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Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

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Economic & Ecological Potential of Geothermal Electricity in Switzerland: A Comparison with other Renewables

WWF – Bern, 23 August 2010

How big is the potential geothermal resource?

All Switzerland, 30 °C/km gradient,

- Heat in place = volume * density * heat capacity * temperature difference
- Heat recovery based on well spacing & geometry
- Generation efficiency is low, based on temperature

Depth interval [km]	Temp. range [°C]	Average Temp. [°C]	Surface area [km2]	Density [kg/m3]	Heat capacity [J/kg*K]	Heat in Place T_{reinj}= 40 °C	Heat recovery factor	Recoverable Heat [J]	Cumulative Heat [J]	Generation efficiency	Electricity Generation [J]	Cumulative Generation [J]
3 – 4	100 – 130	115	41000	2600	840	**6.72E+21**	1.0%	**6.72E+19**	6.72E+19	9.0%	**6.04E+18**	6.04E+18
4 – 5	130 – 160	145	41000	2600	840	**9.40E+21**	2.8%	**2.63E+20**	3.30E+20	11.5%	**3.03E+19**	3.63E+19
5 – 6	160 – 190	175	41000	2600	840	1.21E+22	4.1%	4.90E+20	8.20E+20	13.2%	6.46E+19	1.01E+20
6 – 7	190 – 220	205	41000	2600	840	1.48E+22	4.6%	6.72E+20	1.49E+21	14.4%	9.70E+19	1.98E+20
7 – 8	220 – 250	235	41000	2600	840	1.75E+22	4.9%	8.56E+20	2.35E+21	15.4%	1.31E+20	3.29E+20
8 – 9	250 – 280	265	41000	2600	840	2.01E+22	5.2%	1.04E+21	3.39E+21	16.1%	1.68E+20	4.97E+20
9 – 10	280 – 310	295	41000	2600	840	2.28E+22	5.3%	1.22E+21	4.61E+21	16.7%	2.04E+20	7.01E+20
			Total heat or electricity [J]			1.03E+23		4.61E+21			7.01E+20	
	Total heat or electricity [Gigawatt-years, or GWa]					3.28E+06		1.46E+05			2.22E+04	

36 EJ = 10 PWh = 38 GW for 30 years (<= 5 km, 1 GW ~ 1 large coal plant or nuke)

BUT...

- Too much area (too far from population)
- Too deep (currently infeasible)
- Gradient and recovery factor only approximate (not specific to geology)

In more detail for Northeastern Switzerland

		Upper Crystalline	Upper Muschel-kalk	Upper Malm	Upper Meeres-molasse	Total
Nord Schweiz						
Volume	km^3	4700	650	1500	1300	8150
Ave Temp	°C	105	75	80	30	
Heat in Place	EJ	969	87	209	50	1314
Ave Heat Content	EJ/km^3	0.21	0.13	0.14	0.04	
Usable - 30 yr life						
Class 2 (200m-100°C)	EJ	4.2	1.2	0.036	2.5	8
Class 3 (100°C-5km)	EJ	11.0	1.6	0.045	0.0	13
Class 4 (5-7 km)	EJ	1.8	0.1	0.001	0.0	2
Total	EJ	17.0	2.9	0.081	2.5	22
Recovery factor R		0.02	0.03	0.0004	0.05	0.02
Ost Schweiz						
Volume	km^3	2633	313	1643		4589
Ave Temp	°C	161	*143*	66		
Heat in Place	EJ	850	79	185		1114
Ave Heat Content	EJ/km^3	0.32	0.25	0.11		
Usable - 30 yr life						
Class 2 (200m-100°C)	EJ		0.3	1.8		2
Class 3 (100°C-5km)	EJ	10.7	2.4	0.5		14
Class 4 (5-7 km)	EJ	4.1				4
Total	EJ	14.8	2.7	2.3		20
Recovery factor R		0.02	0.03	0.01		0.02
Nordost Schweiz						
Class 2 (200m-100°C)	EJ	4.2	1.5	1.8		8
Class 3 (100°C-5km)	EJ	21.7	4.0	0.5		26
Class 4 (5-7 km)	EJ	5.9	0.1	0.0		6
Total	EJ	31.8	5.6	2.4		40

