http://www.spiegel.de/fotostrecke/vulkan-tungurahua-nachts-wenn-der-berg-brennt-fotostrecke-135192-8.html

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Energy from the Earth: Potential & LCA of electricity generation with deep geothermal plants

Swiss Life Cycle Discussion Forum 68, 16.04.2018

Outline

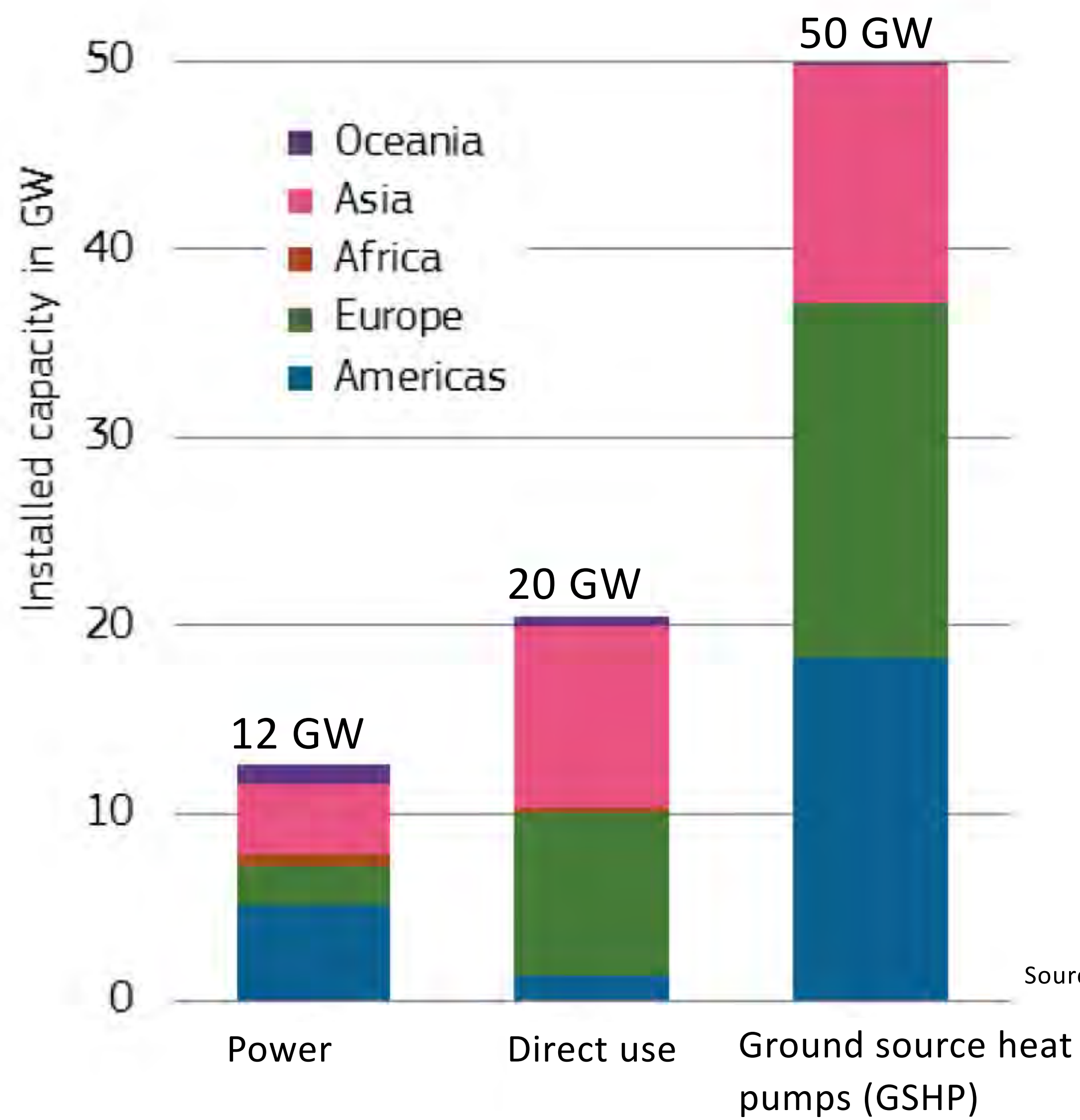
1) Potential: Status quo & projections

2) Geothermal power plant types

3) Environmental impacts of power production

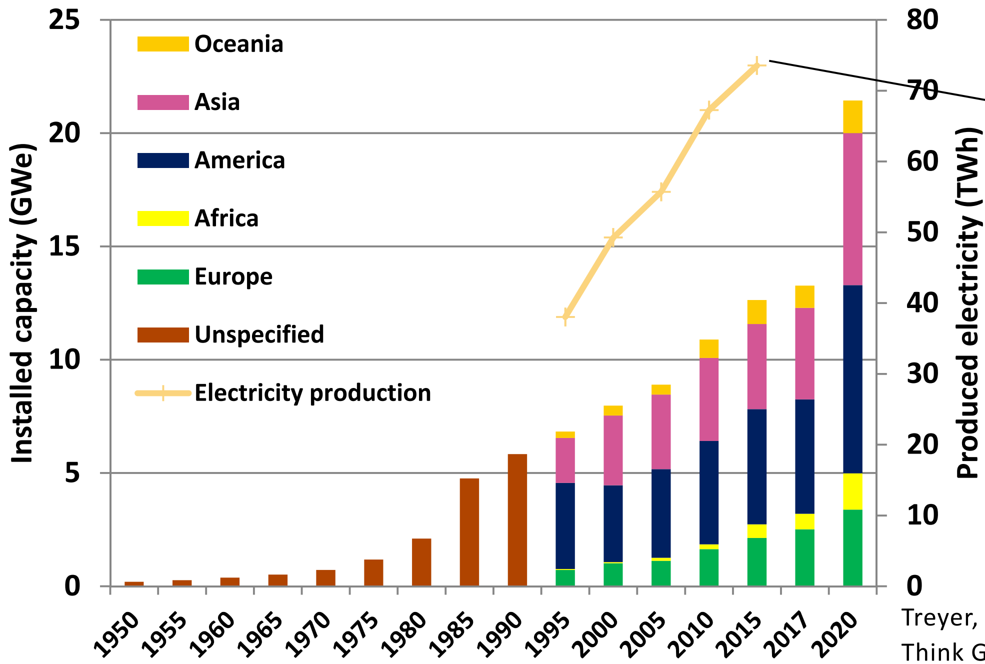
4) Take home messages

Exploitation of geothermal energy (2015)



Source: Sigfusson&Uihlein 2015

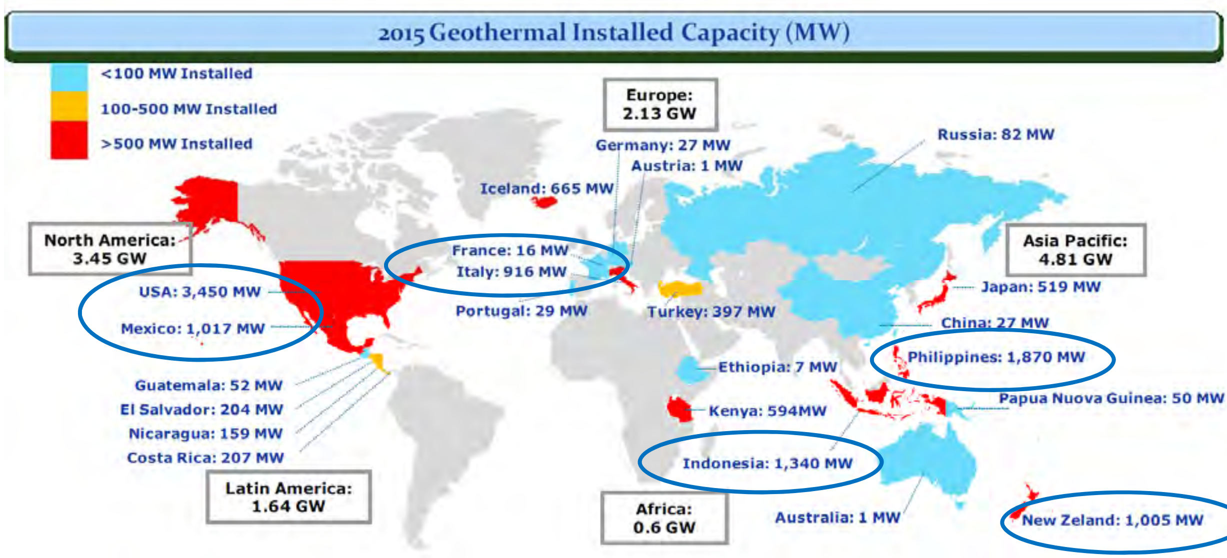
Power generation from geothermal installations



