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Feasibility and Design of Engineered Geothermal Systems using Dry Holes as a Prospective Location

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Outline

- Introduction
- Practical Location
- Regional Geology
- Worldwide Lessons Learnt
- Safety & Environmental Issues
- Geothermal Reservoir Simulation
- Power Plant Design
- Economic Analysis
- Conclusions
- Recommendations

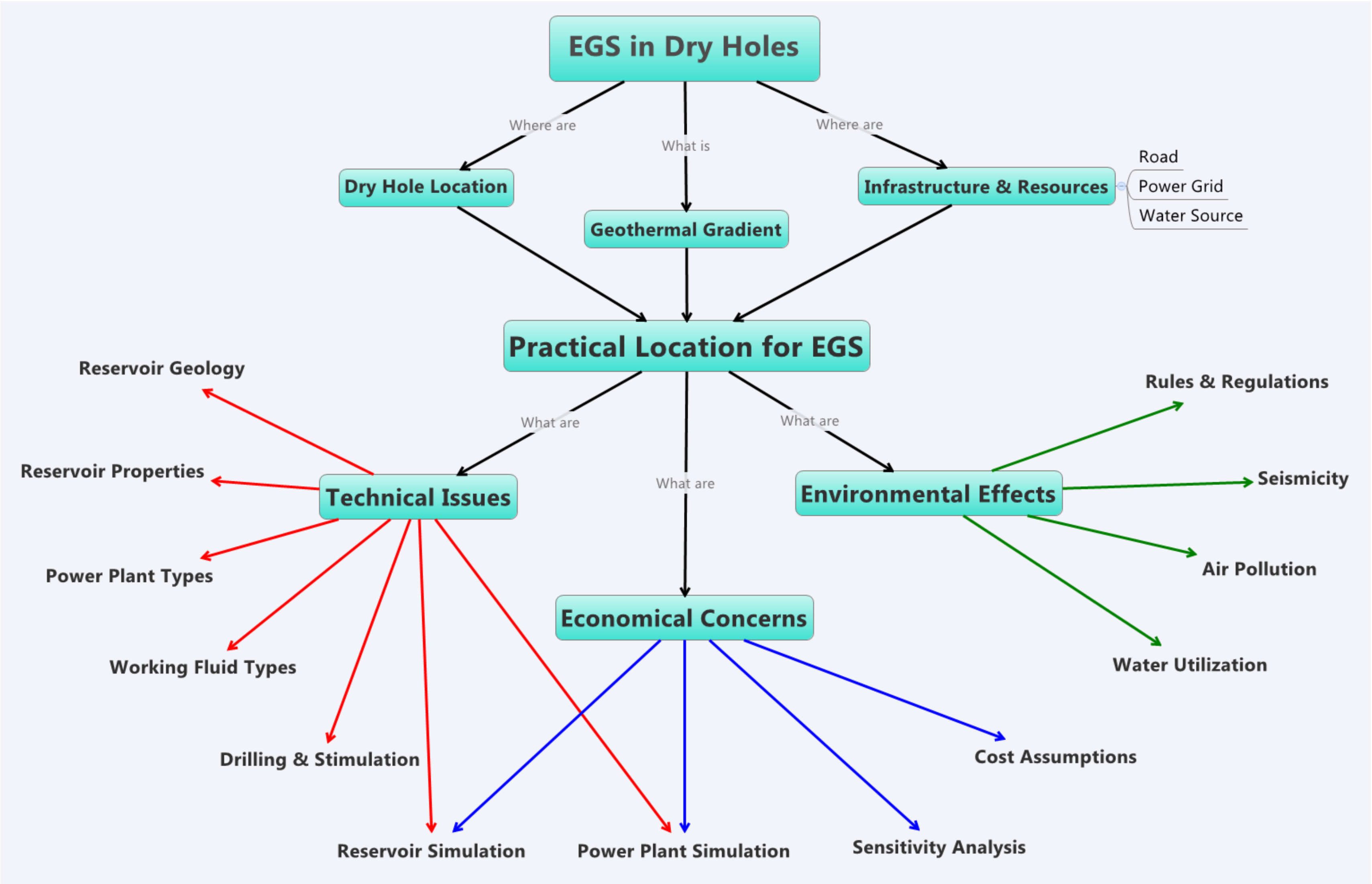
Introduction

Problem Statement

To evaluate the economic, environmental and design viability in extracting thermal energy using Enhanced Geothermal Systems (EGS) from existing dry holes which are located near to existing gas fields

To investigate different power plant designs and to choose the most optimum design

Introduction



Introduction

	Jan. 10			Feb. 10				Mar. 10					Apr. 10				May
Problem Statement																	
Concept Map & Workflow																	
Critical Literature Review																	
Practical Location for EGS																	
Dry Hole Location																	
Geothermal Gradient																	
Infrastructure & Resources																	
Review Data & Literature																	
Information on other EGS projects																	
Geology / Lithology																	
Reservoir Properties																	
Drilling and Stimulation																	
Power Plant Types																	
Working Fluid																	
Water Utilization																	
Air Pollution																	
Seismicity																	
Regulations and Policies																	
Simulation Study																	
Reservoir Simulation																	
Power Plants Simulation																	
Economical Analysis																	
Cost Assumptions																	
Sensitivity Analysis																	
Final Report																	

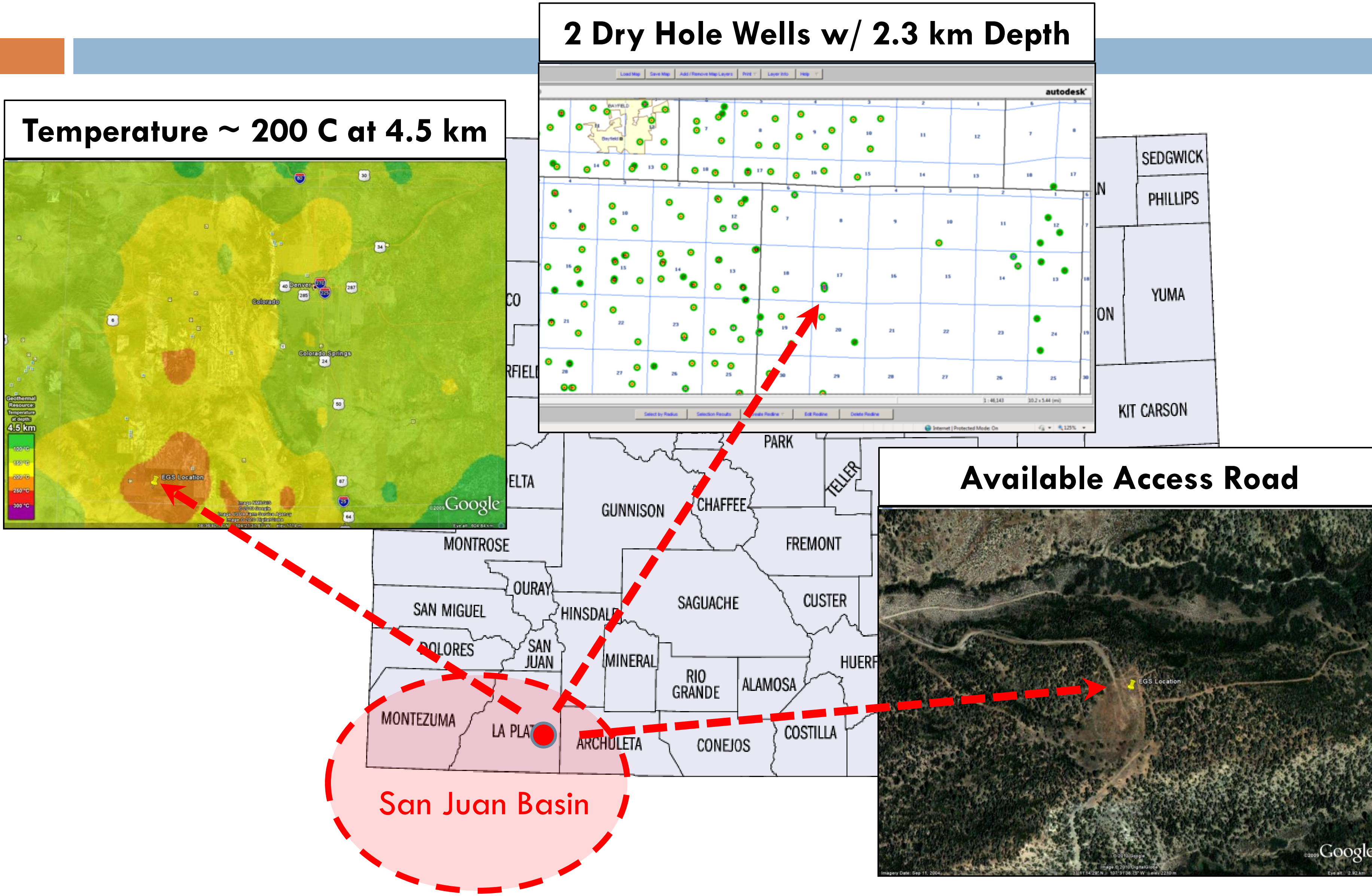
Practical Location

"**Colorado**" has good geothermal development potential due to,

- High Heat Flow – anomaly high heat flow in various regions (>100mW/m2) which results from volcanic activity

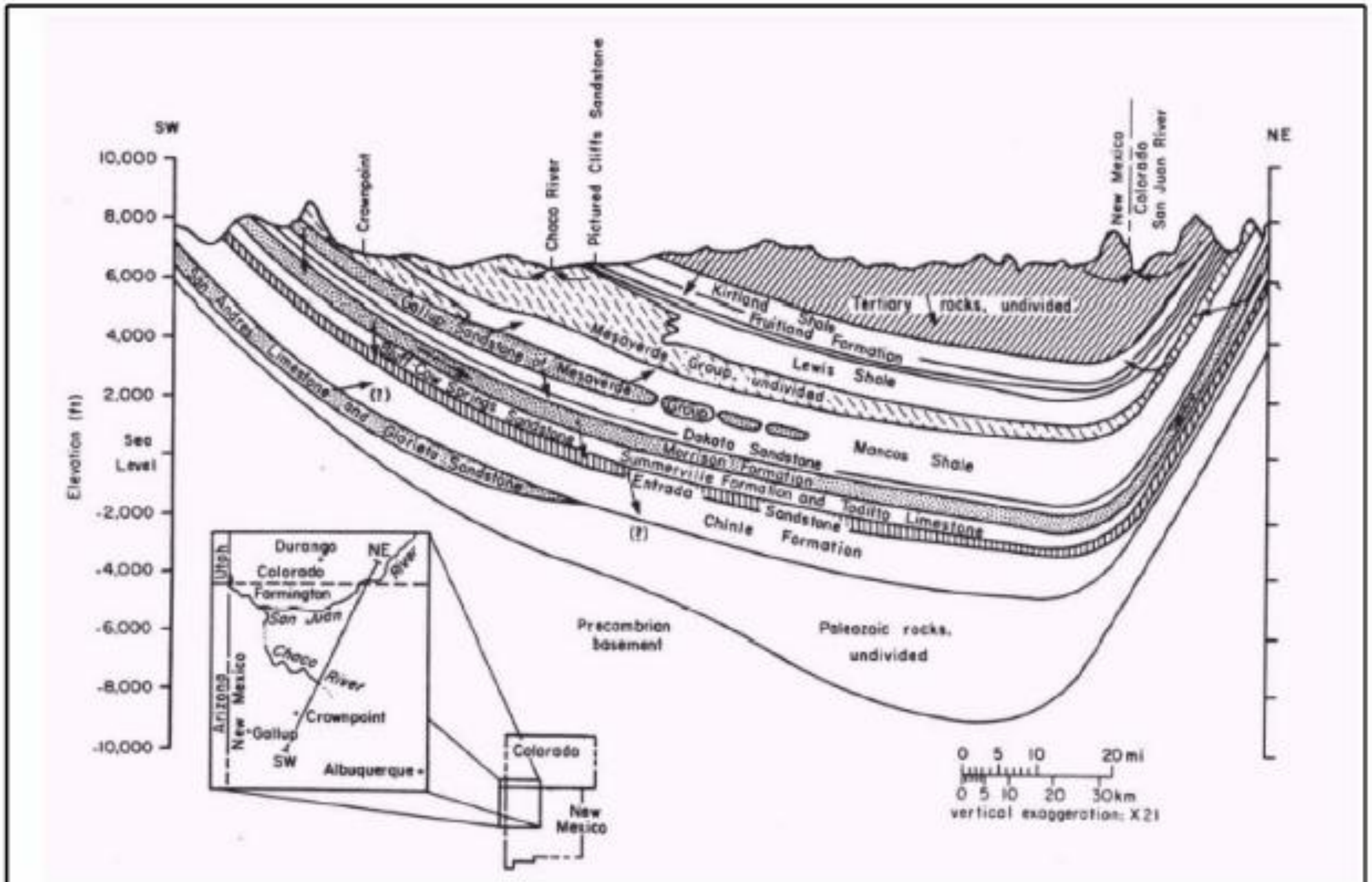
In addition, Colorado has more than 60,000 oil and gas wells and there are a significant number of dry and abandoned locations at reasonable depth (COGCC,2010)

Practical Location



Regional Geology (San Juan Basin)

SPRING CREEK #1-17	
Formation Name	Formation Tops (ft.)
KIRTLAND	2713
FRUITLAND	2952
PICTURED CLIFFS	3108
LEWIS	3294
CLIFF HOUSE	5246
MENEFEE	5654
POINT LOOKOUT	5828
MANCOS	5939
GALLUP	7208
GREENHORN	7862
GRANEROS	7904
DAKOTA	8042



Generalized Hydrogeologic Cross-Section of the San Juan Basin (Stone et al., 1983)

Figure A1-2

Worldwide Lessons Learned *

- Stress field and natural fracture system play a significant role in the growth of the stimulated area.
- With the current technology, it is very difficult to predict what the stress field will be in the vicinity of the well.
- High flow rates (>50 kg/s) were not achieved in previous cases of EGS development.
- Shortcuts, water loss, and retention time are the major problems that may occur with high flow rate EGS plants.