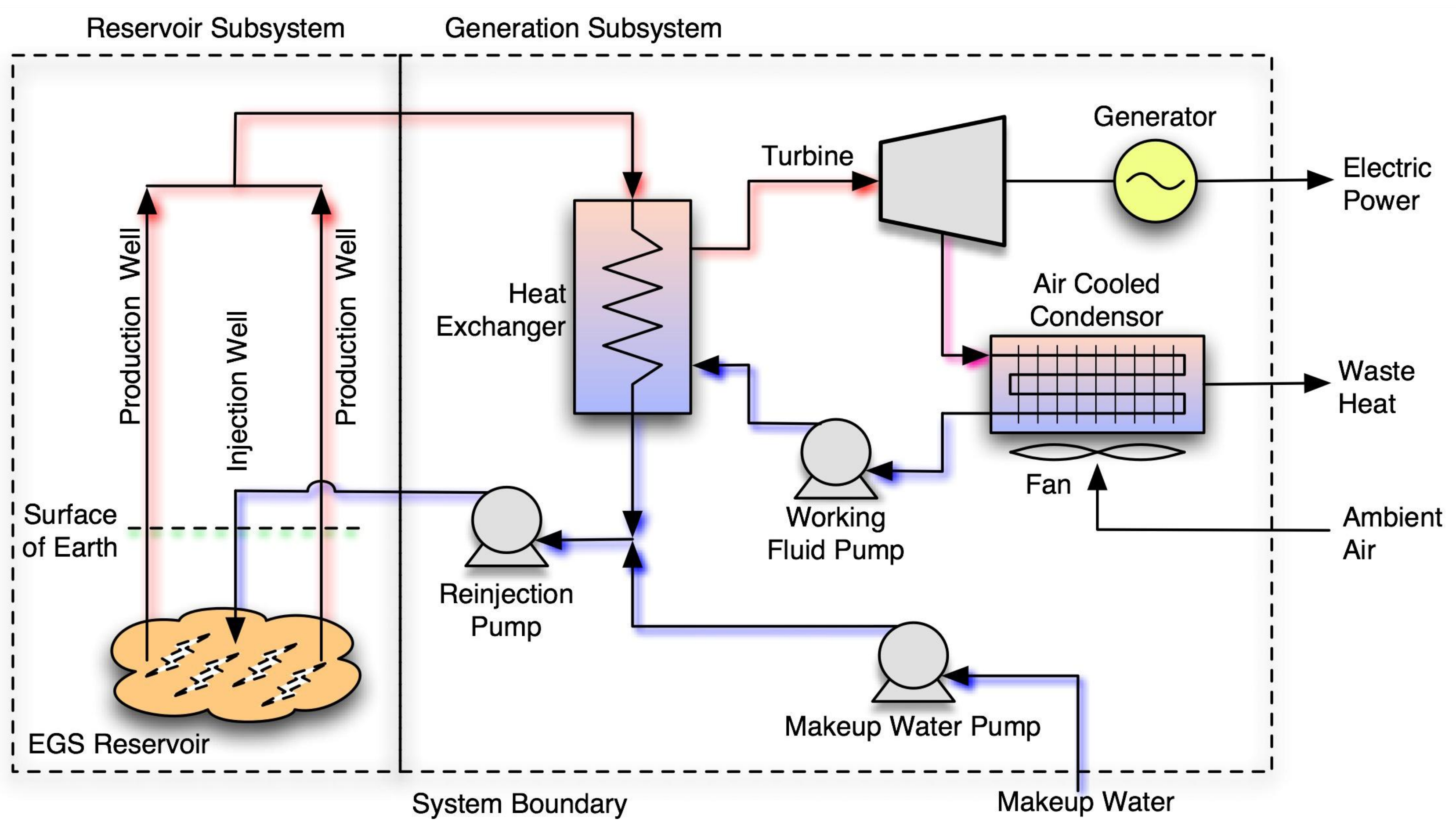
Approximately 10x less heat (and thus electricity).

Comparisons – Swiss primary energy demand = 1.3 EJ/a

Swiss annual electricity demand = ~ 60TWh/a

Source: Geowatt AG

Modeling a geothermal plant (what can change?)

