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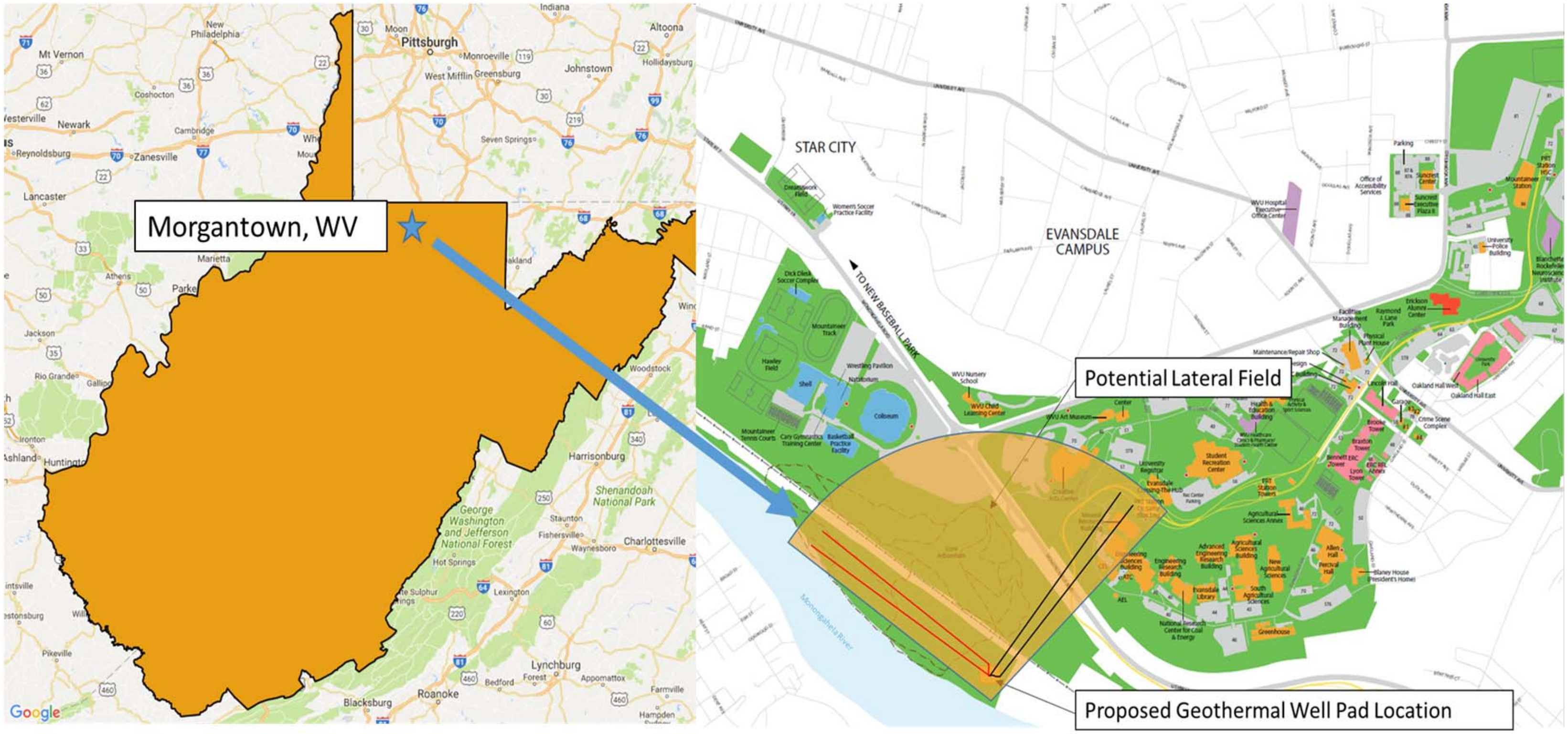


Feasibility of Deep Direct Use Geothermal on the WVU Campus-Morgantown, WV

Project Officer: Arlene Anderson

Total Project Funding: $833,517

November 13, 2017

Co-PI: Nagasree Garapati (presenting)

PI: Dr. Brian J Anderson

West Virginia University

Deep Direct-Use Feasibility Studies Technical and Economic Working Group Kick-Off Meeting

