# NextGen Geothermal Power

## NGP makes $CO_2$ work!

Maturing Geothermal Energy for KSA

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# How to push renewables and carbon capture & storage to meet climate goals?

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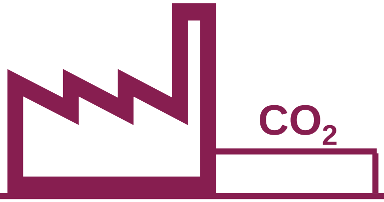


- the world is way off track in meeting the Paris Agreement climate goals
- wind & solar power has limited availability (not 24/7)
- geothermal power is fully dispatchable,
  but hydro-based applications are regionally restricted
- Carbon Capture & Storage (CCS) is essential to limit the global warming below 2 ºC but :
  No value add and recognized as „disposal“

# Combination of geothermal energy with carbon capture & storage

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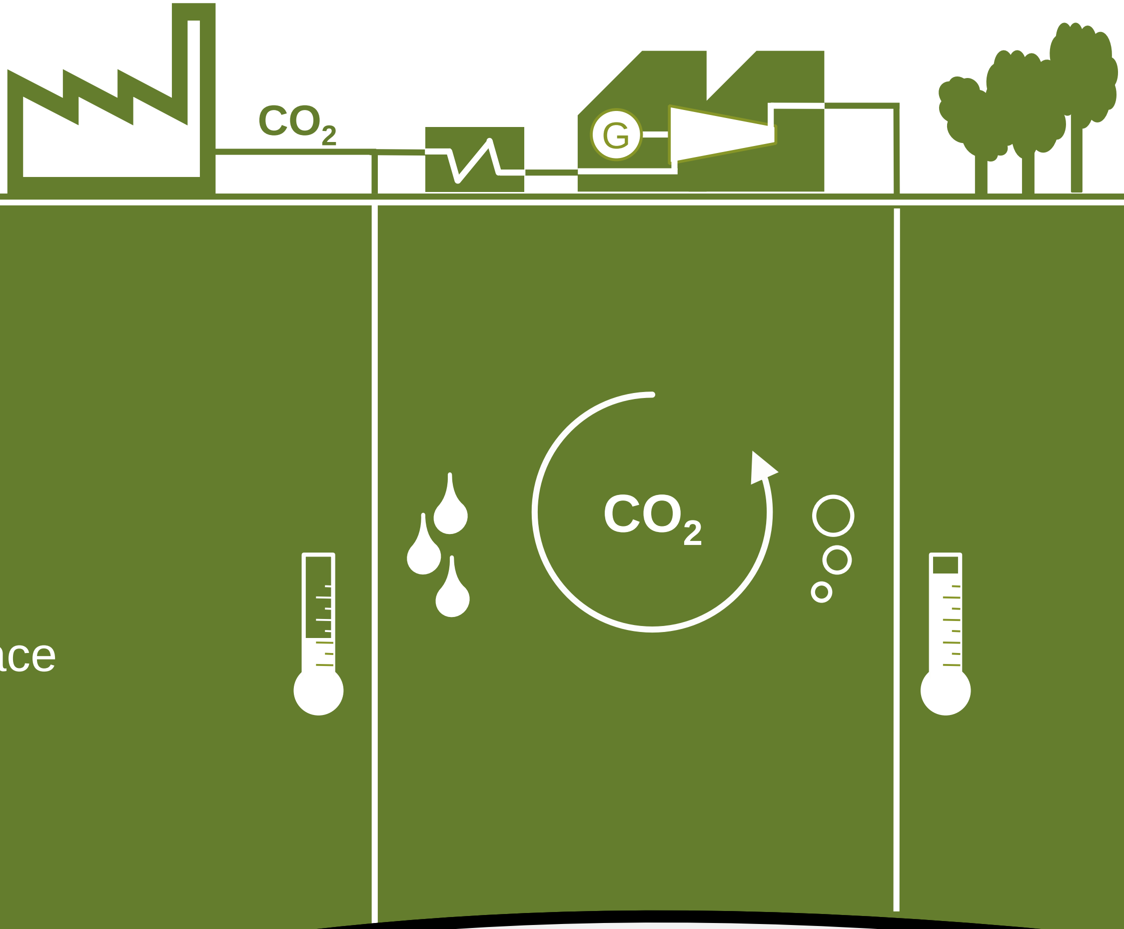


- NGP combines geothermal energy with CCS and transforms CCS to CCUS
- $CO_2$ is injected in sedimentary basins that host high-permeability reservoirs overlain by cap rocks
- heated by geothermal energy, CO2 flows to the surface and expands in a turbine to generate electricity
- NGP creates valuable power that makes CCS comfortable

# Advantages of CO2 as a geothermal working medium thermosyphon effect

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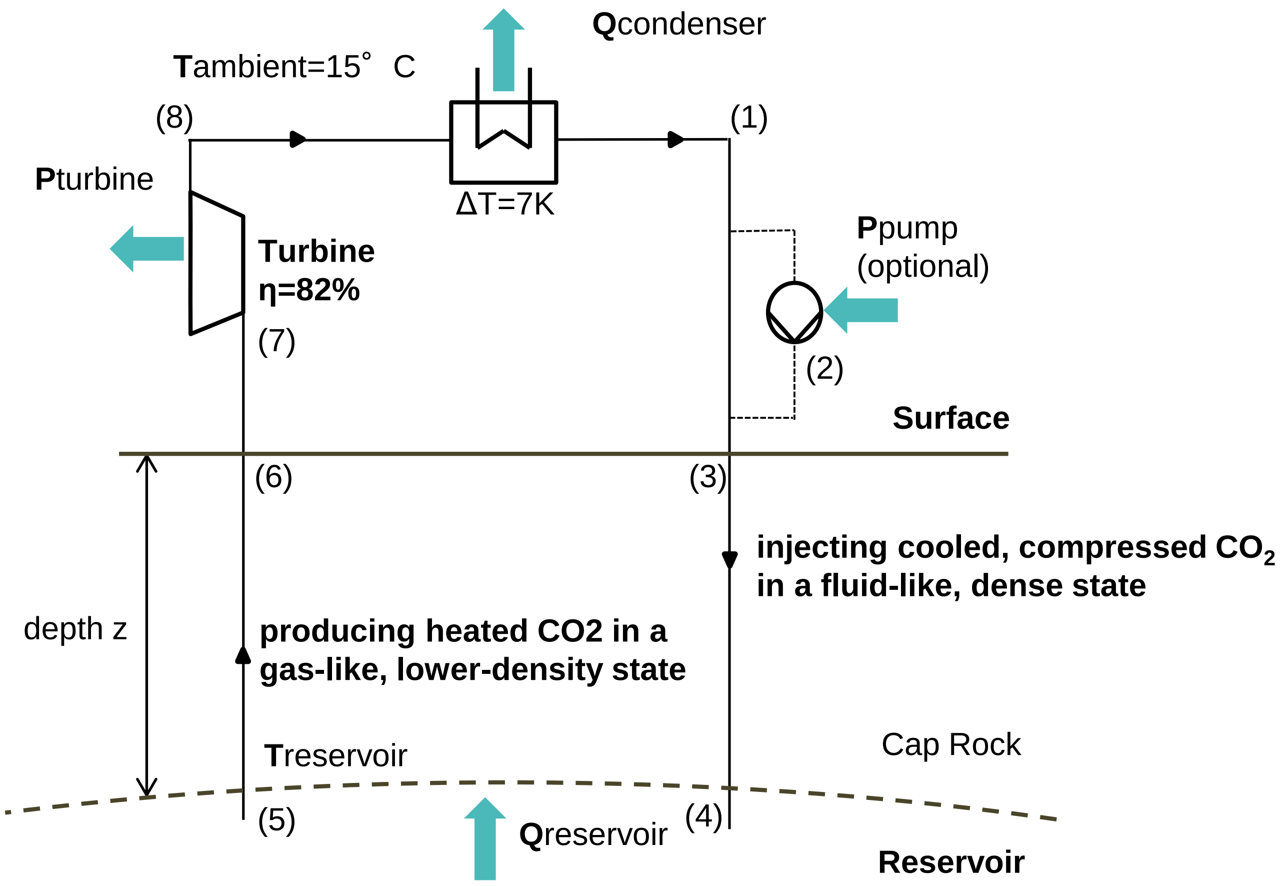
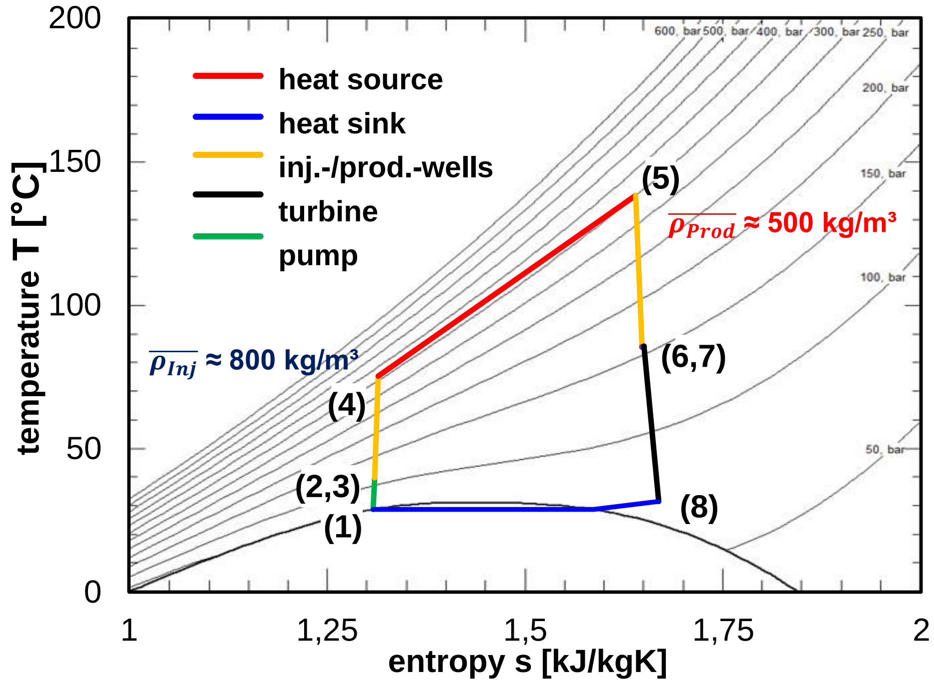