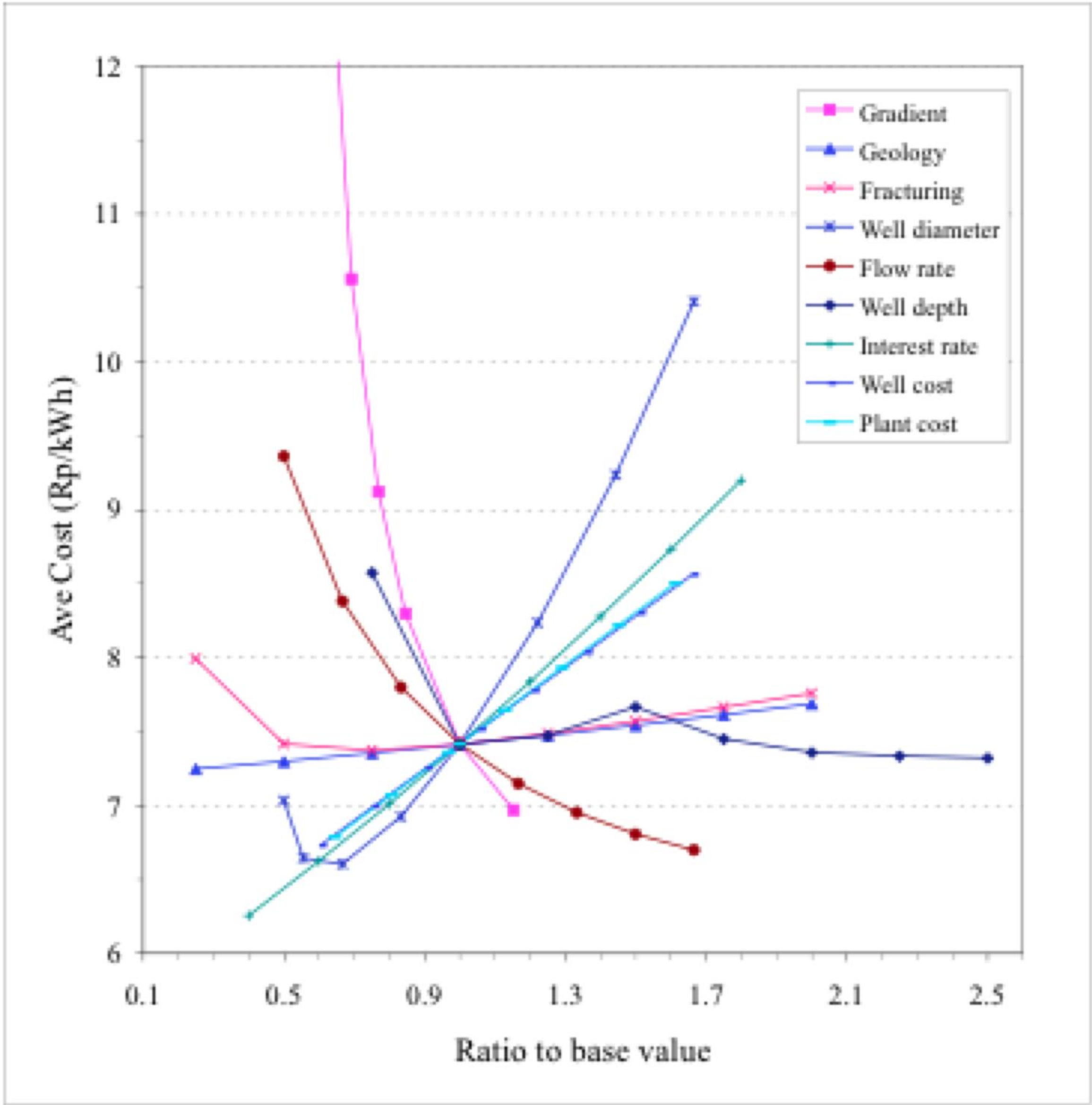


Site specific geology – gradient, permeability

Plant design choices – hydro fracturing, well depth & diameter, flow rate

Sensitivity choices – well cost, plant cost, interest rates

Sensitivity of Costs to Model Factors

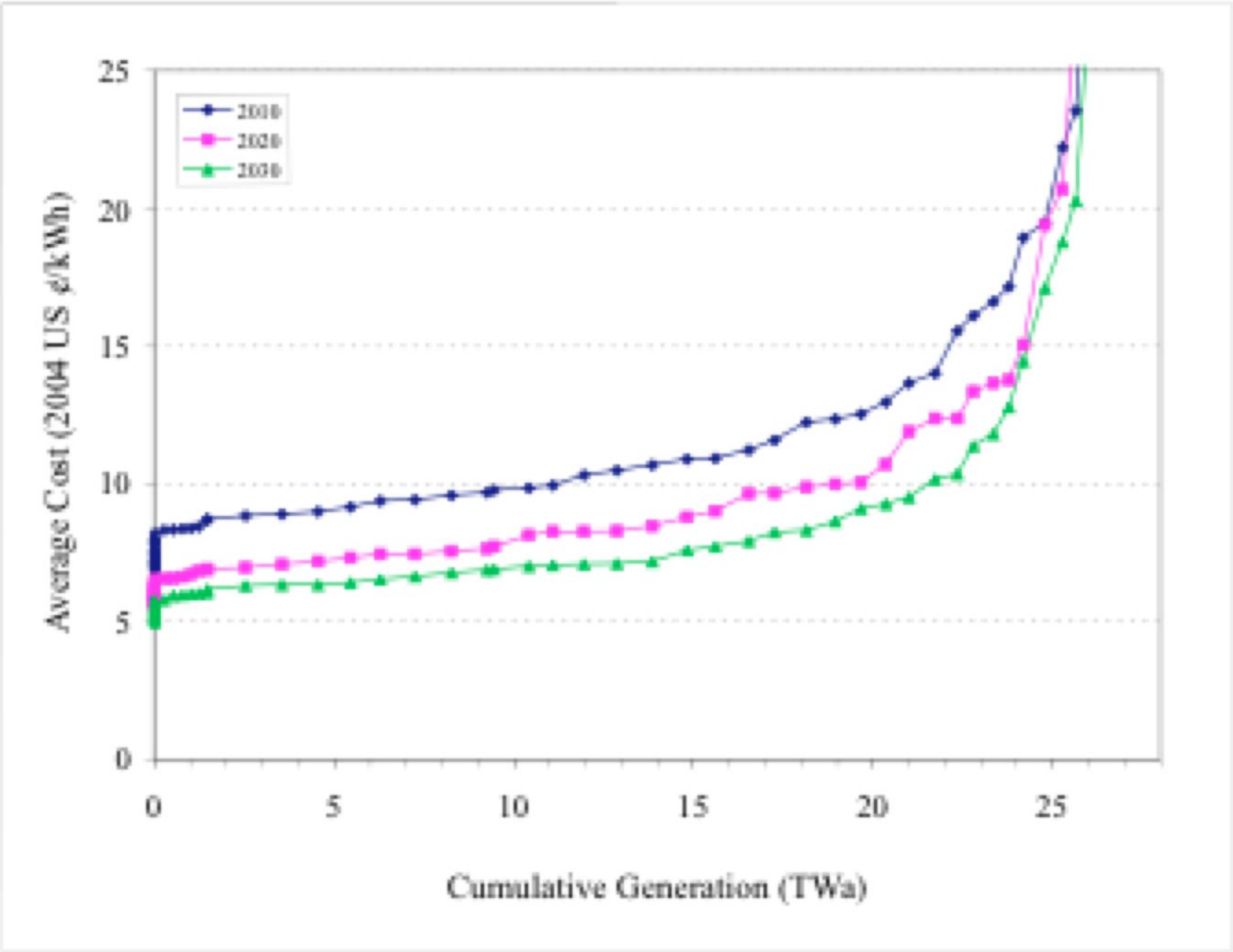