* The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century , Massachusetts Institute of Technology

Worldwide Lessons Learned (Cont.) *

- Well spacing needs to be as large as possible while still making a connection between injector(s) and producer(s).
- Over-stimulating of pre-existing fractures can result in more direct connection between injector(s) to producer(s).
- Second well should be drilled only after drilling, stimulating and monitoring of the first well.

* The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century , Massachusetts Institute of Technology

Safety and Environmental Issues

- Clean air is one of the most significant environmental benefits of geothermal energy utilization.
- Induced seismicity from EGS development is not at the threatening level. However, 2 EGS projects have been terminated / suspended.
- Surface or ground water have to be utilized during project development and operation, but not at a significant level.
- Various federal and state regulations, i.e. Clean Air Act, Colorado Geothermal Resources Act EGS, control EGS project development.

GEOTHERMAL RESERVOIR SIMULATION

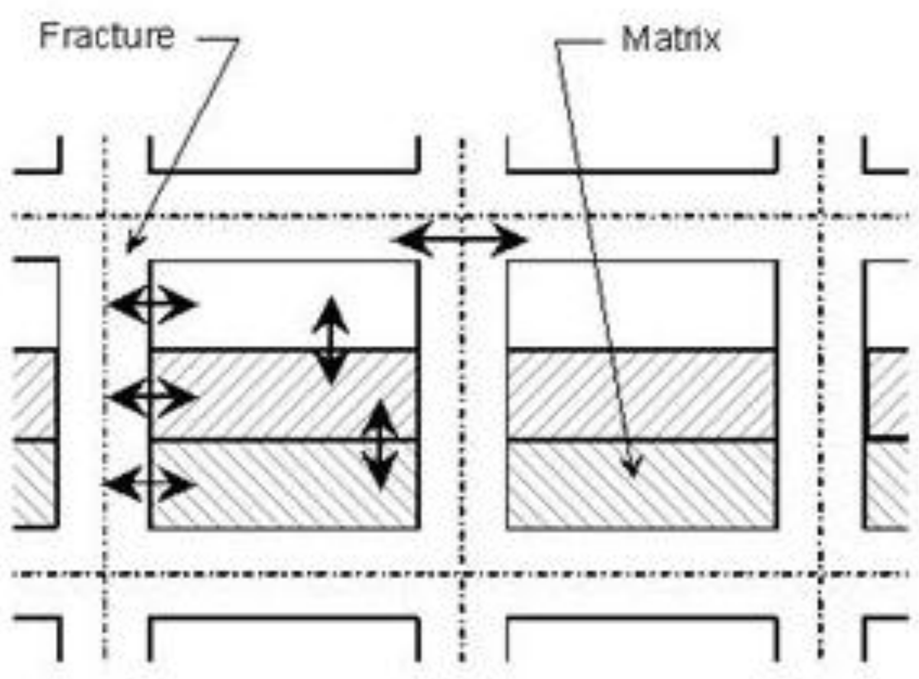
Geothermal Reservoir Simulation

- Simulating a geothermal reservoir essentially provides insight into how much heat and at what rate it can be extracted for a fixed set of operational parameters
- We can model the pressure and temperature variation with time to help determine the optimum development plan dictated by the economics

Geothermal Reservoir Simulation

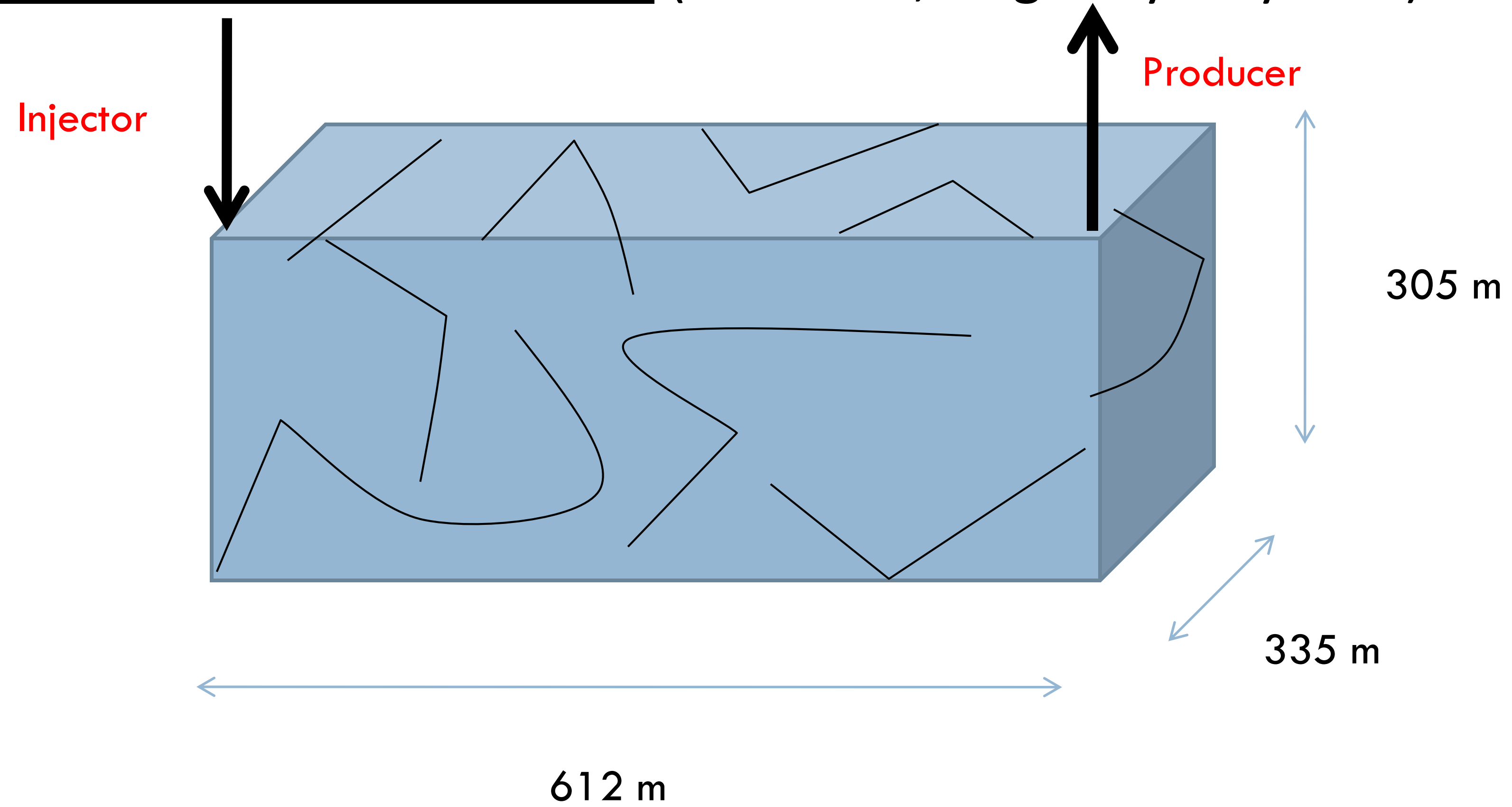
Model Selection (for fractured systems)

- MINC (Multiple Interacting Continua Model) (Pruess & Narasimhan ,1982b)



Geothermal Reservoir Simulation

Geothermal Reservoir Setup (fractured, single layer system)



No. of blocks in the X direction : 11
No. of blocks in the Y direction : 6

Injector & Producer well depth: 4200 m
Grid Type : CARTESIAN

Geothermal Reservoir Simulation

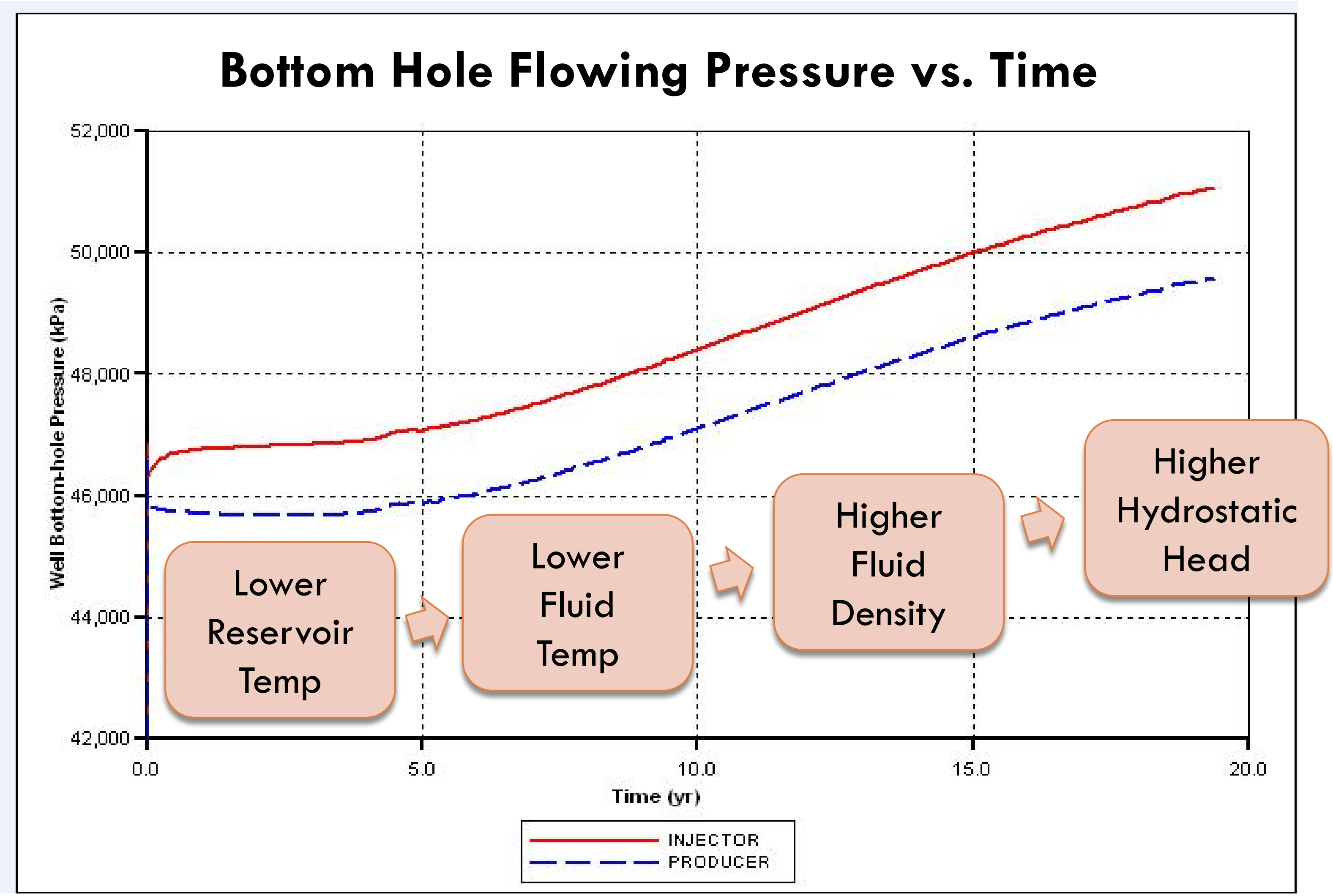
Reservoir & Fluid Properties

Parameters	Values
Fracture Spacing	10 m
Fracture Volume fraction	0.15
Matrix Porosity	0.1
Fracture Porosity	0.1
Matrix Permeability	1×10^{-14} m^2
Fracture Permeability	6×10^{-13} m^2
Injection Rate	3500 m^3/day
Injection Temperature	35 C
Production WHP	10,000 kPa
Initial Reservoir Pressure	42,000 kPa