$$\Delta p_{reservoir} = \frac{\mu \cdot L}{\rho \cdot A} \cdot \frac{\dot{m}}{\kappa} = M \cdot \dot{m} \quad \text{(Darcy's law)}$$




- due to the geothermal heat supply, a density difference between injection and production arises
- the pressure gradient along the wells is different in size and leads to a difference between the well heads

$$\Delta p_{TS} = \left(\bar{\rho}_{Inj} - \bar{\rho}_{Prod}\right) \cdot g \cdot \Delta z$$

- driven by the thermosyphon, pumping work is reduced

# Assessment of NGP Systems

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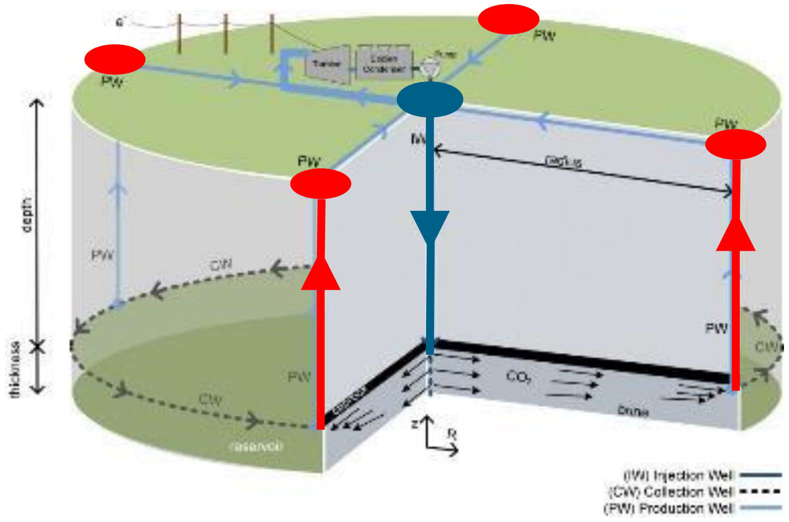
## Geologic conditions – Base Case

| | |
|---|---|
| Coordination number | 1 (5-spot-system) |
| Depth | 2500 m |
| Well diameter | 0,41 m |
| Permeability-thickness product (κh) | 15.000 mD·m |
| Temp. gradient | 35 K/km |



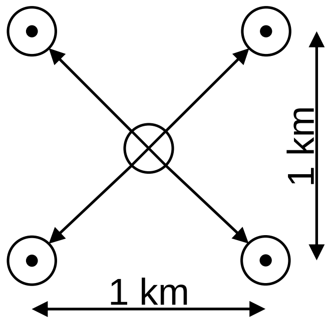

Saar, Adams; Subsurface Energy Storage with $CO_2$; 2018

## Power Cycle Variants

| **direct \| $sCO_2$** | | **indirect \| Brine - Isobutane** | |
|---|---|---|---|
| Thermosiphon only | with supplemental pumping | single pressure | dual pressure |

## Base Case well pattern

⊙ production well
⊗ injection well



# Calculation results for NGP base case

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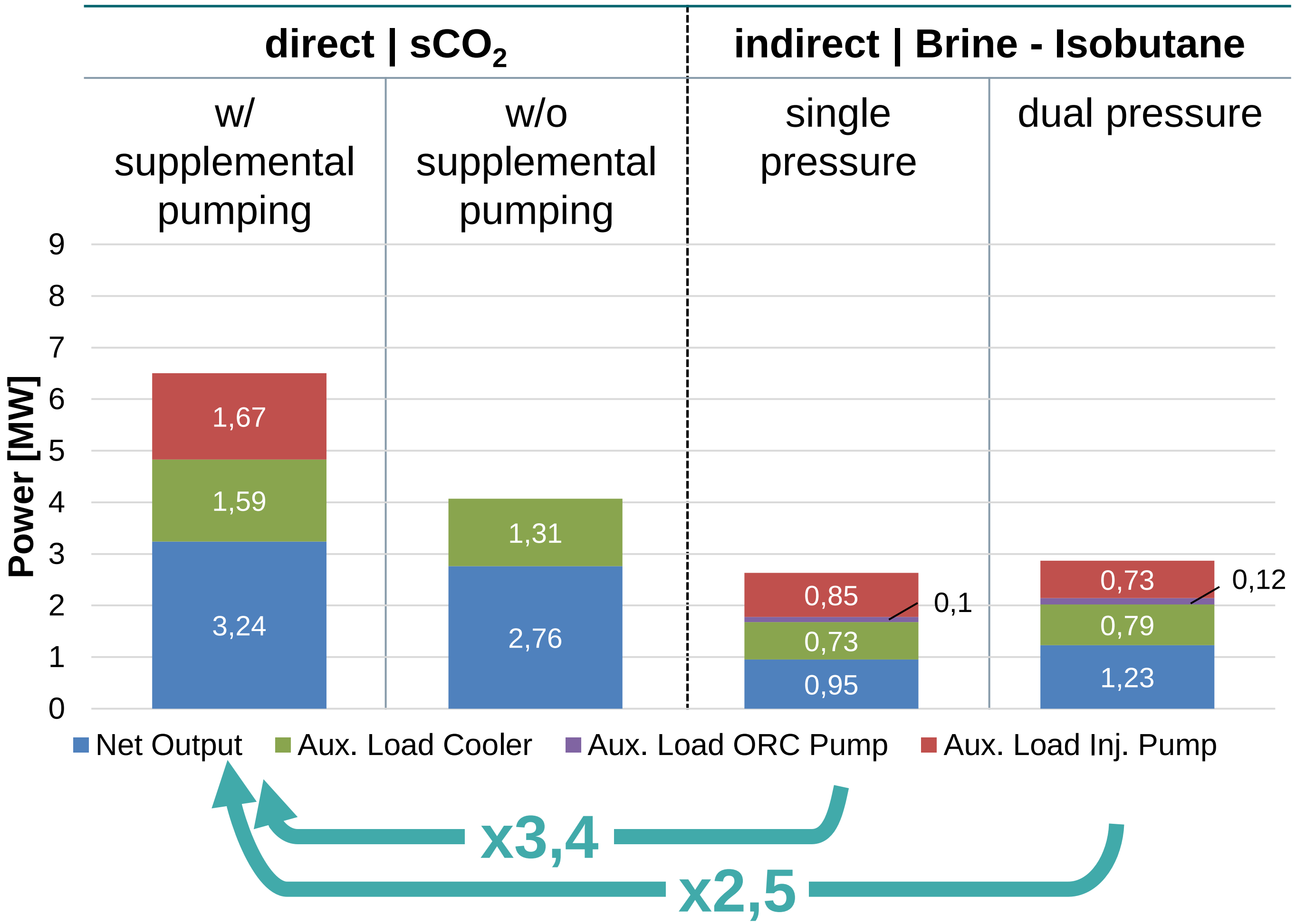
## Power Cycle Variants