Sensitivity factors in order of impact –

- Temperature gradient
- Well depth
- Well diameter
- Flow rate
- Interest rate
- Plant cost
- Well cost
- Fracturing
- Permeability

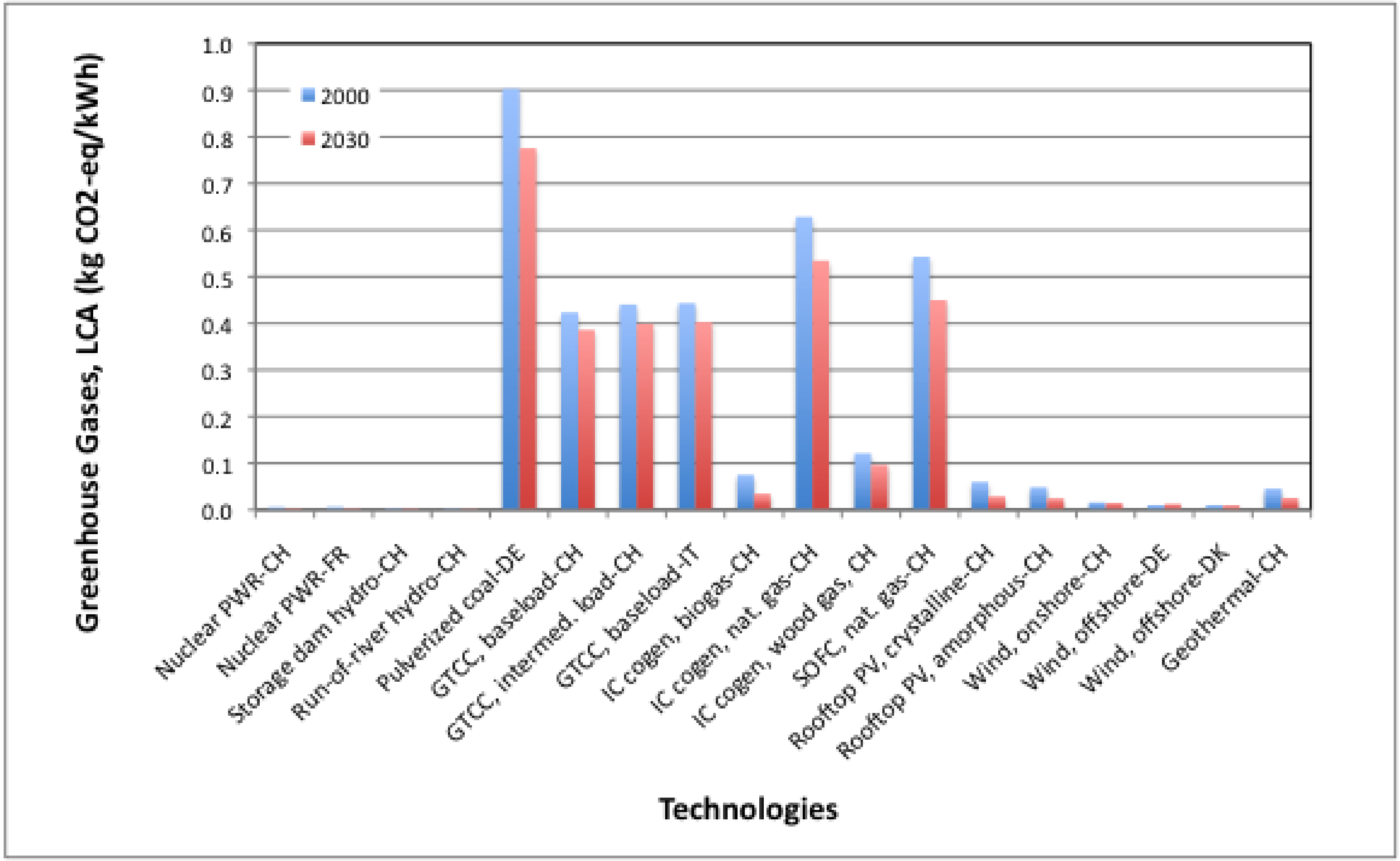
When pump power exceeds generation, cost goes to infinity...

