**About Geothermal Reservoir Simulation Results**

**for “Feasibility of Direct District Heating for the Cornell Campus Utilizing Deep Geothermal Energy”**

 **Tier 2 Submission**

**DE-EE0008103, Earth Source Heat: A Cascaded Systems Approach to DDU of Geothermal Energy on the Cornell Campus**

The purpose of this document is to describe the contents contained within a submission to the Geothermal Data Repository (GDR) node of the National Geothermal Data System (NGDS) in support of Earth Source Heat: A Cascaded Systems Approach to DDU of Geothermal Energy on the Cornell Campus.

**Abstract**: This dataset contains input data, code, readme files, output data, and figures that summarize the results of a stochastic analysis of geothermal reservoir production from two potential geothermal reservoirs that were evaluated for the Cornell University Deep Direct-Use project. These potential reservoirs are the Trenton-Black River (TBR) from 2.27 – 2.3 km depth, and basement rocks from 3-3.5 km depth and 3.5-4 km depth. Several utilization scenarios consisting of different injection fluid temperatures and flow rates were evaluated for each reservoir. Uncertainty in geologic properties, thermal properties, economic costs, and utilization efficiencies were evaluated using a Monte Carlo analysis of the reservoir simulations. Some reservoir simulations of the TBR were completed using the TOUGH2 software, as implemented in PetraSIM. The PetraSIM run files and associated data are provided with this submission. All other reservoir simulations were completed using the GEOPHIRES software, with some modifications to complete the uncertainty analyses. Readme files that describe additions to GEOPHIRES, the GEOPHIRES input data, and the output data are all provided, and references are provided to the code repository. Figures that summarize the reservoir heat production, temperature drawdown, and the probability of meeting targeted building heating demands with the produced heat and fluid temperatures are provided. Detailed descriptions of the contents of this repository are provided below.

**Key Words**: Cornell University, direct-use heating, reservoir simulation, techno-economic analysis, uncertainty analysis

**Citation**: When referencing this data, please use the following citation information:

**Title**: Direct District heating use on the Cornell campus of Deep Geothermal Energy: Geothermal Reservoir Simulation Results

 **Author(s)**: Cornell University

 **Date**: October, 2019

**Note**: On Windows 10 OS and possibly other operating systems, zipped folders need to be unzipped in directories with short names (e.g., in C:\). If not, some files may not be extracted due to “path too long” errors.

**Contents of Submission:**

**Main Folder:** **CornellDDU\_ResSimResults**

**Contents:**

1. **File: MonteCarloGEOPHIRESinParallel\_ForGeophiresv2.docx**

This is the readme file describing files contained within the Code/GEOPHIRES-ModifiedForCornellDDU directory. This document also describes how to run the GEOPHIRES uncertainty analysis.

Additional descriptions of the code for uncertainty analysis of GEOPHIRES may be found within the World Geothermal Congress 2020 conference paper by Smith and Beckers (2020).

1. **File: GEOPHIRES\_InputParameterDescriptions.xlsx**

Provides a list of all GEOPHIRES uncertainty analysis input parameters and their descriptions.

1. **File: GEOPHIRES\_OutputFileDescriptions.docx**

Provides descriptions of all GEOPHIRES uncertainty analysis output folders and files.

1. **Folder: Code**
	1. **PlottingFunctions.R**

This code processes, analyzes, and plots GEOPHIRES output.

The specific GEOPHIRES code that provides the output required as input to this R script is available on GitHub under
commit f26e0aa6e1346e3e9b9ec3b244c6d6f313f037e3 . This commit was made by Jared Smith on Mon Jan 7 11:44:31 2019 to the UncertaintyAnalysis branch of the GEOPHIRES GitHub repository (<https://github.com/kfbeckers/GEOPHIRES>). This repository is currently private, and the license for the code is currently under review. If you require this code, please contact Jared Smith (jds485@cornell.edu).

A more recent commit is available on the Uncertainty Analysis branch of GEOPHIRES, which corrects for some plotting errors (e.g. labels, legend position, etc.). No quantitative analysis changes exist in this commit.
commit 2becc9217fd2ce1286f5dc2264799be67c01d6bb by Jared Smith on Tue Jul 30 12:13:17 2019

* 1. **Plots\_TOUGH2\_PostGEOPHIRES.R**

An R script to process and plot TOUGH2 results to make the figure Run10\_TBR\_TOUGH2\_40yrs\_20Cinj\_ProdTempHeatPostGEOPHIRES.png

* 1. **ProbabilityLifetimePlots.R and ProbabilityLifetimePlots\_Basement.R**

R scripts to process, analyze, and plot GEOPHIRES output, as described in the SummaryProbabilityPlots sections for TBR and basement rock simulations, respectively.

1. **Folder:** **Basement\_ReservoirSimulations**
	1. **18 folders of the format:** **Run11\_BasementDepth\_ReservoirModelType\_UncertainParameterType\_SimulationLifetime\_InjectionTemperature\_FlowRate\_FractureSpacing**

These folders contain GEOPHIRES results for basement rock geothermal reservoir simulations: 9 folders are for 3 - 3.5 km depth scenarios, and 9 folders are for 3.5 - 4 km depth scenarios.

Folder name format:
The run number (11) is the same for these folders because they rely on the same probability distributions.

The basement depth is either 3p5, corresponding to a reservoir from 3 – 3.5 km depth, or 4p0, corresponding to a reservoir from 3.5 – 4.0 km depth.

The reservoir model type is mpf for multiple parallel fractures.

The uncertain parameter type is GeoEco for uncertainty in both geologic property parameters and economic and utilization parameters.