2015: 0.33% of the world's total electricity production

2050:
- 140 GWe (8.3%) (Bertani 2015)
- 1400 TWh (3.5%) (IEA 2011)

Treyer, K. in Bauer, C. et al. 2017
Think Geo Energy 2017



13 GWh in 24 countries, number could double until 2050

Bertani 2015

Bracket opened

(

Geothermal power: advantages + main barriers/R&D

- Base-load generation; world average capacity factor: 70-80%
- Seasonal variation only in the case of air-cooled binary plants
- Load balancing potentially possible
- Centralised or distributed
- Electricity / heat only or combined heat and power plants

Main barriers:

- Technical & economic
- Policy framework: regulations, market facilitations, R&D support

Main R&D:

- Accelerating resource assessment
- Development of more competitive drilling technology
- Improving EGS technology
- Management of health, safety and environmental concerns

Renewable?

- Constant terrestrial heat flow to surface
- Sustainability depends on heat extraction rate
- Heat removed from the resource needs to be replaced on a similar time scale

Bracket closed

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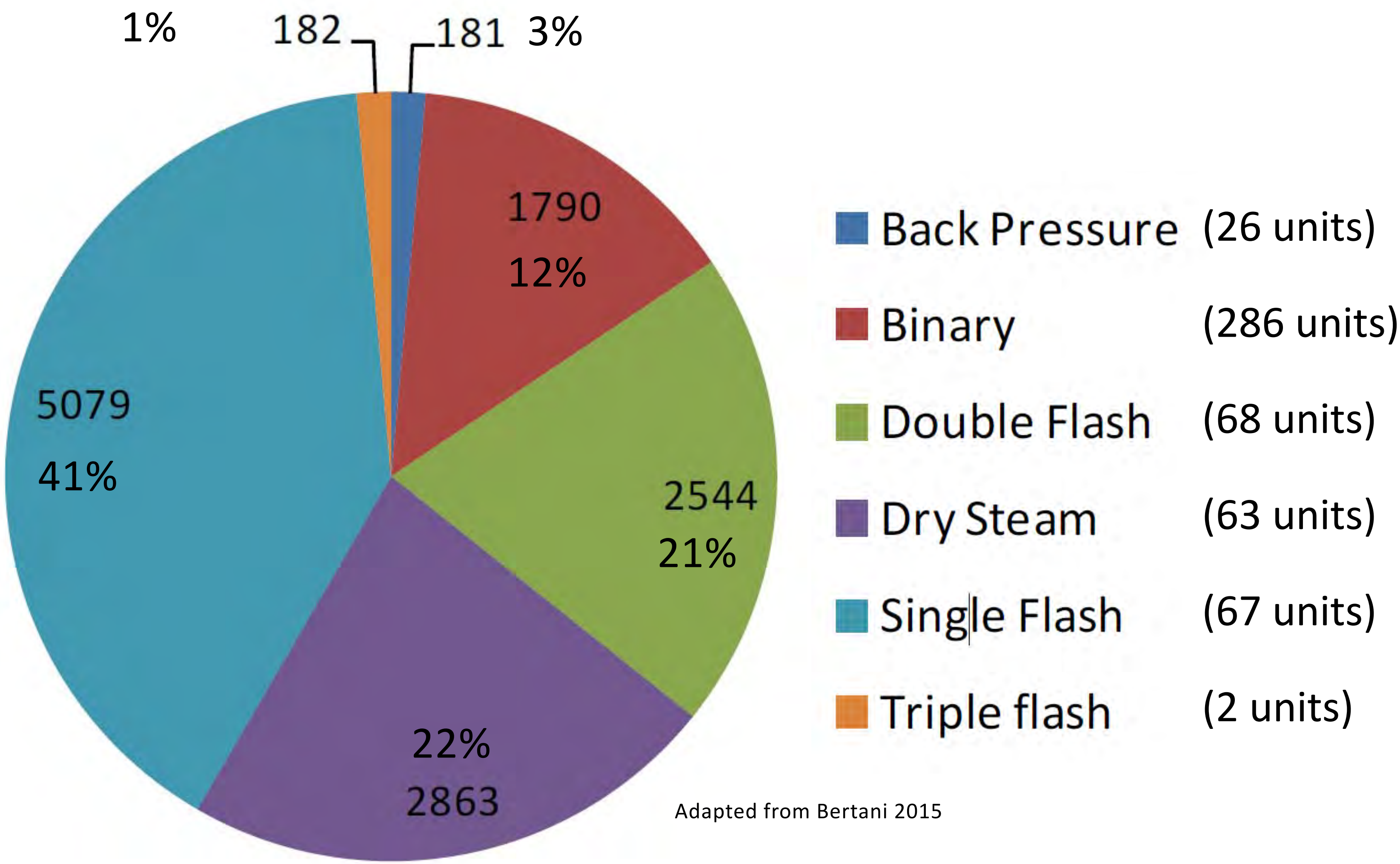
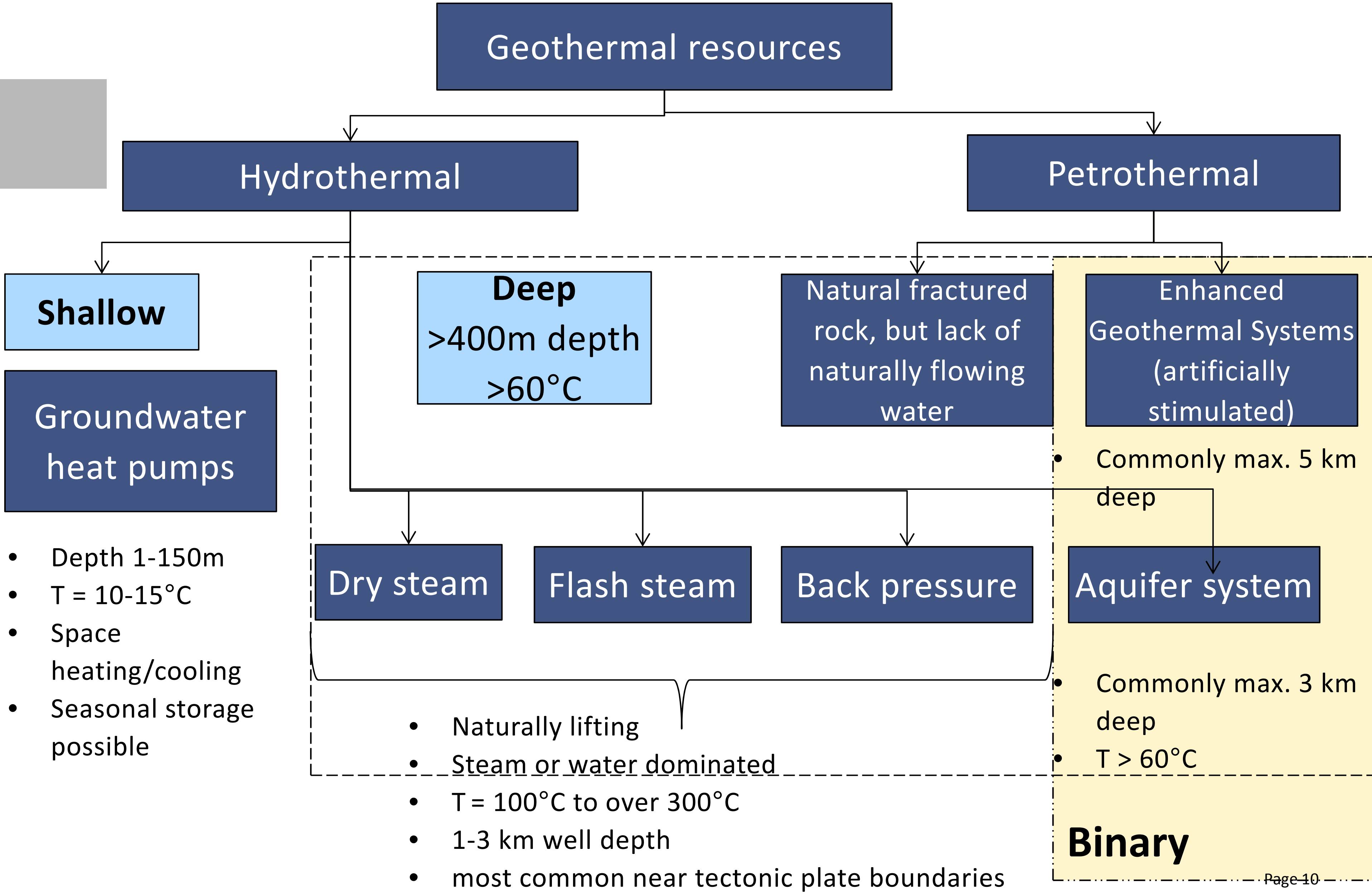
Power generation from geothermal installations



