Pennsylvania State University

Energy Engineering

GEOTHERMAL ENERGY ENGINEERING

Underground Thermal Energy Storage

Sidney Green

April 27, 2021

12:05 EDT

Team Members include:

Sidney Green
Enhanced Production, Inc. & Univ. of Utah Research Professor

John McLennan, Univ. of Utah

Palash Panja, Univ. of Utah

Richard Allis, Retired Head Utah Geological Survey

Kevin Kitz, Geothermal Engineer and Private Consultant

Richard Newhart, Retired Encana Energy

Joseph Moore, Univ. of Utah

Part of this work has been supported by the National Science Foundation in collaboration with ARMA and with the support of Peter Smeallie and Gen Green. The previous work of the Idaho National Laboratory, for which some of the authors participated, and of NREL is noted.

Focus Today is:

Large-Scale and Long-Term

Heat Storage for Future

Electricity Generation

.

Panja, P., McLennan, J., Green, S., "Temperature and Pressure Profiles for Geothermal Battery Energy Storage in Sedimentary Basins", ARMA 20-1411, Jun 2020

Green, S., McLennan, J., Panja, P., Allis, R., Kitz, K., Moore, J., "Questions and Misunderstandings about the Geothermal Battery Energy Storage", White Paper, Apr 2020, www.epirecovery.com/news

McLennan, J., Panja, P., Green, S., "Geothermal Battery Energy Storage", Final Report, NSF EAGER Grant 1912670, Jun 2020, www.epirecovery.com/news

Green, S., McLennan, J., "Large-scale Subsurface Seasonal Solar Heat Storage for Future Value", On-Line NSF-Univ. of Utah Workshop, May 19, 2020, www.epirecovery.com/news

Green, S., McLennan, J., Panja, P., Allis, R., Kitz, K., Newhart, R., Moore, J., "Large-Scale and Long-Term Deep Subsurface Heat Storage for Future Electricity Generation", ARMA Underground Storage & Utilization Community, Presentation, Aug 6, 2020, www.epirecovery.com/news

Green, S., "What Happens when the Sun isn't Shining—Renewable Energy Storage", Univ. of Utah Graduate Seminar, Oct 5, 2020, www.epirecovery.com/news

Green, S., McLennan, J., Panja, P., Kitz, K., Allis, R., Moore, J., "Geothermal Battery Energy Storage", *Renewable Energy*, Volume 164, 777-790, 2020

Panja, P., Green, S., Deo, M., Allis, R., Newhart, R., Kitz, K. Moore, J., McLennan, J., "Multi-Layer Reservoir Thermal Energy Storage in the Uinta Basin", ARMA 2021, 20-23 June–1 July, Houston, Texas, 2021

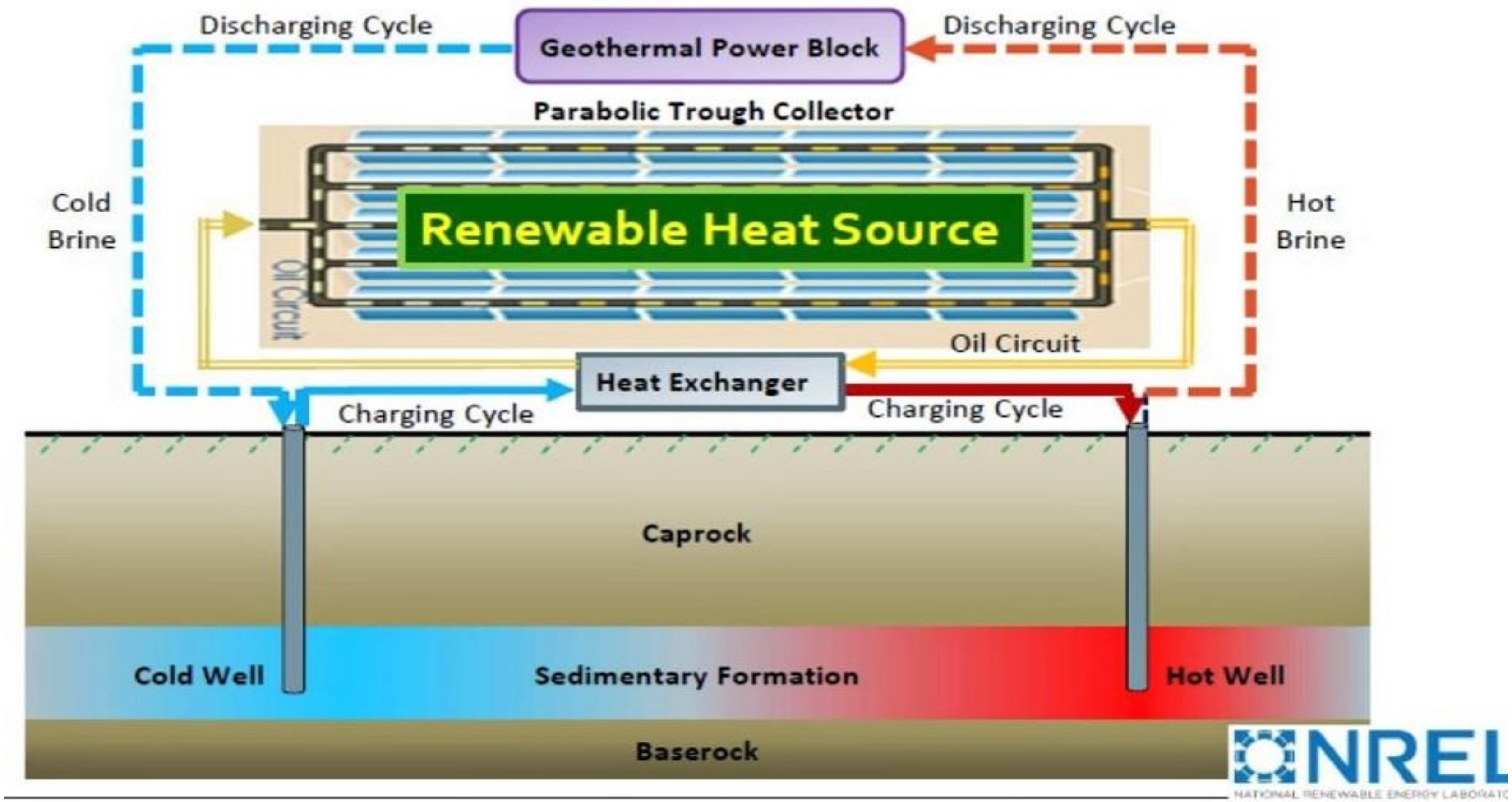
Panja, P., McLennan, J., Green, S., "Impact of Permeability Heterogeneity on Geothermal Battery Energy Storage", *Advances in Geo-Energy Research*, 5(2), 2021

