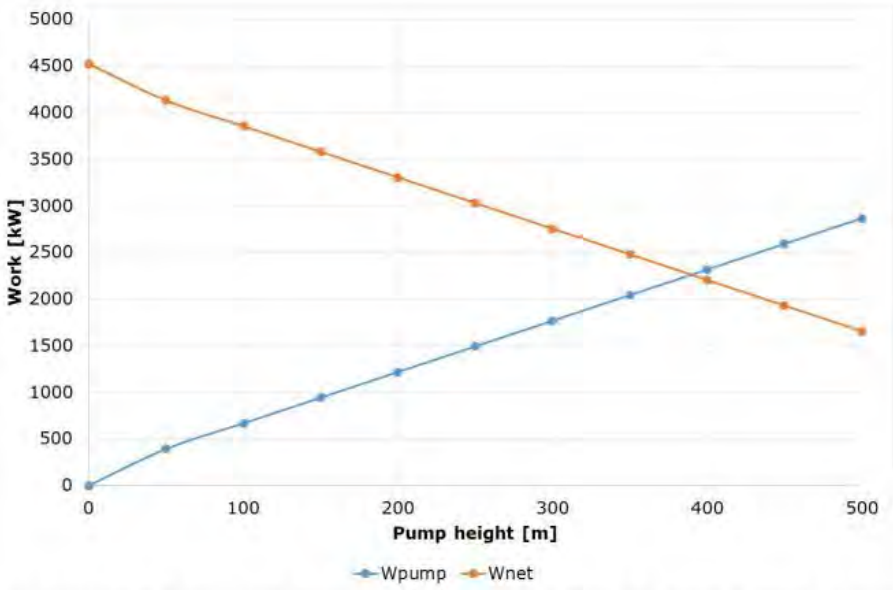
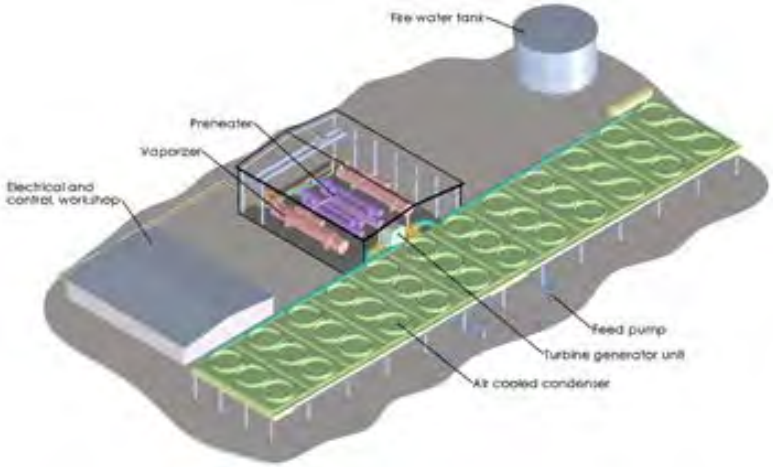