Installed capacity in MWe for each plant typology (total 12.6 GW as per 2015) // Produced power in % from each plant typology (73 TWh as per 2015)

Geothermal plant types



Typical plant components

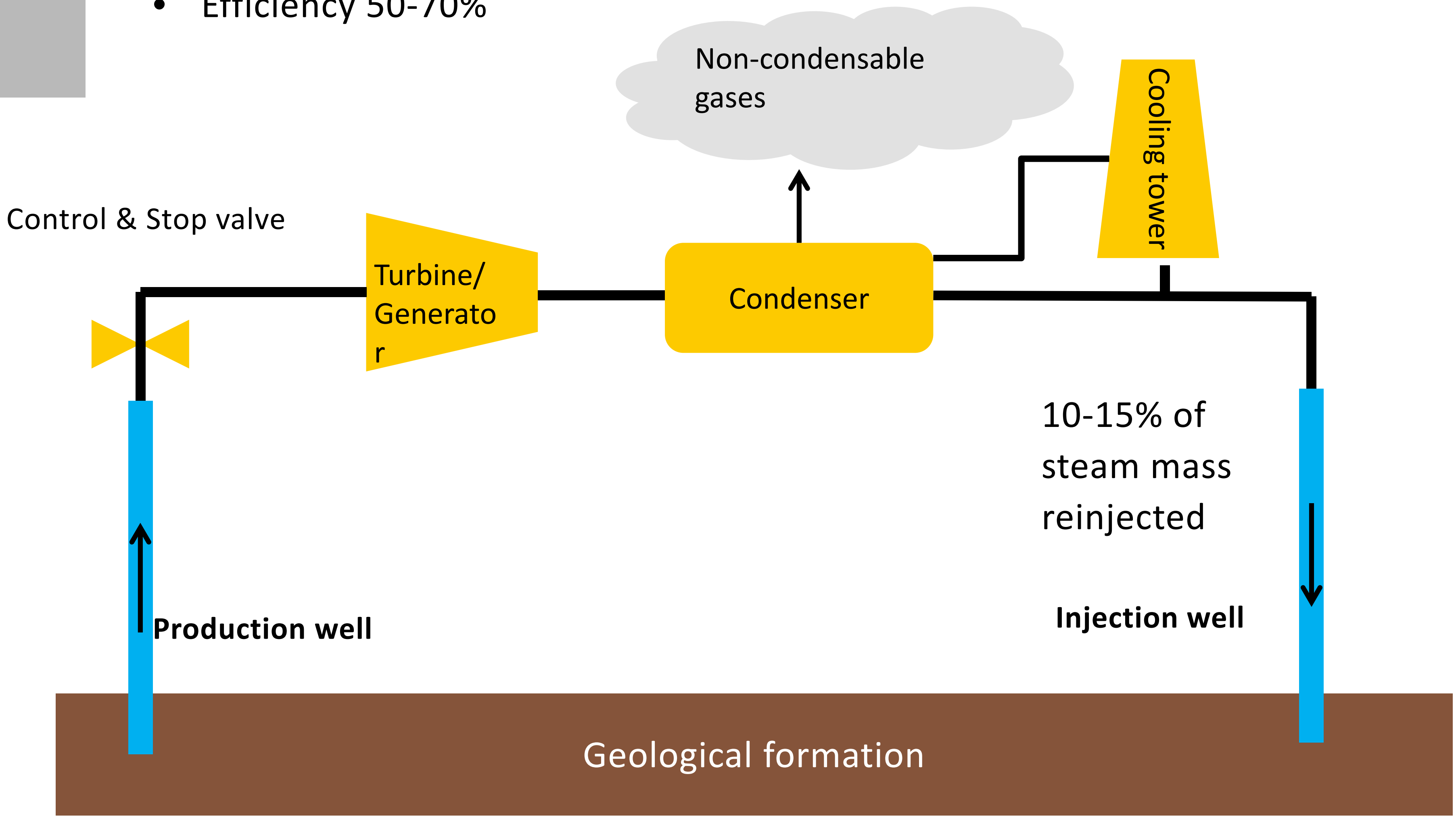
- Production/injection well (drilling, casing)
- Steam turbine/generator
- Condenser
- Separator
- Heat exchanger
- Pumps
- Cooling tower (wet/dry)
- Land use

The Nesjavellir Geothermal Power Station in Iceland

https://techcentral.co.za/should-sa-tap-geothermal-energy/59737/

Dry steam power plant

- Permeable rock with little to no liquid => Vapour only
- $T_{reservoir}$ > 240°C
- Efficiency 50-70%