Panja, P., McLennan, J., Green, S., "Influence of Permeability Anisotropy and Layering on Geothermal Energy Battery Storage", *Geothermics*, Volume 90, 101998, 2021

Wendt, D., Huang, H., Zhu, G., Sharan, P., McTigue, J., Kitz, K., Green, S., McLennan, J., "Geologic Thermal Energy Storage of Solar Heat to Provide a Source of Dispatchable Renewable Power and Seasonal Energy Storage Capacity", GRC Transactions, Vol. 43, 2019

Sharan, P., Kitz, K., Wendt, D., McTigue, J., Zhu, G., "Using Concentrating Solar Power to Create a Geological Thermal Energy Reservoir for Seasonal Storage and Flexible Power Plant Operation", ASME J *Energy Resources Technology*, Vol. 143 / 010902-1, Jan 2021

Concept



Kitz, K., et. al., "*Geologic Thermal Energy Storage of Solar Heat*", GRC Presentation, Sept 2019

Sharan, P., "*Using Concentrating Solar Power to Create a Geological Thermal Energy Reservoir for Seasonal Storage and Flexible Power Plant Operation*", J Energy Resources Technology by ASME, Vol. 143/010902-1, Jan 2021

Solar Collectors to Heat Water

Lovegrove, K., et. al., “Comparison of Dispatchable Renewable Electricity Options”, ARENA, Technologies for an Orderly Transition, info@itpau.com.au, 2018

Background

Aquifer Heat Storage Has Been Considered for Decades, but not to store Water at 250 C or Higher, nor for High Porosity (10-15%) / High Permeability (~100 mD) Deep Formations

Holbrook, J., NSF "SedHeat Project"—Sedimentary Basins for Geothermal Energy

Green, S., NSF 2017 High Porosity Sedimentary Basin Formations for Hot-Water Storage ("*Geothermal Battery Energy Storage*")—Concept Feasibility

Idaho National Laboratory Considered High Porosity Formations for Heat Storage - "GeoTES" [DOE seems to refer to Reservoir Thermal Energy Storage (RTES)]

Green, S. & McLennan, J., et.at., NSF "*Geothermal Battery Energy Storage" and* Publications on Reservoir Assessment

Panja, P., et.al., Publications on Calculations

Major Observations

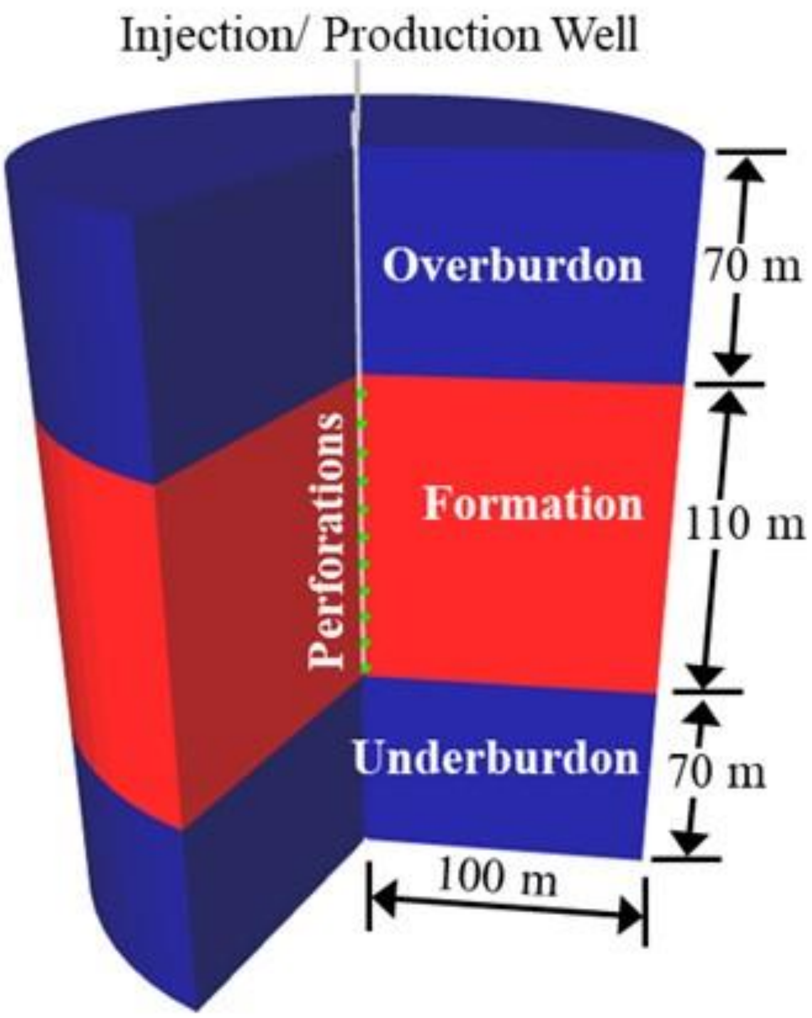
<u>**Three things became apparent:**</u>

1. **Rock mass volume for the “storage container” is small**

2. **Time for equilibration of temperature and pressure is short and reservoir temperature variations are small**

3. **Geochemistry issues must be carefully managed and could be a “deal breaker”**