**Reservoir conditions:**
base case

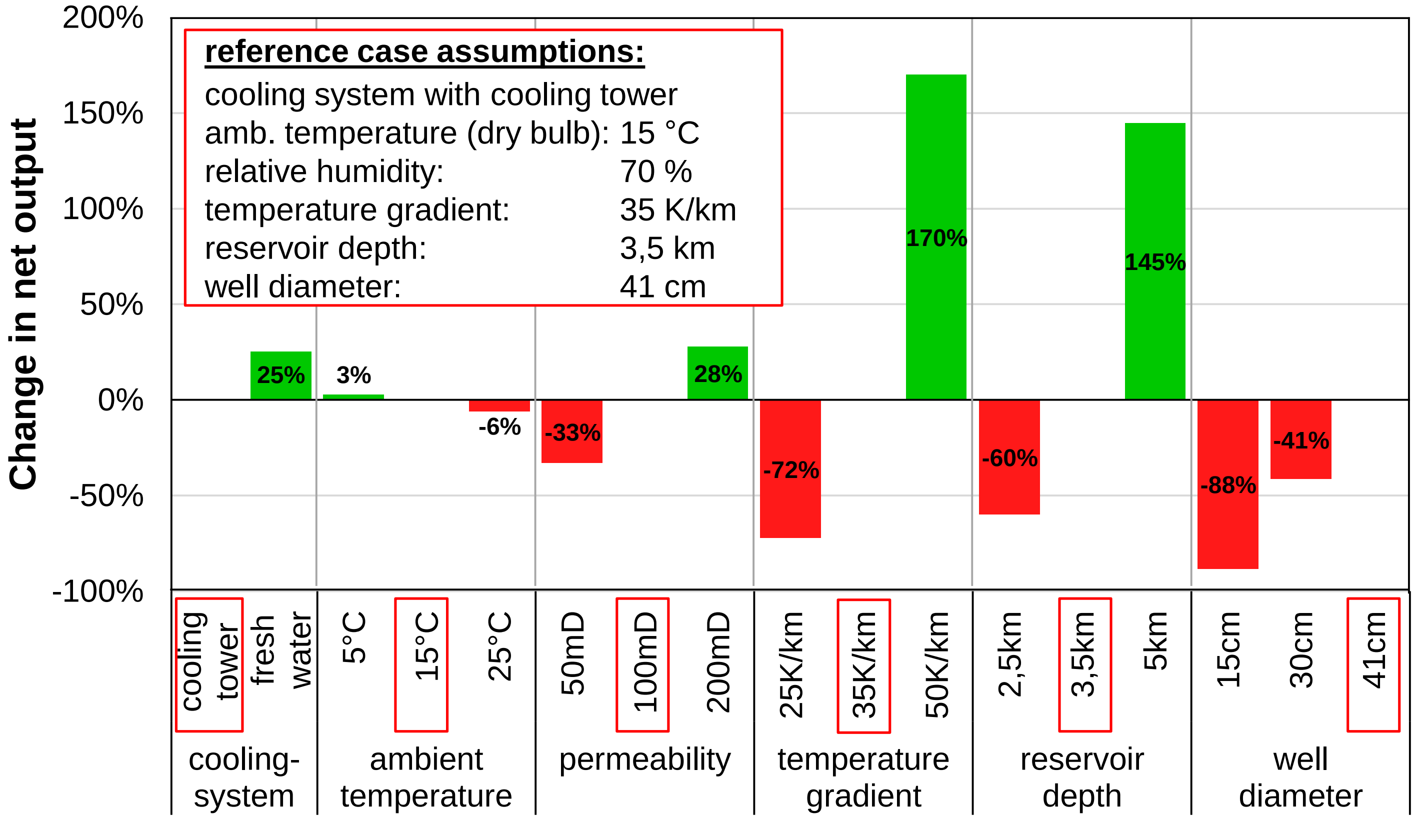
| | |
|---|---|
| Depth | 2500 m |
| Temp. gradient | 35 K/km |
| Permeability-thickness product* (κh) | 15.000 mD·m |
| injection-/ production well diameter | 0,41 m |

**Assumptions:**

| | |
|---|---|
| $T_{ambient}$ | 15°C |
| ΔT-Pinch Condenser | 7 K |
| ΔT-Pinch HX | 5 K |

**2,5-3,4 times higher net output**
compared to brine based systems at base case

# Effects of geologic and ambient boundary conditions on net output




- For fresh water cooling, net power output increases due to a lower temperature of heat rejection and the elimination of auxiliary power for a mechanical draft cooling tower.
- The increase at lower ambient temperature is smaller, as the reservoir temperature also lowers.
- Regarding geological conditions, **power rises with high permeability, temperature gradient and depth**
- Large wells reduce pressure losses, the diameter must be determined depending on the permeability

# Calculation results for NGP base case optimized heat rejection

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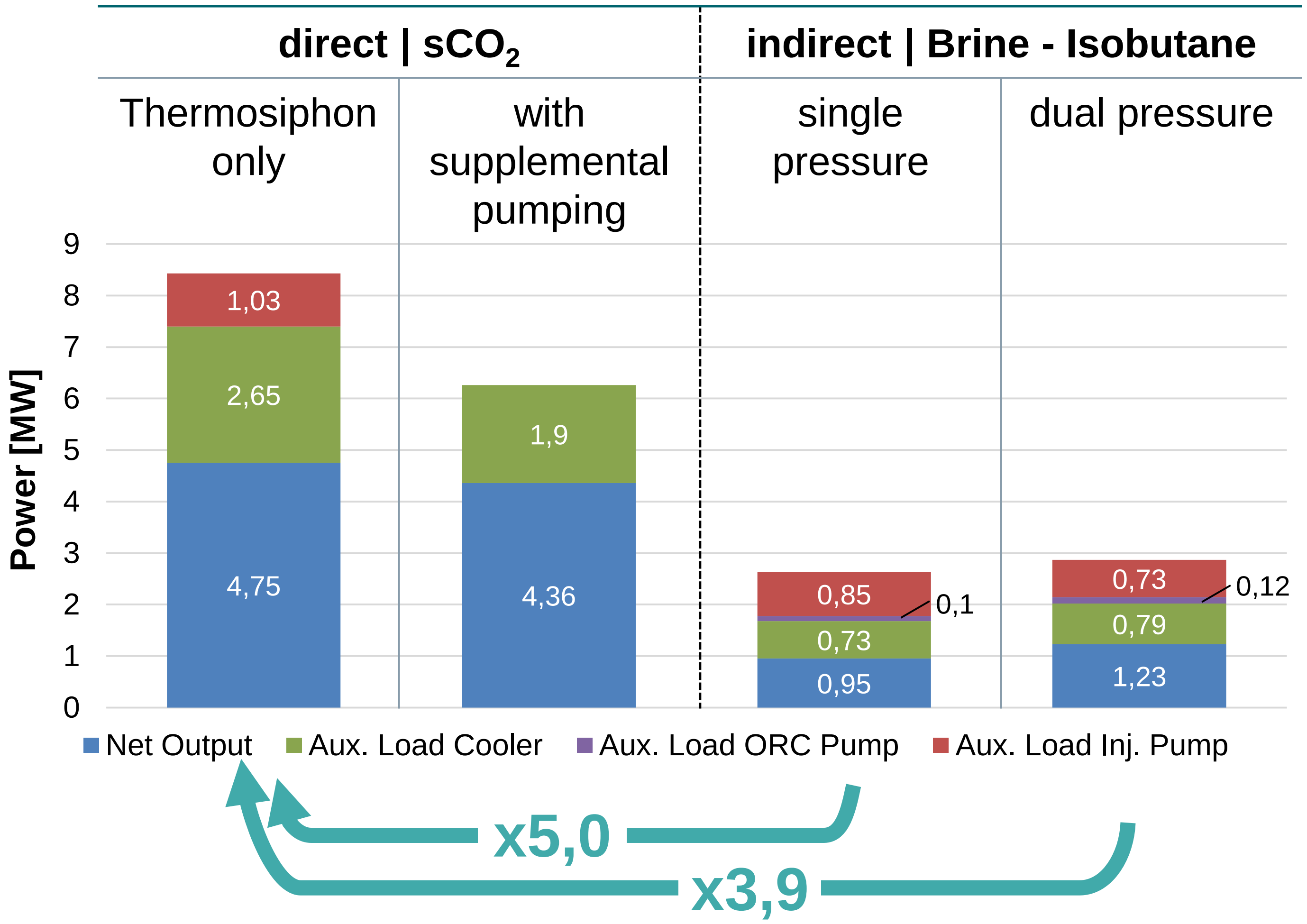
## Power Cycle Variants




