Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin (GPFA-AB) Statement of Project Objections

This document contains the Statement of Project Objections for our project including the primary tasks, subtasks and milestones for DOE Contract Award Number: DE-EE0006726.

1. **<u>Task 1.0: Project Organization, Data Review, and Thermal Resource Quality Assessment</u>:** The purpose of this task and its several subtasks are to research and assemble the available data in the published literature as well as that data available from non-published sources, to establish the data infrastructure for the project, and to carry out the assessment of the first of the proposed Risk Factors (RF1), Thermal Resource Quality.

1.1 Subtask 1.1: Literature Review and Database Assembly

1.1.1 Assemble Data (thermal, well logs, etc.) from the National Geothermal Data System and other project files

1.1.2 Review literature, including porosity, permeability and reservoir information relevant to portions of the Appalachian Basin within New York, West Virginia and Pennsylvania

1.1.3 Work with State Geological Surveys to select wells for detailed analysis

1.1.4 Work with State Geological Surveys to compile the detailed analysis for the subset of wells

1.2 Subtask 1.2: Data Management and Analysis Infrastructure. Select and assemble required hardware, data infrastructure and software needed to assess, display, compile, spatially analyze, share back-up and otherwise manage the information collected and utilized throughout the project.

1.3 Subtask 1.3: Thermal Reservoir Modeling and Analysis

1.3.1 Combine the existing maps of the three states (NY, PA and WV) and use this as the baseline (note: "baseline" below refers to this current state of knowledge)

1.3.2 Subdivide basement provinces using potential field data

1.3.3 Compile thermal conductivity values for Appalachian basin lithologies

1.3.4 Combine in one dataset the many thousands of wells in all three states that were used in producing the existing maps, apply a uniform numerical approach, apply basement heat flow appropriate to the basement provinces, apply thermal conductivities appropriate to the Appalachian basin formations, krige and analyze semi-variograms, and produce a set of region-wide temperature-at-depth maps that improve on the baseline.

1.3.5 Establish uncertainty levels for the regional thermal resource maps

1.3.5.1 Select approximately 100 test wells based on criteria of data quality, of locations that span the full range of thermal quality predicted by the existing maps, and of proximity to the small set of existing wells for which there are thermally equilibrated temperature profiles

1.3.5.2 Develop location-specific thermal models that utilize the full suite of geological properties of the approximately 100 individual wells

1.3.5.3 Validate the well-specific temperature estimates by comparison with existing equilibrated thermal profiles, where available; iterate thermal model methods if comparison is not judged adequate.

1.3.5.4 Compare the well-specific results to the combined pre-project baseline maps as well as to the newly improved three-state temperature maps.

1.3.5.5 Decide whether or not to continue using the compiled pre-project maps, or the then-current uniform maps, or to revise the model on which the maps are computed and repeat the prediction and uncertainty analysis. One of the decision criteria will be based upon the standard error of prediction expressed as a percentage of the predicted value, and its absolute magnitude relative to the required precision of the economic analysis.

1.3.5.6 If the uncertainty on the maps is judged to be unsatisfactory, team will create a new set of region-wide maps based on the test well set only, with corresponding analysis of spatial uncertainty.

1.3.5.7 Based on a map of the depth to 80 °C rock temperatures, for which the shallower depths designate the most favorable resources, select four counties per state with the most favorable thermal resource.

1.3.6 Evaluate thermal resources in four counties per state with most favorable thermal resource:

1.3.6.1 Estimate temperature field based on thermal modeling of full geological data for approximately 10 wells per county.

1.3.6.2 Use kriging and semi-variograms to analyze uncertainty associated with thermal field maps of most favorable counties.

1.3.7 Create maps of entire region ranking thermal quality

1.3.7.1 As a project team, assign thresholds for depths to 80 °C corresponding to Green/Yellow/Red classes based on current knowledge of technical and economic thresholds.