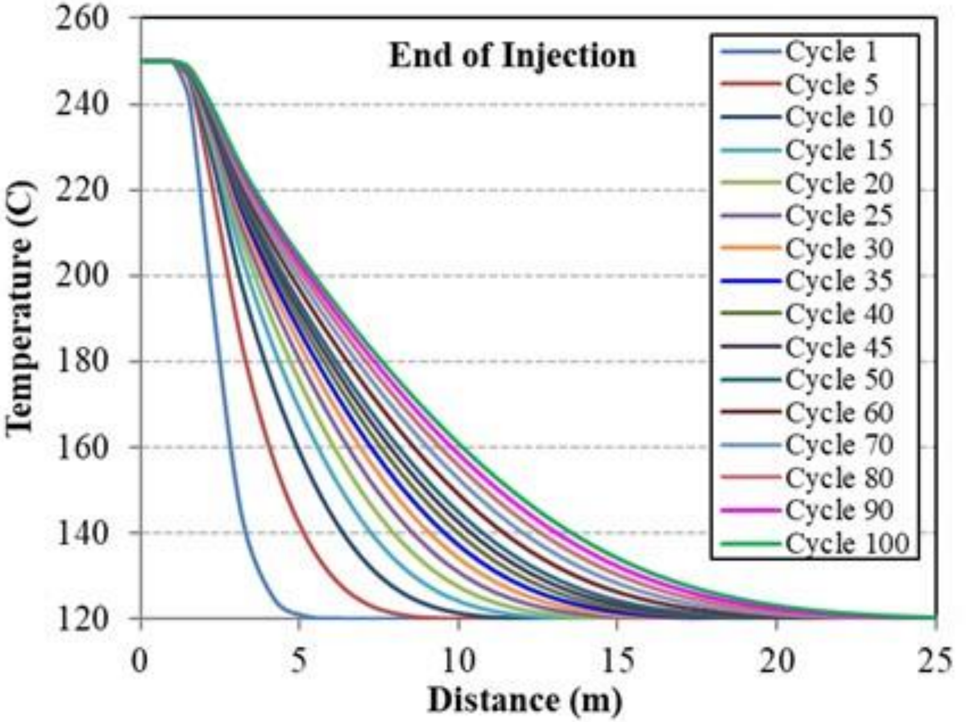
Calculations



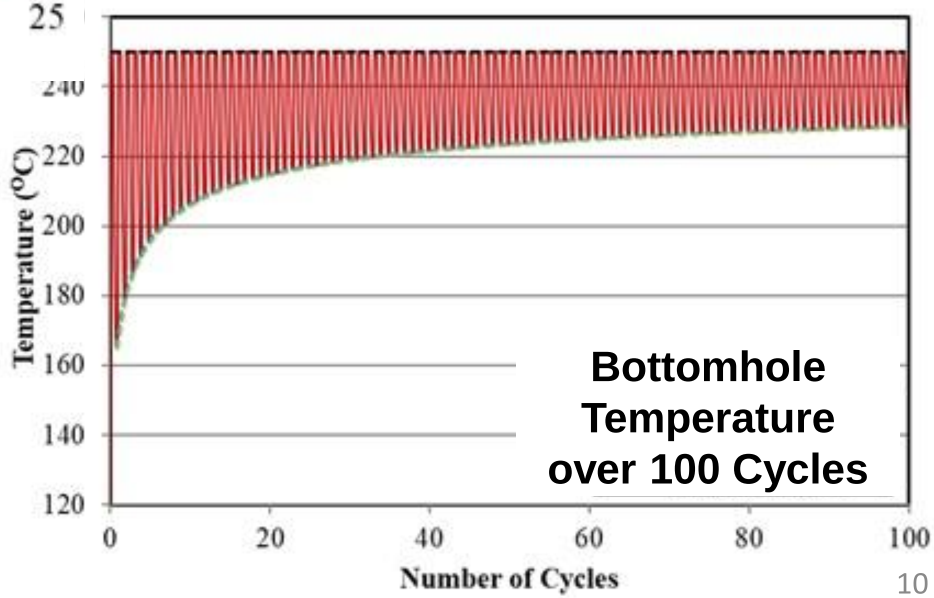
Parameters	Formation	Overburden/ Underburden
Specific heat of rock (J/(kg-K)	930	770
Thermal Conductivity (W/(m-K)	2.5	1.05
Density (kg/m^3)	2000	2500
Horizontal permeability, k_x, k_y (mD)	100	0.0001
Vertical permeability, k_z (mD)	10	0.0001
Porosity (%)	15	2.5
Initial Temperature (^{o} C)	120	120
Initial Pressure (MPa)	12	12
Thickness (m)	110	70

Calculations by Dr. Palash Panja using CMG Star computer code.