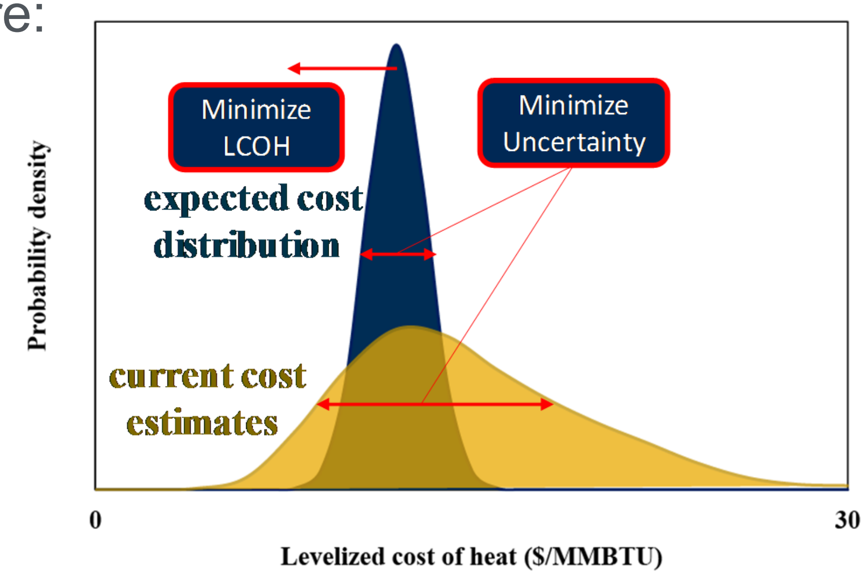
Project Objectives

- **Technical Challenges**

The two critical subsurface risk factors are:

1. the achievable flowrate of geofluid through target formations in the Appalachian Sedimentary Basin,

2. the temperature of the produced geothermal brine.



The target location of the WVU campus in Morgantown, West Virginia, affords an optimal and unique combination of critical factors necessary to develop deep direct use geothermal.

The proposed system is unique because it will allow for utilization of the geothermal heat as both heating and an energy source for absorption cooling, thus an amortization of system costs across a full, 12-month year.

Project Objectives

- **Technical Merit & Innovation**:
  - Optimizing a geothermal well field incorporating multiple horizontal lateral wells.
  - Sedimentary fracture dominated geothermal systems will be assessed which are currently under-explored.
  - Year-round utilization of the DDU system will significantly lower the annual levelized cost of heat, thus providing a lower barrier for a *first demonstration in the eastern U.S.* of DDU.

Project Objectives

- **Impact of Technology Advancement:**
  The impact of this project on advancing the state-of-the-art in geothermal deep direct use is three-fold:

  1. We will design the subsurface geothermal system incorporating the current state-of-the-art in unconventional hydrocarbon development.

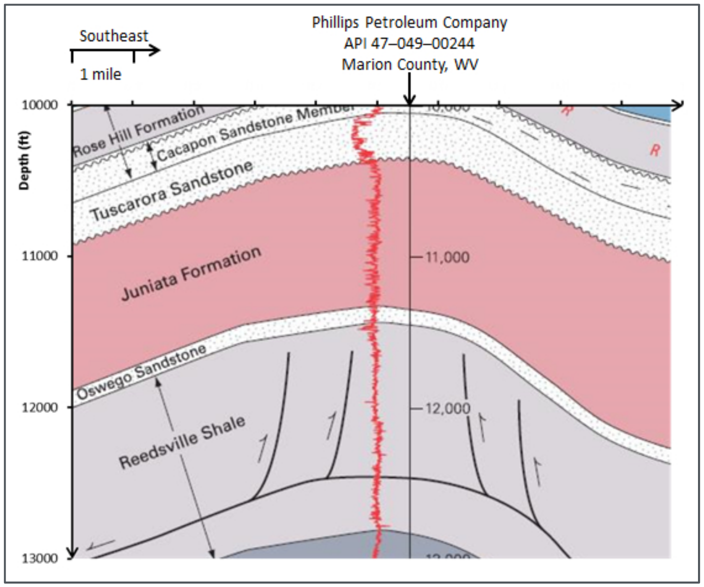
  2. The development of our GDHC system on the Morgantown, WVU campus will be the first geothermal DDU heating and cooling system in the eastern U.S., demonstrating that geothermal is a national resource not limited to the western states.