Making a Cost Supply Curve for Geothermal



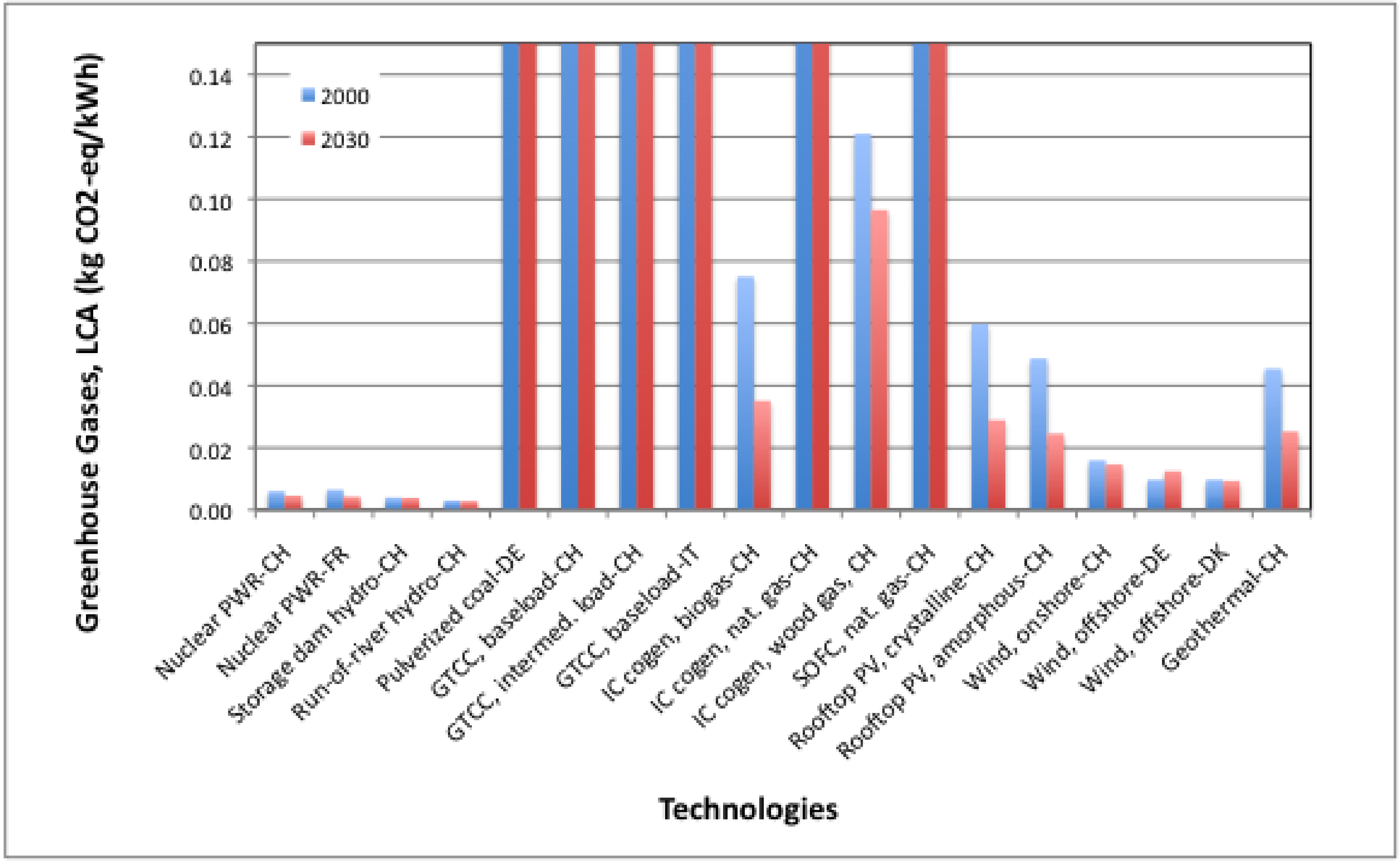
Weighted average of individual curves for different gradients and depths.