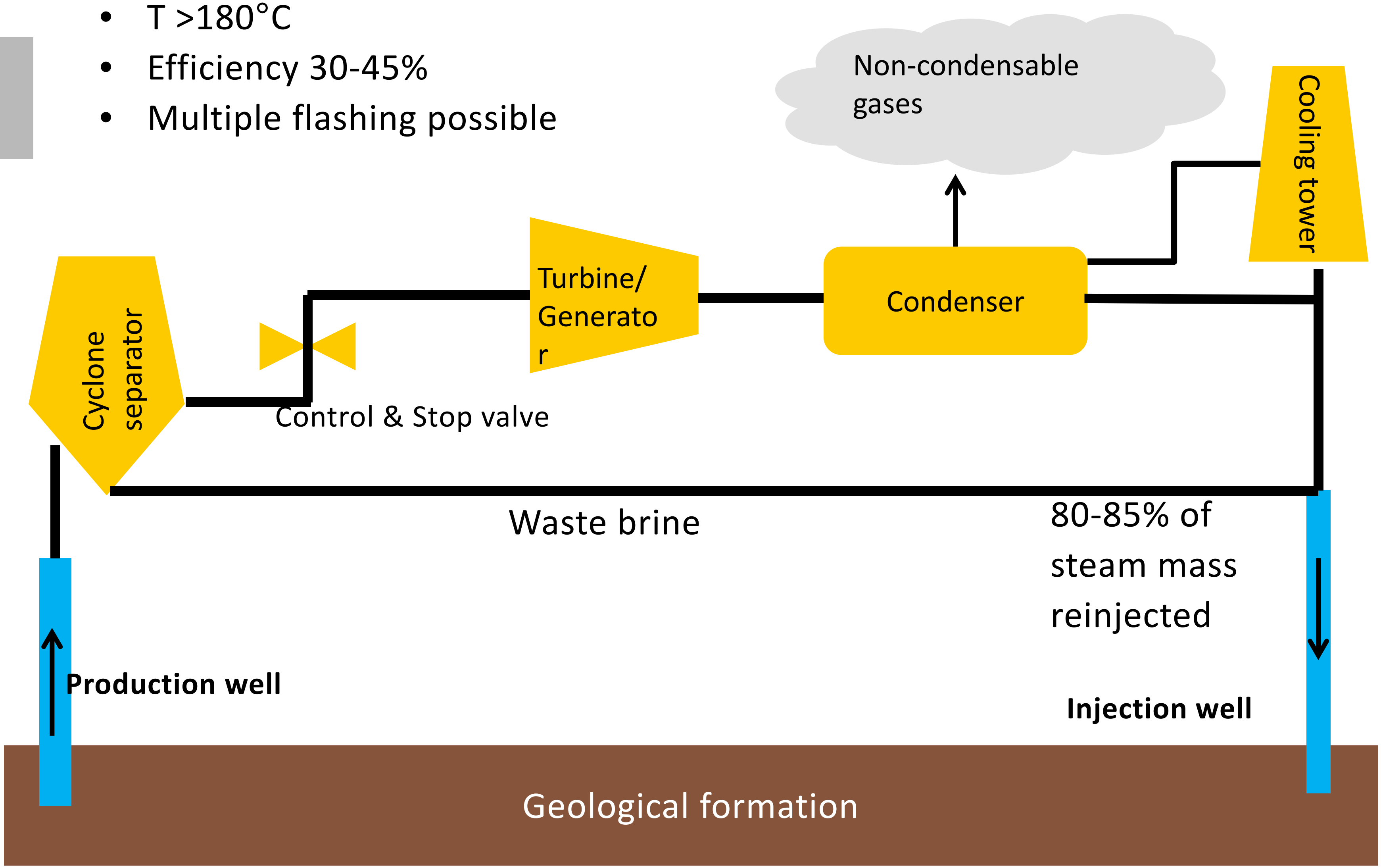


Non-condensable gases

- Present in the geofluid (<10% wt. of the steam)
- Mainly CO_2 (>95%), H_2S, NH_3 , CH_4
- Trace gases: e.g. He, H_2, Ar, N_2, CO, Hg
- Corrosive effect on materials
- Abatement methods present to certain extent, mainly for H2S

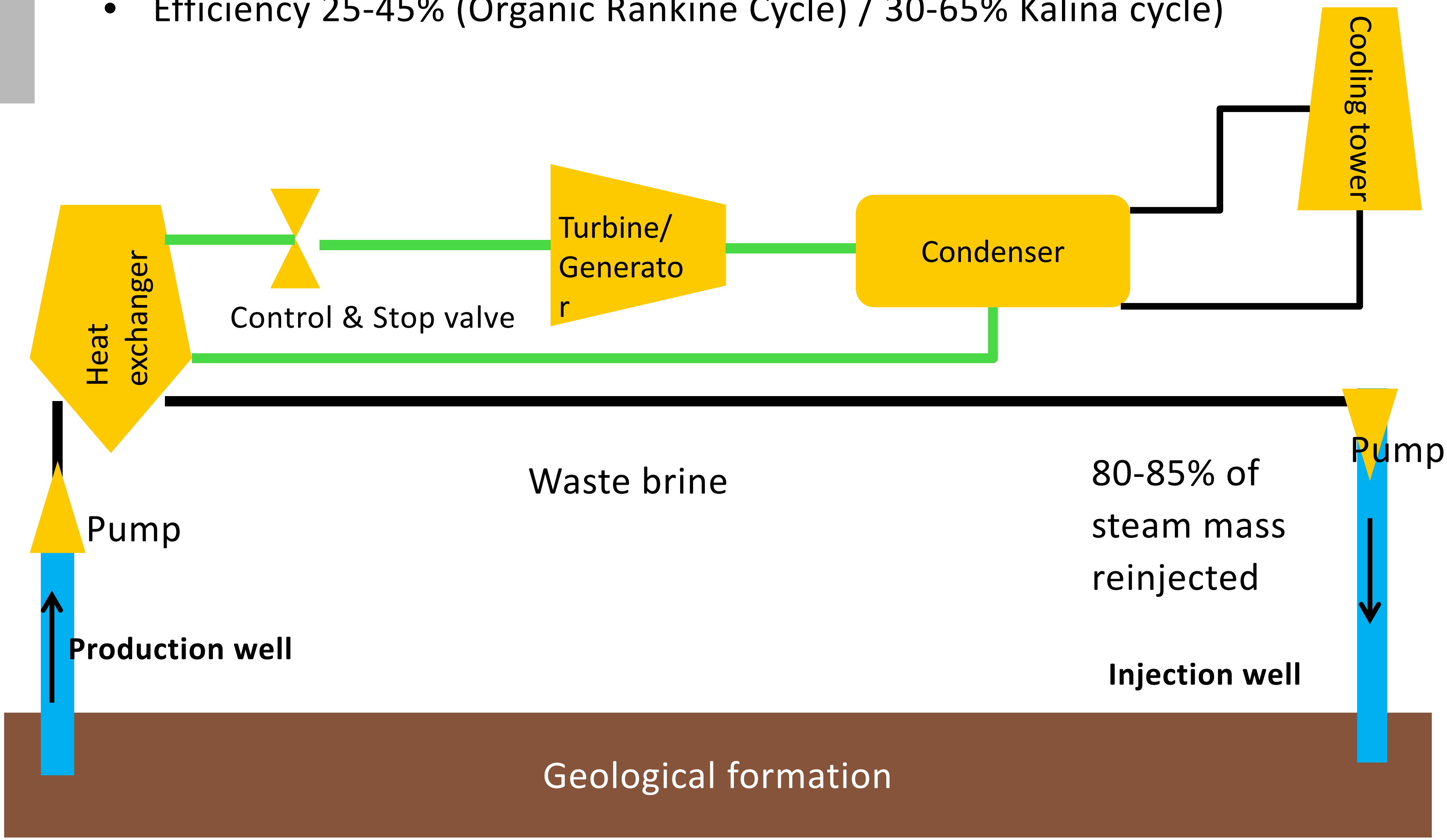
Flash steam power plant

- Steam AND liquid rise in the well
- T >180°C
- Efficiency 30-45%
- Multiple flashing possible



Binary plant

- Liquid-dominated reservoir
- T<180°C
- Efficiency 25-45% (Organic Rankine Cycle) / 30-65% Kalina cycle)



LCA of different types of geothermal power plants

- **Goal of study/Functional unit:**

Harmonise existing LCI data to allow fair comparison of production of 1 kWh net electricity with different geothermal plant types.