**Reservoir conditions:**
base case

| | |
|---|---|
| Depth | 2500 m |
| Temp. gradient | 35 K/km |
| Permeability-thickness product* (κh) | 15.000 mD·m |
| injection-/ production well diameter | 0,41 m |

**Assumptions:**

| | |
|---|---|
| $T_{ambient}$ | 15°C |
| ΔT-Pinch Condenser | 7 K |
| ΔT-Pinch HX | 5 K |

**3,9-5,0 times higher net output**
compared to brine based systems at base case

# scaled geothermal cycle – wellfield pattern

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**Configuration Number N:**
equals the number of five-spot pattern on a side

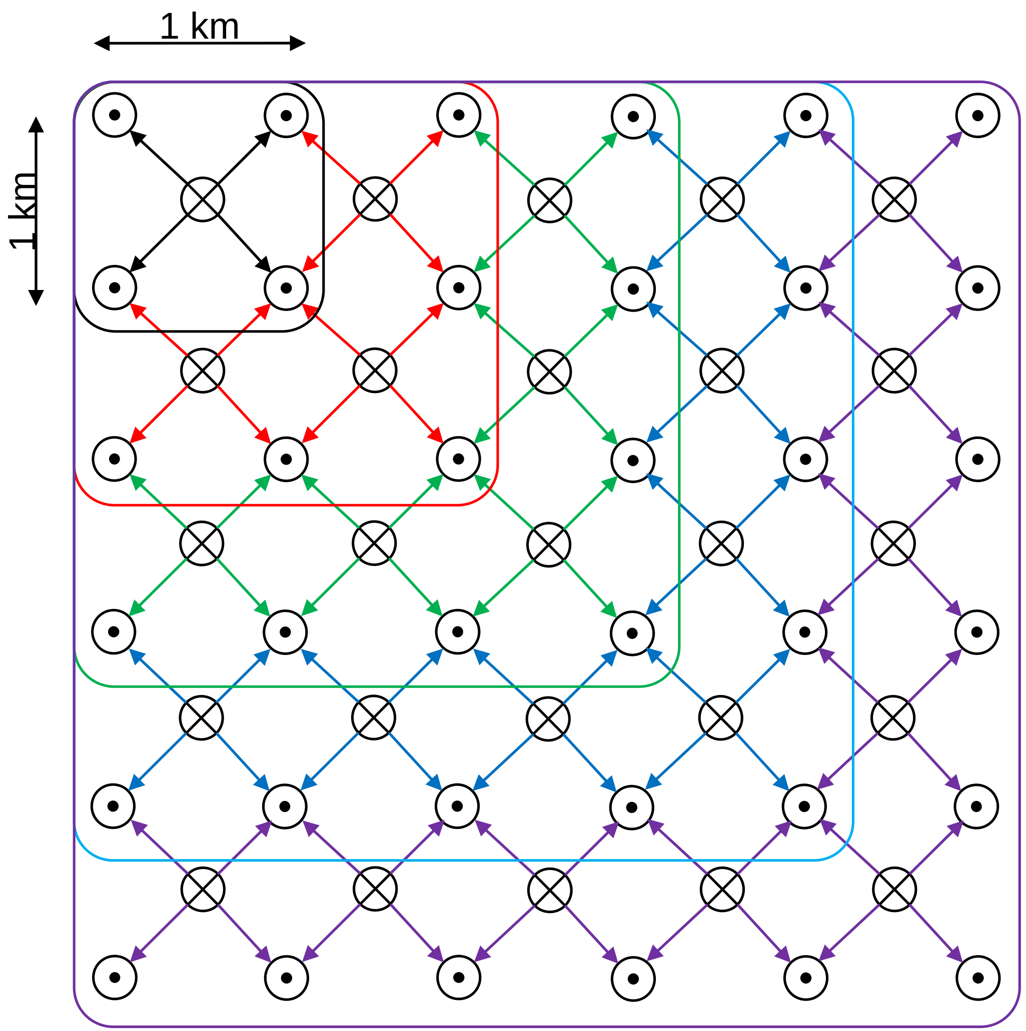
**N = 1 (1x1km)**
**(five-spot pattern)**

**N = 2 (2x2km)**

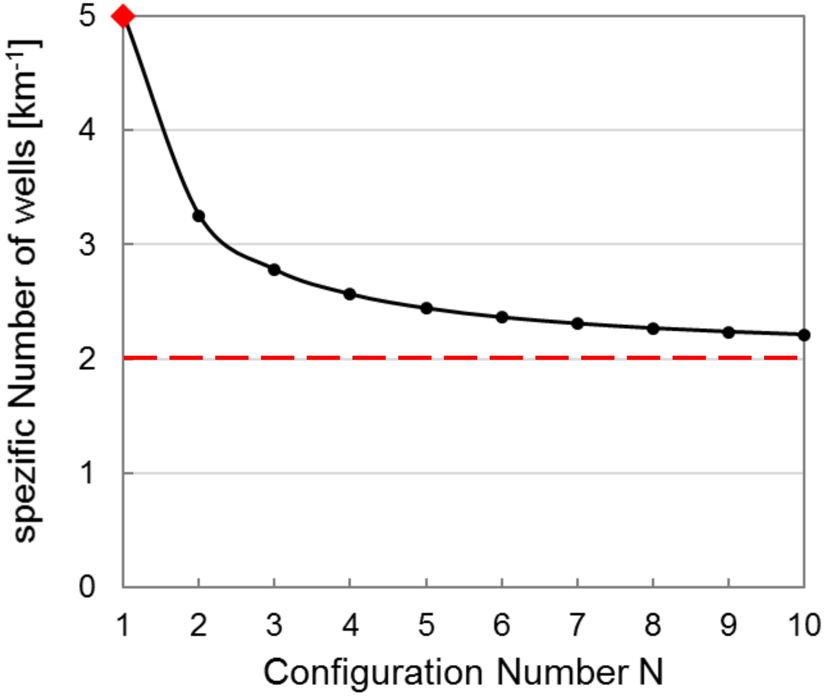
**N = 3**

**N = 4**

**N = 5**




⊙ production well
⊗ injection well




**significant savings by scaling from N = 1 to N = 2**

almost no further savings when scaling larger than N = 5

# identifing suitable locations for geothermal power plants

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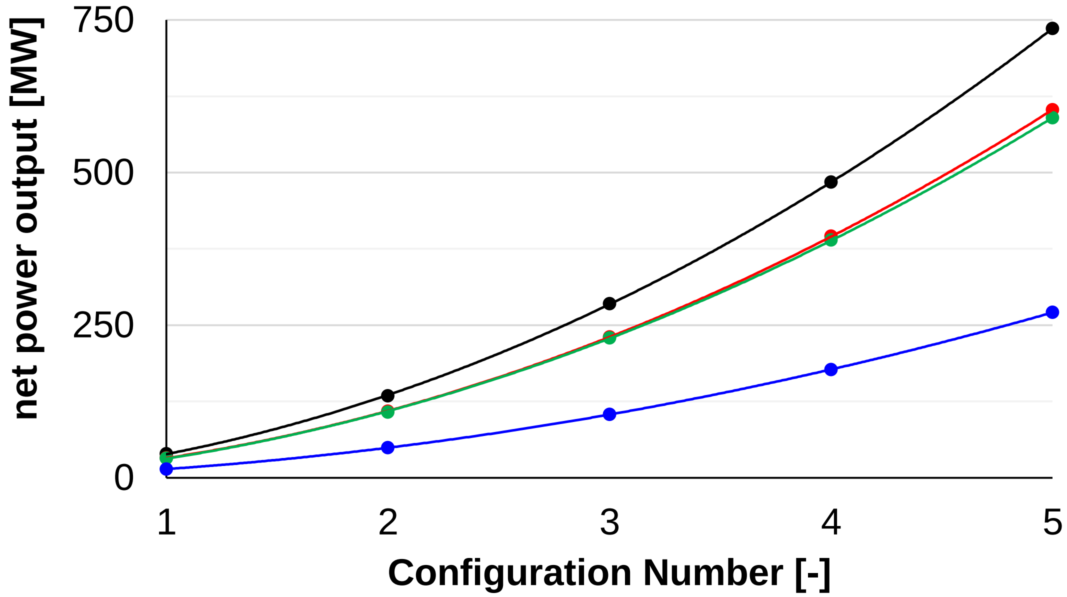
1 **political framework conditions**
Target region: North America (USA, Canada)
12 of 18 large-scale CCS projects in operation in this region

