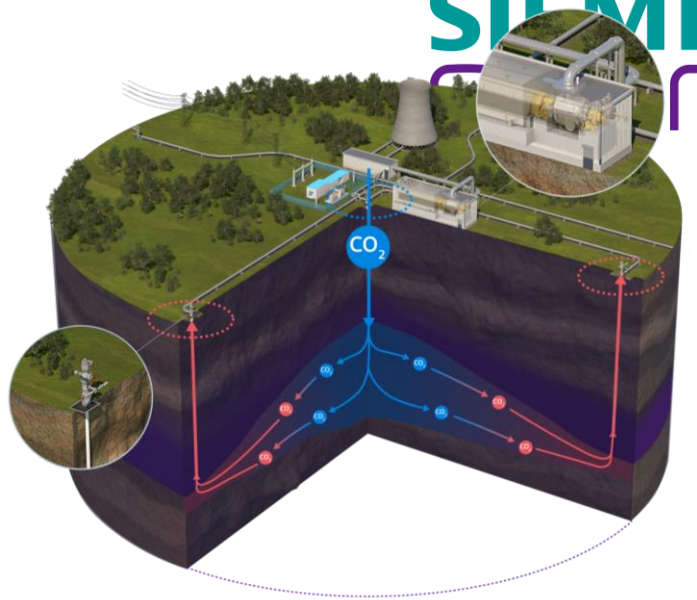
Geothermal Energy Machinery and Systems Workshop (GEMS)

NextGeneration Geothermal Power (NGP)

NextGeneration Geothermal Power (NGP) functionalizes stored CO2 from CCS or DACCS to power the energy transition



THE CHALLENGE

Wind and solar power are intermittent

Hydro and traditional geothermal are regionally restricted

CCS is essential to limit global warming, but recognized as “disposal” with no value-add

THE CONCEPT

NGP combines geothermal energy with CCS

NGP as supplement to CCS accelerating energy transition (electrification, H2, DAC…etc)

Establishing a closed loop by means of strong natural circulation (thermosiphon),

THE VALUE

- Renewable, firm, & dispatchable energy
- Up to 6 x higher net power vs. hydro based geothermal
- Second life for depleted reservoirs and infrastructure
- Stored CO2 can help power the energy transition

CCS – Carbon capture and storage

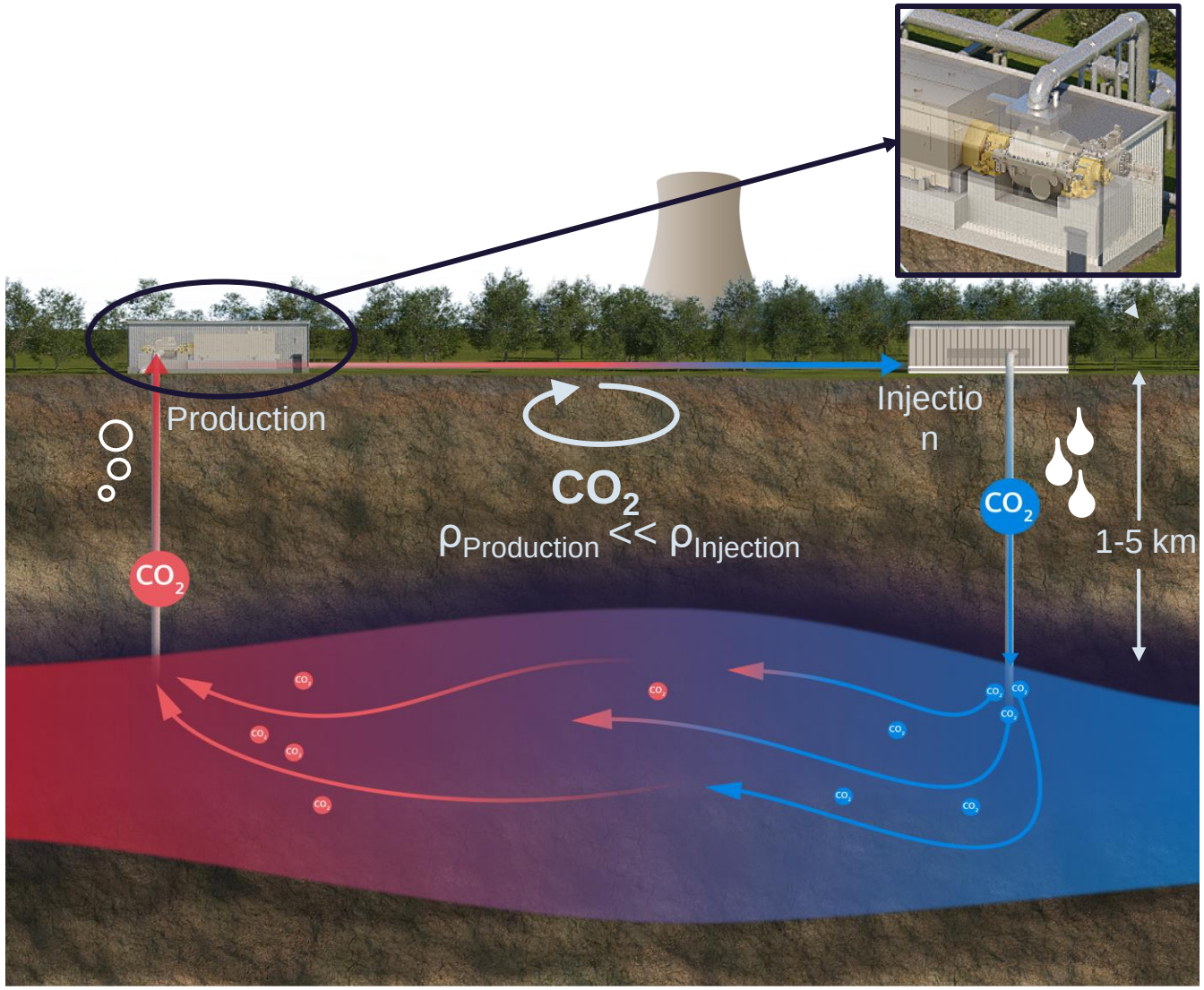
DACCS – direct air carbon capture and storage

Concept Overview

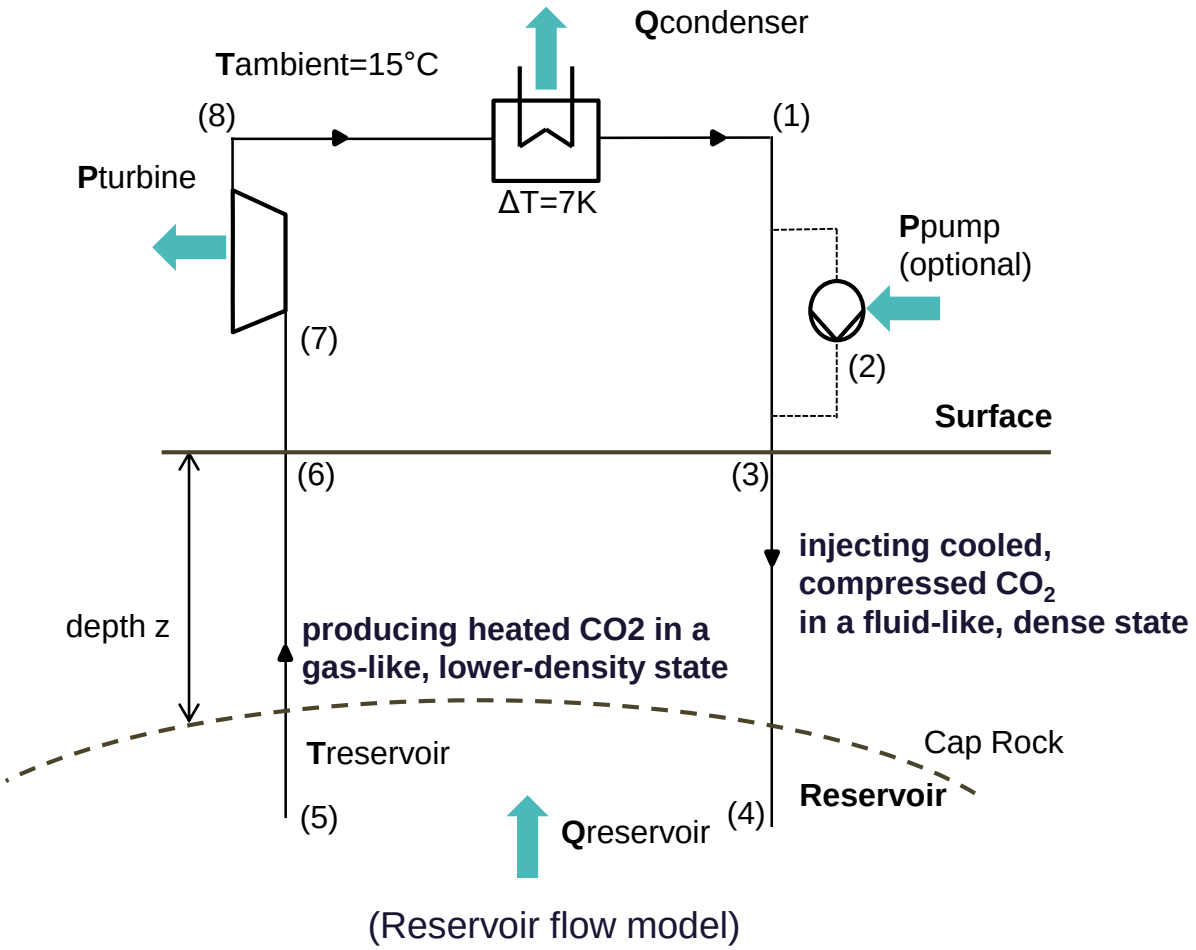
CO2 is injected into sedimentary basins that host high-permeability reservoirs overlain by cap rocks