- ReCiPe Midpoints (H), ecoinvent background database (allocation, recycled content), SimaPro

Harmonisation of existing LCI

- Recent peer-reviewed reports on LCA of geothermal power with documented, detailed & high-quality LCI data

Harmonisation:

- Life Cycle Phases considered:
  - **Drilling**: Creation of boreholes for extraction and reinjection of geothermal fluid.
  - **Construction**: One deep geothermal subsurface plant unit of a specific plant type and size
  - **Operation & Maintenance**
  - **End-of-Life** – decommissioning of plant & closing of wells
- Recalculation of results
- Modelling electricity only plants

Studies overview

	Dry steam	Flash steam I	Flash steam II	EGS
Region	Tuscany, italy	Guadeloupe, France	Hellisheidi, Iceland	Switzerland
Capacity [MW]	20	11 (single flash)	270 (single flash) 33.3 (double flash) (+130 $MW_{thermal}$)	5.5
Capacity Factor [%]	90	91	87	86
Production [GWh/a]	92	78	2312	50
Production wells	8	2 use, 1 unused	47	2
Injection wells	No data	2	17	1
Make-up wells	None	None	16	3
Depth [m]	1000	1250	2220	5000
Plant lifetime [a]	20	30	30	30
Main reference	Buonocore et al. 2015	Marquand et al. 2014	Karlsdóttir et al. 2015	Treyer et al. in Bauer et al. 2017

Harmonised Life Cycle Inventory

«-» = neglected, no data

Phase	Element	Dry Steam	Single Flash Steam I	Single Flash Steam II	Binary EGS
Drilling [per m drilled]	Energy Use [MJ]	852 Diesel	1,558 Diesel	2,240 Diesel	14,745 Diesel
	Land Use [m^2]	-	0.8	-	0.6
	Direct Emissions	-	To river (e.g. Na, Ca, Mg)	-	-
	Drilling Waste [kg]	196	196	196	466
	Water Use [kg]	-	1,412	8,860	500 (drilling) 1,330 (stimulation)
	Material Input	Mainly steel, concrete, drilling fluid			
Construction [per power plant unit]	Land Use [m^2]	7,120	16,457	-	8,000
	Material Input	Mainly steel, concrete			
Operation & Maintenance [per kWh produced over plant lifetime]	Cooling Water [kg]	0 (Evaporation of geofluid at Cooling Tower)	0.304 (Cooling Tower)	0 (Evaporation of geofluid at Cooling Tower)	0 (Air Cooling)
	Energy Use [MJ]	0.275 Diesel	1.35E-05 Diesel	14.4 Own power demand	-
	Direct Emissions:	NCG[H] and chemicals to air	NCG to air	NCG to air	None, Closed-Loop System
	To air [g]:				
	CH_4	0.94	0.0027	0.034	0
	CO_2	162	34.5	22.53	0
	H_2S	5.79	0.85	5.79	0
	Other	Hg, As, NH_3	0	0	Benzene leakage
	Material Input	Lubricating Oil, PVC, Aluminium, Steel	Lubricating Oil	Sodium Hypochlorite[I]	Benzene leakage
End-Of-Life [per power plant unit]	Construction Waste	Yes	Yes	Yes	Yes
	Filling of Well	-	Cement & Gravel	-	-
	Energy Use [MJ]	-	-	-	-