  3. The project will perform a fully-integrated assessment and optimization of the potential to incorporate DDU into an existing district heating system.

Thermal resource and site suitability

The elevated temperatures and high flow conductivity makes the proposed site an ideal geothermal resource for direct use.

- The thermal resource has been informed by an ongoing project (MSEEL) led by WVU.
- The extrapolated temperature of the Tuscarora at 10,000 ft is approximately 100° C.

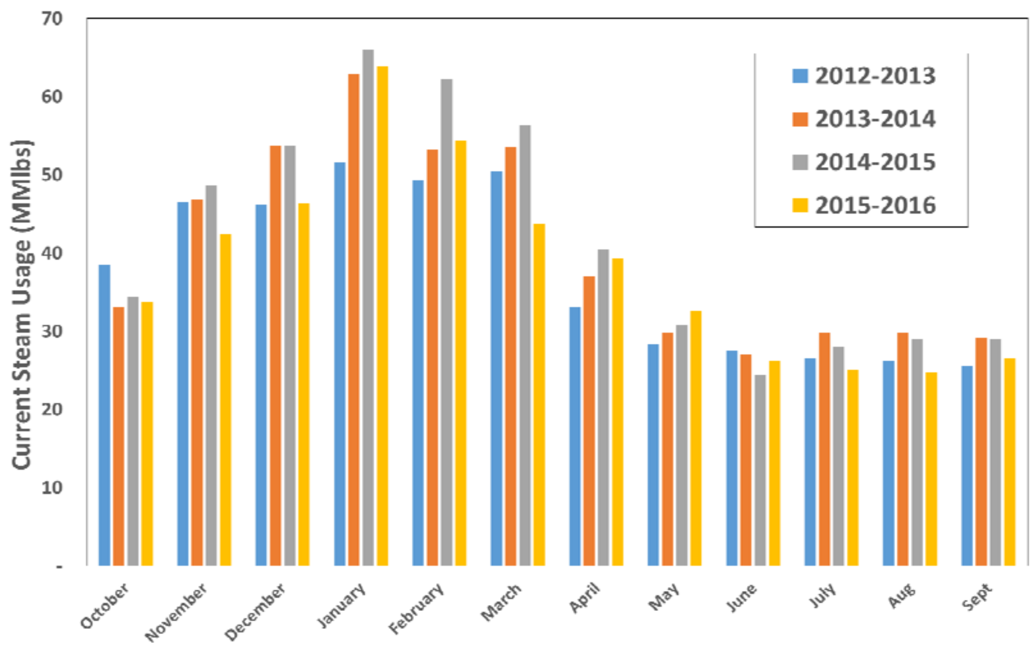


WVGES geologic cross section D-D' near Morgantown, WV illustrating the expected depth of the target formation.

- Based on the resistivity logs and gas production histories in the Tuscarora, significant porosity and permeability is expected.
- Core analysis performed on the Tuscarora core (API 4703300079) resulted in average fracture permeability of up to 20 mD. However, the formation has been productive for gas from fractures

Energy end use potential

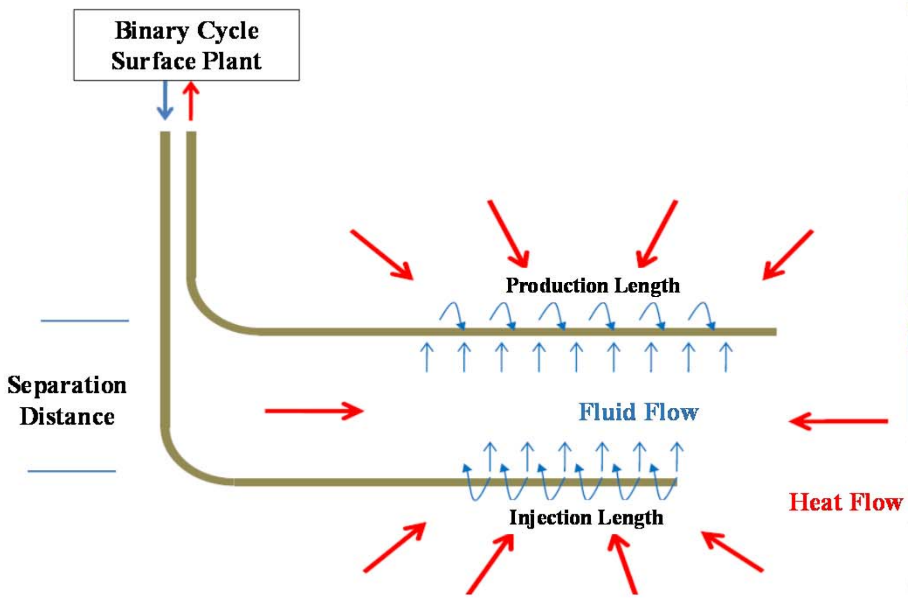
- The market for the geothermal resource will be the WVU Campus.
- Geothermal heating at WVU, thus, would result in year-round utilization of the DDU system, lowering the levelized cost of heat by fully amortizing the system over 12 months.