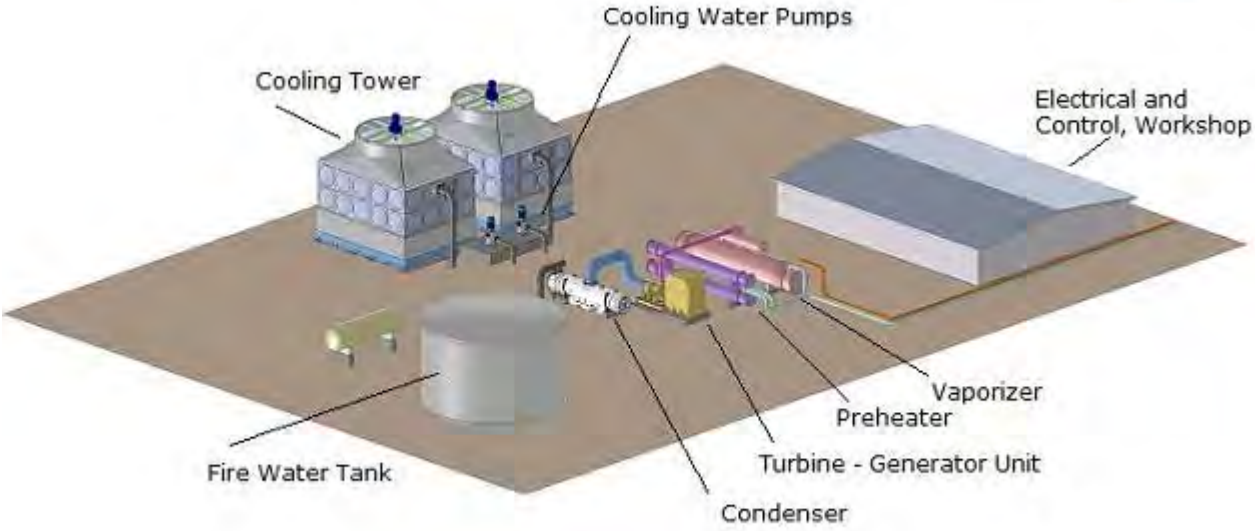
Figure 3-3 Effect of pumping height on net output of 5 MW binary plant. Geothermal resource temperature 120°C.

Plant Electrical Production Options

- Parallel operation with a big and stable network (full output)
- Island operaton (variable operation)
- Paralell operation with diesel generators (partial loads)
- External power load is required for startup of the plant.

Layout


Fire water tank
Preheater
Vaporizer
Electrical and control, workshop
Feed pump
Turbine generator unit
Air cooled condenser


Cooling Water Pumps
Cooling Tower
Electrical and Control, Workshop
Vaporizer
Preheater
Turbine - Generator Unit
Fire Water Tank
Condenser

Existing plants

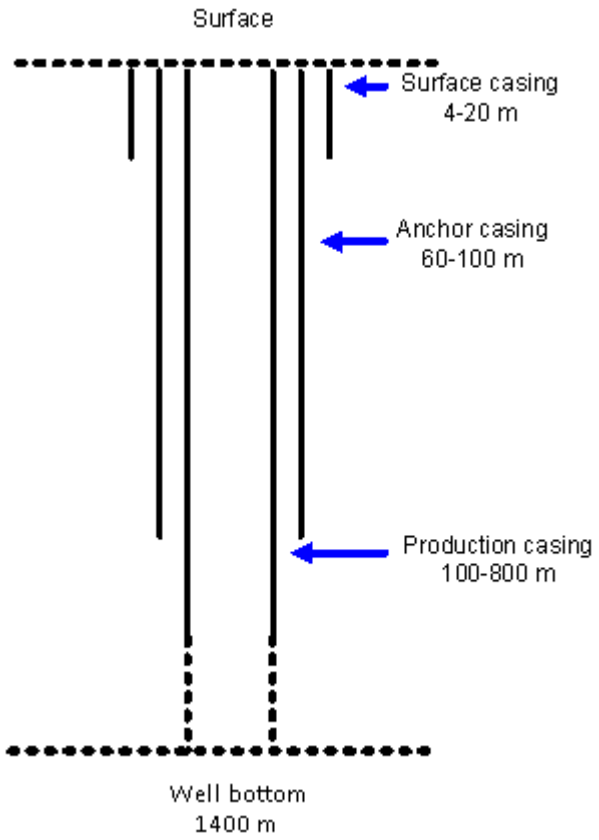
Investment Cost – Geothermal Field

Capital cost of individual well

Item	Total (MUSD)
Well, 1.400 m deep	2,00
Line shaft pump	0,25
Miscellaneous, 15%	0,20
Design, supervision, commissioning	0,15
Total, one well	**2,60**

Capital cost for 40 l/s per well

Item	Total (MUSD)
1 production well with installed pump	2,60
0,5 reinjection well	1,30
Gathering system+	0,08
Reinjection system	0,04
Total, for 40 l/s	**4,02**