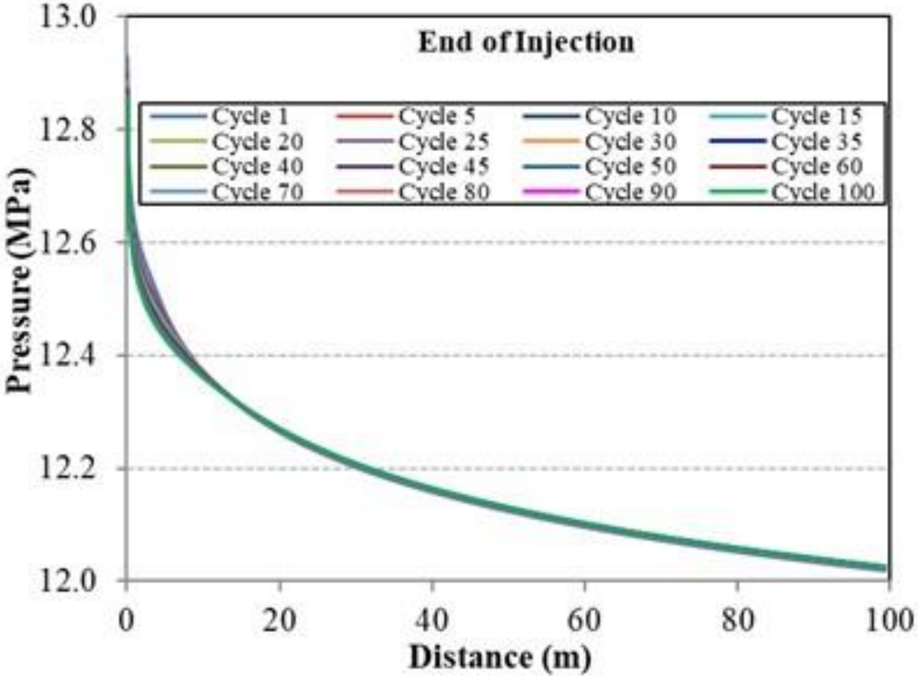
Storage Reservoir Temperatures



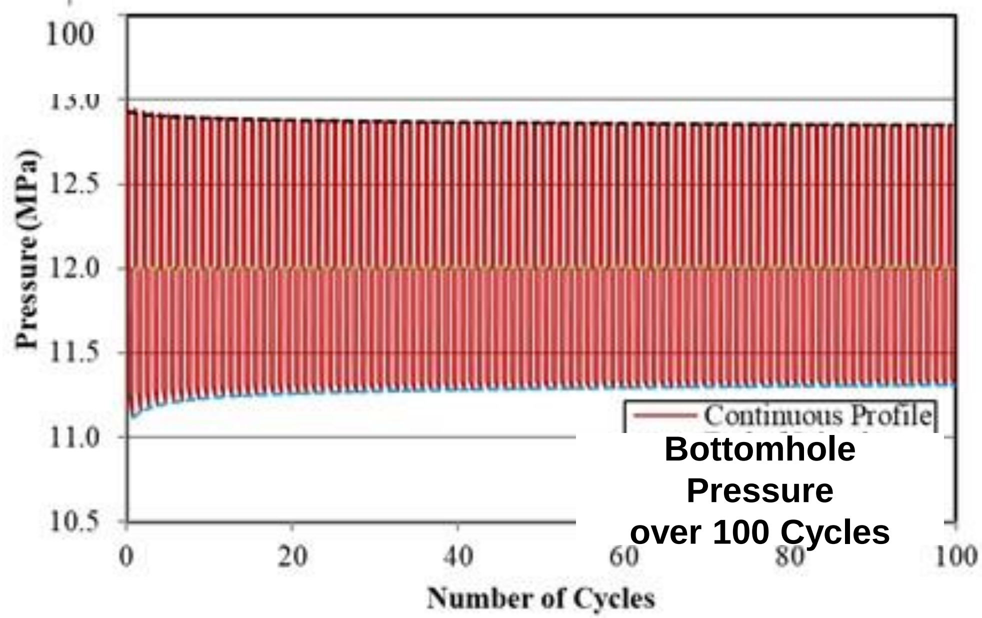
<u>Cycle:</u> Daily, injection of 40 kg/second 250 C water for 8 hours, production of same mass over 10 hours, stabilized for 6 hours.