Annual WVU campus steam consumption proposed to be replaced by the GDHC system

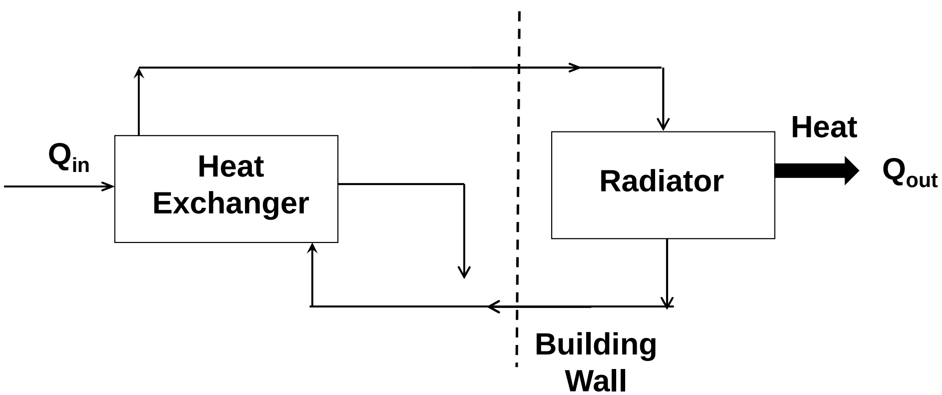
Proposed Technology and Preliminary Design Concept

- The proposed geothermal system will consist of one or multiple production wells, one injection well, and the surface plant.
- The produced geothermal fluid will be sent to the central heat exchanger where the heat from the geothermal fluid is exchanged with the secondary fluid (water) and the *spent geothermal fluid is reinjected* back into the reservoir.

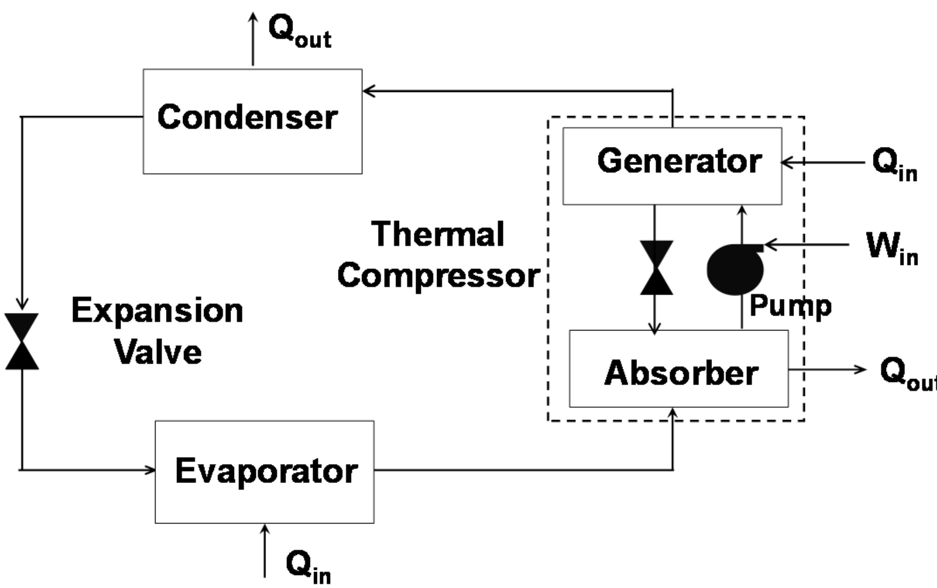


Proposed Technology and Preliminary Design Concept

- The proposed surface plant is the retrofit of the existing heating and cooling system with replacement of the current steam heat exchanger with a new heat exchanger designed for geothermal fluid.
- The majority of project economics depend on the design of new heat exchanger and any contingencies in the distribution system.