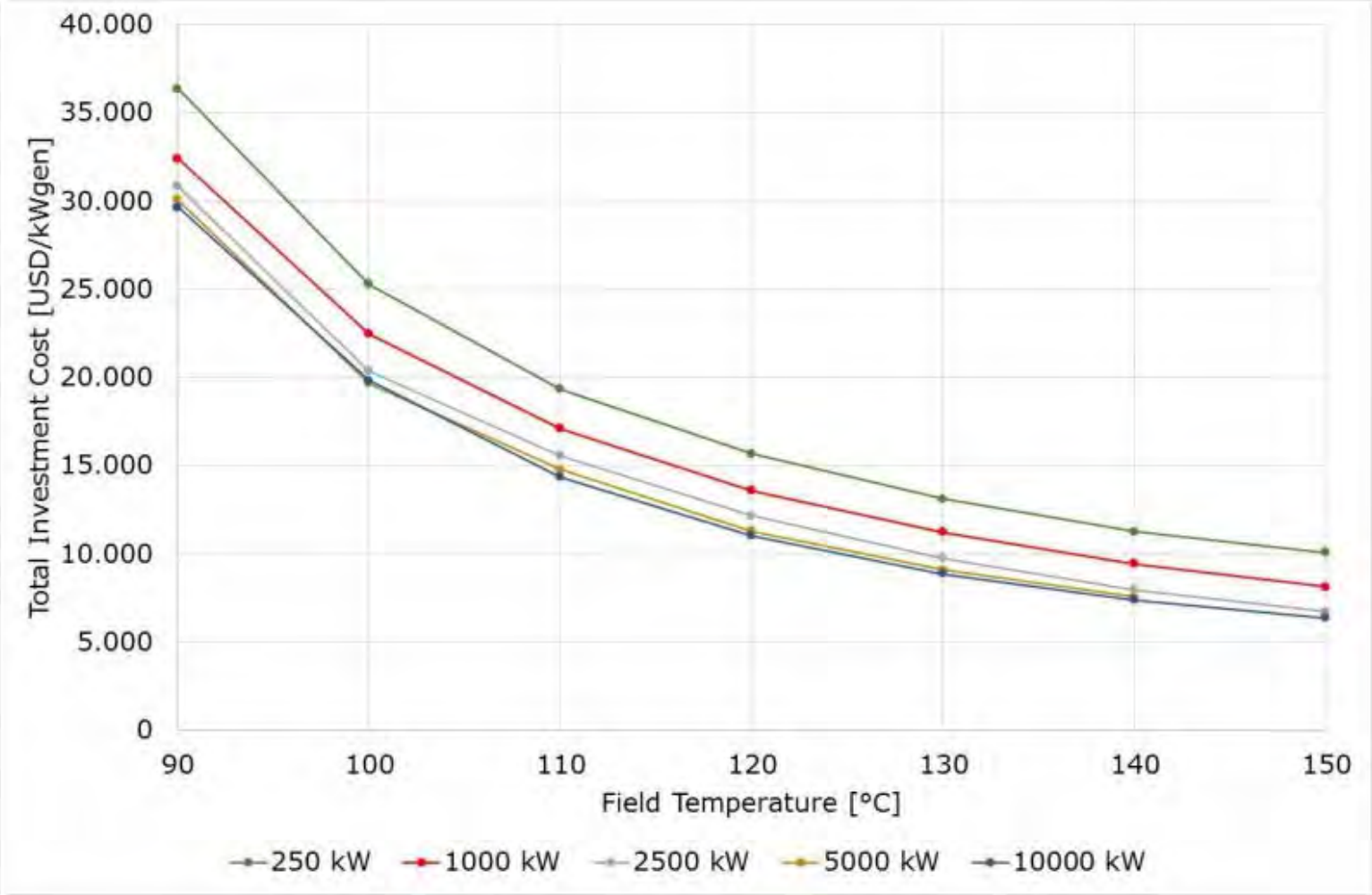
Investment Cost Power Plant

Items included in the main cost items

Direct Cost	
Mechanical Equipment	Turbine, generator, incl. lube oil unit, control etc. Heat exchangers (vaporizers, preheaters and recuperators) Air cooled condensers (excl. foundations) Cycle pump Auxiliary systems Compressed air systems Valves and controls Firefighting system Piping, materials and installation, not icl. in other
Electrical & Control	Transformers (main and auxiliary) Local connection to the grid MV switchgear Control, protection and MCC'a Sensors and transmitters Cables, materials and installation not incl. in other
Civil Work	Excavation Foundations Service facilities
Indirect cost	
	Engineering, supervision and commissioning, 10% of direct cost General Contingency, 15% of direct cost

Investment Cost

Total investment cost per kW generated – single stage cycle



Total Investment Cost

Total Investment Cost							
		Single stage ORC cycle			Two stage ORC cycle		
	Generated Power kW	Cost, MUSD			Cost MUSD		
		Power Plant	Steam Field	Total	Power Plant	Steam Field	Total
90°C	250	1,6	8,2	9,7	1,9	5,3	7,2
	1000	5,2	21,6	26,9	6,3	16,3	22,6
	2500	10,8	54,2	65,0	13,0	40,8	53,7
	5000	19,0	103,2	122,1	22,7	78,7	101,4
	10000	35,0	201,0	236,0	42,0	154,9	196,9
100°C	250	1,5	5,3	6,8	1,8	5,3	7,1
	1000	5,0	16,3	21,3	6,0	13,5	19,5
	2500	8,6	37,9	47,1	12	29,8	40,7
	5000	14,6	70,6	86,4	20,4	54,2	73,3
	10000	30,9	135,8	166,7	37,1	103,2	140,3
110°C	250	1,4	5,3	6,7	1,6	5,3	7,0