Storage Reservoir Pressures

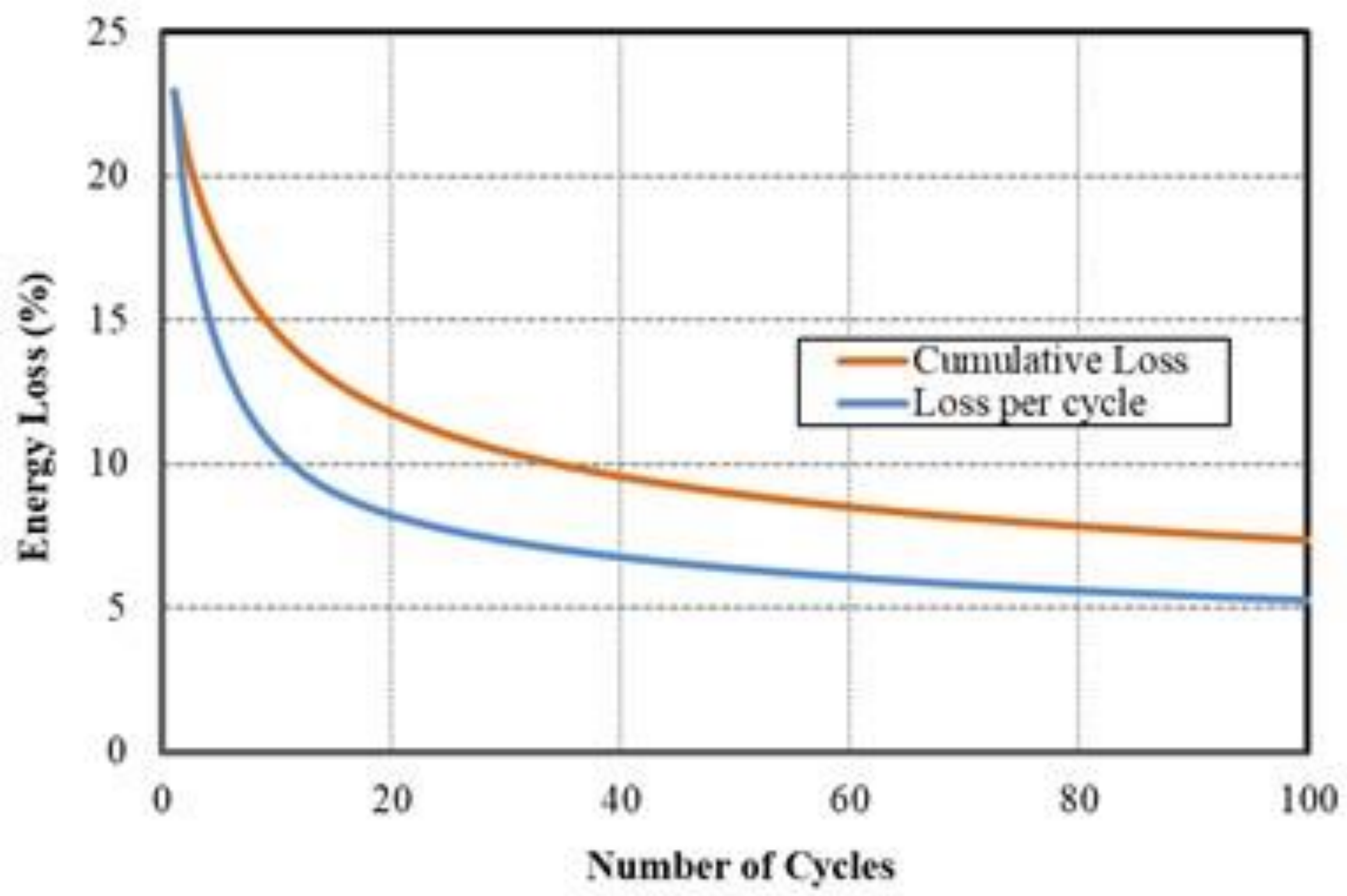


Cycle: Daily injection of 40 kg/second 250 C water for 8 hours, production of same mass over 10 hours, stabilized for 6 hours.