The simulation lifetime is 150 years

The injection temperatures are either 20, 30, or 50 °C

Flow rates are either 30, 50, or 70 kgs. 70 kgs uses wells with a larger pipe diameter than the other two flow rates.

Fracture spacing is 30 m.

For details about the contents of these folders, refer to the file: GEOPHIRES\_OutputFileDescriptions.docx

* 1. **Folder: Run11\_SummaryProbabilityPlots\_Basement**

Figures that summarize the probability results computed from each of the 18 simulations. Plots show the year when the probability is < 95% that the produced fluid will provide > X MWth heat, > T °C, or jointly provide > X MWth and > T °C.

1. **Folder:** **TBR\_ReservoirSimulations**
	1. **Folder: Run10\_TBR\_GEOPHIRES**
2. **18 folders of the format: Run10\_TBR\_ReservoirModelType\_UncertainParameterType\_SimulationLifetime\_InjectionTemperature\_FlowRate\_FractureSpacing**
These folders contain GEOPHIRES results for Trenton-Black River (TBR) geothermal reservoir simulations: 9 folders are for the multiple parallel fractures reservoir model (mpf), and 9 folders are for the plug flow reservoir model (pf).

Folder name format:
The run number (10) is the same for these folders because they rely on the same probability distributions.
The reservoir model type is mpf for multiple parallel fractures, or pf for plug flow.
The uncertain parameter type is GeoEco for uncertainty in both geologic property parameters and economic and utilization parameters.
The simulation lifetime is 40 years
The injection temperatures are either 20, 30, or 50 °C
Flow rates are either 30, 50, or 70 kgs. 70 kgs uses wells with a larger pipe diameter than the other two flow rates.
Fracture spacing is 20 m for the mpf models.

For details about the contents of these folders, refer to the file: GEOPHIRES\_OutputFileDescriptions.docx
3. **Folder: Run11\_SummaryProbabilityPlots\_Basement**Figures that summarize the probability results computed from each of the 18 simulations. Plots show the year when the probability is < 95% that the produced fluid will provide > X MWth heat, > T °C, or jointly provide > X MWth and > T °C.
	1. **Folder: Run10\_TBR\_TOUGH2simsAndGeophires**
4. **Folder: TBR\_TOUGH2sims**
5. **3 folders of the format: TBR\_Temperature**

Temperatures are Cold5, Med, and Hot5 for the coldest 5th percentile, median, and hottest 5th percentile of the predicted temperatures at depth, respectively.

Each of these folders have similar file contents.

* + - 1. **3 folders of the format: Prod\_T20QXX**

The X corresponds to the selected flow rate.

Within each of these folders there is a file with a .sim extension. This is the PetraSim runfile for the production scenario. It calls all of the other files within the folder for the simulation and visualization of the results. To see the results, load the SAVE file into PetraSim.

* + - 1. **A .sim file, and other files required to set up the TOUGH2** initial conditions. The .sim file is the PetraSim runfile for establishing the initial conditions. It calls all of the other files within the folder for the simulation and visualization of the results. To see the results of the initial conditions used for the production scenarios, load the SAVE file into PetraSim.
1. **Folder: TBR\_Diagram\_Hot5TempPressurePics**
2. **Folder: Pressure**

Contains 9 figures of pressure change over time in the TOUGH2 reservoir simulation. Three times (4, about 20, and 40 years) are selected for each of 3 flow rates (30, 50, and 70 kg/s). The injection temperature is 20 °C. The reservoir initial conditions correspond to the hottest 5th percentile of the predicted temperatures at depth.

1. **Folder: Temperature**

Contains 9 figures of temperature change over time in the TOUGH2 reservoir simulation. Three times (4, about 20, and 40 years) are selected for each of 3 flow rates (30, 50, and 70 kg/s). The injection temperature is 20 °C. The reservoir initial conditions correspond to the hottest 5th percentile of the predicted temperatures at depth.

1. **File: TOUGH2TempsPressures\_Hot5.ppt**

Contains slides that aggregate the temperature and pressure figures into 9-panel plots.

1. **Folder: TBR\_GEOPHIRES**
2. **9 folders of the format: Run10\_TBR\_TOUGH2\_Eco\_40yrs\_20Cinj\_FlowRate\_InitialReservoirTemperature**

These folders contain GEOPHIRES results for post-processing of the TOUGH2 simulations to account for production wellbore heat transfer.

Folder name format:

The run number (10) is the same for these folders because they rely on the same probability distributions.

The uncertain parameter type is Eco for uncertainty in only economic and utilization parameters.

The simulation lifetime is 40 years

The injection temperature is 20 °C

Flow rates are either 30, 50, or 70 kgs. 70 kgs uses wells with a larger pipe diameter than the other two flow rates.

The initial reservoir temperature is either the coldest 5th percentile, median, or hottest 5th percentile (Cold5, Med, Hot5).

For details about the contents of these folders, refer to the file: GEOPHIRES\_OutputFileDescriptions.docx

1. **Run10\_TBR\_TOUGH2\_40yrs\_20Cinj\_ProdTempHeatPostGEOPHIRES.png**

This figure summarizes the temperature and heat production results from post-GEOPHIRES simulation of the TOUGH2 results to account for production wellbore heat transfer.

**Reference**

Smith, J.D. and K.F. Beckers. (2020). Uncertainty and sensitivity analysis for geothermal reservoir performance and techno-economic assessments: A software package for GEOPHIRES. *Proceedings World Geothermal Congress 2020*. Reykjavik, Iceland, April 26-2.