	1000	4,7	13,5	18,2	5,6	8,2	13,8
	2500	9,0	24,5	33,4	10,8	21,6	32,4
	5000	14,7	48,9	63,7	17,7	37,9	55,6
	10000	26,1	95,0	121,1	31,3	73,4	104,7
120°C	250	1,3	5,3	6,7	1,6	5,3	6,9
	1000	4,4	8,2	12,6	5,3	8,2	13,5
	2500	8,3	21,6	29,9	9,9	16,3	26,3
	5000	13,1	37,9	51,0	15,7	29,8	45,4
	10000	24,0	70,6	94,5	28,8	57,1	85,9
130°C	250	1,3	5,3	6,6	1,5	5,3	6,8
	1000	4,2	8,2	12,3	5,0	8,2	13,2
	2500	7,6	16,3	23,9	9,2	13,5	22,6
	5000	12,2	29,8	42,0	14,6	24,5	39,1
	10000	22,6	54,2	76,9	27,2	46,1	73,3
140°C	250	1,2	5,3	6,5	1,4	5,3	6,8
	1000	3,9	8,2	12,0	4,6	5,3	10,0
	2500	6,6	13,5	20,1	7,9	13,5	21,4
	5000	11,5	24,5	36,0	13,8	21,6	35,5
	10000	21,9	46,1	68,0	26,3	37,9	64,2
150°C	250	1,2	5,3	6,5	1,4	5,3	6,8
	1000	3,6	5,3	8,9	4,3	5,3	9,7
	2500	6,1	13,5	19,6	7,3	8,2	15,5
	5000	11,2	21,6	32,8	13,4	16,3	29,8
	10000	21,7	37,9	59,6	26,0	29,8	55,8

Operational Cost

Cost schedule for plant operation and maintenance cost

	Definition
Capacity factor	96%
Fixed costs	
Personnel	See table 7.1.11
Temporary contractors	Production stops one week per year.
Maintenance	
Inclusive spare parts and consumables	1,6% total capital cost of the plant and well pump.
Production wells	
Well replacement	1% capital cost of wells

Requirement for employees per shift

Plant size (kW)	Operators (24 hours)	Skilled Workers (8-hours, weekdays)	Security (24 hours)	Support services	Total number of employees
250	1		1		**10**
1.000	1		1		**10**
2.500	2	1	1		**17**
5.000	2	2	1	1	**18**
10.000	2	2	1	2	**19**