CO2 is heated by geothermal energy, flows to the surface and expands in a turbine to generate electricity and is reinjected again (closed CO2 loop)

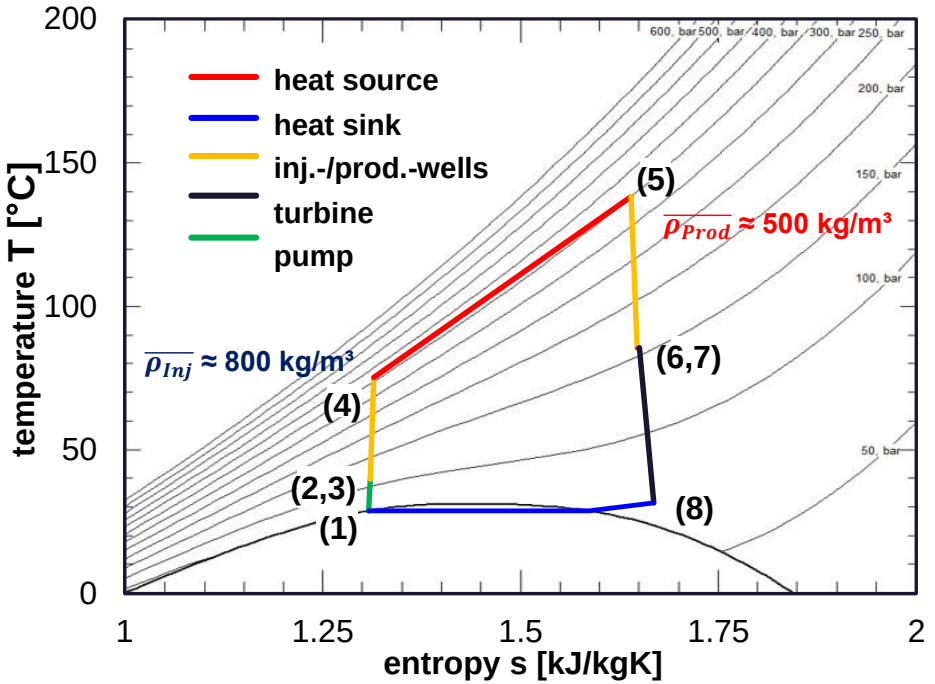
Reservoir conditions for NGP can be more modest than other geothermal technologies



The Cycle Concept



(Reservoir flow model)



- Geothermal heat supply leads to density difference between injection and production, that leads to pressure difference between wellheads

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

- Due to lower viscosity of CO2 compared to water pressure loss in the reservoir and seismic activity can be reduced

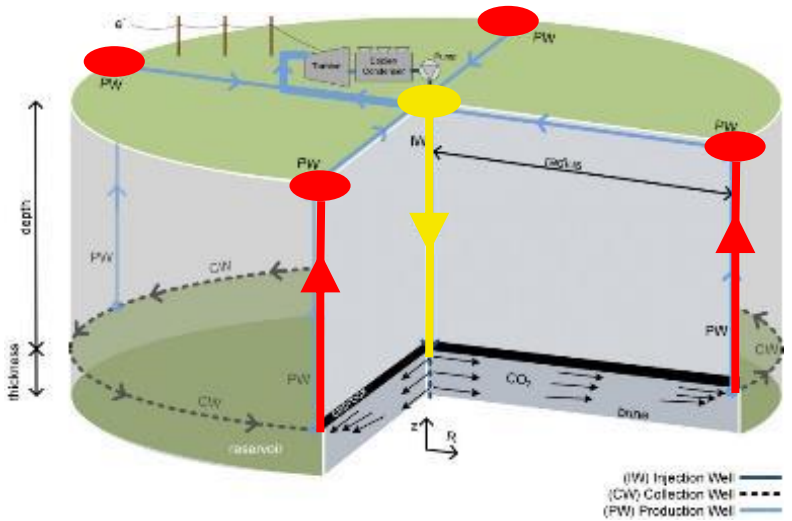
NGP Example

Geologic conditions – Base Case

Coordination number (configuration)	1 (5-spot-system)
Depth	2500 m
Well tubing diameter (well casing diameter @ target)	0.32 m /12.6” (18 5/8“) /(0.47 m)
Permeability*thickness (transmissivity κh)	300 mD * 50 m (15,000 mD·m)
Temp. gradient	35 C/km

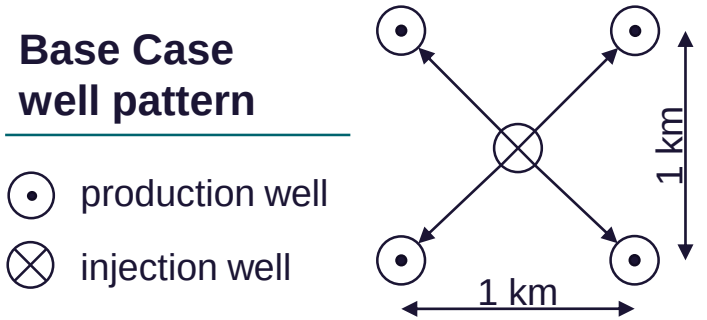
Power Cycle Variants

direct | sCO_2		indirect | Water / ORC	
Thermosiphon only	with supplemental pumping	single pressure	dual pressure