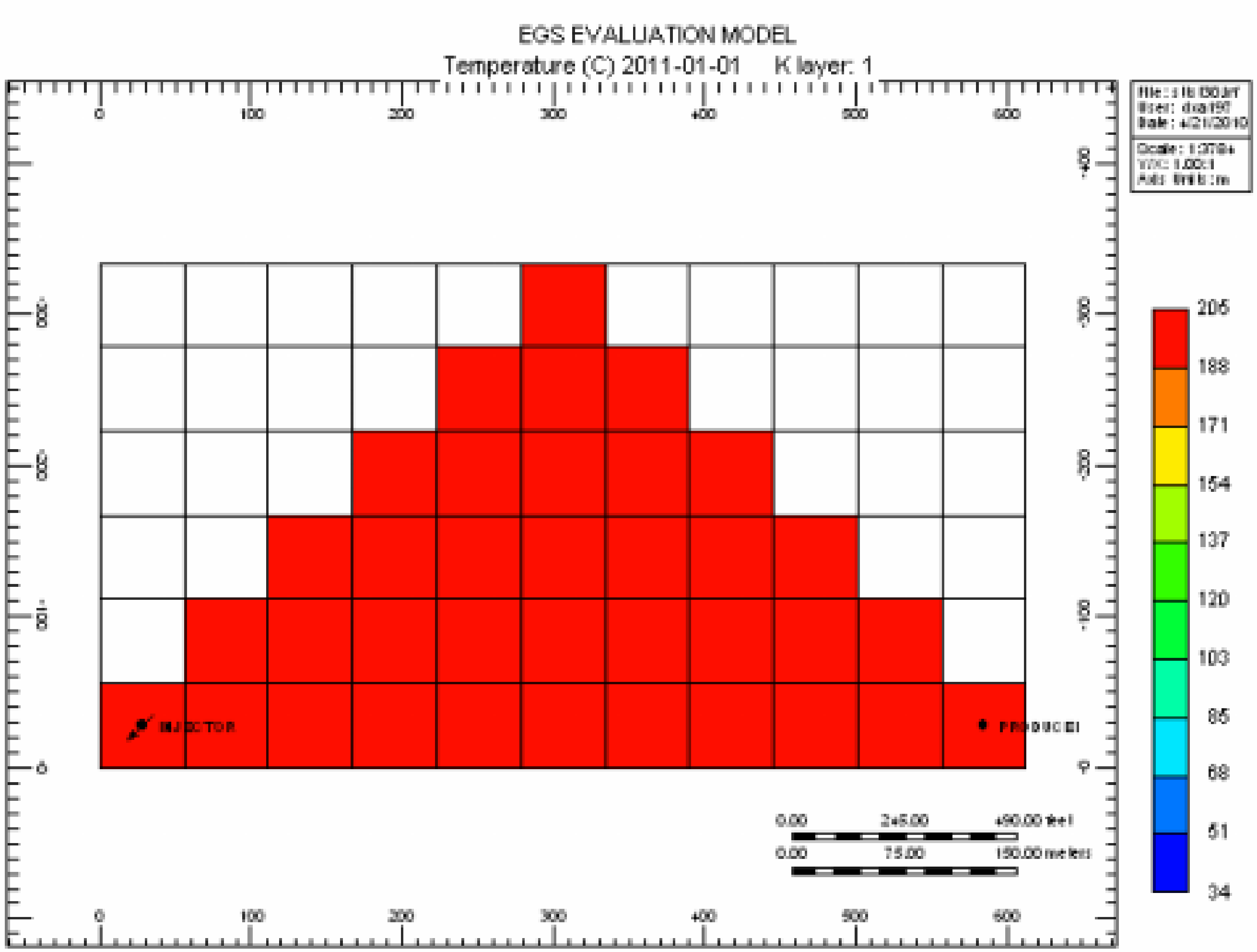
Parameters	Values
Initial Formation Temp	205 C
Rock Compressibility	4.4×10^{-7} 1/kPa
Rock Heat Capacity	2.65×10^6 J/m^3 C
Rock Thermal Conductivity	1.929×10^5 J/ m-day-c
Heat Capacity of Overburden	2.683e6 J/(m3*C)
Heat Capacity of Underburden	2.683e6 J/(m3*C)
Thermal Conductivity of Overburden	1.047e6 J/(m*day*C)
Thermal Conductivity of Underburden	1.047e6 J/(m*day*C)
Water Saturation	99%
Period of Operation	20 years

Pruess Data for a Geothermal Reservoir, Water Resources Research, Vol. 19, No. 1, February 1983, pp.201