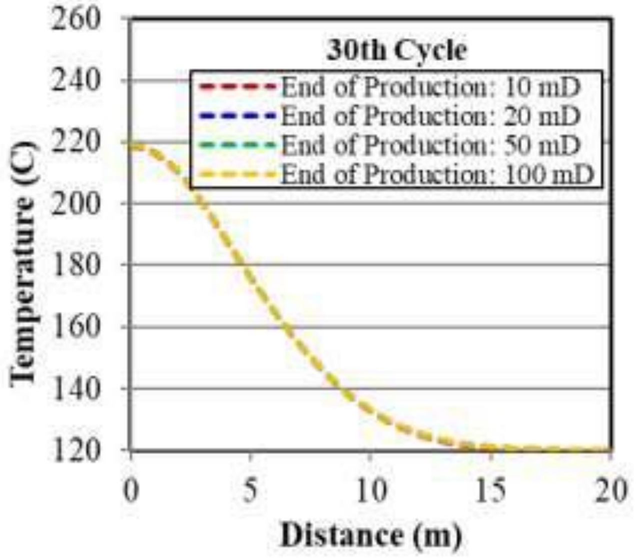


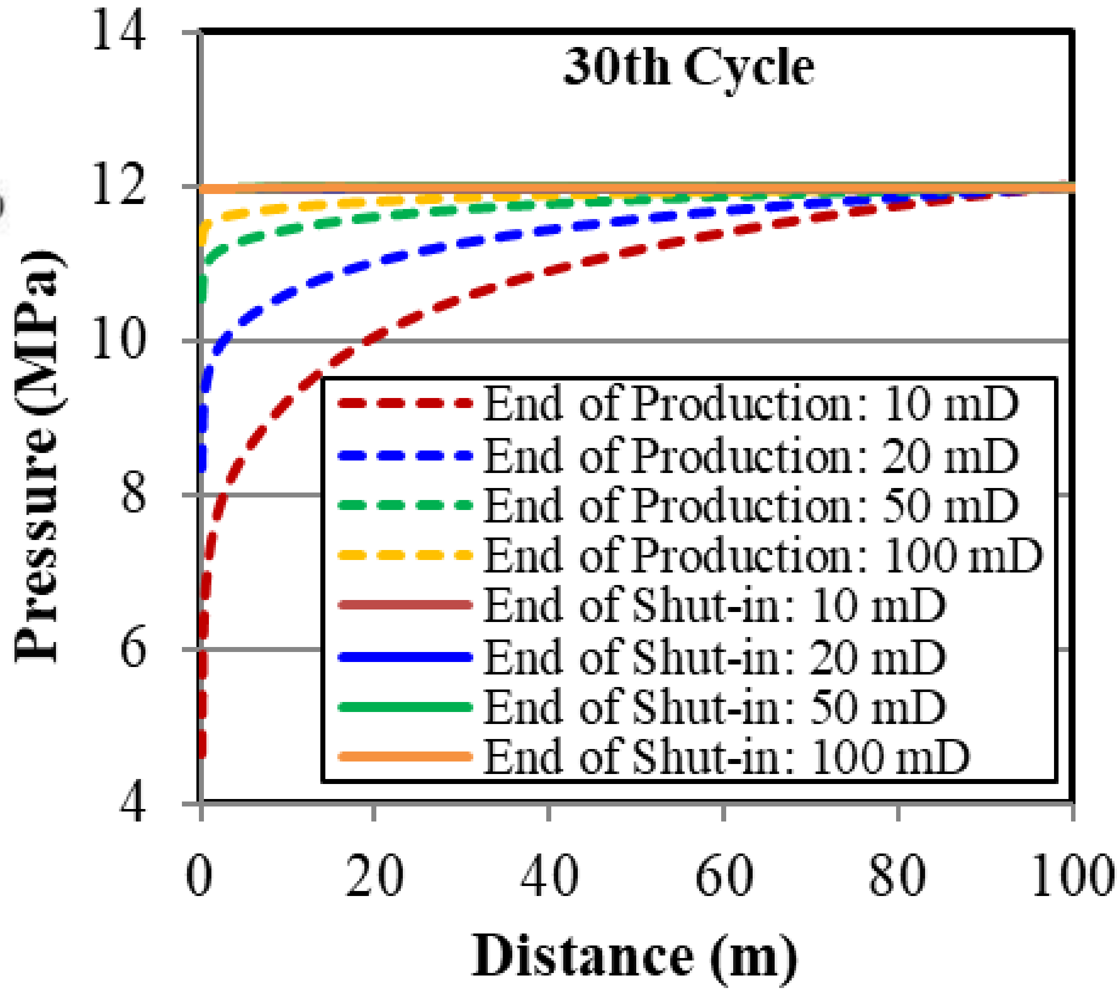
Bottomhole Pressure
over 100 Cycles

Heat Recovery



Permeability Variations

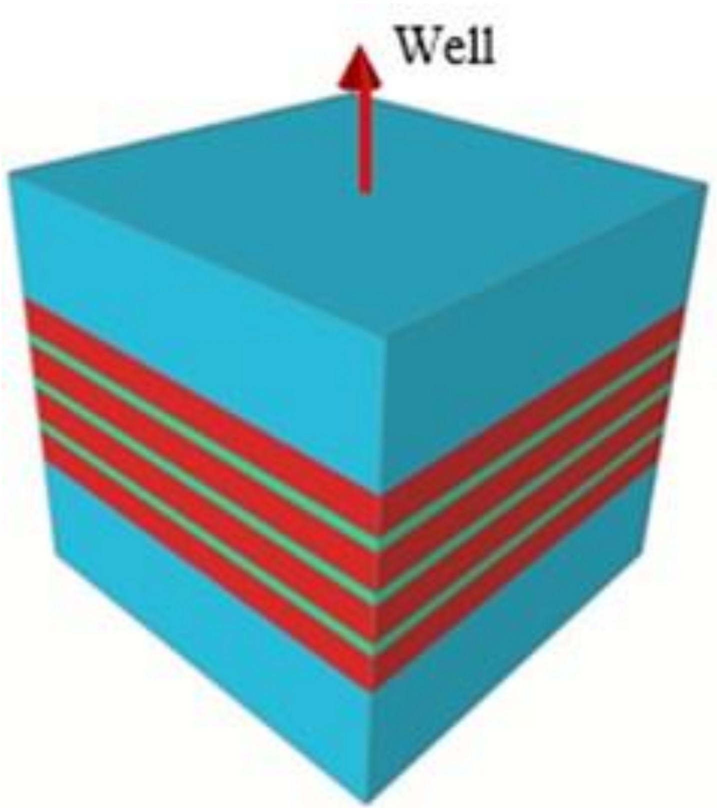




Panja, P., et.al., "Temperature and Pressure Profiles for Geothermal Battery Energy Storage in Sedimentary Basins", ARMA 20-1411

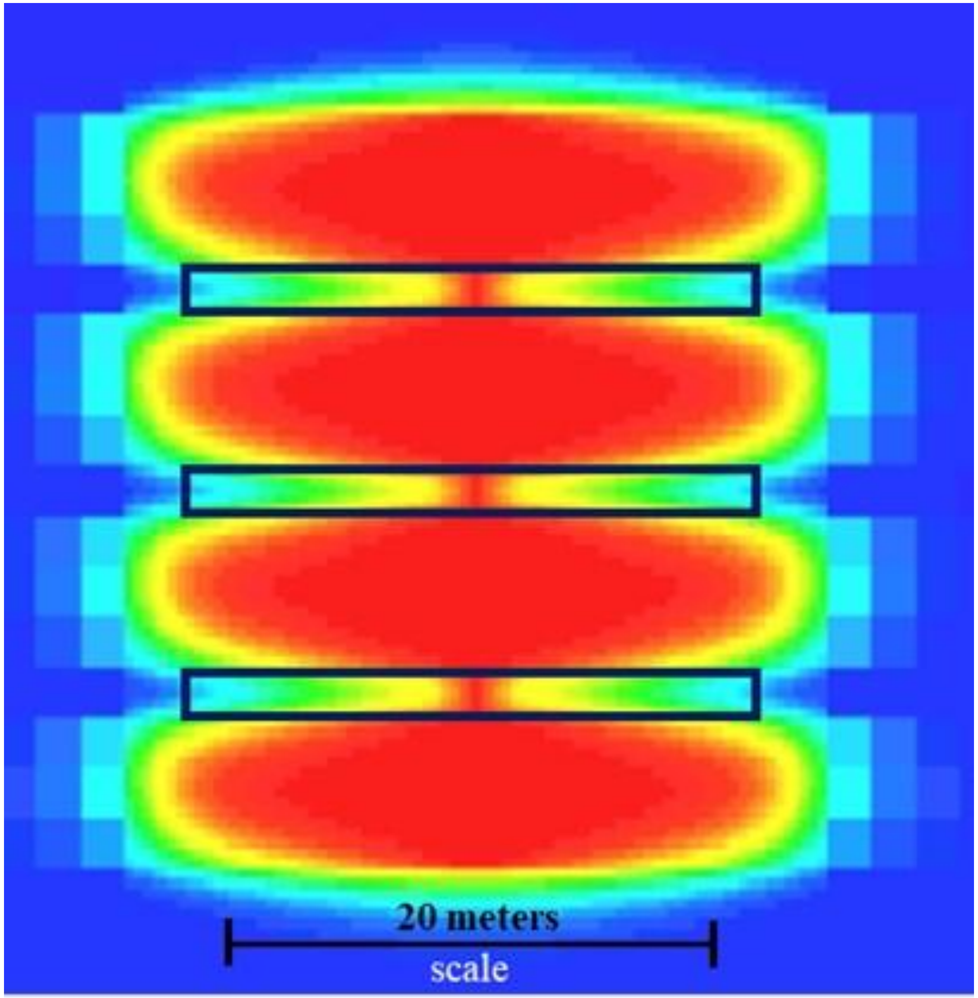
Panja, P., et.al., "Influence of permeability anisotropy and layering on geothermal battery energy storage", Elsevier, *Geothermics* 90)2021) 101998