2 **reservoir analysis**
deep reservoirs, large temp. gradients, high permeability

3 **heat rejection conditions**

4 **coverage of CO2 demand**
Proximity to large, stationary CO2 emitters

5 **population and building density**




| **Reservoir 1** | |
|---|---|
| depth: | 5 km |
| temp.gradient: | 35 K/km |
| permeability: | 200 mD |
| thickness: | 100 m |
| amb. temp.: | 10 ºC |
| direct cooling | |

| **Reservoir 2** | |
|---|---|
| depth: | 3,5 km |
| temp.gradient: | 50 K/km |
| permeability: | 100 mD |
| thickness: | 100 m |
| amb. temp.: | 10 ºC |
| cooling tower | |

| **Reservoir 3** | |
|---|---|
| depth: | 5 km |
| temp.gradient: | 35 K/km |
| permeability: | 200 mD |
| thickness: | 100 m |
| amb. temp.: | 15 ºC |
| cooling tower | |

| **Reservoir 4** | |
|---|---|
| depth: | 3,5 km |
| temp.gradient: | 35 K/km |
| permeability: | 100 mD |
| thickness: | 200 m |
| amb. temp.: | 5 ºC |
| cooling tower | |

# Turbine blade path design

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speed:
60Hz → 30Hz

optimized
geometry

**1 first approach**

Siemens intermediate-pressure turbine I50-V4-M2A-60Hz

→ unfavorable pressure-to-enthalpy drop ratio

**2 half-speed turbine**

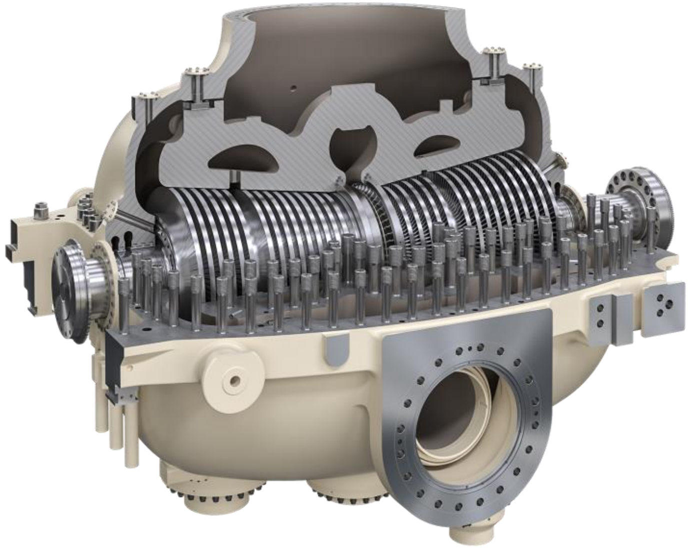
with same geometry

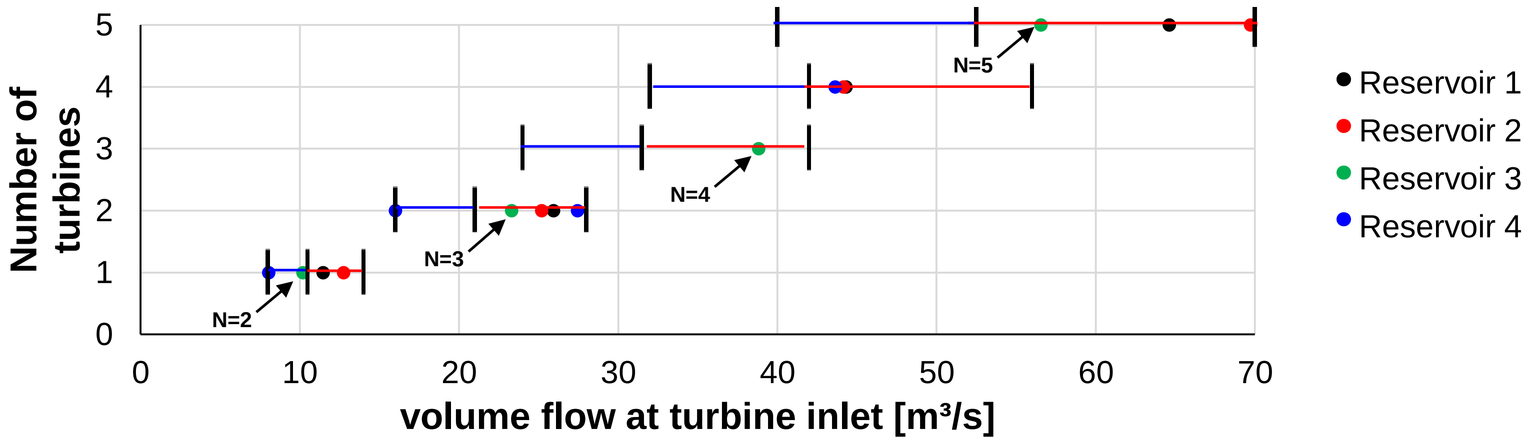
→ increased blading efficiency, lowered root stresses

**3 CO2 turbine**

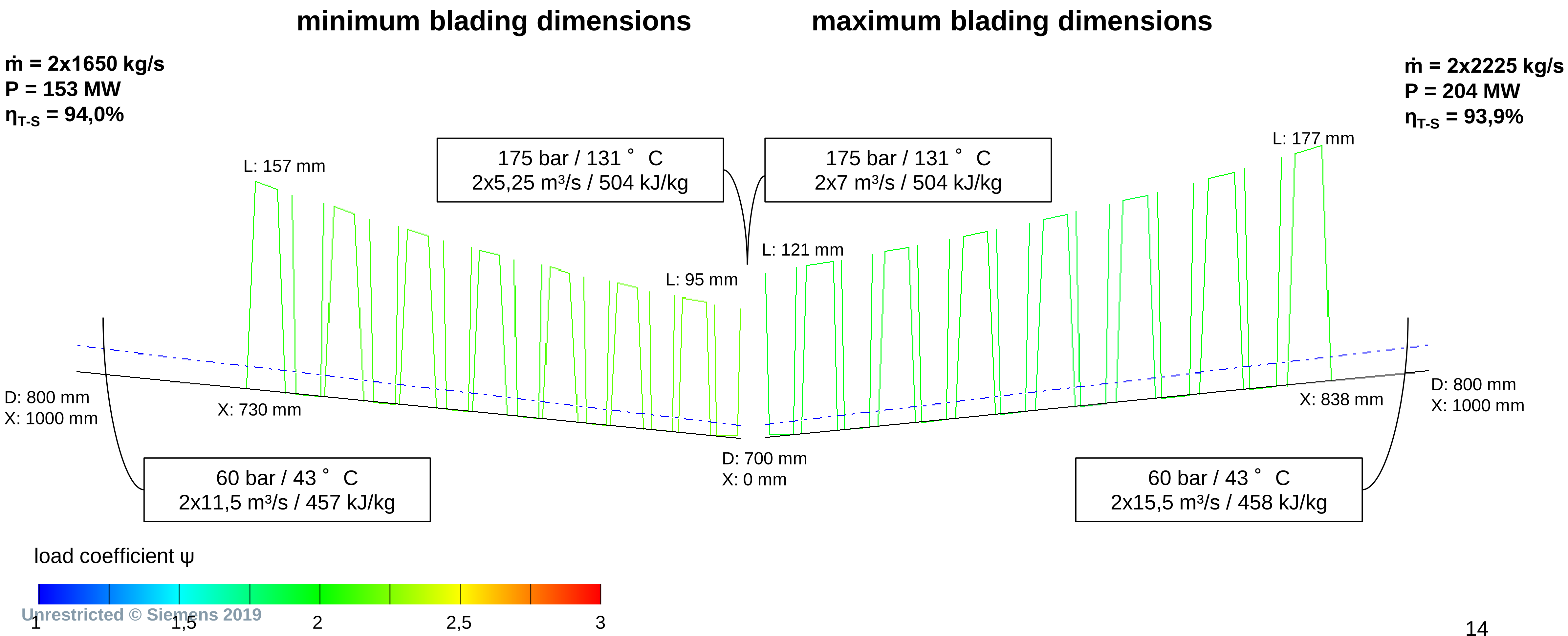
geometry adjusted acc. to:
shaft-to-tip ratio
groove-to-shaft ratio