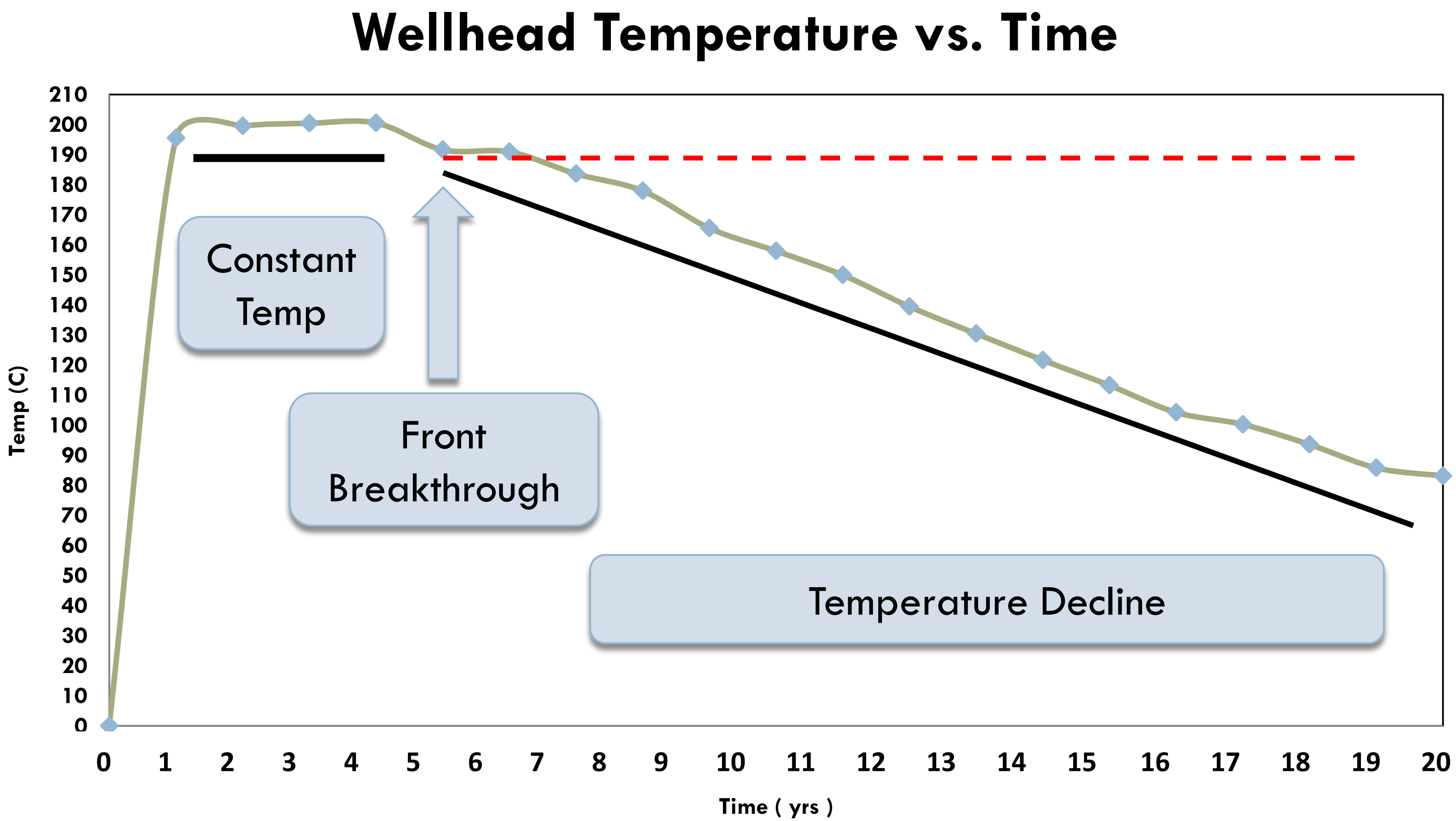
Geothermal Reservoir Simulation



Geothermal Reservoir Simulation



Geothermal Reservoir Simulation

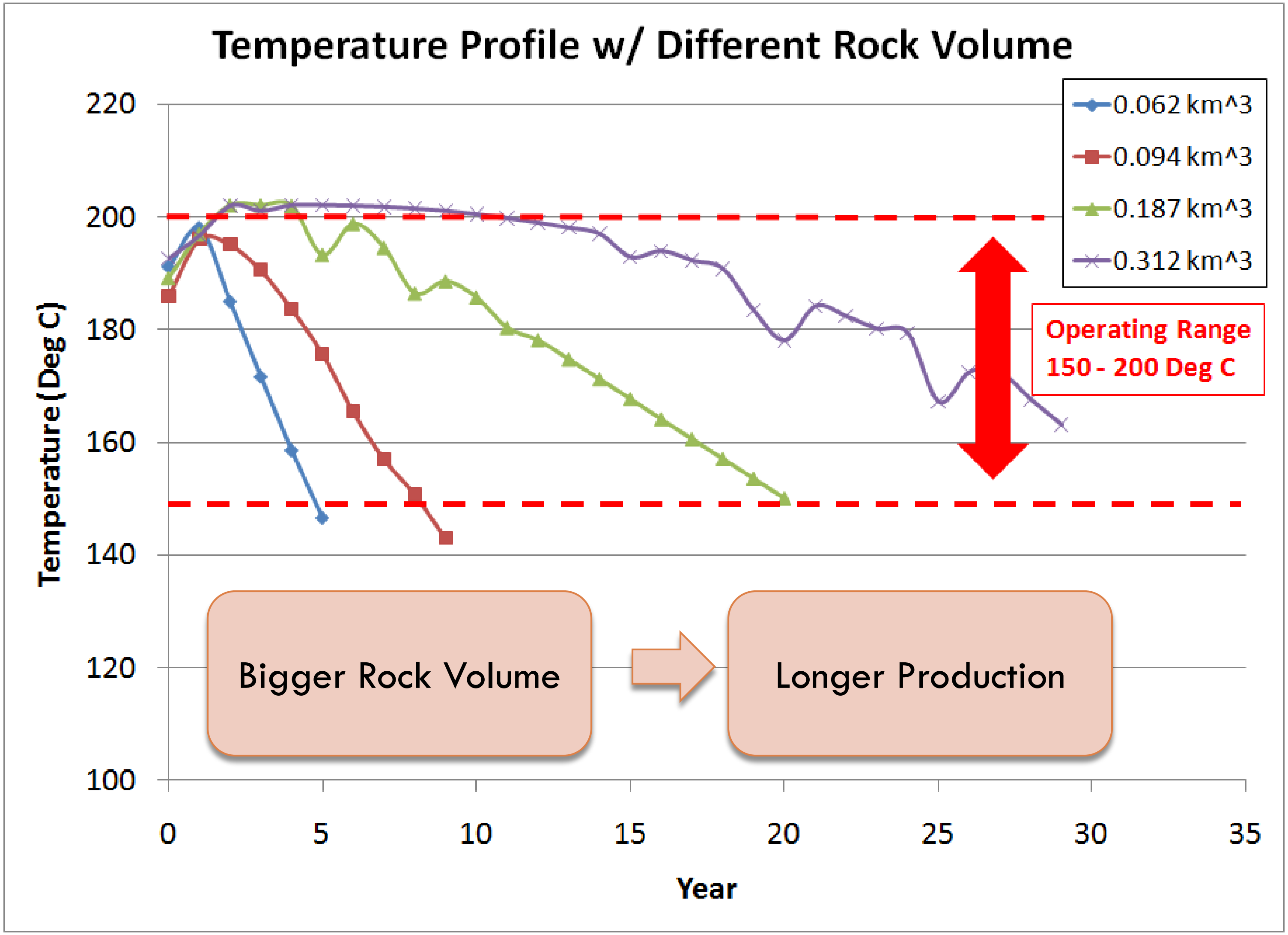


Geothermal Reservoir Simulation

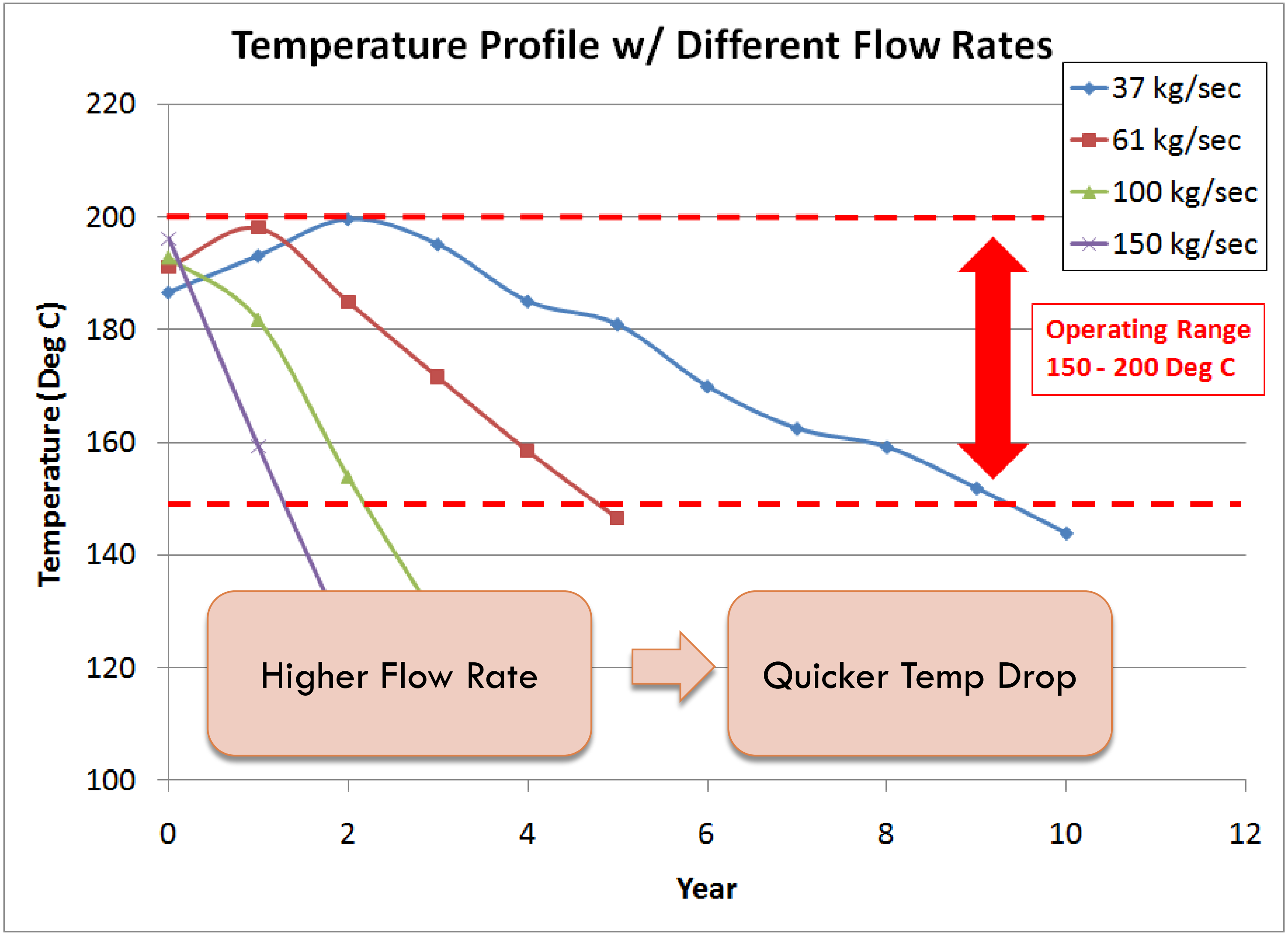
Scenarios

Case #	Rock Volume		Fracture	Water Inject Rate		Res Temp	WHP
	km^3		Spacing	kg/sec	m^3/d	(C)	(Mpa)
Case 1	0.062	100%	50	37	3197	205	10.0
Case 2	0.062	100%	50	61	5270	205	10.0
Case 3	0.062	100%	50	100	8640	205	10.0
Case 4	0.062	100%	50	150	12960	205	10.0
Case 5	0.062	100%	10	37	3197	205	10.0
Case 6	0.062	100%	10	61	5270	205	10.0
Case 7	0.062	100%	100	37	3197	205	10.0
Case 8	0.062	100%	100	61	5270	205	10.0
Case 9	0.094	150%	50	37	3197	205	10.0
Case 10	0.094	150%	50	61	5270	205	10.0
Case 11	0.031	50%	50	37	3197	205	10.0
Case 12	0.312	500%	50	61	5270	205	10.0
Case 13	0.187	300%	50	61	5270	205	10.0

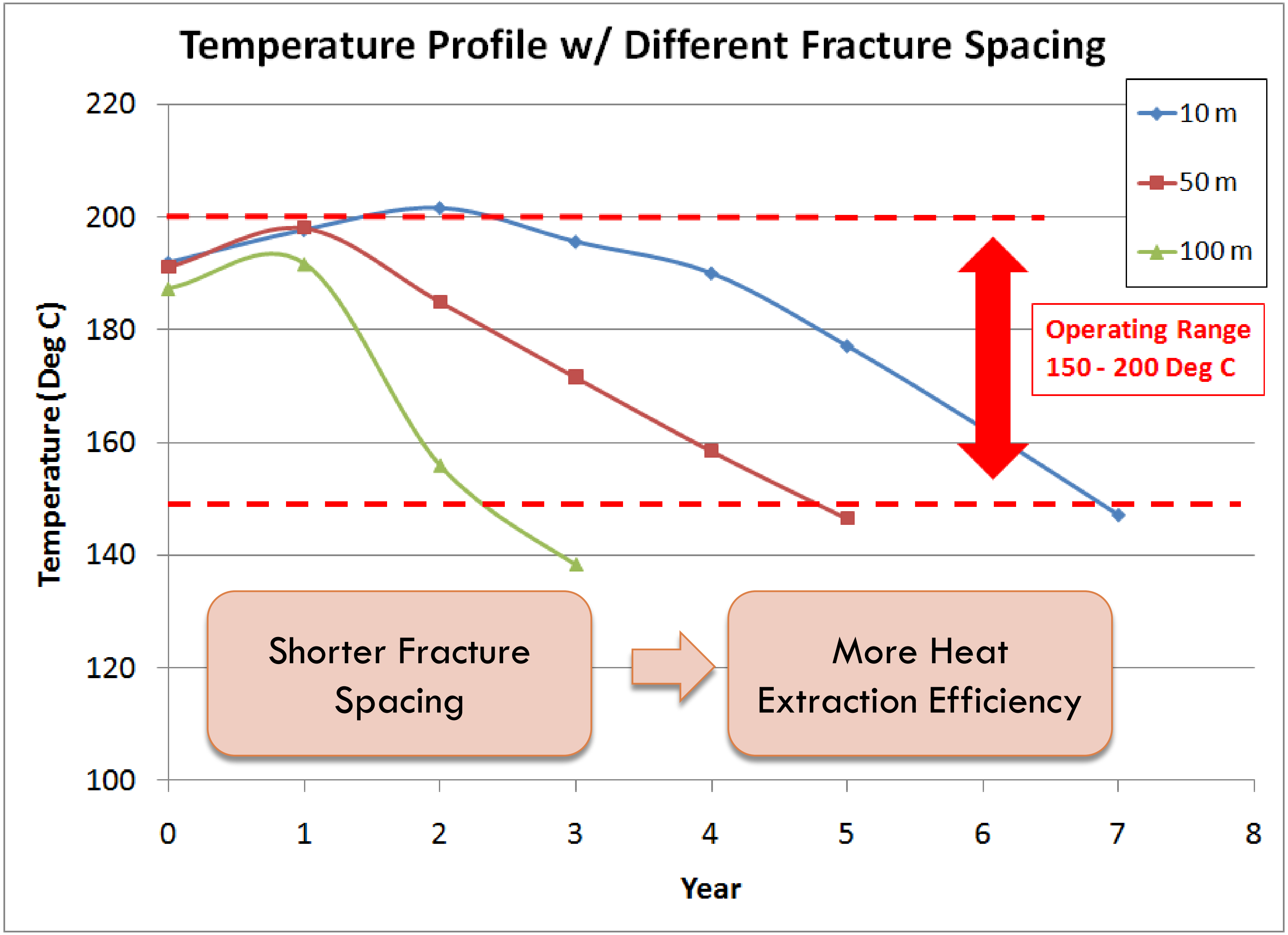
Geothermal Reservoir Simulation



Geothermal Reservoir Simulation



Geothermal Reservoir Simulation



POWER PLANT DESIGN

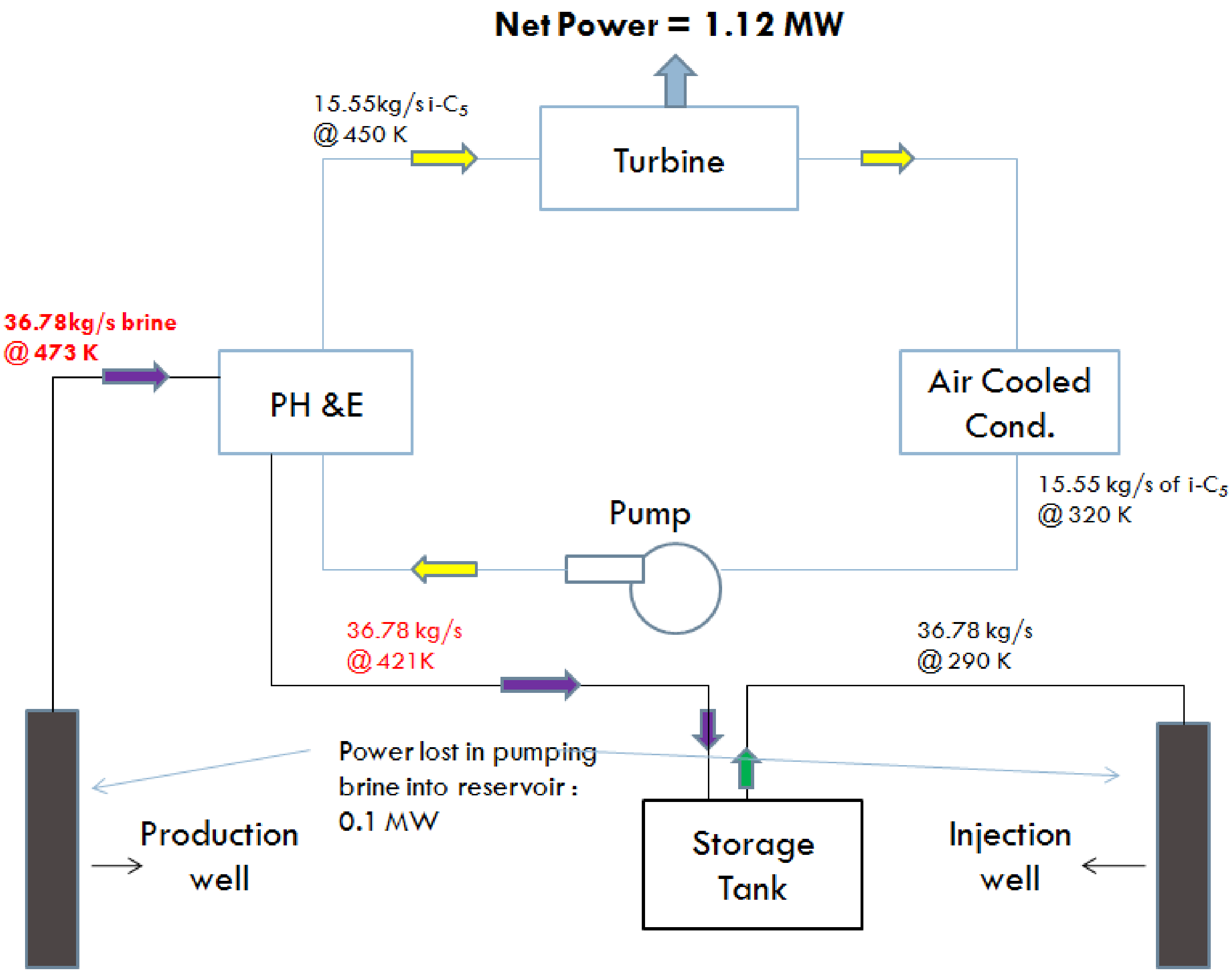
Power Plant Design

Factors Affecting Power Plant Design

- Temperature of the geothermal fluid
- Flow rate of the geothermal fluid
- Power plant type.
- Properties of working fluid