Multi-Layer Reservoir

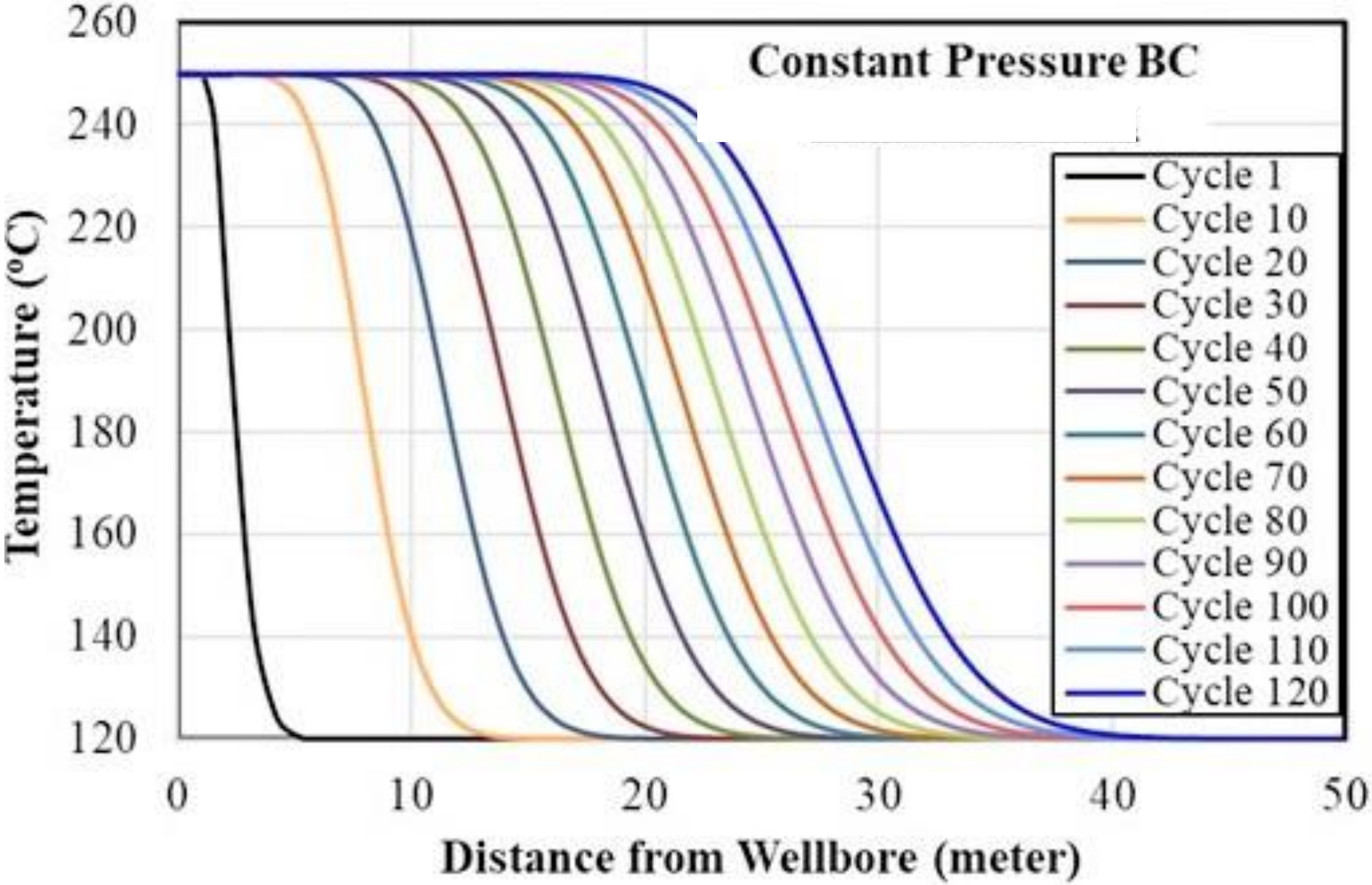


Panja, P., et.al., “Multi-Layer Reservoir Thermal Energy Storage in the Uinta Basin”, ARMA 21-385

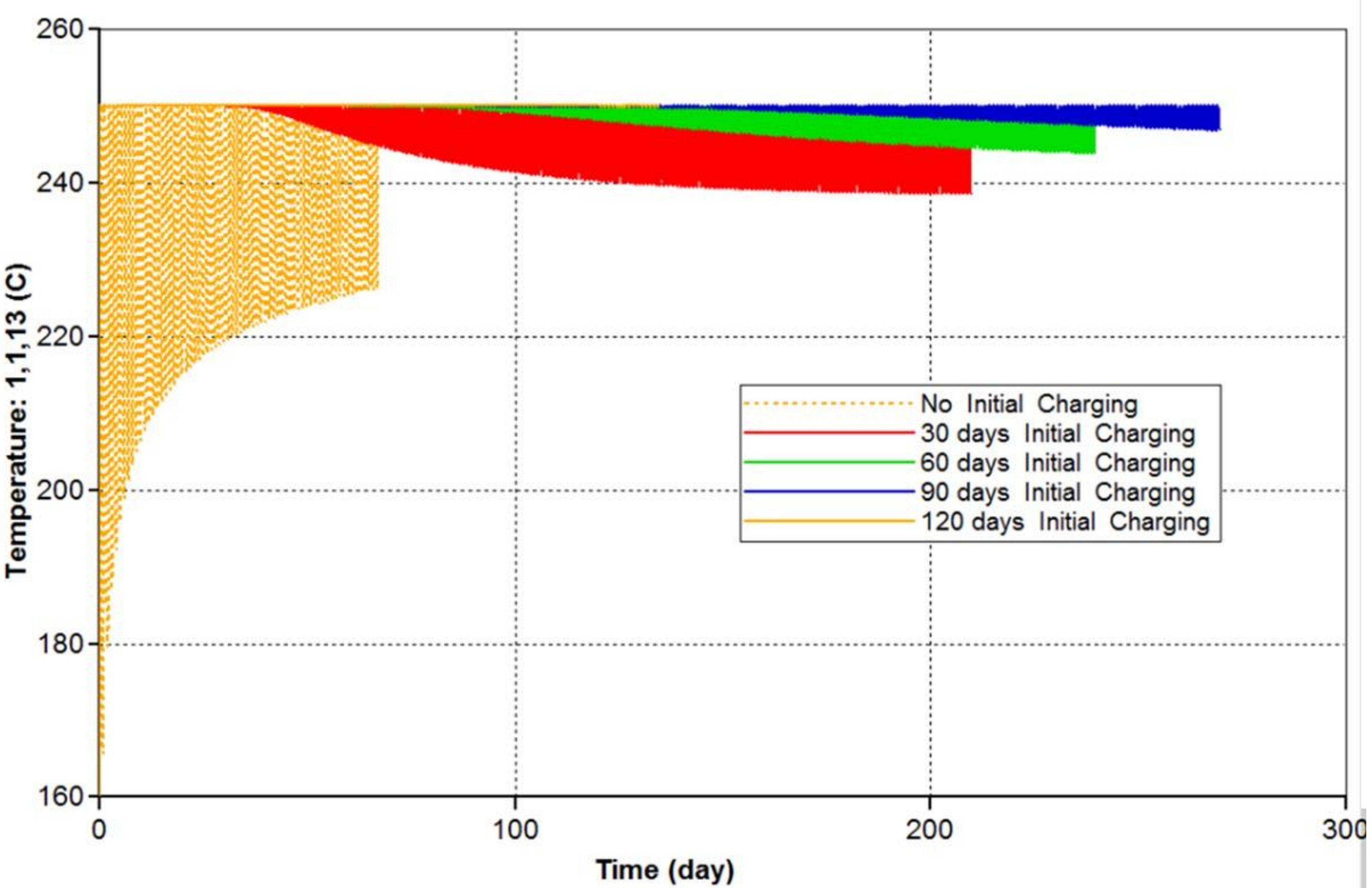
Temperature profiles for four-layer model after injection for 120 days (“in-between” 15-meter thick formations are outlined in black)