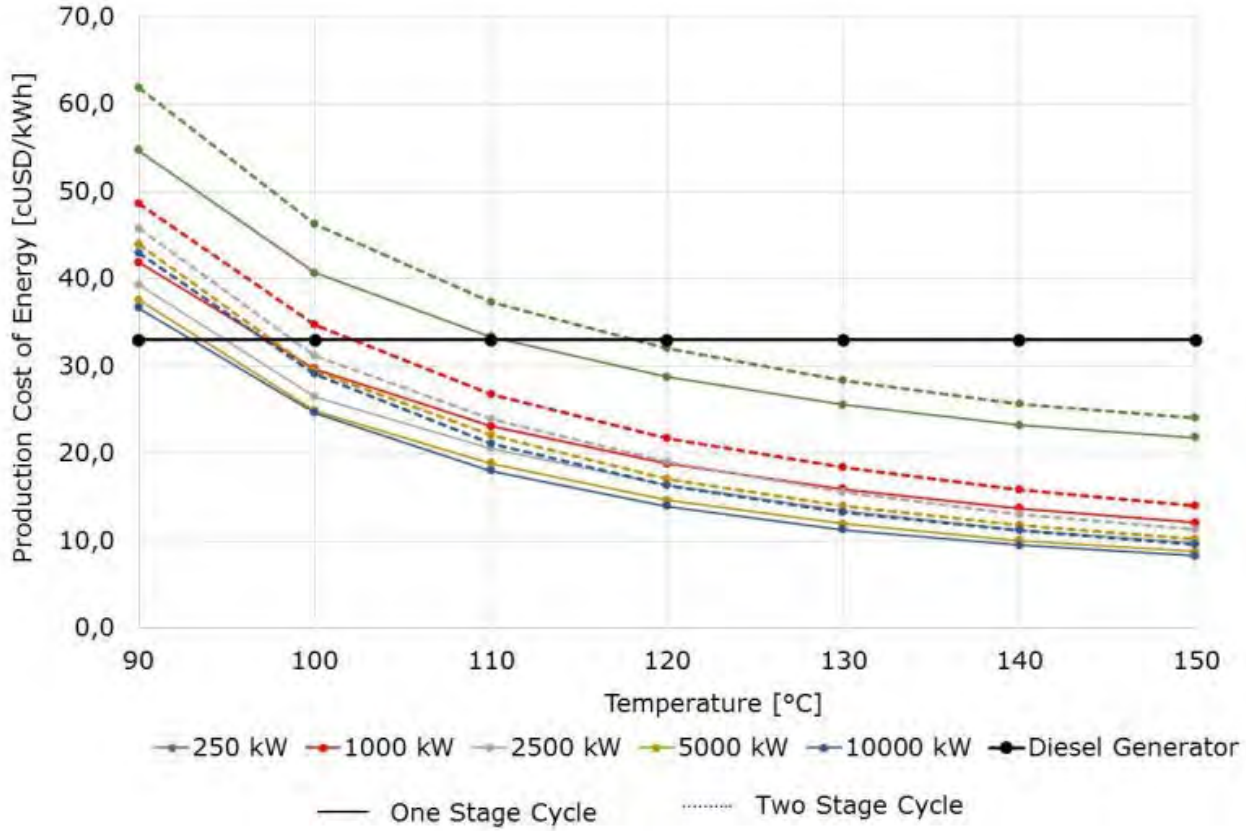
Yearly cost per employee

	$USD/year
Management staff total	40.000
Operators	24.000
Workers	12.000
Security	4.500