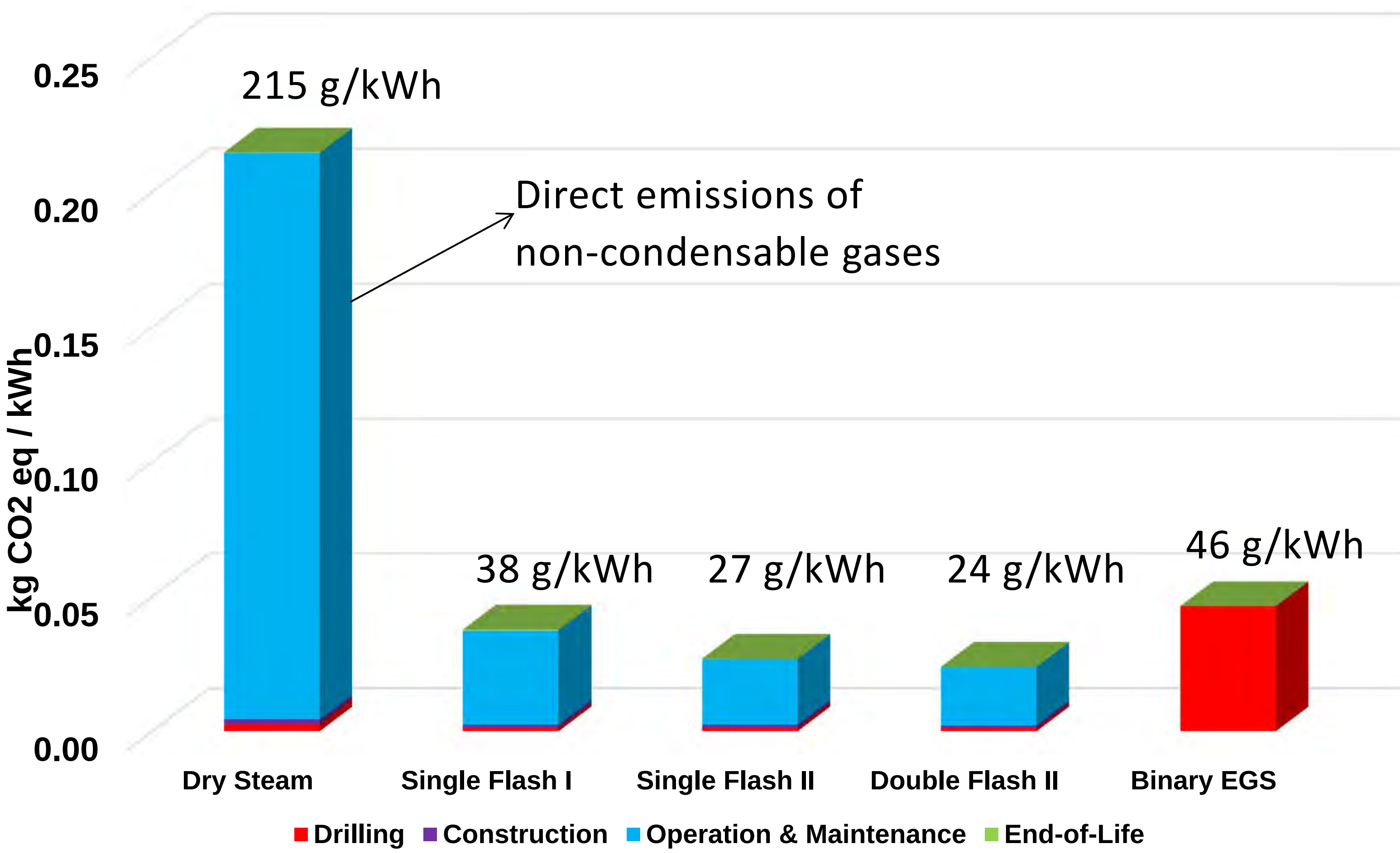
Discharge of geofluid into river

Larger diameter for EGS well

Large network of pipes => pumping power needed

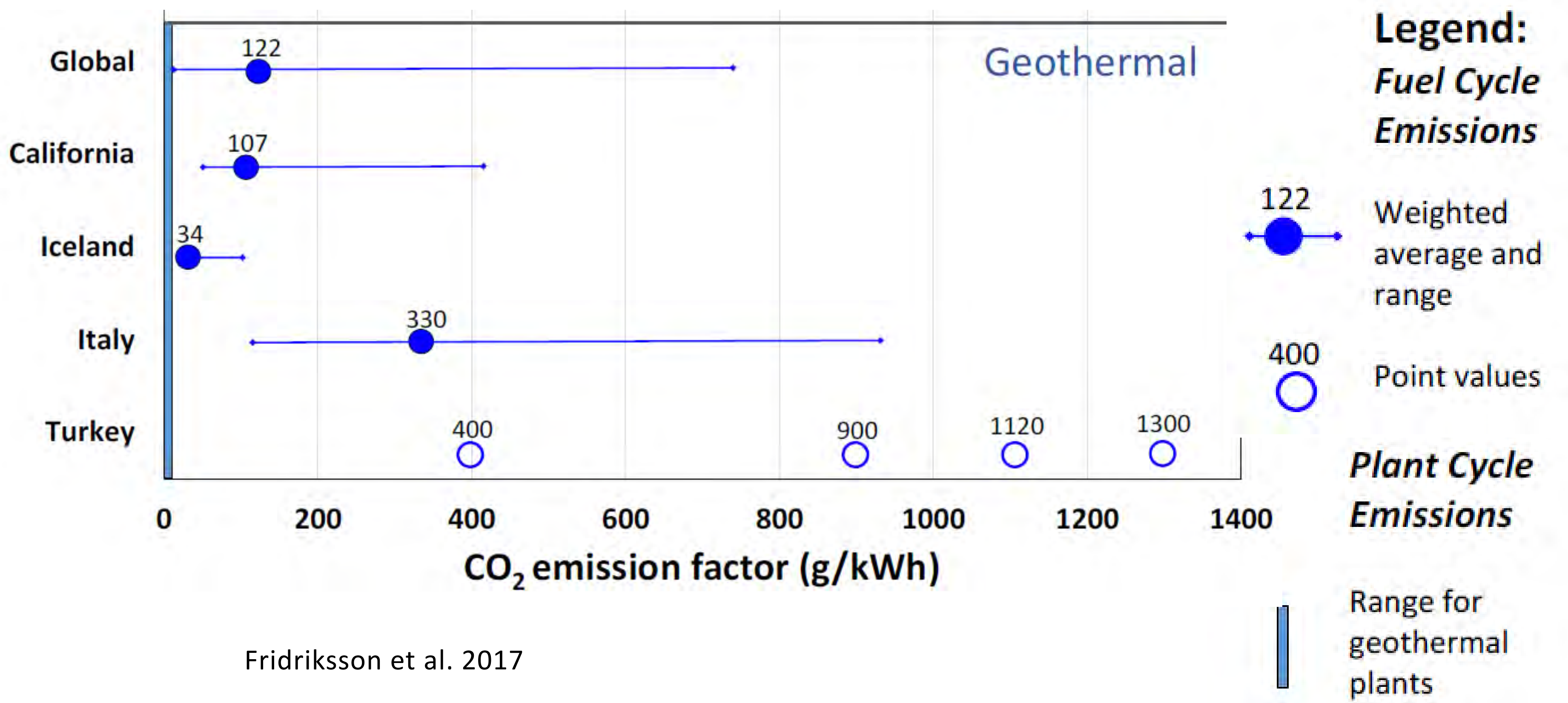
Much less emissions due to reinjection rate of 90-100%

LCIA results: Climate change



Direct emissions of greenhouse gases

Direct CO_2 emissions of high-temperature resources span between 4 to 740 g/kWh with a weighted average of 122 g/kWh (Bertani &Thain 2002)



Fridriksson et al. 2017

Direct emissions of greenhouse gases: Variation over lifetime

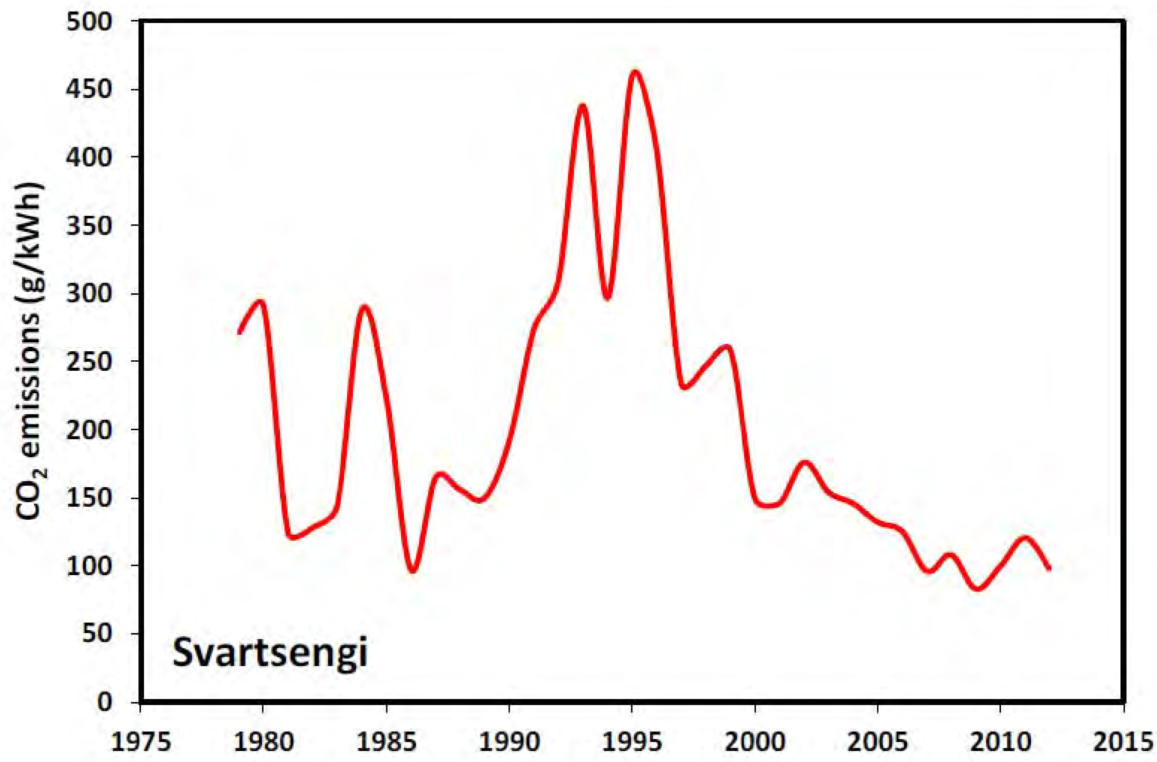
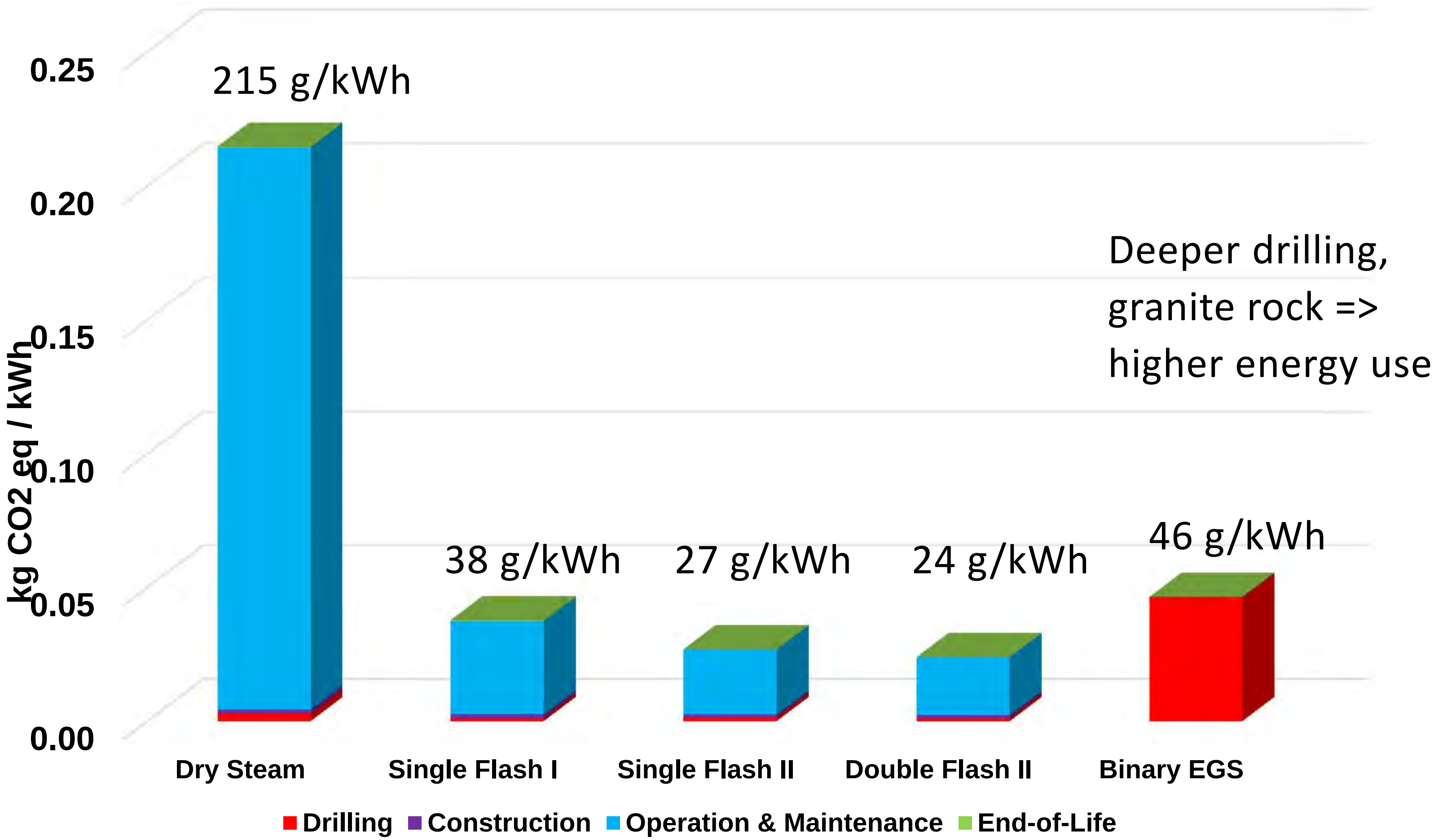