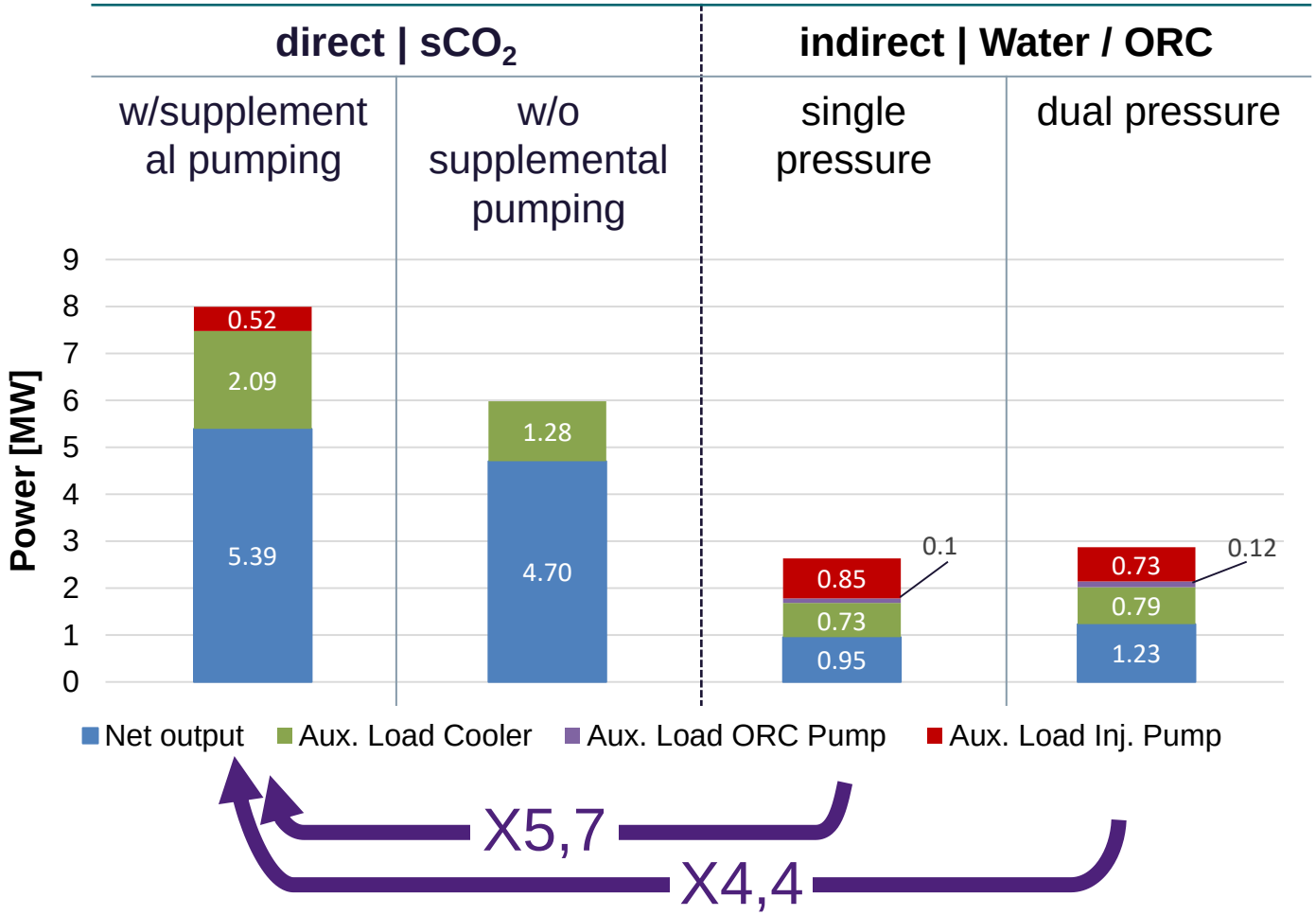
Saar, Adams; Subsurface Energy Storage with CO_2; 2018

Base Case well pattern



How Does NGP Compare?

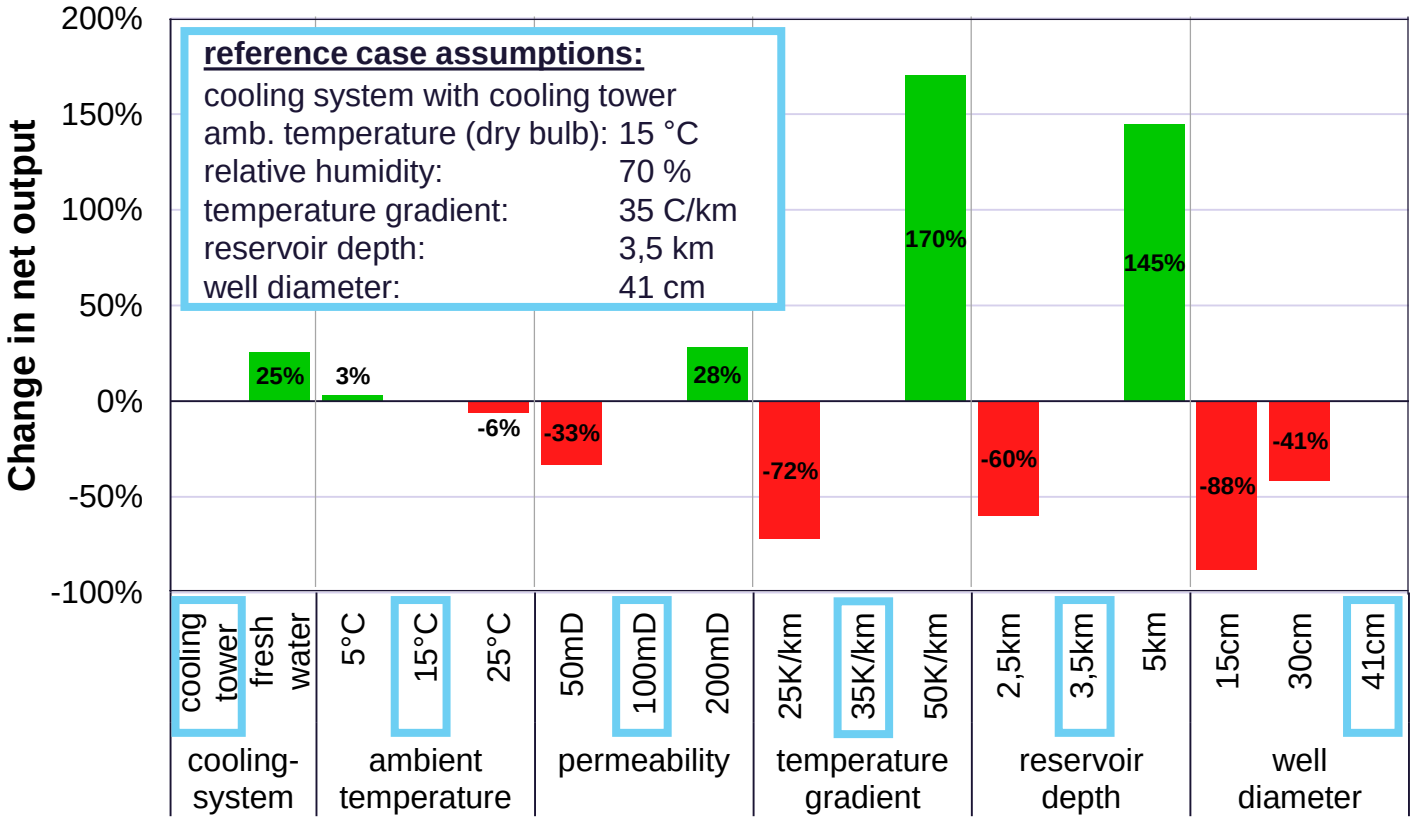
Power Cycle Variants



- Same Reservoir conditions for both cycles
- Same Ambient conditions for both cycles
- Smaller well diameter for NGP (Tubing included)
- Higher turbine efficiency for NGP cycle

Up to ~ 6 x net power output
compared to water based systems at base case

What is the Sensitivity to Changes in Geologic and Ambient Conditions?



- Sensitivity study with one variable
- Fresh water cooling reduces losses (pumps vs. fans) and provides lower temperature of heat rejection improving net power
- Net power increases with higher temperature gradient, permeability, and depth
- Large wells diameters reduce pressure losses
  - diameters will be determined based on permeability and depth

How many wells?

Wellfield pattern:

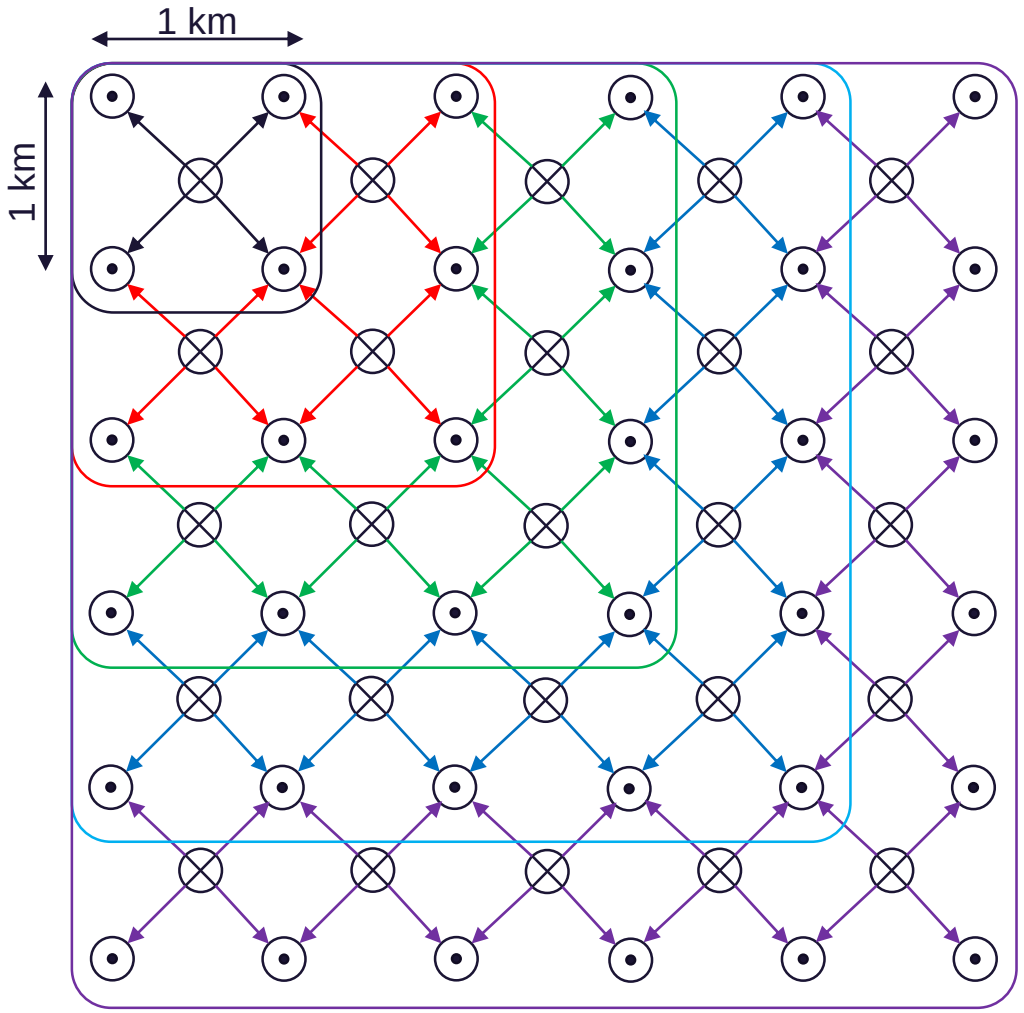
1x1km
(five-spot pattern)