Charging the Reservoir



Produced Water Temperature



Panja, P., Unpublished Calculations, 2020

Summarize

Heat Storage Reservoir

1. What about Fractures / Faults?
2. What about Non-Isotropic Rock Permeability?
3. What about Multi-Layer Reservoirs?
4. What about Horizontal Wells for the GB?
5. What would not Work as a Reservoir?
6. Could "More Conventional" Geothermal Formations Work?
7. Could a Depleted Oil/Gas Reservoir Work?

***Green, S., et.al., "*Questions and Considerations Regarding the Geothermal Battery Energy Storage Reservoir", White Paper, July 2020, www.epirecovery.com**

Conclusions

The big finding is that for the right reservoir, high porosity and permeability, nearly one-hundred percent of the injected heat can be practical recovered.

The DOE *"Energy Storage Grand Challenge: Draft Roadmap 2020"*, speaks to RTES [heat] storage (page 96) and suggests that further support may be provided.

Questions

Closing Comment

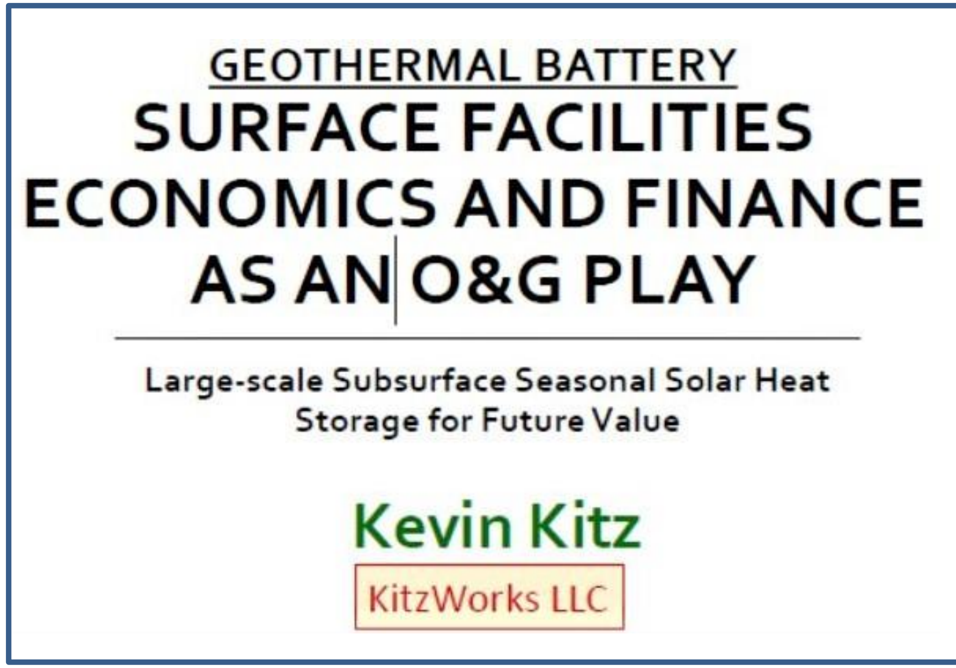
J.P. Morgan, Tenth Annual Energy Paper, June 2020

[iii] Thou shalt toil mightily to store energy that you produce

Some de-carbonization proposals for the grid entail substantial over-building of wind and solar power with the goal of storing excess electricity generation to draw upon later, allowing natural gas peaker plants to eventually be retired. **However, long-term utility-scale energy storage via electrochemical batteries is an industry that is still in its infancy.** Less than 1% of US electricity generation was stored in 2019, and almost all of this storage occurred in decades-old pumped hydro facilities (see below) rather than in batteries. **A much larger storage buildout would be needed to displace natural gas peaker plant generation,** which is currently 10x the amount of stored-and-then-dispatched electricity. **There are plenty of "hockey stick" forecasts for electrochemical battery deployment, as there were for electric vehicles a decade ago and which turned out to be way too high.** Due to the complexities around reimbursement and cost recovery allowances for utilities that invest in storage, **some battery storage forecasts are likely to be too high as well.**

Complete Subsurface System

McLennan, J., et.al., "On-Line Workshop: Large-scale Subsurface Seasonal Solar Heat Storage for Future Value", NSF Sponsored, May 19, 2020, Univ. of Utah or www.epirecovery.com



Excess solar and wind electricity may be used immediately for surface resistive water heating.

Well Layout for "Unit" Geothermal Battery