Greenhouse Gas Emissions – Life Cycle Analysis



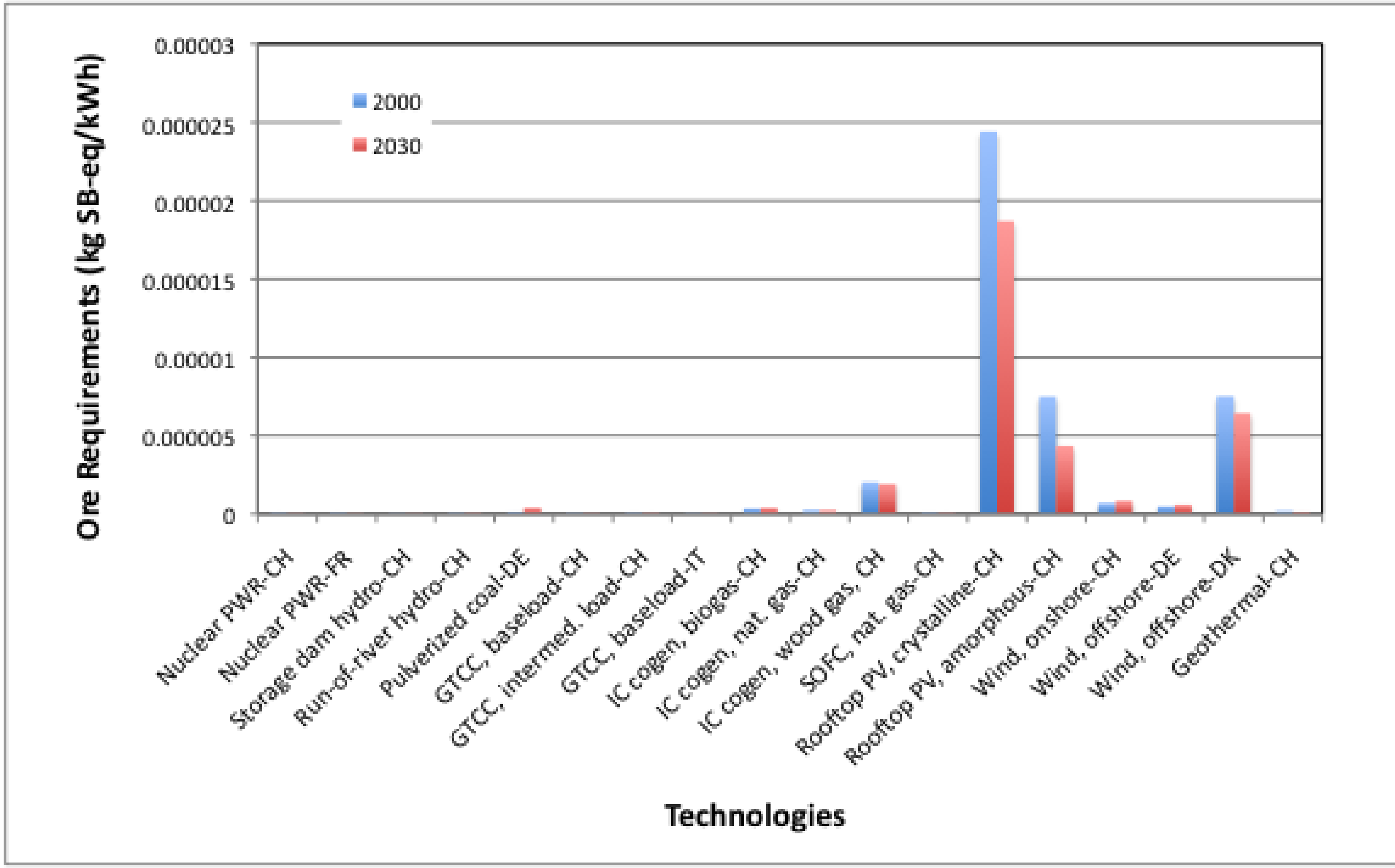
Source: PSI, Axpo project.

Greenhouse Gas Emissions – Life Cycle Analysis



Source: PSI, Axpo project.