* J.W.Tester, MIT report, 2006; DiPippo, Geothermal Power Plants, Elsevier, 2005

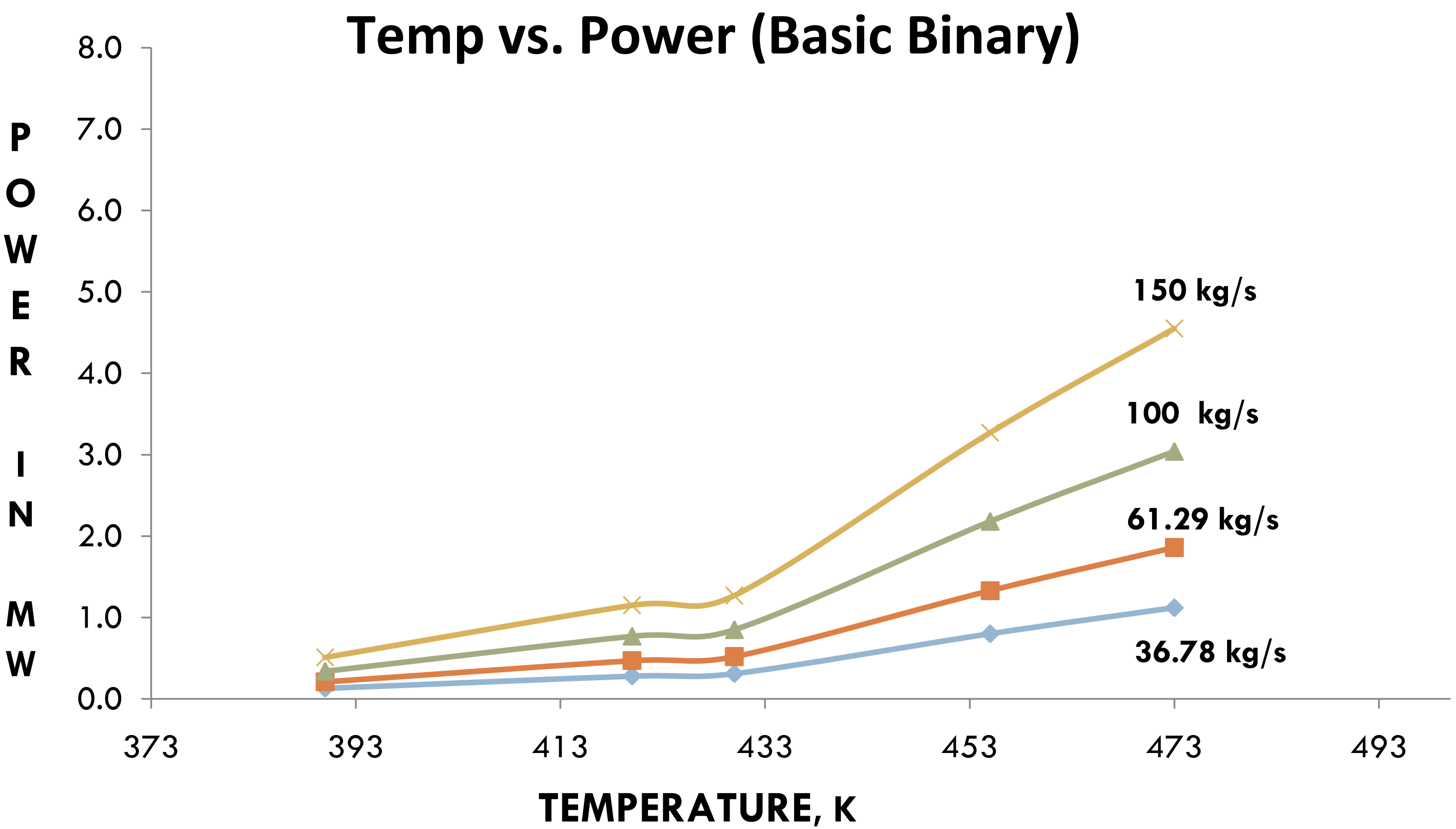
Power Plant Design



Basic Binary Power Plant

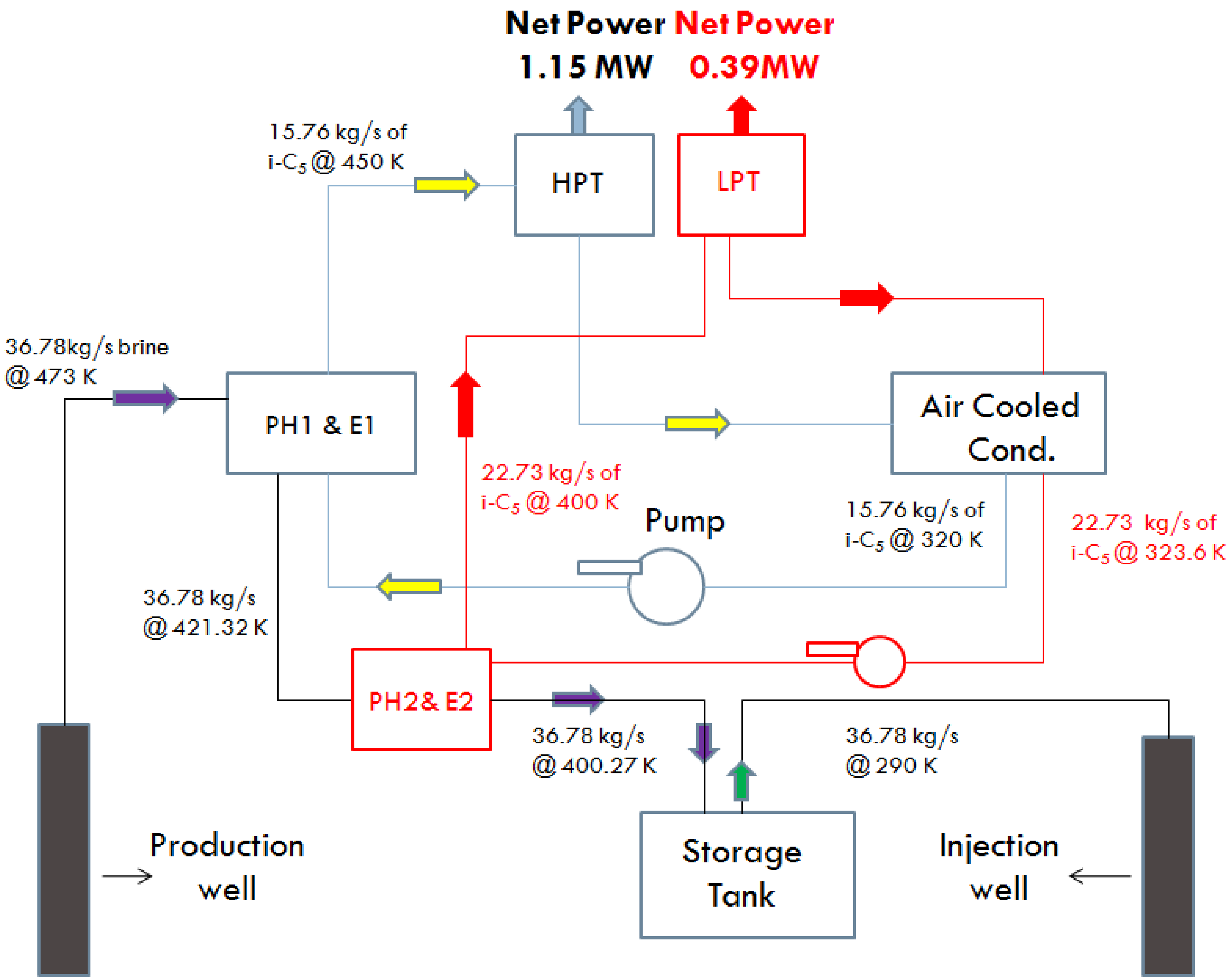
- Efficiency = 18.83%

Power Plant Design



Inefficient and therefore lower net power generated

Power Plant Design



Dual Pressure Binary Power Plant

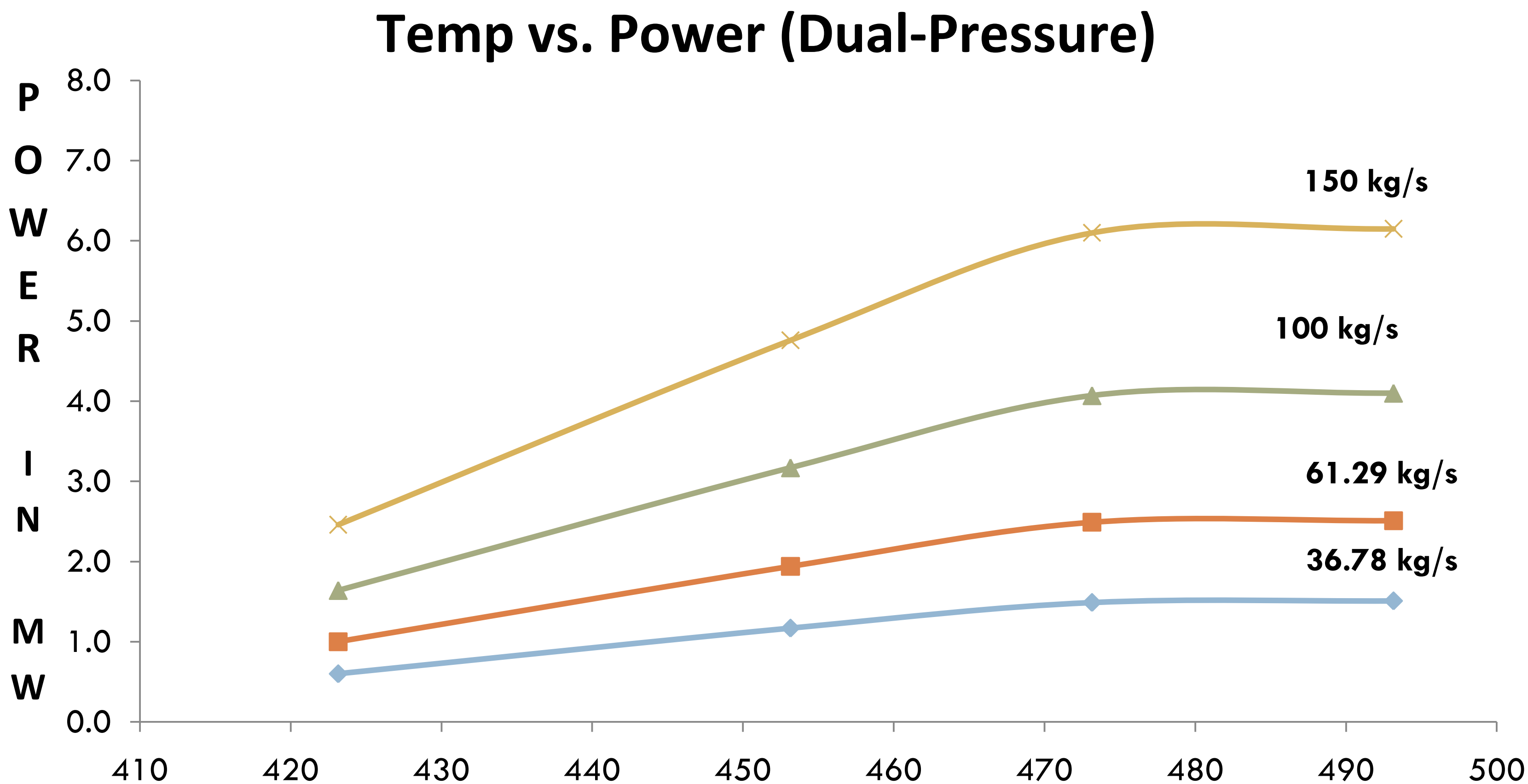
- Efficiency = 22.71%

(+ 3.88 % from Basic Binary Power Plant)