2x2km

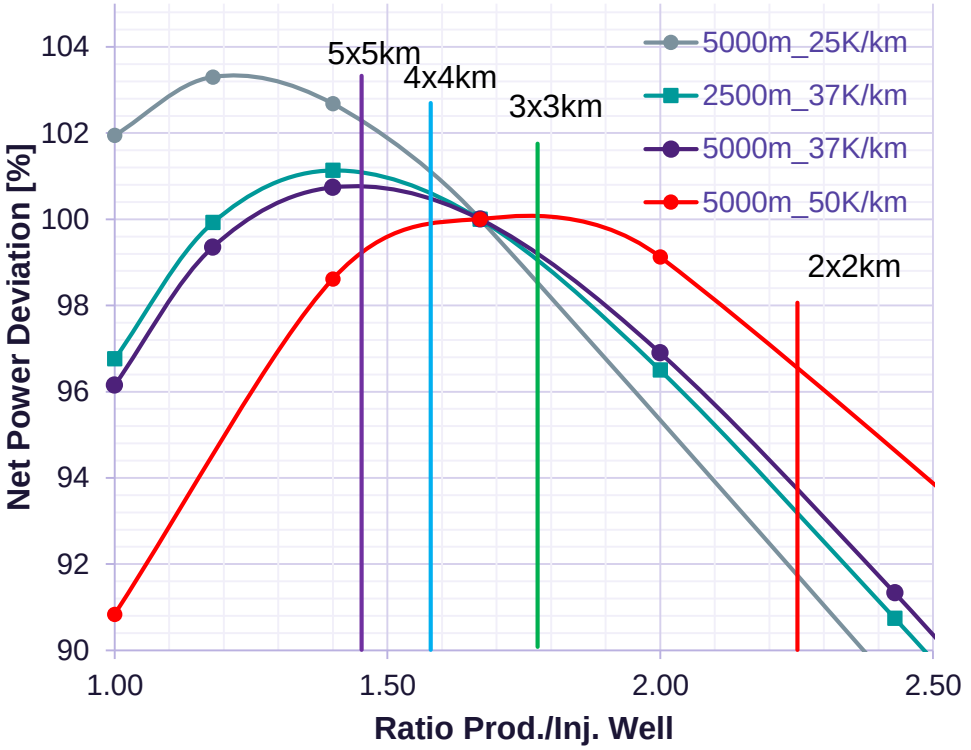
3x3km

4x4km

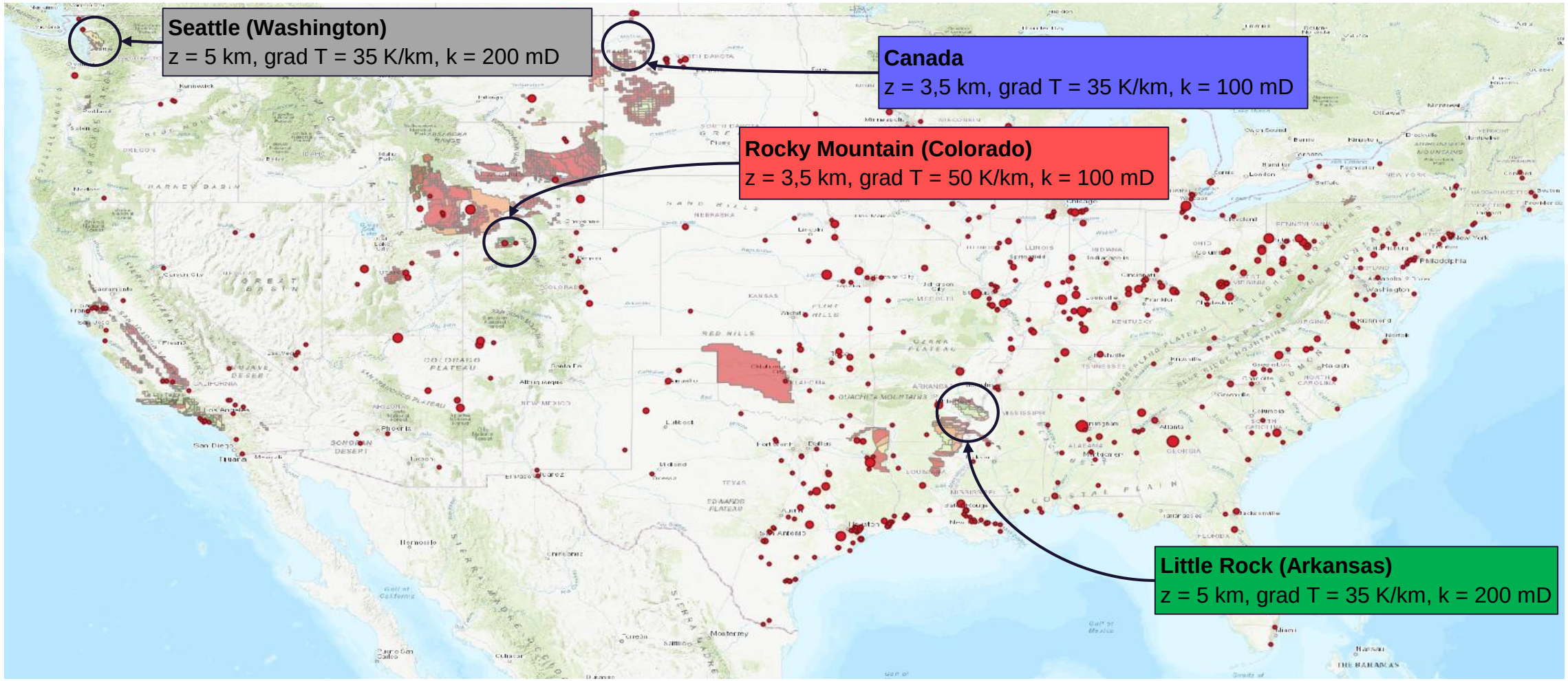
5x5km



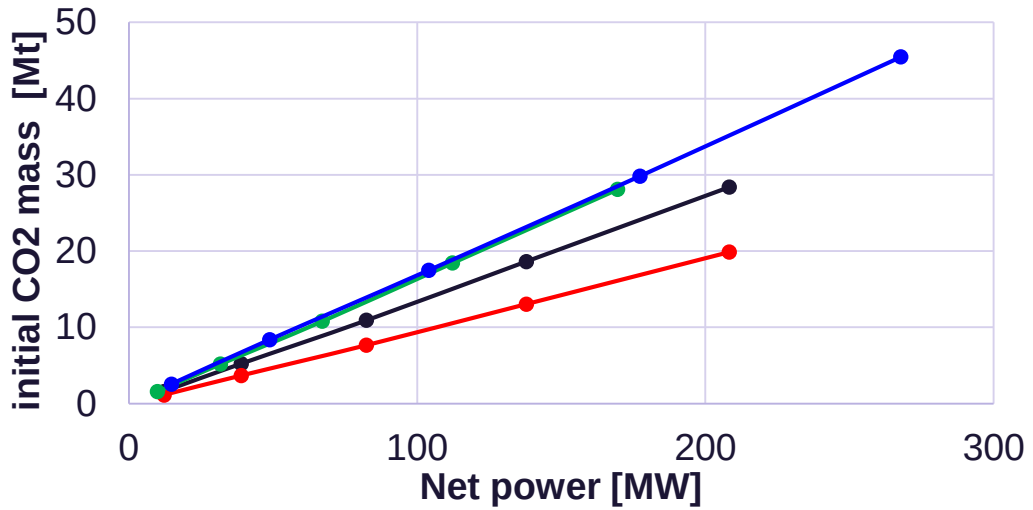
⊙ production well
⊗ injection well

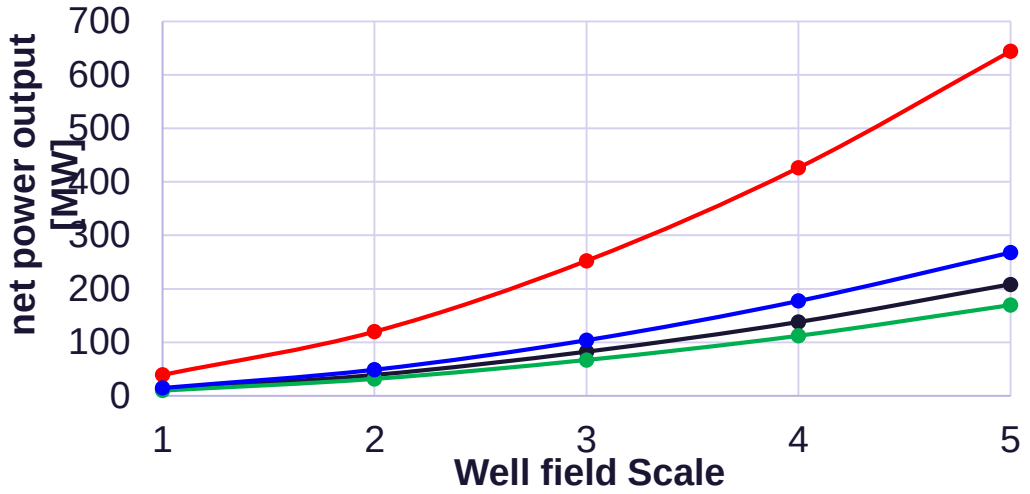


- **Optimal Prod / Inj ratio dependent on reservoir conditions**
- **Main driver: temperature gradient**



How much CO2 and How much Power?





Reservoir 1 Seattle	
depth:	5 km
temp.gradient:	35 C/km
permeability:	200 mD
thickness:	100 m
amb. temp.:	10 ºC
direct cooling	

Reservoir 2 Rocky M.	
depth:	3.5 km
temp.gradient:	50 C/km
permeability:	100 mD
thickness:	100 m
amb. temp.:	10 ºC
cooling tower	

Reservoir 3 Little Rock	
depth:	5 km
temp.gradient:	35 C/km
permeability:	200 mD
thickness:	100 m
amb. temp.:	15 ºC
cooling tower	

Reservoir 4 Canada	
depth:	3.5 km
temp.gradient:	35 C/km
permeability:	100 mD
thickness:	200 m
amb. temp.:	5 ºC
cooling tower	

Project Capital Expenditures

SIEMENS energy

Wells (Partner)

- Drilling
- Casing
- Corrosion protection
- Project management

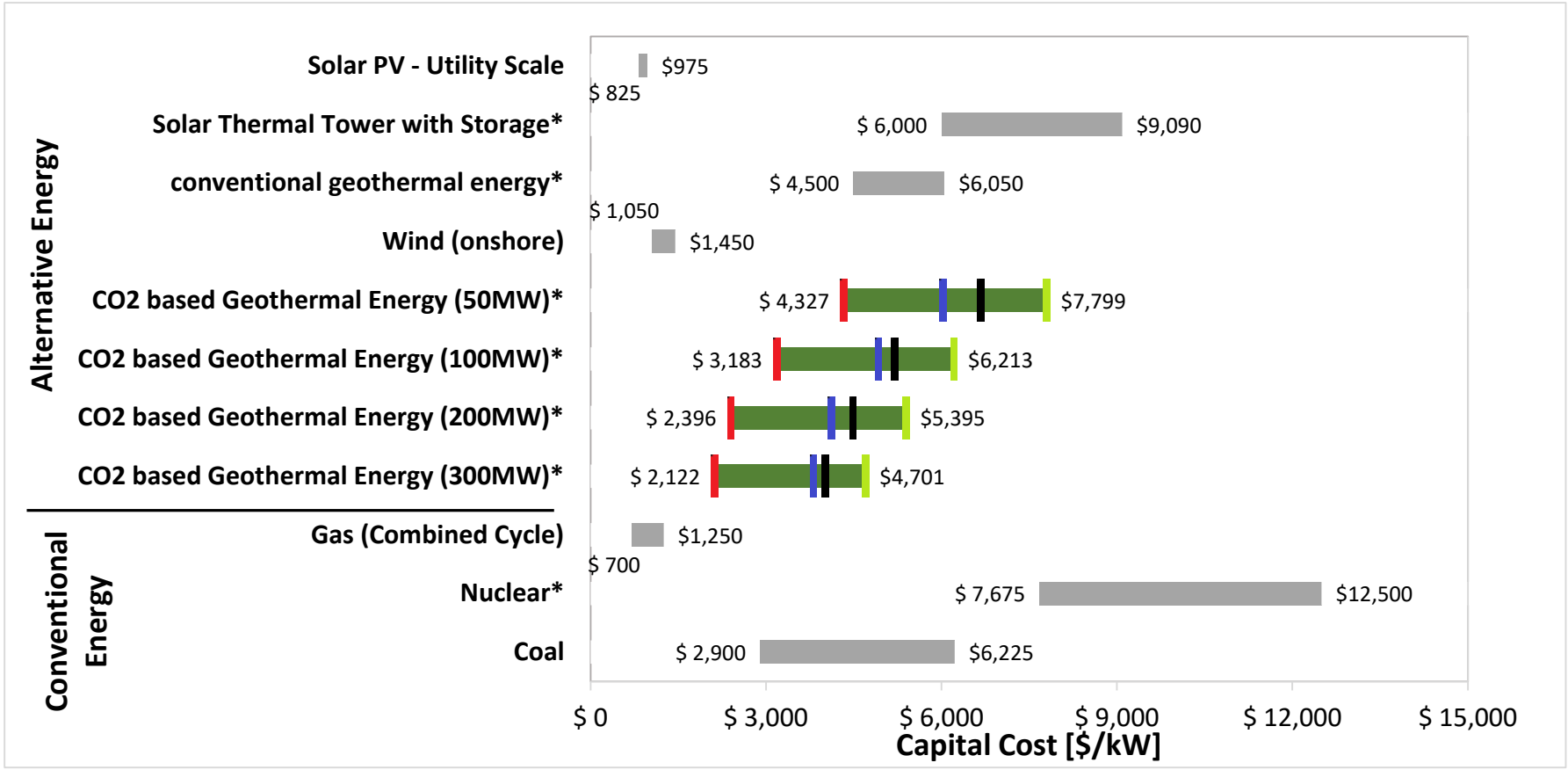
Surface Piping (Siemens Energy / Partner)

- Piping wells to surface
- Piping network to power plant
- Civil works

Power Plant (Siemens Energy)

- Turbomachinery
- Gas cooler
- Cooling tower
- Pumps
- Transmission interconnect
- Civil works
- Project management
- Control System

Capital Cost Comparison ($/kW)