→ two compact designs with high efficiency and low root stresses





# Turbine blade path design – 150-200 MW class – 30 Hz



# Assessment of Capital expenditure and LCOE

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## Capital expenditure

- Surface power plant
- Surface Piping
- Well field / Well field development

Siemens AG — EPA // GETEM *)

## Lazard's Analysis

- Corporate tax rate
- Interest rates
- Cost escalation
- Depreciation schedule
- capital structure

## Levelized Cost of Electricity (LCOE)

**Surface Power Plant** → turbine train, gas cooler, pump, cooling tower, civil & small systems, electrics, engineering, project management, logistics, erection, commissioning

**Surface Piping** → pipelines between wells and surface power plant incl. raw material, fabrication, transportation, installation, engineering

**Well field** → wells incl. drilling, corrosion protection, engineering, project management

**Well field development** → development incl. (well) monitoring equipment, stimulation, engineering, project management

Cash Flow: Revenue, Cost

$$NPV = \sum_{t=1}^{n} \frac{\overbrace{LCOE \cdot M_{t,el}}^{\text{Revenue}} - \overbrace{(I_t + A_t)}^{\text{Cost}}}{\underbrace{(1+i)^t}_{\text{weighted average cost of capital}}} \overset{!}{=} 0$$

NPV: net present value, $M_{t,el}$: electricity produced in year t, $I_t$: capital expenditures in year t, $A_t$: annual expenses in year t, n: operation lifetime, i: interest rate





*) EPA: United States Environmental Protection Agency, 2008
GETEM: Geothermal Electricity Technology Evaluation Model

# Capital Cost - Comparison of technologies, locations and scaling

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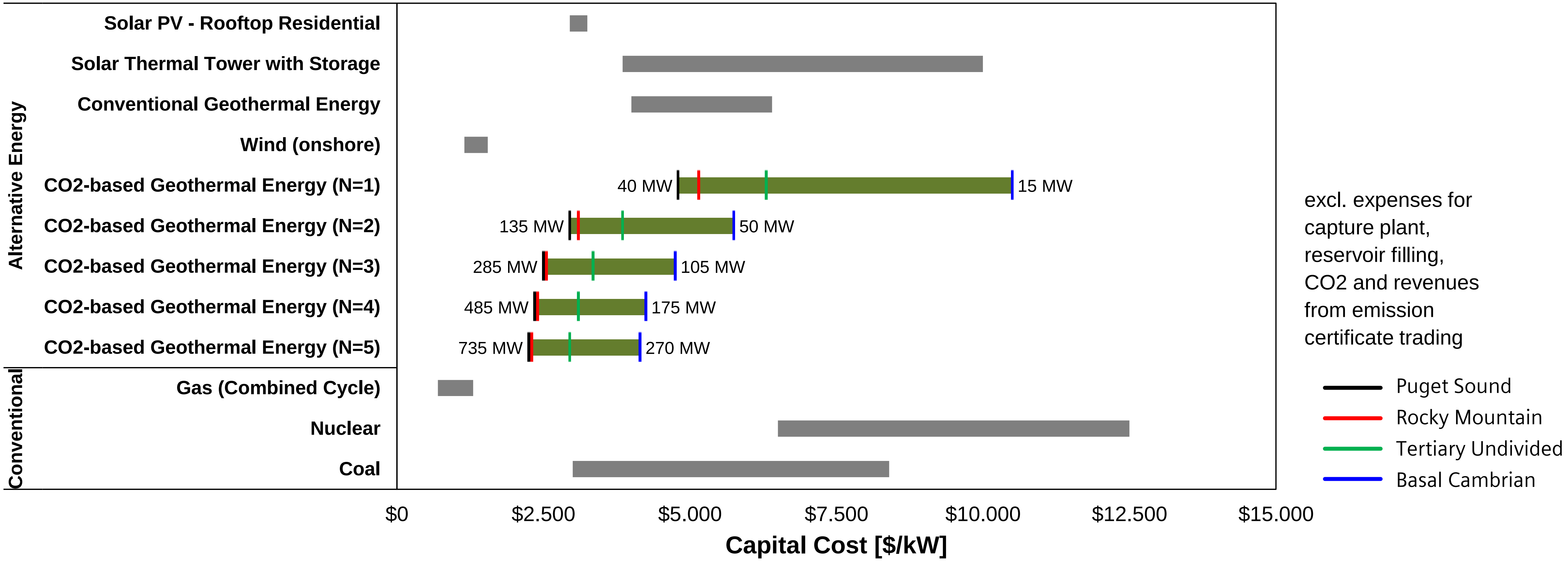


- **strong dependence of capital costs on size and ambient conditions of the plant.**
- **absolute values are in the range of other baseload-capable and carbon-neutral plants (*).**

# LCOE - Comparison of technologies, locations and scaling

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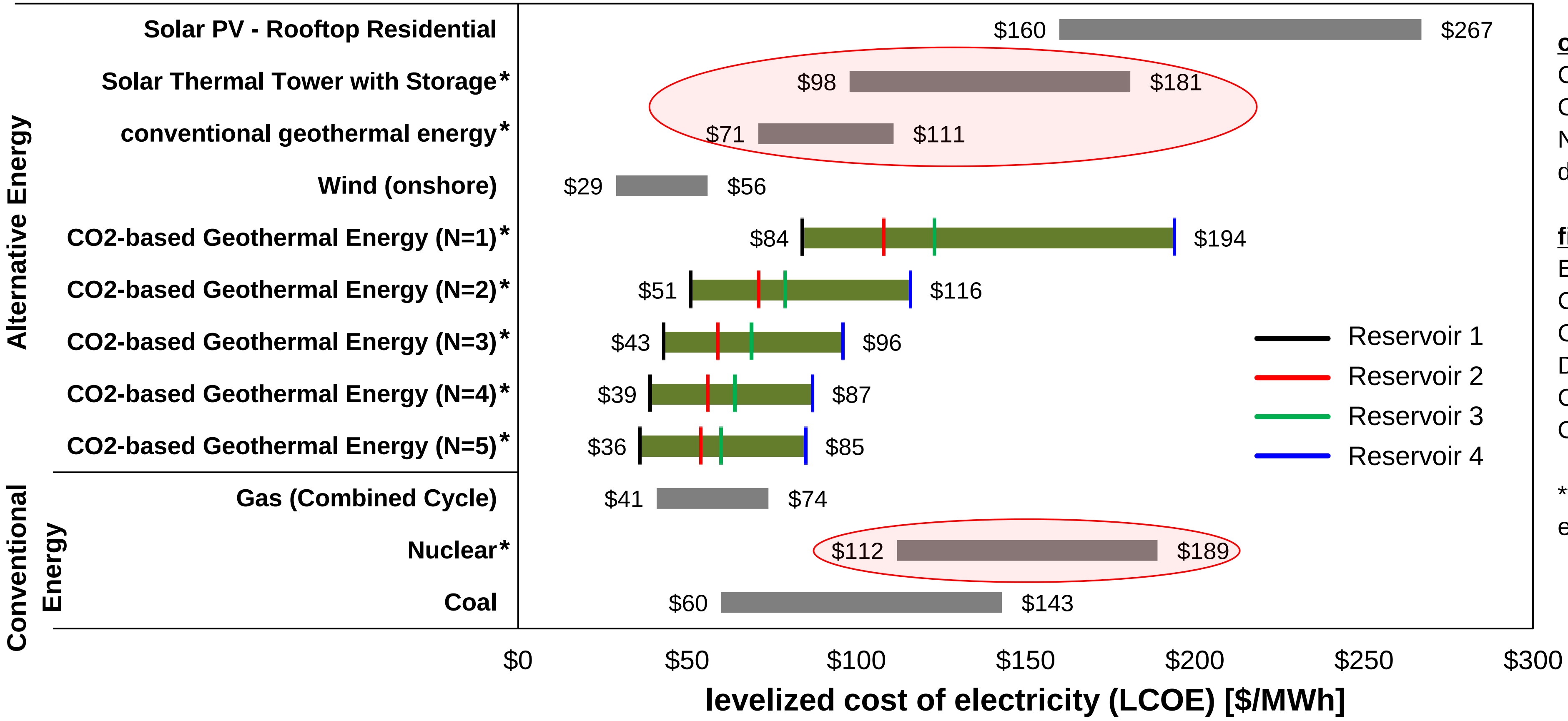