Figure 5: CO_2 emission factors for the Svartsengi geothermal power plant.

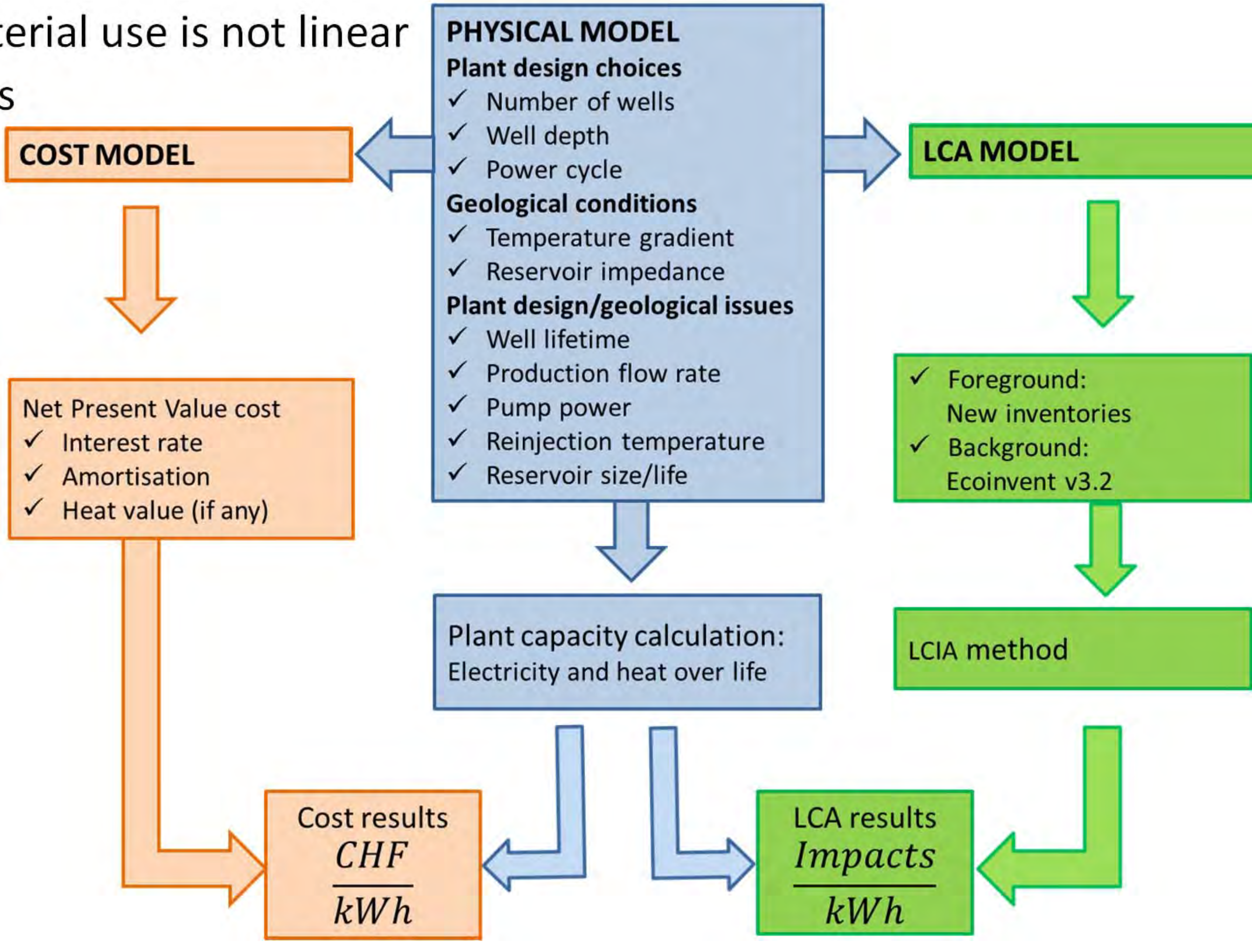
Fridriksson et al. 2017

LCIA results: Climate change



Environmental impacts of EGS plants

- Not mature technology, but planned 4.4 TWh until 2050 in Switzerland (Prognos 2012)
- Stimulation of the rock needed
- Drilling energy & material use is not linear
- Uncertain parameters