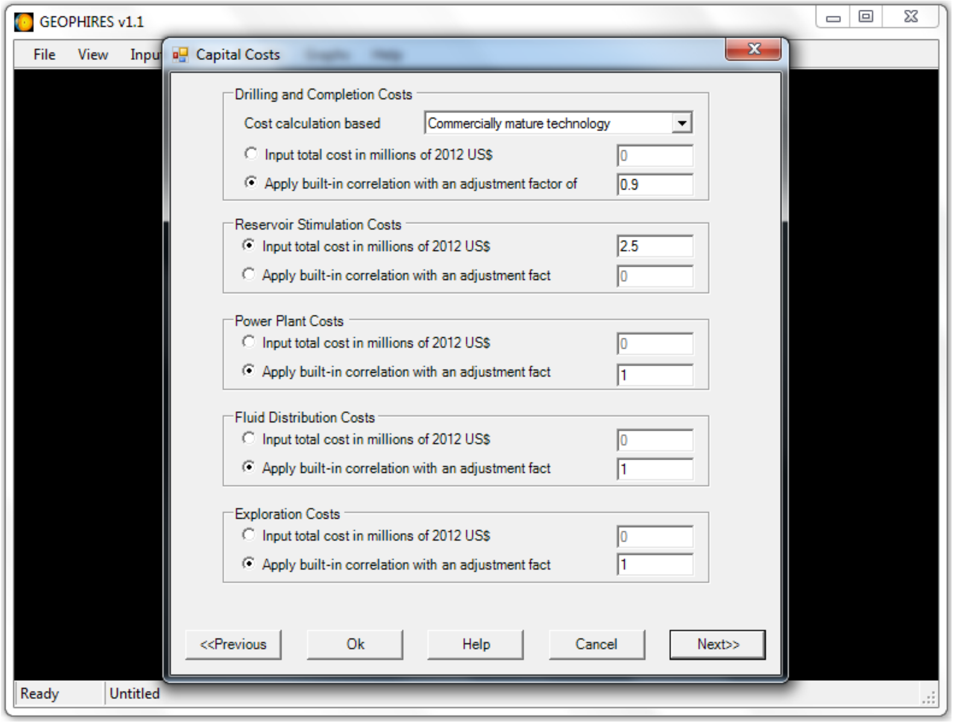
Schematic of the building heating unit of a GDHC system



Schematic of the absorption chiller

Methods for estimating project costs and benefits

- An economic analysis for the GDHC will be performed using GEOPHIRES[1]
- Surface plant capital cost will mainly consist of central heat exchanger and the retrofitted components cost.
- For calculating LCOH, BICYCLE[2] levelized cost model will be used.
- The feasibility of the GDHC system will be determined by comparing costs and benefits with the existing system.



[1]Beckers et al., 2013, Proceedings, Thirty-Eighth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA.
[2]Hardie, R. W. 1981, “BICYCLE II: A Computer Code for Calculating Levelized Life-Cycle Costs”, LANL, Los Alamos, NM.

Technical Objectives & Milestones

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- Objective 1: Characterize the Geothermal Site

Task Number	Subtask Title	Milestone Type	Milestone Number	Milestone Description	Milestone Verification Process	Months from Start of the Project
1.1	Perform Core Analysis and estimate temperatures	Milestone	M 1.1	Completed formation property measurements.	PI verifies data obtained from WVGES and WVU	4
1.2	Estimate Reservoir properties for modeling	Milestone	M 1.2	Processed the raw data from the previous task and the properties of the target reservoir are quantified.	PI receives reservoir property data and upload to Geothermal Data Repository (GDR)	6
1.3	Develop 3D Reservoir Model	Milestone	M 1.3	The representative 3-D model of the physical system (reservoir) is completed.	WVU receives 3D reservoir model from LBNL.	7
		Milestone	M 1.4	Review summary results with the DDU Feasibility Study Technical and Economic Working Group (DDU FSTEWG) and upload resulting data to the DOE Geothermal Data Repository (GDR)	DDU FSTEWG meeting minutes and GDR confirmation email	7