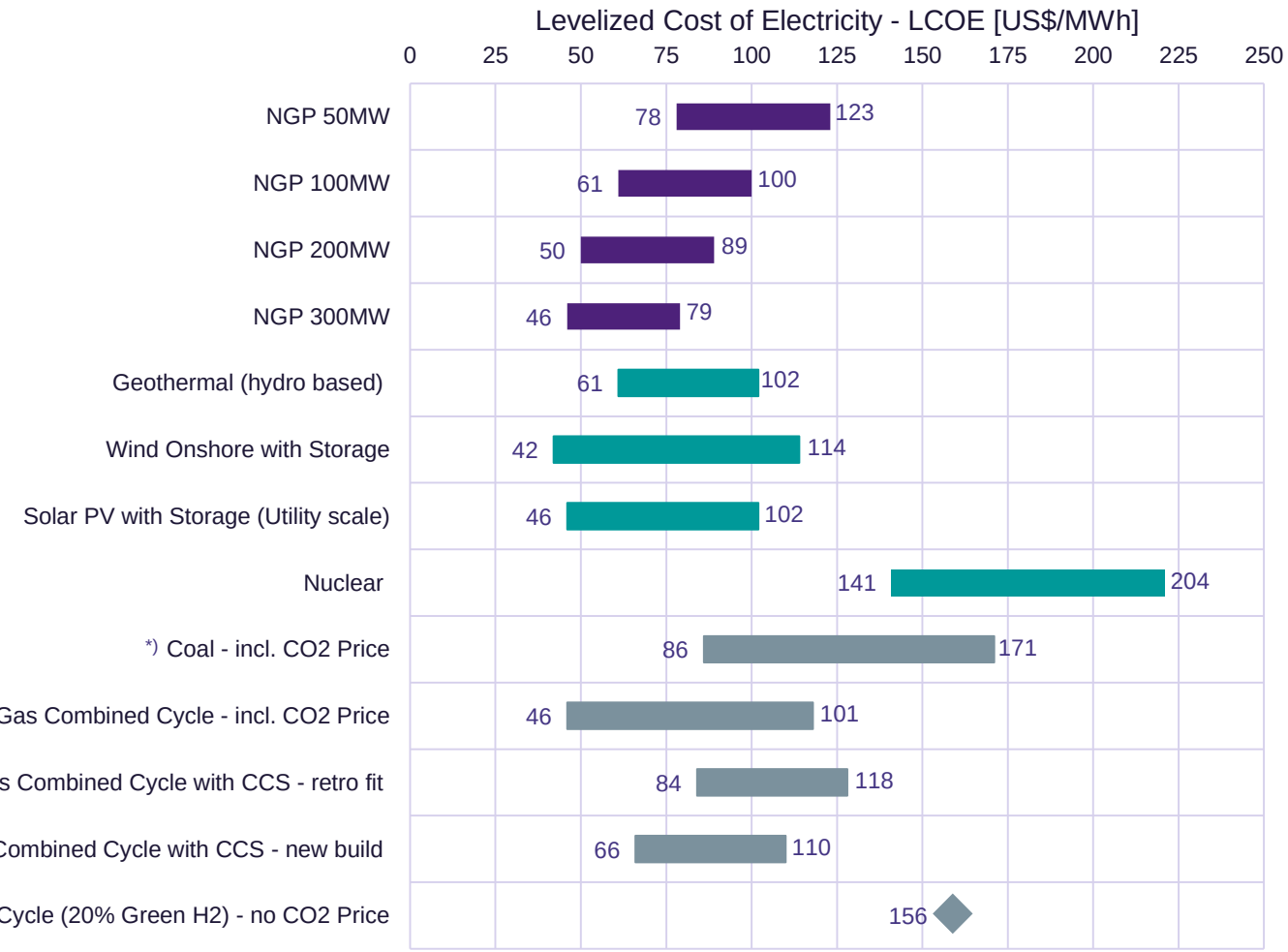
excl. expenses for capture plant, reservoir filling, CO2 and revenues from emission certificate trading

** baseload/dispatchable energy resource with CO2 "free" steady state operation*

https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf

LCOE Comparison ($/MWh)

NGP represents a competitive alternative to existing CO2 emissions “free” baseload/dispatchable energy technologies.



NOTE: Well costs for NGP power production validated by Halliburton

NGP LCOE are calculated based on different use cases in the US and Canada
Teal and **grey** columns represent results calculated by Lazard 2023:
https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/
NGP results are calculated with the same financial boundary conditions as in Lazard LCOE report
*) – 20 – 40 $/Ton of CO2 **) Gas fuel price $3,45/MMBTU – $4.15/kg Green Hydrogen

Proof of Concept

Partner:

MOL Group

Location:

Hungary

Depleted oil and gas reservoir

Usage of existing assets

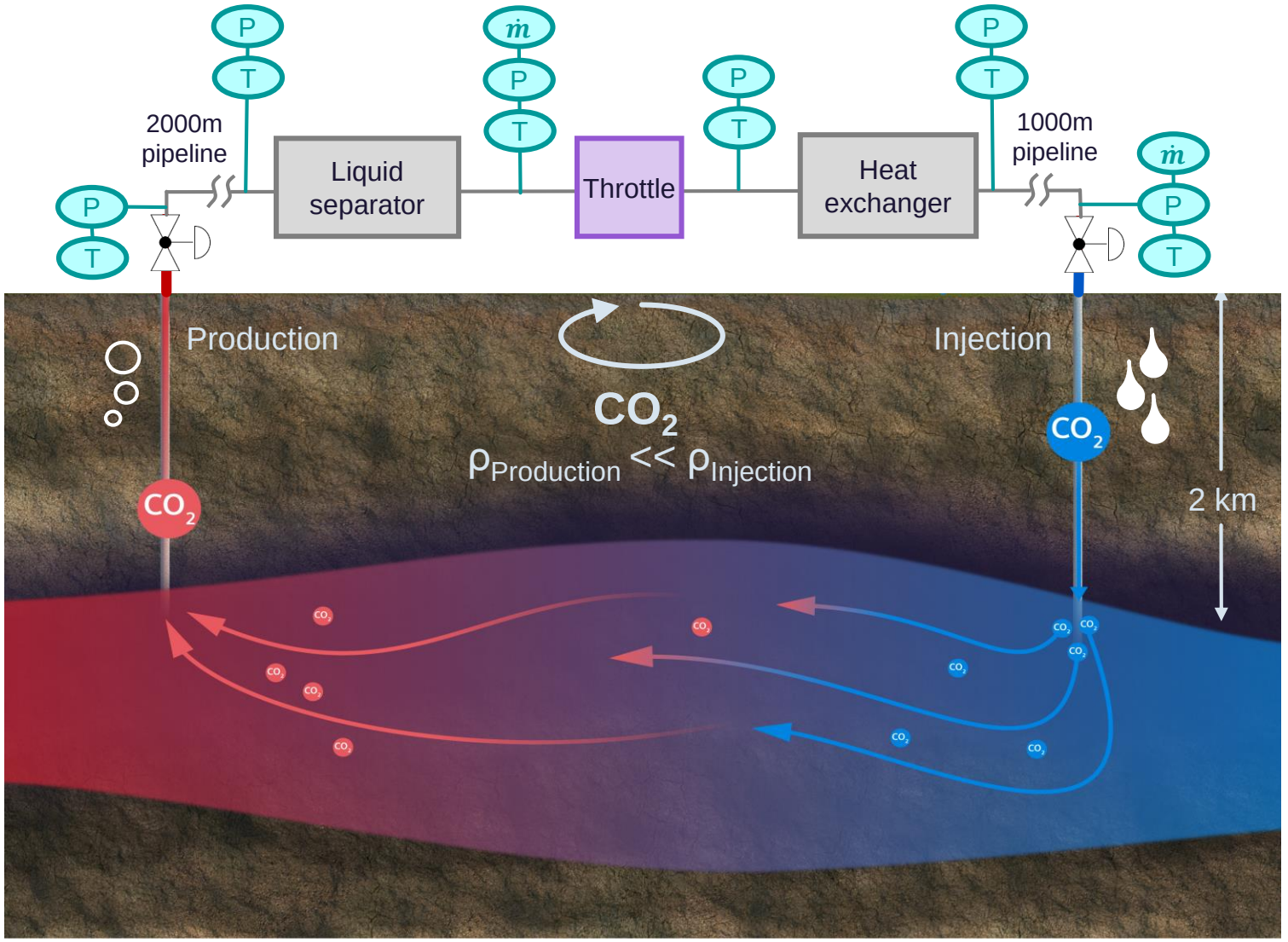
Achivements:

Stable CO2 circulation

Validation of calculation models

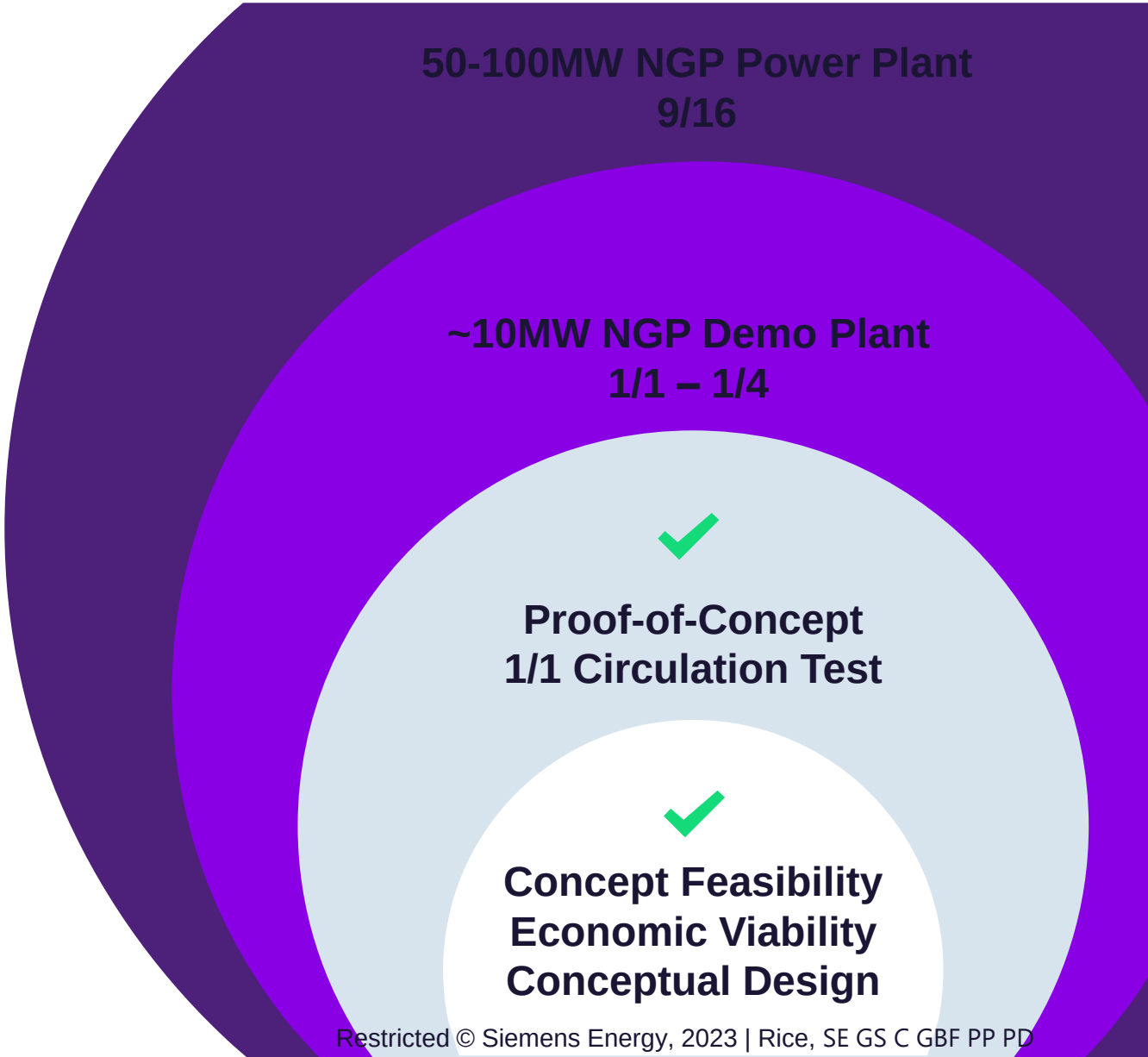
System regulation

Proof of thermosiphon concept



Next Steps

	Minimum Conditions
Temperature Gradient [°C/km]	30
Reservoir Thickness [meter]	50
Reservoir Permeability (millidarcy) [mD]	20
Reservoir Transmissivity (permeability x thickness) [mD*m]	1,000 (e.g. 50m thickness x 20mD permeability = 1,000mDm)
Well Depth [meter]	1,000
Total Mass CO2 [Mega tonne]	1-2
CO2 of Reservoir Contents [%-volume]	90% CO2
Well Injection Rate/ CO2 Mass Flow Rate (kg/sec)	220-600 7Mt/a-19Mt/a



Next-Gen Geothermal Power Opportunity

Pilot Project Business Case

Levelized Cost of Electricity (LCOE) Forecast

Power Plant		
Capacity	5	Mwel.
Load Factor	90	%
Operating time per year	39,420	MWh
Lifetime	25	years

Capex		
Power Plant (excl. cooling)	12.5	$m
Cooling	5.25	$m
Power Plant Piping	1	$m
CO2 Transfer Piping	Not incl.	$m
Wells (Injection & Production)	50	$m
Total	**68.75**	**$m**

Opex		
Variable (to MW output)	197,100	$
Fixed	150,000	$
Well O&M	150,000	$
Total	**497,100**	**$**

Financial (Placeholders)		
Opex escalation rate	2.25	%
Discount Rate (WACC)	10	%
Effective tax Rate	27	%

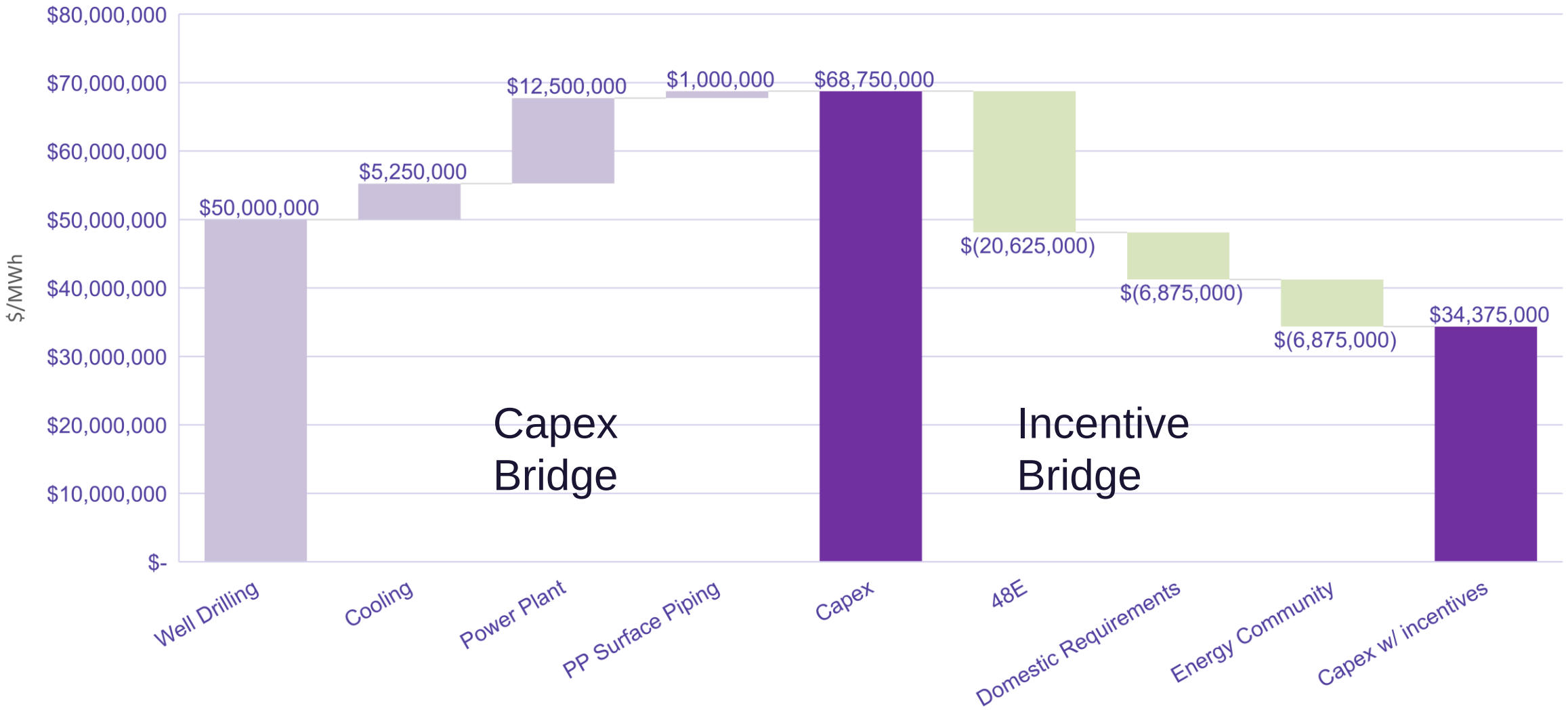
LCOE Calculation Scheme

LCOE = 218 $/MWh

$$LCOE = \frac{\sum_{t=0}^{n} \frac{C_t + M_t + F_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}} = 218\ \$/MWh$$

$$NPV = \sum_{t=0}^{n} \frac{(LCOE * E_t - Costs)_t}{(1+r)^t} = 0$$

Capex Forecast



Clean Electricity Investment Tax Credit & Clean Energy Production Tax Credit

January 1st, 2025 - 2033

Background:

Post-January 1st, 2025 Inflation Reduction Act (IRA) sections 45 & 48 will expand to all qualified facilities with net-zero emissions. Sections 45Y, Clean Energy Production Tax Credit, and 48E, Clean Electricity Investment Tax Credit, will continue IRA benefits until emission targets are achieved post-2033.

Base Credit Rate: Elect Section 48E or 45Y

48E: Clean Electricity Investment Tax Credit

- **30% tax credit rate**. These credits will start to phase out for projects under construction after 2033 or when emission targets are achieved.
- To qualify under section 48E an energy storage project must satisfy prevailing wage and apprenticeship requirements or only be eligible for base 6% tax credits.

45Y: Clean Energy Production Tax Credit

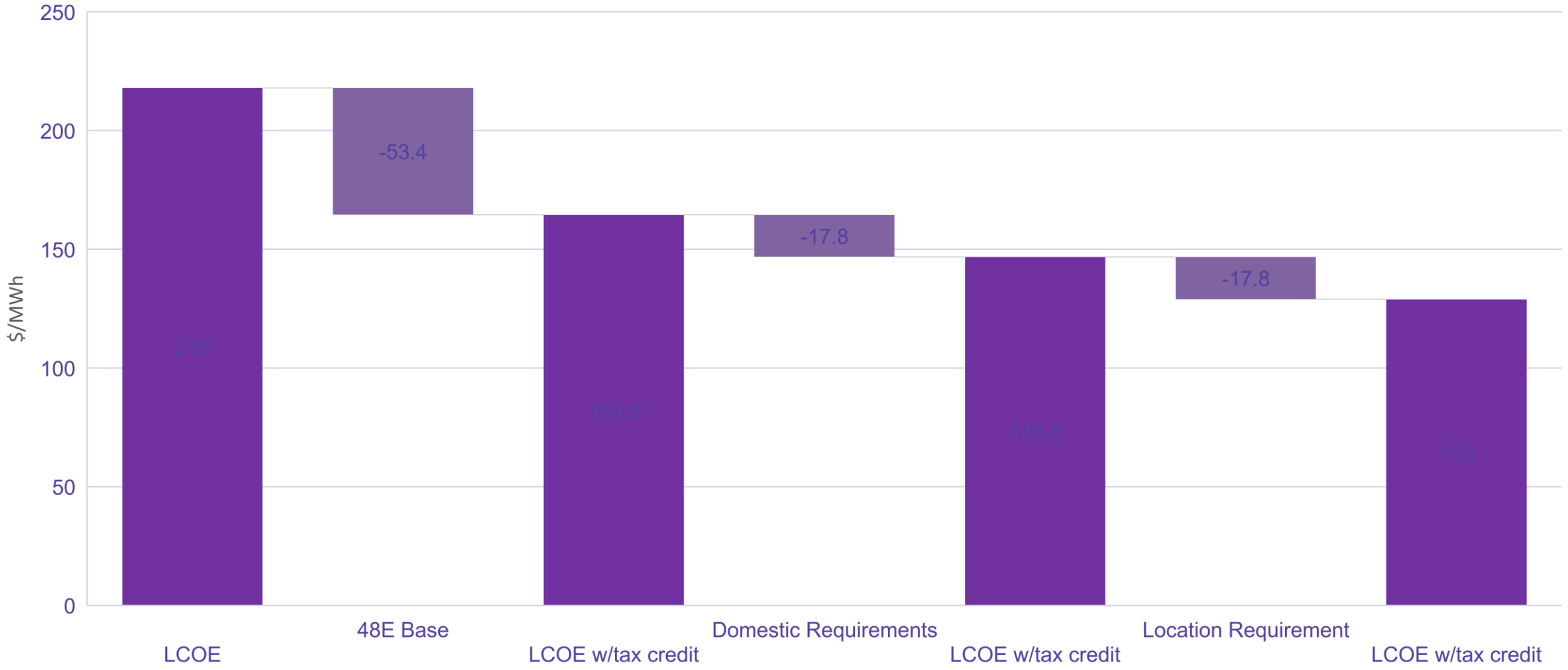
- **$15/MWh adjusted for inflation base year 1992. Adjusted PTC ≈ $27.50**
- $3/MWh without prevailing wage and apprenticeship requirements.

Additional Credits	Max Bonus Credits
Domestic Content Minimums • 100% iron/steel. The domestic standard for iron/steel products does not apply to iron/steel components incorporated into other manufactured products, but only to those products made "primarily" of iron/steel. • 40% total costs of manufactured products that are components of the facility. Likely to increase to 45% before 2025, 50% before 2026, and 55% for construction projects starting after 2026.	**ITC: +10%** **PTC: +$1.5/MWh**
Siting in an Energy Community • ex. Brownfield site, area related to mining operations	**ITC: +10%** **PTC: +$1.5/MWh**
Siting in Low-Income Community or on Indian Land (<5 MW_{AC})	**ITC: +10%** **PTC: N/A**

Wage and Apprenticeship Requirements:

Workers must be paid prevailing wages at the rates published for Davis-Bacon Act purposes both during construction and for repairs during the credit period (10 years for the PTC and 5 years for the ITC); and a certain percentage of workers must be qualified apprentices during construction.

Levelized Cost of Electricity (LCOE) Forecast Subsidized with IRA 48E ITC



45Q CCS/CCUS Tax Credit

Background:

First introduced in 2008, Section 45Q of the Unites States Internal Revenue Code provides a tax credit for CO2 storage. The policy is intended to incentivize deployment of carbon capture, utilization and storage (CCUS), and a variety of project types are eligible.

In 2022, the US introduced a significant stimulus for CCUS investment with the passage of legislation (the Inflation Reduction Act) to expand and extend the 45Q tax credit.

45Q: Capacity Requirements

- 18,750 tons per year for power plants (provided at least 75% of the CO2 is captured)
- 12,000 tons per year for other facilities
- 1,000 tons per year for DAC facilities

IRA Direct Payment Options:

- Carbon capture project developers can receive 45Q as a fully refundable direct payment as if it were an overpayment of taxes.
- For-profit, tax-paying entities can only realize the direct pay option for five years after the carbon capture equipment is placed in service.
- Tax-exempt entities such as states, municipalities, Tribes, and cooperatives can realize the direct pay option for the full 12 years after the carbon capture equipment is placed in service.

Transferability of Credit:

- Recipients of the 45Q tax credit may transfer all or any portion of the credit value credit to any third-party, tax-paying entity in exchange for a cash payment during any portion of the 12-year credit window.
- The cash payment received by the original recipient of 45Q will not be taxable.

	2018 BBA-45Q Credit	2022 IRA-45Q Credit
QCO Captured by Industrial Facility (Non-EOR/non-utilized)	$50/MT	$85/MT
QCO Captured by Industrial Facility (Used in EOR/ utilized)	$35/MT	$60/MT
QCO Captured by DAC (Non-EOR/Non-Utilized)	$50/MT	$180/MT
QCO Captured by DAC (Used in EOR/Utilized)	$35/MT	$130/MT

45Q Projects must commence construction January 1, 2033: Projects must begin physical work by then to qualify for the credit.

IRS Guidance: https://www.irs.gov/pub/irs-drop/n-23-18.pdf

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