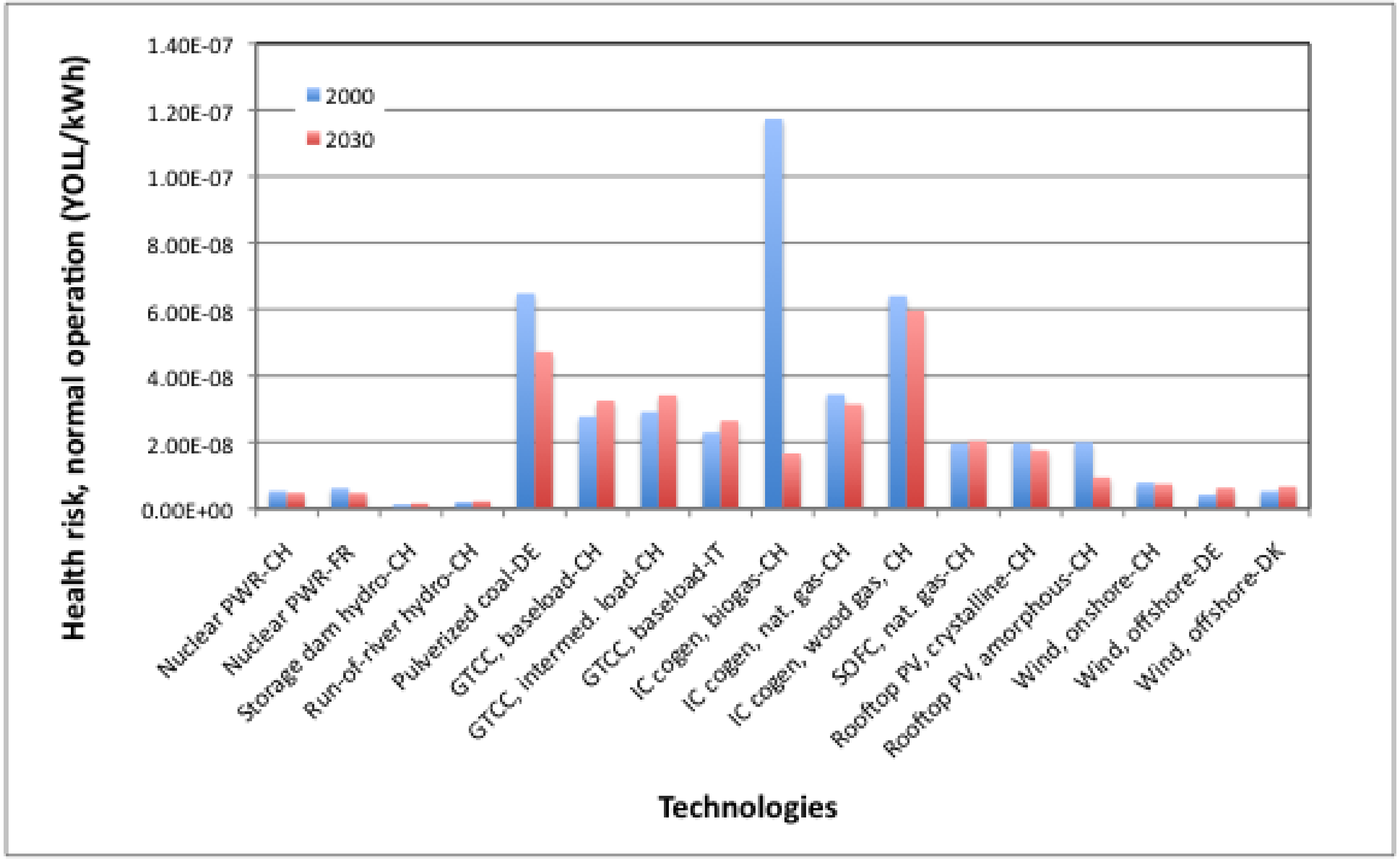
Resource Requirements



System definitions matter, but energy density is fundamental.

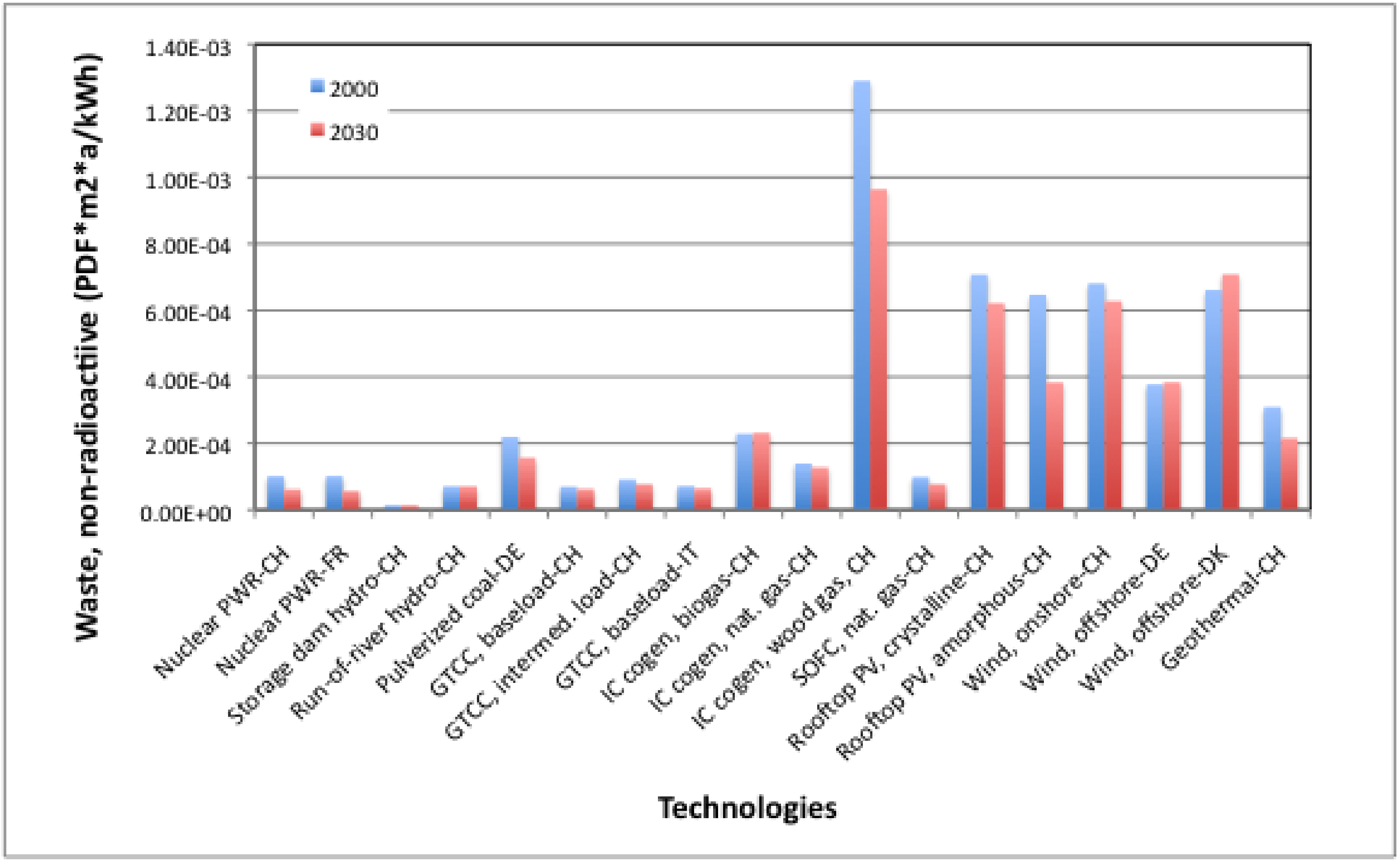
Source: PSI, Axpo project.