Technical Objectives & Milestones

- Objective 2: Characterize Existing Infrastructure

Task Number	Subtask Title	Milestone Type	Milestone Number	Milestone Description	Milestone Verification Process	Months from Start of the Project
2.1	Characterize Energy demand	Milestone	M 2.1	Determine Energy demand per building and provided data to team.	WVU Facilities will report the data to PI.	12
2.2	Perform Integration Assessment for Current District Heating System	Milestone	M 2.2	Current district heating system integration assessment, including quantification and valuation of existing distribution system retrofit capability, lifetime, cost, and opportunities for future expansions is done.	WVU Facilities will report the assessment of current DHS to PI.	7
2.3	Develop Base Case Surface Facility Design	Milestone	M 2.3	Defined Surface infrastructure base case.	WVU presents the surface facility design to team.	15
		Milestone	M 2.4	Review summary results with the DDU FSTEWG and upload resulting data to the DOE GDR	DDU FSTEWG meeting minutes and GDR confirmation email	15

Technical Objectives & Milestones

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- Objective 3: Create Subsurface Model and Design

Task Number	Subtask Title	Milestone Type	Milestone Number	Milestone Description	Milestone Verification Process	Months from Start of the Project
3.1	Simulate Base Case Vertical and Horizontal Well Configurations	Milestone	M 3.1	Completed Production simulations for base case vertical and horizontal well configurations.	PI analyses the base case geothermal production results.	9
3.2	Determine Well Configuration and Orientation/Economic Analysis	Milestone	M 3.2	Well configuration and orientation is determined.	PI verifies the decision on optimum well configuration and orientation	12
3.3	Perform Subsurface Uncertainty Analysis	Milestone	M 3.3	Quantified the effect of uncertainty in reservoir properties on geothermal fluid production.	LBNL will submit subsurface uncertainty analysis data to WVU and PI will report to DOE the uncertainty in the subsurface characterization and updates the risk factor data.	12
		Milestone	M 3.4	Review summary results with the DDU FSTEWG and upload resulting data to the DOE GDR	DDU FSTEWG meeting minutes and GDR confirmation email	12
		Go/No-Go Decision Point	D1	Based on energy demand characterization, subsurface uncertainty analysis, and well head LCOH cost a go/no-go decision is made	The Recipient will not proceed beyond this point until approval has been granted by the DOE Contracting Officer through a review and concurrence of successful completion of activities to date.	12

- Objective 4: Develop and Optimize Integrated GDHC System

Task Number	Subtask Title	Milestone Type	Milestone Number	Milestone Description	Milestone Verification Process	Months from Start of the Project
4.1	Estimate Base Case Levelized Cost of Heat (LCOH)	Milestone	M 4.1	Performed feasibility and cost estimation of the base case GDHC.	PI verifies the base case LCOH value.	15
4.2	Optimize Integrated GDHC System	Milestone	M 4.2	Optimized system design and LCOH is estimated	PI verifies the optimum Integrated GDHC system	21
4.3	Quantify Minimized System Uncertainties & Development Risks	Milestone	M 4.3	Probability of the LCOH of the optimum GDHC system is determined	PI verifies the LCOH Probability data	24
		Milestone	M 4.4	Review summary results with the DDU FSTEWG and upload resulting data to the DOE GDR	DDU FSTEWG meeting minutes and GDR confirmation email	24
		End of Project Goal		Uncertainties in LCOH for proposed GDHC system is quantified	Final report and relevant data will be submitted to DOE office and WVU.	24

Technical Objectives & Milestones

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Lawrence Berkeley National Laboratory AOP Tasks

- 1.3 Develop a 3D Geological Model Based on
  - Geological maps and cross sections
  - Interpreted seismic profile
  - Borehole logging and core analysis
  - Fault maps and well locations
- 3.3 Perform Subsurface Uncertainty Analysis Using
  - Reservoir models from Task 3.1 and 3.2
  - iTOUGH2 – the uncertainty quantification software for TOUGH models