- Outlet brine temperature is lower than Basic Binary Power Plant

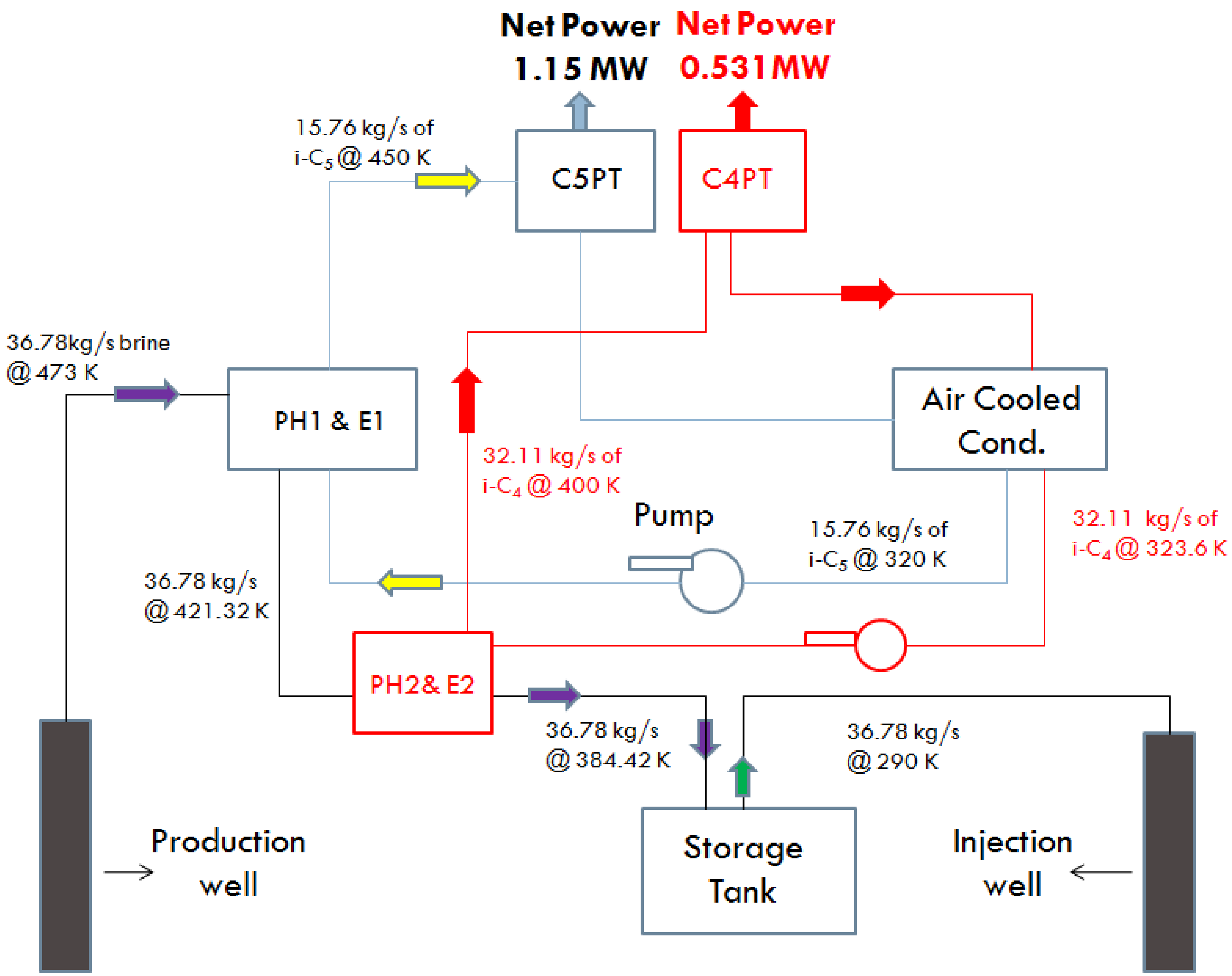
(400 K vs. 421 K for Binary Power Plant)

Power Plant Design



Unutilized energy increases at temperature >200 °C for a given flow rate of working fluid

Power Plant Design



Dual Fluid Binary Power Plant

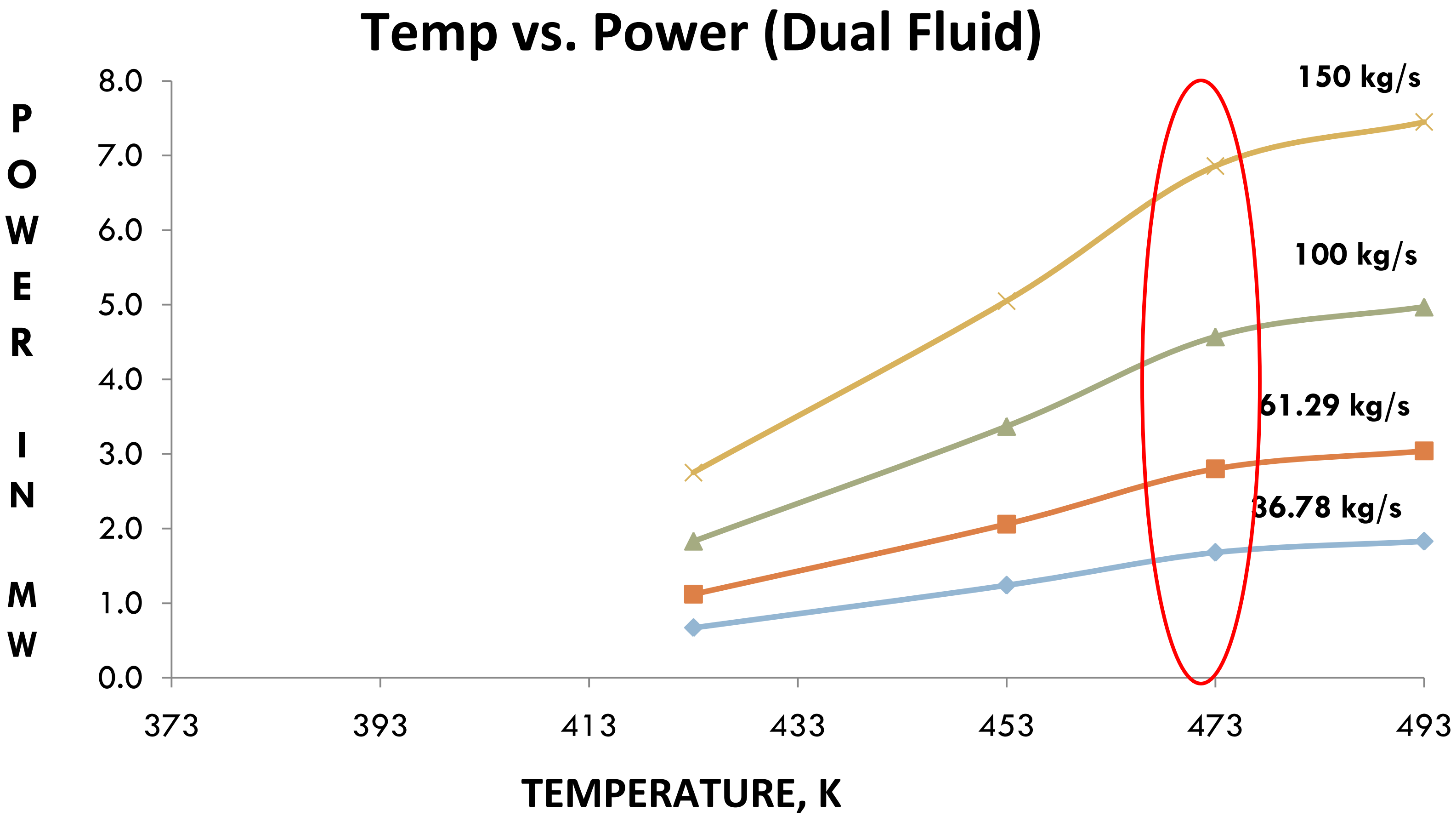
- **Efficiency = 28.23%**

(+ 9.40 % from Basic Binary Power Plant)

- **Outlet brine temperature is much lower than Basic Binary Power Plant**

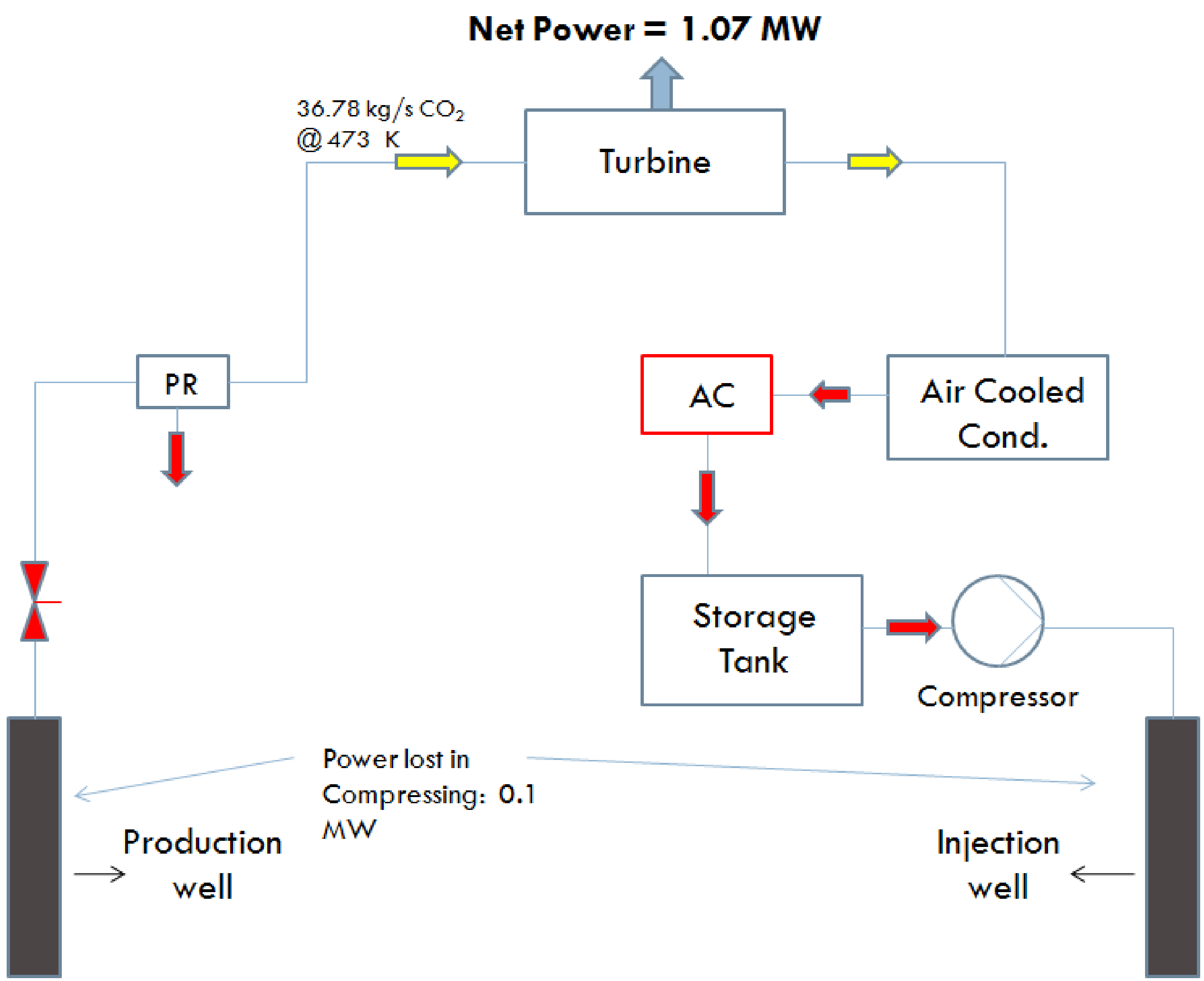
(384 K vs. 421 K for Binary Power Plant)