Financial cost assumptions

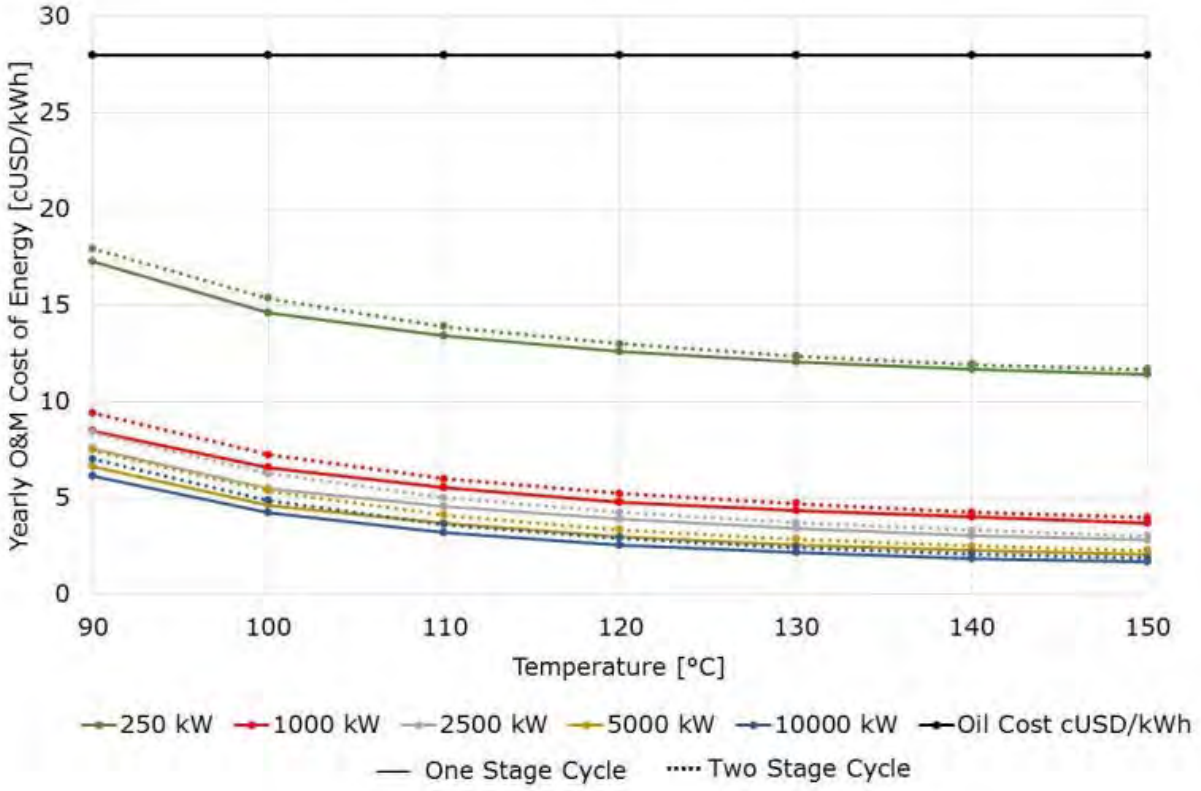
	Financial Cost I	**Financial Cost II**
Equity	30%	15%
Return on equity	**15%**	**15%**
Loan ratio	70%	85%
Depreciation rate	**25 years**	**25 years**
Total finance cost (Average Interest rate loan 3,71% and equity 15%)	7,1%	5,40%

Production Cost of Energy



Comparison of total production cost per net kWh produced in a binary power plant.

Operation and maintence cost comparison



O&M cost per net kWh in a binary plant and the corresponding operational cost of a diesel plant

Feasibility of the Projects

- Financial feasibilty of the project depends on
  - Investment cost
  - Operational cost (Low)
  - Parasitic load
    - Pumping of brine and reinjection
  - Accsess to market
  - Energy market electricity prices and demand

Project Implementation Schedule

Rough draft of a development plan for a binary plant

Year	1		2		3		4		5	
Licence for exploration	■									
Surface exploration		■	■	■						
Prefeasibility report				x						
Drilling and exploration (production) wells				■	■	■	■	■	■	
Environmental impact of the power plant				■	■					
Feasibility report					x					
Decision of contstruction					x					
Design and construction of the power plant					■	■	■	■	■	■
Operation										■

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