**operating conditions: **)**
Capacity factor: 90 %
Operation lifetime: 25 years
No significant thermal decline during lifetime

**financial boundaries:**
Equity – Debt: 40 % - 60 %
Cost of Equity: 12 %
Cost of Debt: 8 %
Debt Payback Period: 25 years
Combined Tax Rate: 40 %
O&M escalation rate: 2,25 %/year

**): for sCO2-based geothermal energy

- **wide spread of LCOE shows the importance of a well targeted selection of the location**
- **results show the competitiveness of CO2-based geothermal energy, especially when scaled**

# Conclusion and Outlook

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- verification of performance benefits of direct $CO_2$ systems
- increased power output of NGP plants by optimized heat rejection and scaling of the well pattern
- significant reduction of LCOE
- need for a well-targeted selection of plant site due to strongly fluctuating site-specific power output
- competitive with other fully dispatchable and emission-free power plants

→ proof of concept / realization of NGP demonstrator
→ verification of the overall business case
→ realization of commercial projects

# Second Life of Combine Cycle Power Plants

## Life Cycle Scheme of Combine Cycle Power Plants

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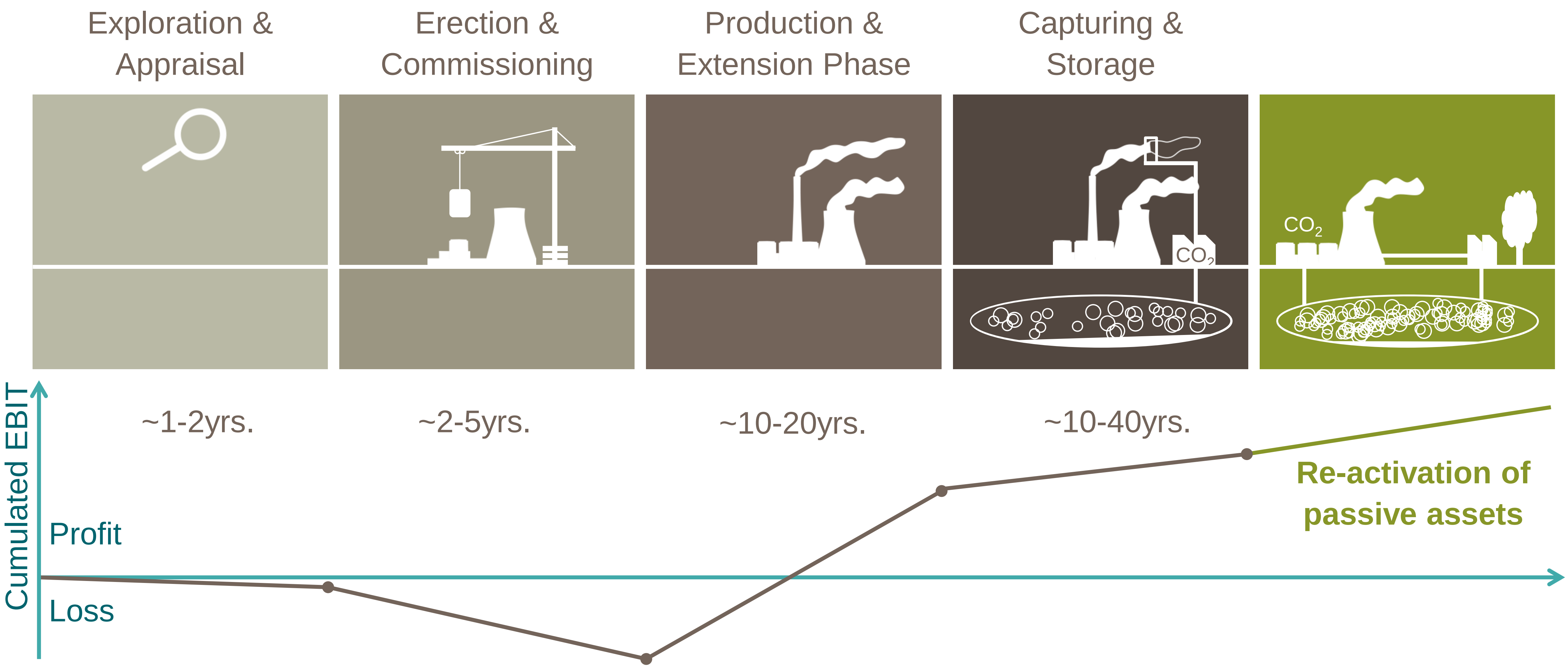

# NGP makes CCPP emmission free

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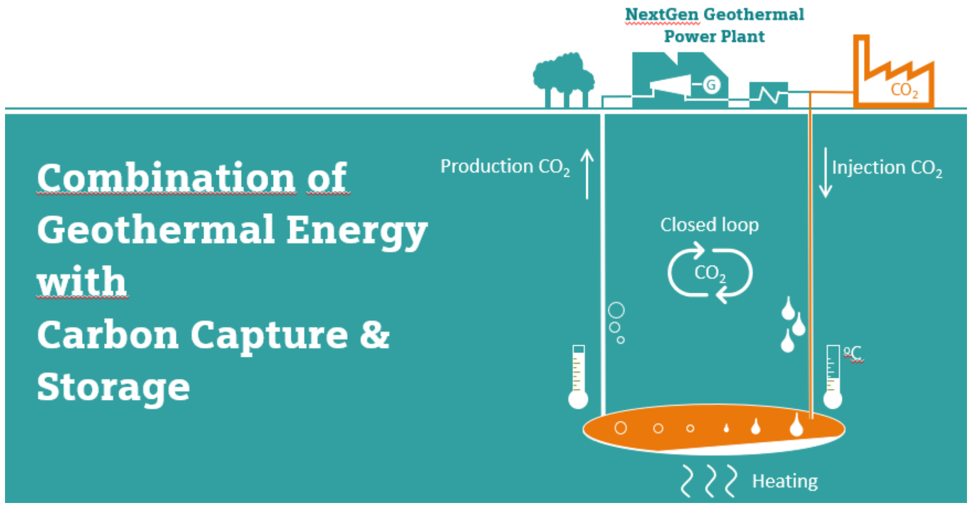