Power Plant Design



More efficient and therefore higher net power generated

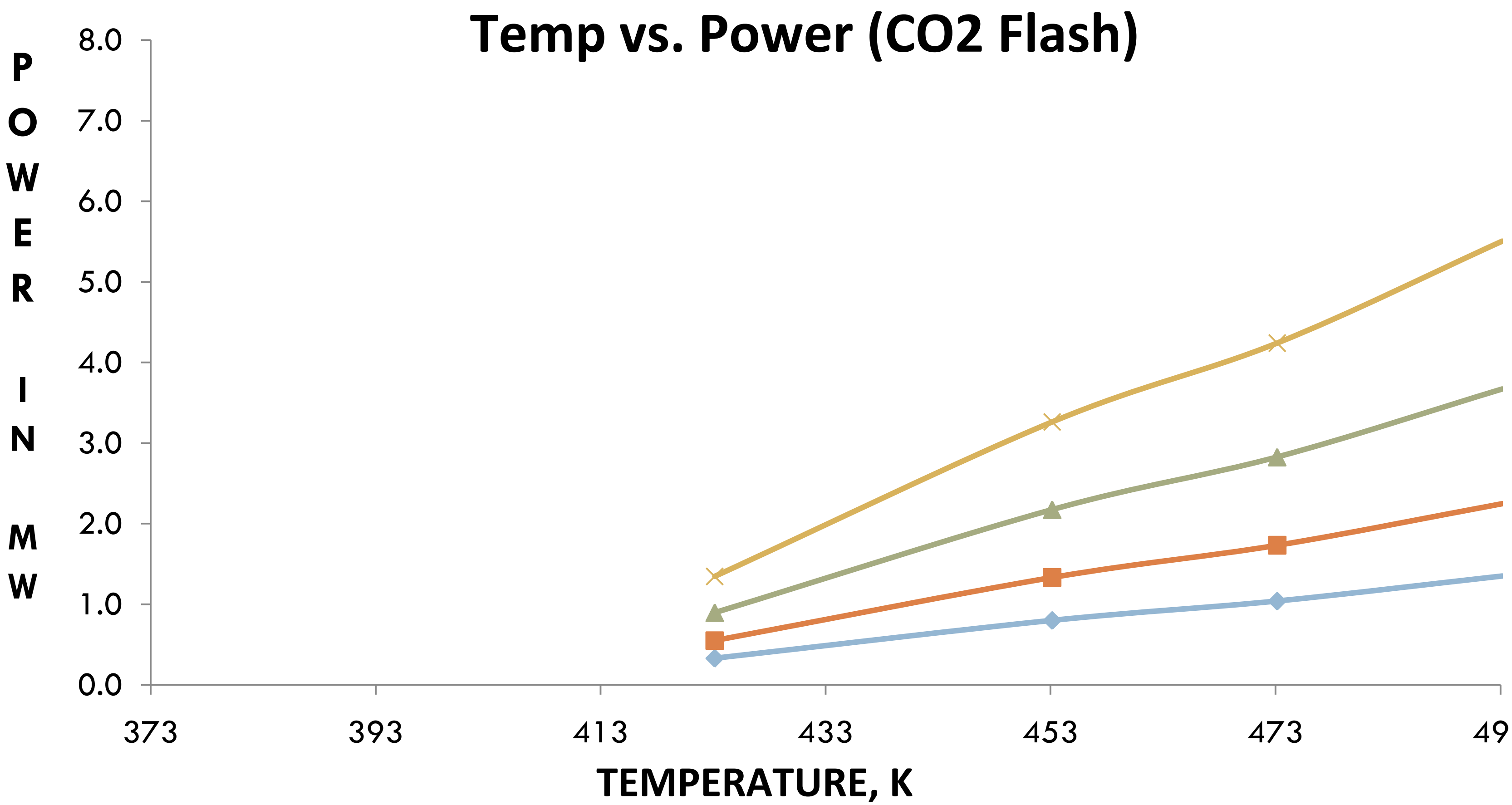
Power Plant Design



CO2 Flash Power Plant

- **Efficiency = 30.51%**

Power Plant Design



Flash power plants are favorable only above 473 K; whereas, the CO2 flash plant is comparable for net power generated with basic binary power plant and dual pressure binary power plant

Power Plant Design

- Dual fluid power plant generates maximum power and more efficient among the binary power plants
- CO_2 flash powered plant has higher utilization efficiency
- Basic Binary power plant is considered to be inefficient among all the binary power plant.
- Effective utilization of the sensible heat from the condenser is not possible due to the demographic location of the plant.

ECONOMIC ANALYSIS

Economic Analysis

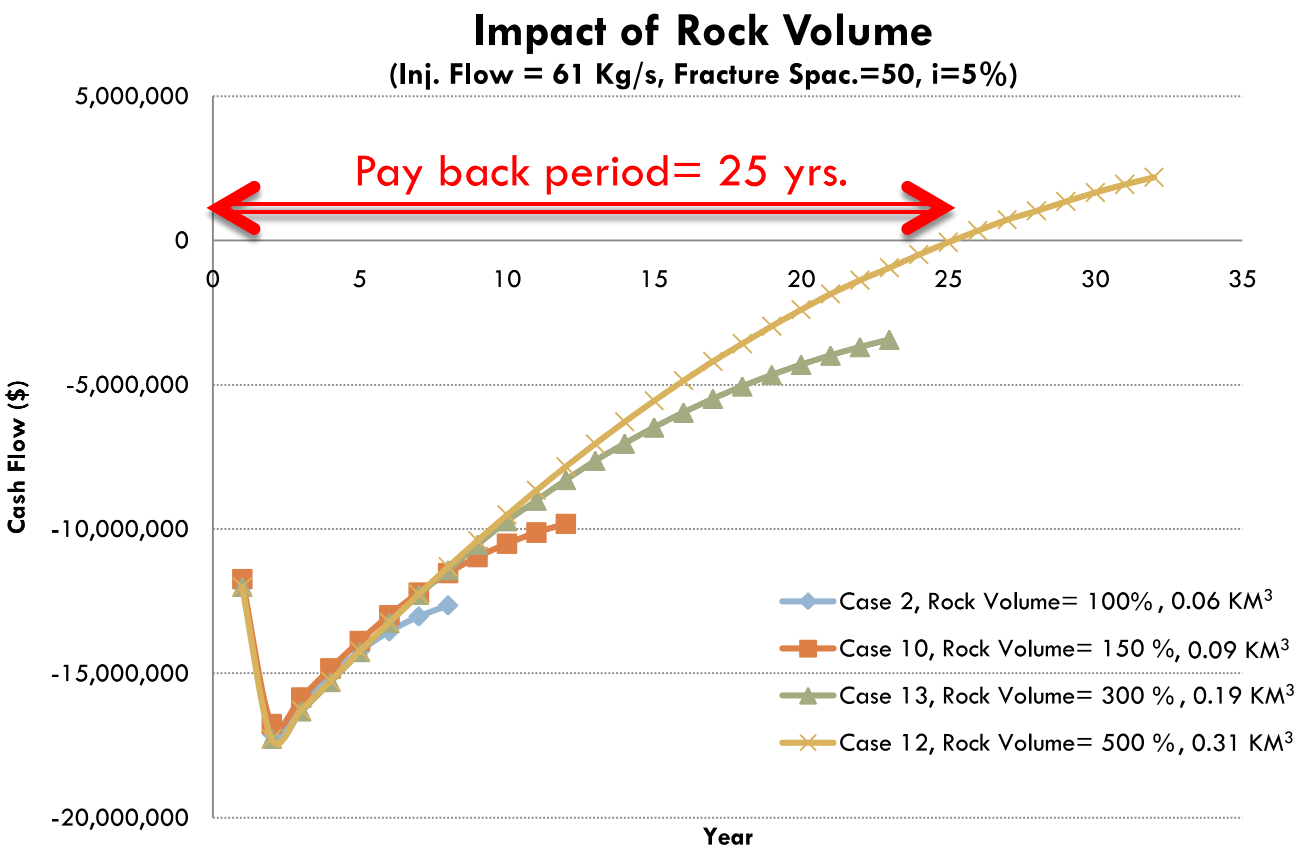
Using Dry Holes, we saved almost 6 Million $ in Drilling

Case #	Rock Volume		Fracture Spacing	Inject Rate	Res Temp	Produce WHP	Pumping Cost ($)	Designed Power Plant (Mwatt)	Adjusted Power Plant Cost $/kWh	Power Plant Cost ($)	NPV at 5% Cost of Capital ($)	Rate of Return (%)
		km^3		kg/sec	(C)	(MPa)						
Case 1	100%	0.06	50	37	205	10.0	408000	1.70	3362.5	5,716,250	-9,033,115	-11.39
Case 2	100%	0.06	50	61	205	10.0	764775	2.70	3362.5	9,078,750	-12,647,874	N/A
Case 3	100%	0.06	50	100	205	10.0	1177584	4.00	2690	10,760,000	-14,855,844	N/A
Case 4	100%	0.06	50	150	205	10.0	1842954	6.25	2690	16,812,500	-20,856,968	N/A
Case 5	100%	0.06	10	37	205	10.0	471192	1.75	3362.5	5,884,375	-7,491,550	-5.04
Case 6	100%	0.06	10	61	205	10.0	795555	2.75	3362.5	9,246,875	-10,846,690	-13.84
Case 7	100%	0.06	100	37	205	10.0	428880	1.50	3362.5	5,043,750	-10,094,089	N/A
Case 8	100%	0.06	100	61	205	10.0	710055	2.50	3362.5	8,406,250	-13,677,158	N/A
Case 9	150%	0.09	50	37	205	10.0	470160	1.65	3362.5	5,548,125	-6,694,719	-2.86
Case 10	150%	0.09	50	61	205	10.0	747675	2.60	3362.5	8,742,500	-9,818,069	-9.89
Case 11	50%	0.03	50	37	205	10.0	370572	1.25	3362.5	4,203,125	-11,295,375	N/A
Case 12	500%	0.31	50	61	205	10.0	798975	2.75	3362.5	9,246,875	2,191,091	6.00
Case 13	300%	0.19	50	61	205	10.0	798120	2.75	3362.5	9,246,875	-3,436,274	2.63
Case 13-A	300%	0.19	50	61	205	10.0	798120	2.75	3362.5	9,246,875	102,354	5.31

Downtime= 5%
Electricity Price (2010) = 0.1 $/kWh
Electricity Price Change rate = 1 %
Production Well Drilling Cost= 3,200,000 $

Injection Well Drilling Cost= 3,200,000 $
Surface Costs= 400,000 $
Stimulation Cost= 782,500 $