Technical Objectives & Milestones

Lawrence Berkeley National Laboratory

Quarterly Milestones

- Collect basic information needed for building a geological model
- Develop a preliminary geological model
- Finalize the geological model and prepare a summary report for the geological model including a description of data used
- Collect initial reservoir model parameters for uncertainty quantification
- Quantify impact of parameter uncertainty in production
- Finish a summary report for uncertainty quantification results

Proposed Metrics

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Thermal resource and site suitability

- Core analysis for reservoir property measurements.
- Mini-permeameter measurements for matrix, fracture and overall permeability
- Thermal conductivity measurements for temperatures
- The uncertainty in the subsurface reservoir permeability parameters is reduced and managed by performing uncertainty analysis using iTOUGH2[1].

Energy end use potential

- Fluid stream temperatures and flowrates at the entry and exit of each building.
- Energy losses during transmission
- Average and peak heating and cooling demand.
- Monthly energy usage per building over a year will be determined.

Proposed Metrics

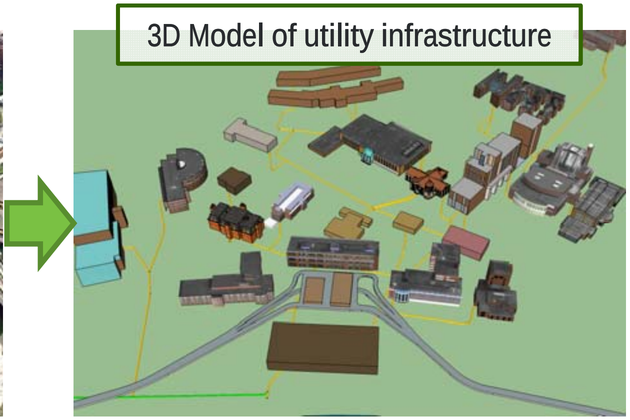
Technology

- The production simulation will be carried out for two different well configurations using TOUGH2/EOS1
- The performance of vertical and horizontal well configurations will be evaluated based on achievable flow rates and production fluid temperatures.
- Preliminary economic analysis of well head levelized cost of heat (LCOH) for different arrangements will be performed.
- Based on the performance and cost, the final well configuration will be selected for further analysis.
- Performance of GDHC system is modeled using Aspen plus.

Proposed Metrics

Methods for estimating project costs and benefits.

- The feasibility of the GDHC system will be determined by comparing costs and benefits with the existing system.
- The current cost is ~$15/MMBTU for steam.
- In our preliminary assessment the calculated LCOH was $11.73/MMBTU[1] for geothermal district heating.



WVU GDHC System Development Timeline

Start Date	June 2017	June 2019	Spring 2020	Spring 2021	Summer 2022	Summer 2023	Summer 2025	September 2026	March 2027
Task	Feasibility Project Start	Exploratory Well Planning	Exploratory Well Drilling and Evaluation	Injection Well Drilling and Formation Evaluation	Production Well Drilling and Flow Testing	Distribution System Upgrading	Building Integration	Commission-ing	New System Start

[1]Nandanwar, M., 2016, Numerical modeling and simulations for techno-economic assessment of non-conventional energy systems, WVU

Collaboration:

- Through the DDU Working Group, we will quickly assess standard methods of determining Levelized Cost of Heat (LCOH) as well as collaborate on ideas for reducing risk
- Existing, accepted community standards will be used where possible.
- Where there are ranges of values which members of the scientific community find acceptable the WVURC team will document our rationale for selecting specific data to be used and collaborate with the technical review team(s) to determine the most appropriate values to be used for this study.
- Relevant National Geothermal Data System (NGDS) data exchange models will be used wherever possible

Data Management Plan:

- All data and metadata will be made available in the primary content and format used in the study.
- Data will be uploaded to the U.S. DOE Geothermal Data Repository as it is generated or no later than the quarter in which it is generated.
- In addition, WVURC will preserve all data for the term of the project on our own secure servers.
- Our intent is to provide free exchange of ideas and information developed as part of this project, to further DDU technology.
- Providing all data sources, inputs, and outputs will ensure that all viable data and strategies developed will be available to other researchers in the field and help promote a positive societal impact.