Treyer, K. et al. in Hirschberg et al. 2015/Bauer et al. 2017

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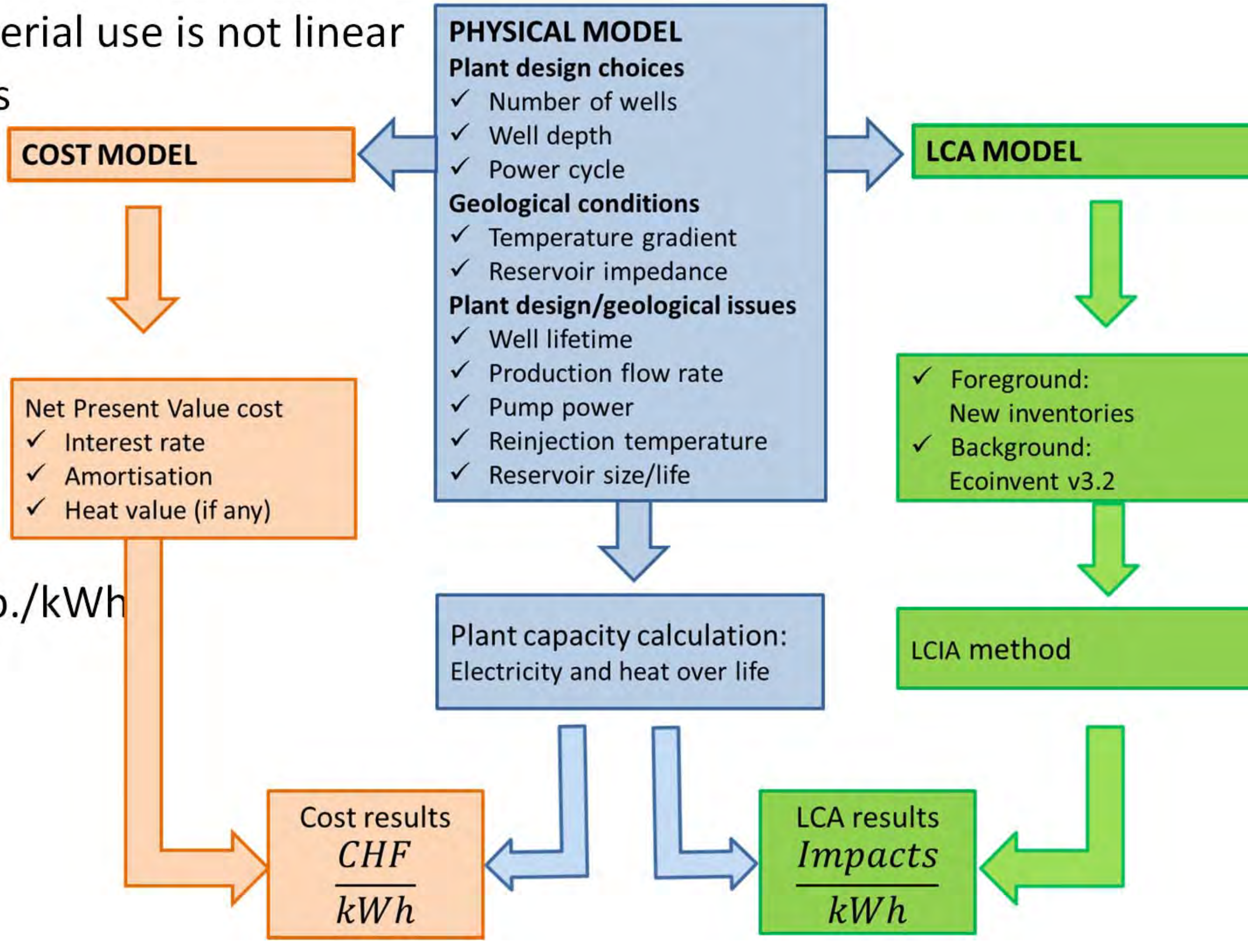

- Scenario analysis:

20-80g CO_2eq/kWh

1.2 MWel – 5.2 Mwel

16.2 Rp./kWh – 58.1 Rp./kWh

Treyer, K. et al. in Hirschberg et al. 2015/Bauer et al. 2017

Topics neglected

- **Heat and power co-generation** not modelled
- **Hydrothermal binary plants** not modelled
- **Water depletion** not investigated in detail

- **Risk and toxicity issues:**
  - Induced seismicity is not part of the LCA
  - Emersion of radioactive materials not studied in detail
  - Chemical deposition (scaling) in pipes, vessels, cooling tower not considered
  - Reinjection can potentially contaminate fresh water aquifers
- **Corrosion protection** not included in LCI
- Potential **mining of mineral resource deposits** not considered (silica, lithium, zinc)

Take home messages

- **Large theoretical potential** of geothermal energy use.
- Power production with geothermal power is **environmentally favorable** compared to fossil-based technologies and partially to renewables.
- LCA results **depend mainly on**
  - Reservoir characteristics
  - Geothermal fluid chemistry
  - Power plant type, technology & performance

- Greenhouse gas emissions from dry steam plants can be significant
- Future plant designs might avoid these direct emissions from operation
- EGS plants promising in theory but face technological (and economic) challenges

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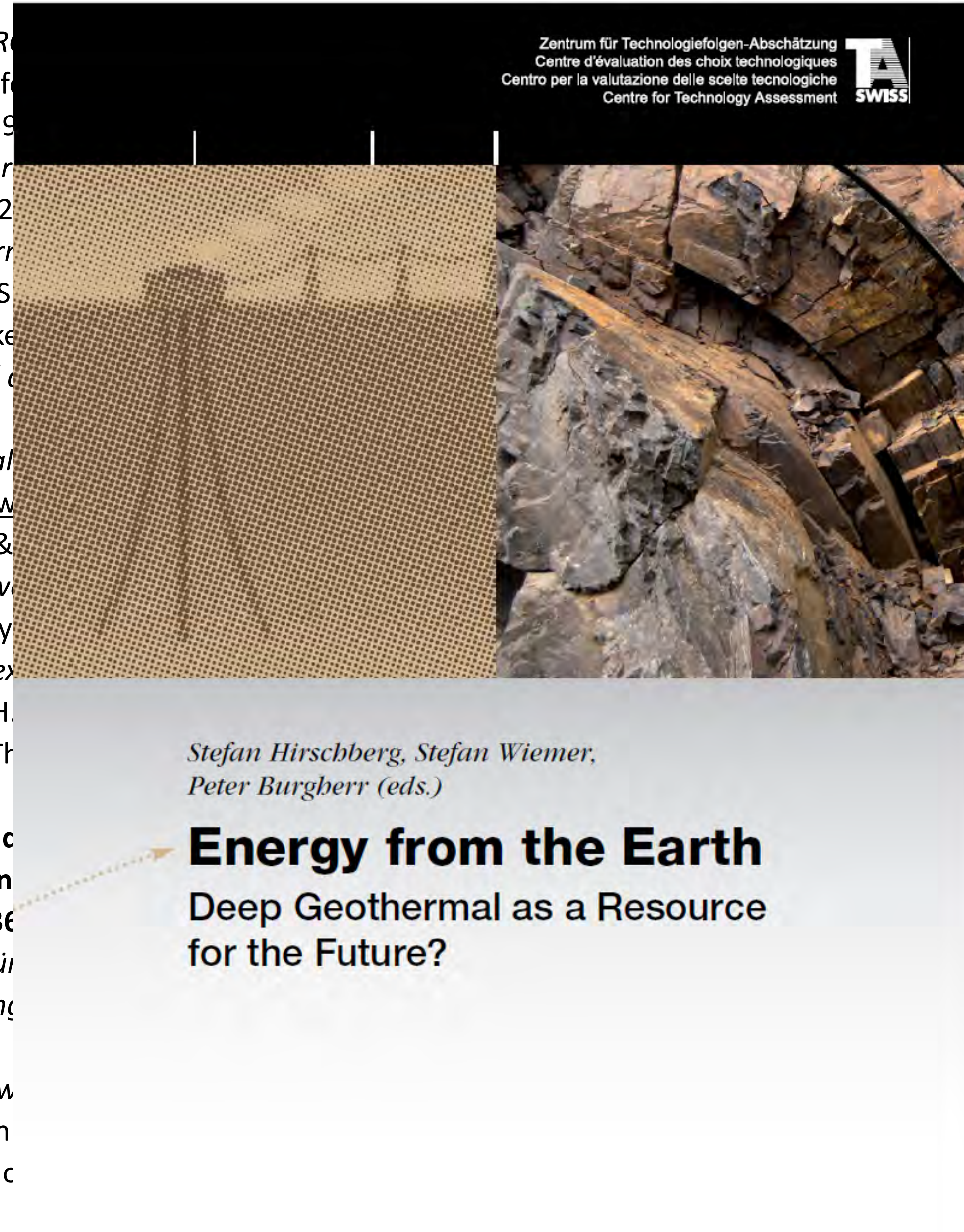

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