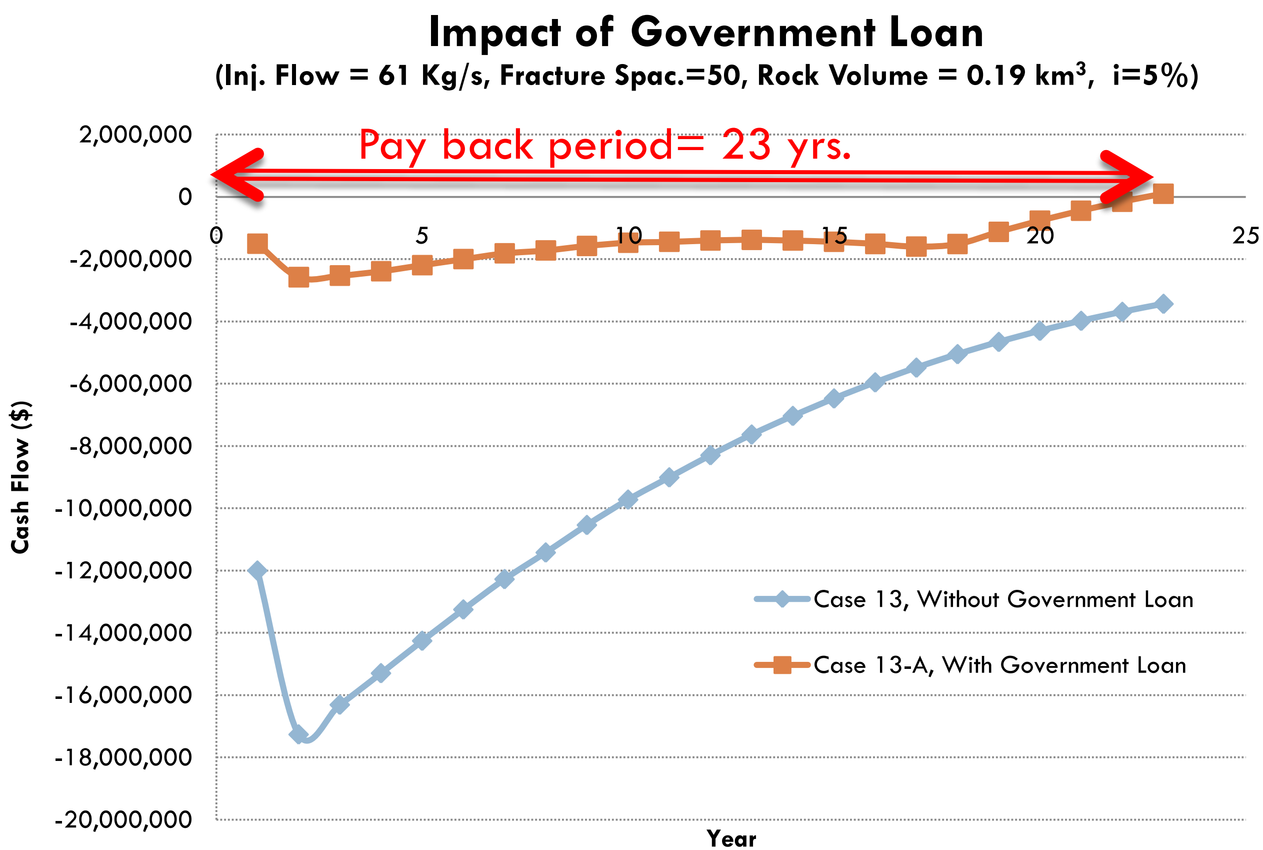
Economic Analysis



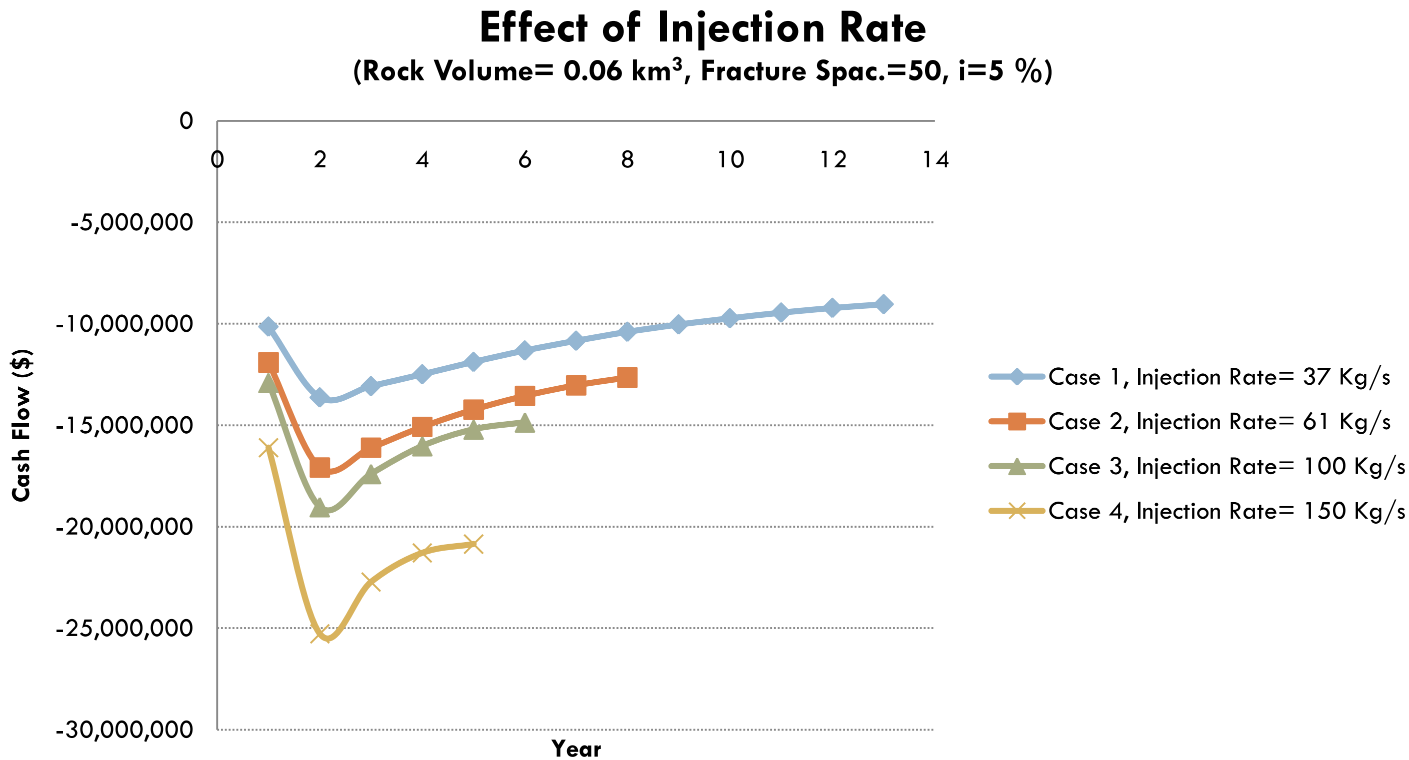
Soultz Project: 0.27 Km^3

Cooper Basin: 0.70 Km^3

Economic Analysis



Economic Analysis

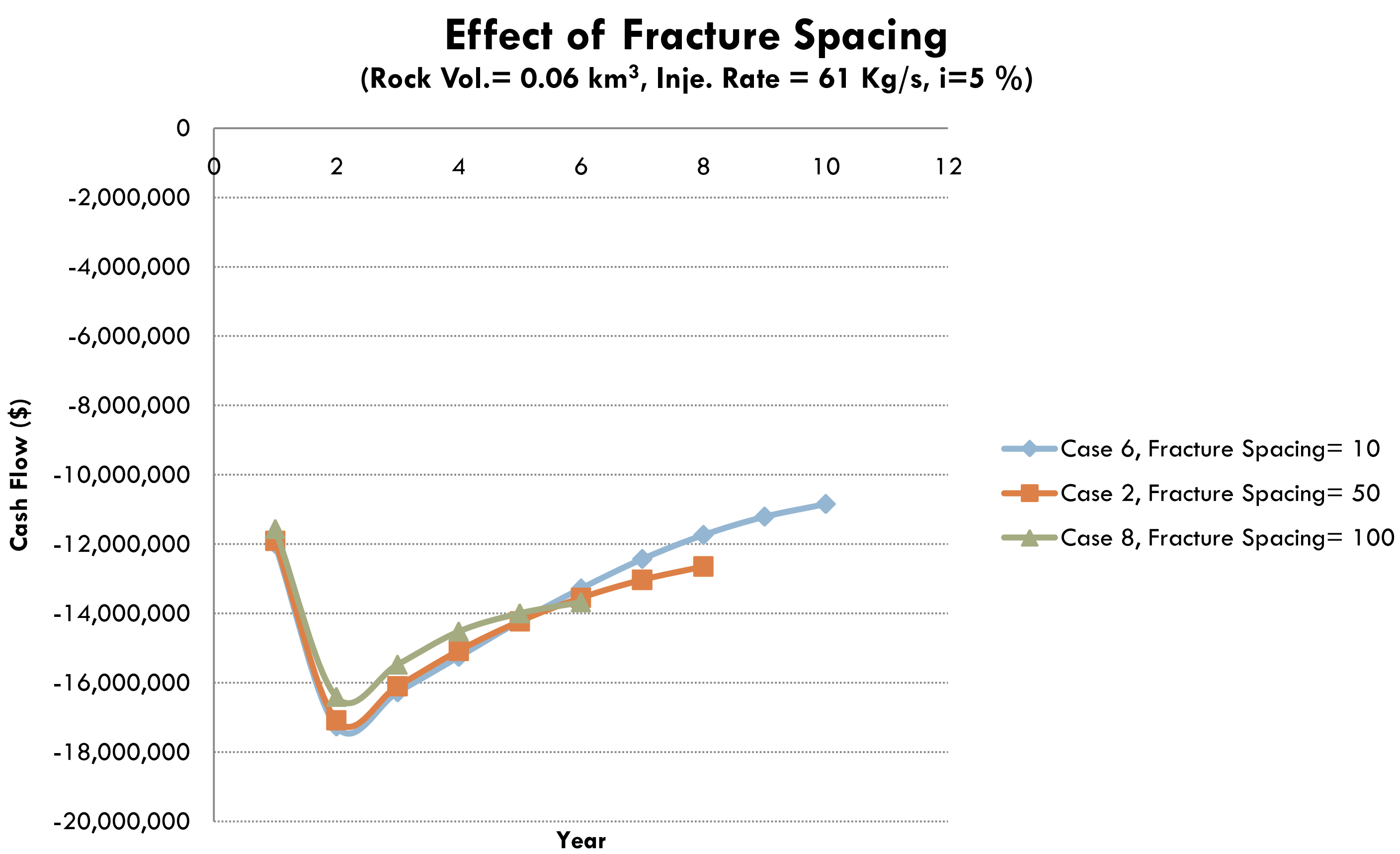


In higher injection rate case, project lifetime would decrease.

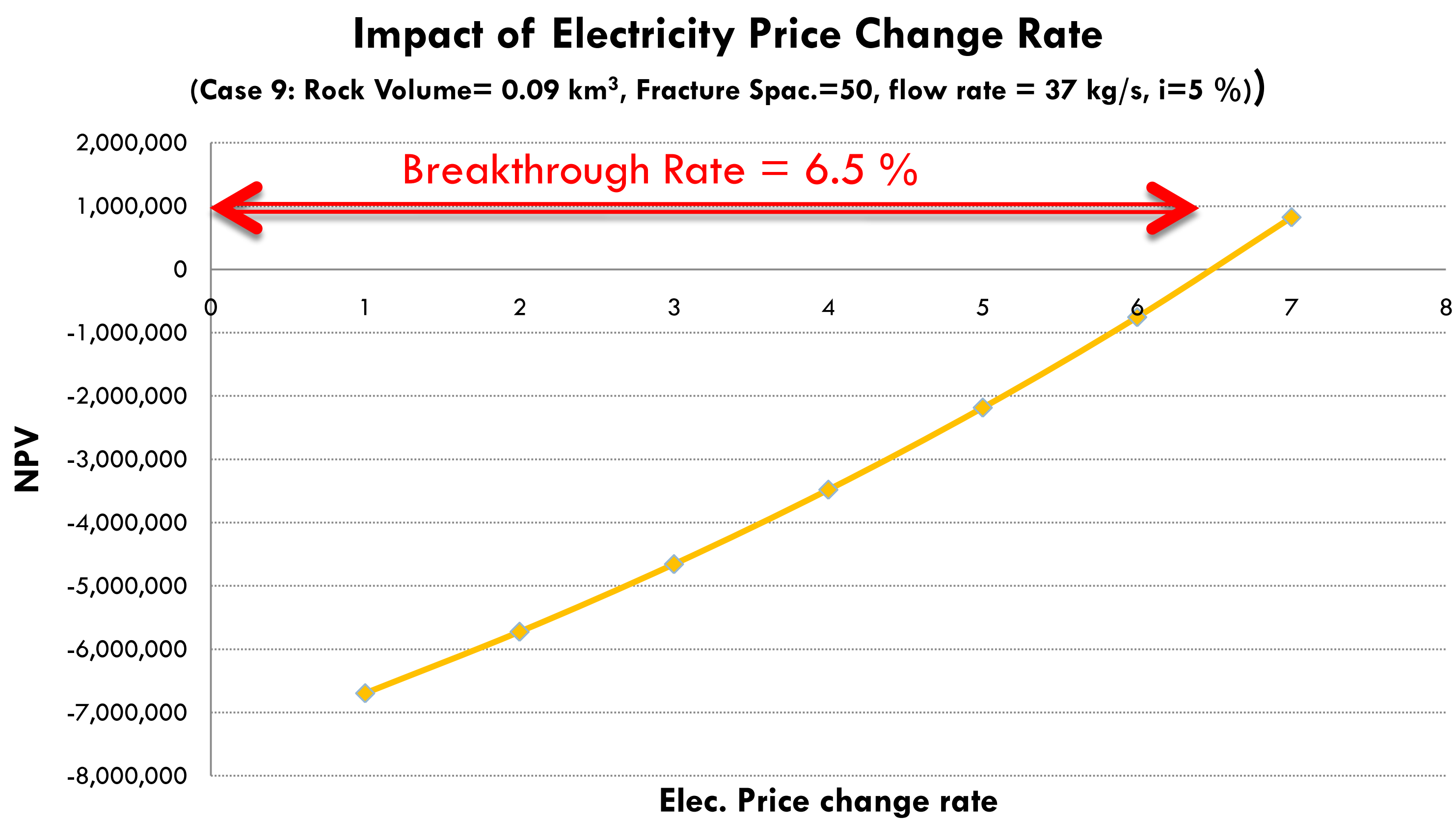
Also, we have to invest more capital cost for power plant and pumping.

HIGH INJECTION RATE IS NOT NECESSARILY BETTER

Economic Analysis



Economic Analysis



Conclusions

- With the assumptions we made, it seems that EGS is not economically feasible, even after utilizing dry holes
- The most significant factors that could make this project feasible are
  - Large resources (large rock volume)
  - Environmental friendly policies i.e. low interest rate loan or Cap & Trade
  - Highly escalated electricity price
  - Reasonable injection rate which still able to maintain the wellhead temperature for long period of time (>20 yrs.)

Recommendations

- Find better locations of dry holes at reasonable distance apart with good depth
- Better cost assumptions
  - i.e. power plant, drilling, and stimulation
- More geological information
  - i.e. stress regime, pre-existing fractures, underground water
- Study various types of fracture modeling
- Study potential production problem
  - i.e. scale build-up
- Evaluate CO2 as geothermal working fluid
- Evaluate possibility of hybrid power plants

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Thank You !!!