Health Risks of Normal Operation



YOLL = Years of Life Lost, i.e. average shortening of expected lifespan during normal operation of each technology. (Large change in IC cogeneration due to engine change leading to lower NOx emissions. Source: PSI, Axpo project.

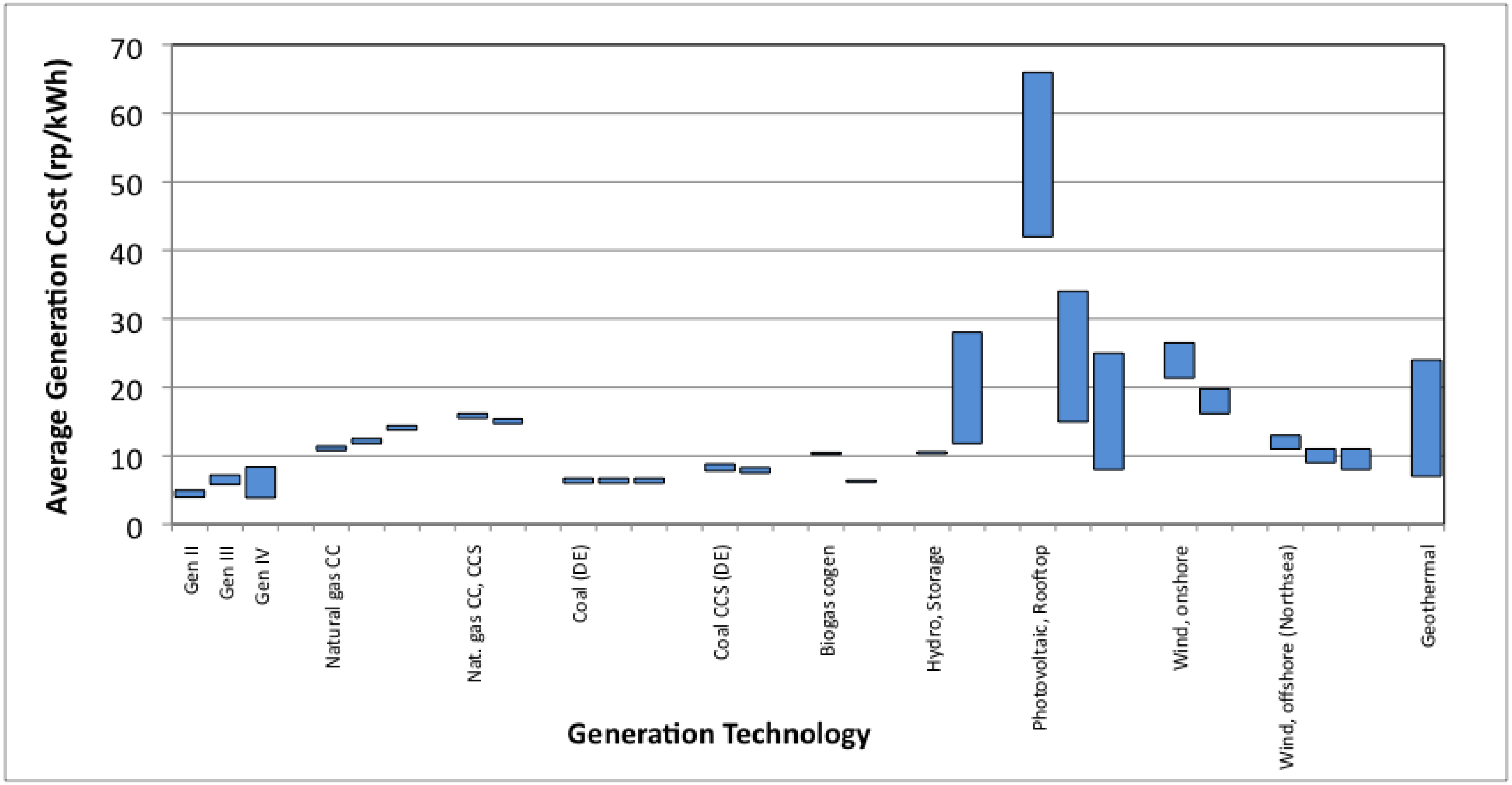
Waste in Special Repositories (non-radioactive)



Toxic waste in repositories results primarily from metals processing (energy density again).

Source: PSI, Axpo project.

Average Generation Cost by Generation Technology



Triplets of data bars reflect current 2010, 2030 and 2050 cost estimates (some technologies not available in 2010).

Source: EnergieSpiegel 20. Geothermal from Axpo project.

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Other comparisons with other renewables

Operating Characteristics and Other Properties

- Base load (but dispatchable)
- Resource scale
- Resource quality
- Resource dependability – Non-interruptible, i.e. domestic,and non-stochastic
- „Renewable“ (but recharge times very slow)
- Waste heat (uses and value)

Conclusions

- Great resource characteristics,
- Safety fears and waste heat are drawbacks
- Positive on most environmental measures
- Cost competitive with other renewables in right locations
- Drilling advances should continue to drive costs down

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Thanks for your attention!