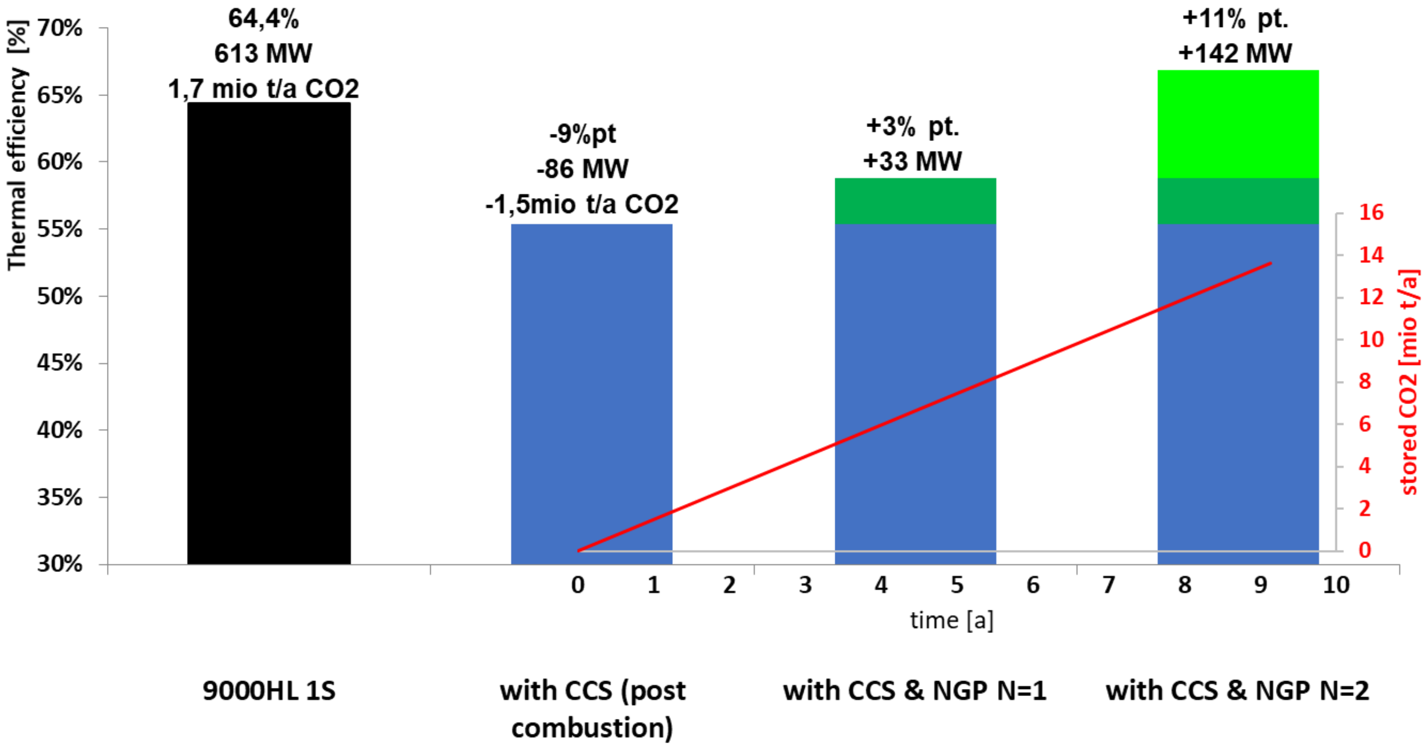


**Combination of CCPP with CCS and NGP provides emission free power generation at highest efficiency level**

Example:
CCPP with SGT 9000 HL 1S
Reservoir data acc. to Rocky Mointain Conditions, i.e 5000 m, kxA= 10000 mDxm, 50 °C /km

# Next Level Geothermal Power (NLGP)

## Life Cycle Scheme of Oil & Gas Fields & Power Plants

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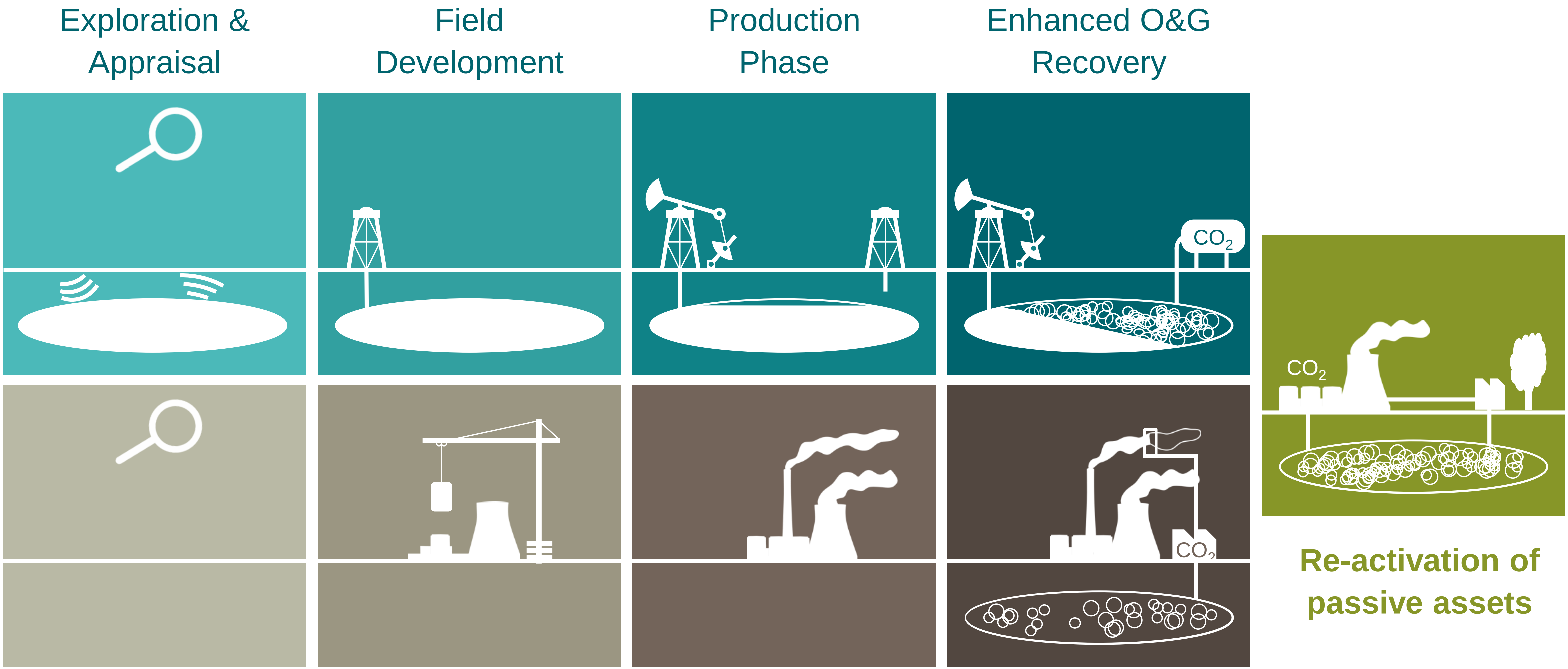

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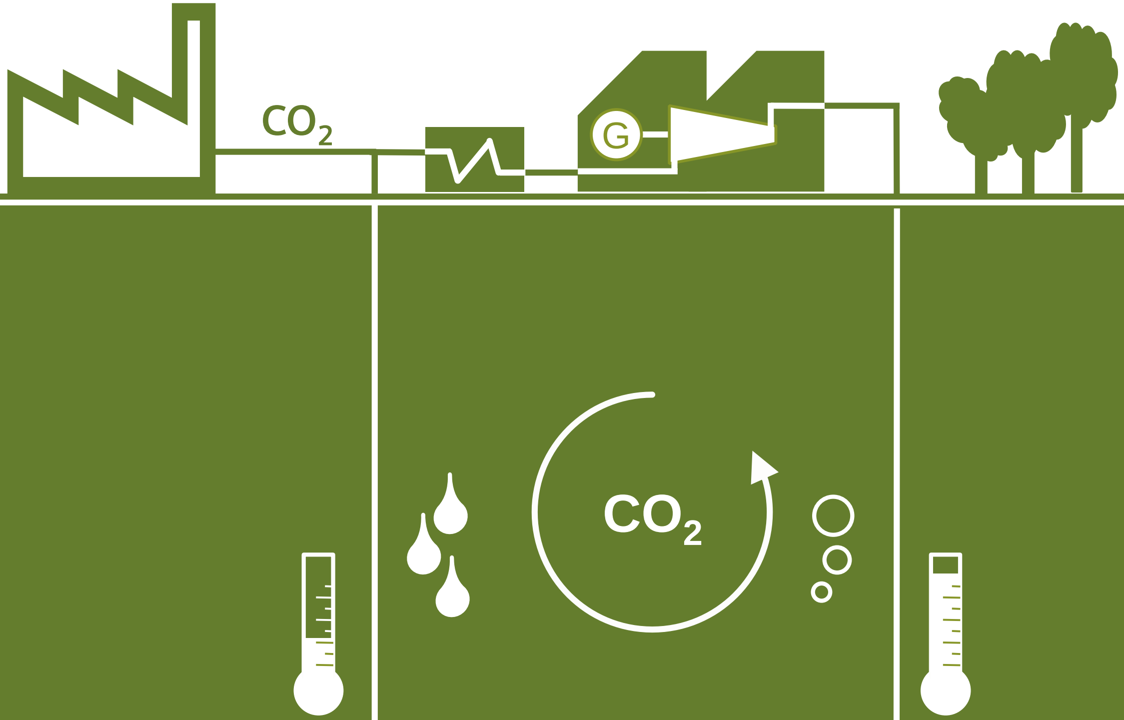


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