1.3.7.2 Create maps using these depth thresholds.

Task 1 Deliverable: Deliver an improved region-wide map of depths to 80 °C isotherm and a county map for four counties per state, as well as a Green-Yellow-Red-ranked thermal resource map for the region and for the four counties per state, as derived from all the considerations described in Task 1, including lithologies, updated conductivity, and updated basement heat flux model, etc. as well as the supporting data according to the Data Management Plan and thermal models for the NY, PA and WV region of the Appalachian Basin.

2. Task 2.0: Natural Reservoir Quality: The purpose of this task is to develop the supporting database, to evaluate, and to map the distribution of potential geothermal reservoirs. The result will be Ranking Maps and supporting data for natural reservoirs in a majority of the Appalachian Basin of West Virginia, New York and Pennsylvania.

2.1. Collate from prior reports and NGDS and/or state databases the spatial and depth distribution of known hydrocarbon reservoirs and saline aquifers and record the information in GIS databases:

2.1.1. Determine locations as well as rock and fluid properties of historical conventional reservoirs;

2.1.2. Compile, from carbon sequestration inventories and from prior studies conducted in support of analyses of the potential for injection wells, the locations, depths and properties of saline aquifers with high pore volume;

2.2. Characterize, based upon the collated information, case studies of each major category of natural reservoir

2.2.1. Identify categories of natural reservoirs based on rock and fluid properties

2.2.2. Extract data for reservoir quality and variability from databases

2.2.3. Produce database tied to reservoir categories of porosity and, where reported in prior databases, the permeability, hydraulic conductivity and fluid pressure

2.3. Create ranking categories of reservoir as best, worst, and intermediate capacity for production

2.3.1. Use the GIS 3D locations of potential natural reservoirs to identify reservoirs at < 4000 m. Restrict further analysis only to this depth range.

2.3.2. Classify the potential reservoir categories by porosity, permeability and pressure criteria to identify the reservoirs with greatest potential for high flux of natural reservoir water during production and recirculation

2.3.3. As a project team, assign weights to i) the values of thickness of each reservoir category at a specific location, as well as for b) the reservoir category itself. Select a combination of thickness and reservoir category weights that serves as a threshold, below which it is judged that an insufficient production rate of formation fluids is plausible. This decision will be informed by Task 4.

2.4. To create a regional map, first rank areas that fall below the threshold noted immediately above as Red. Then for all other depths and regions, combine the 3D distribution of thickness and category(ies) of the available reservoirs with their weighting factors to create a grid of the location-specific suitability of potential reservoirs. The project team will decide upon the most suitable algorithm for this combination of factors. Divide the gridded values into the upper half (to be designed green) and the lower half (to be designated yellow).

2.5. Produce maps of Green/Yellow/Red conditions for the three-state area.

<u>Task 2 Deliverable</u>: Deliver reservoir quality maps, supporting data and related models for the NY, PA and WV region of the Appalachian Basin incorporating information such as reservoir quality and variability, porosity, permeability, and hydraulic conductivity and other information as described in Task 2.

3. **<u>Task 3.0: Risk of Seismicity</u>:** The purpose of this task is to review seismicity (excluding enhanced geothermal systems –EGS) as a Risk Factor and identify regions with enhanced likelihood for inducing unintended seismic activity during preparation of a reservoir, or during the course of geothermal heat production. The result of the task will be maps for the study area in the Appalachian Basin in NY, PA and WV of faults and of faults that are active.

3.1. Compile fault maps

3.1.1. Extract fault locations from reports and literature, recording detection method used in original report;

3.1.2. Locate additional faults using potential field data

3.1.3. Accounting for scale differences in the data that underlie the methods, use differences among maps of faults identified by potential field methods and NYS existing detailed maps, to estimate the likelihood a fault is missed by the potential field methods.

- **3.1.4.** Extract locations of faults detectable with similar criteria across the 3-state area

3.2. Determine distribution of active seismicity at shallow depths:

- **3.2.1.** Based on earthquake catalogs compile hypocenters
- **3.2.2.** Create map of ongoing (2014-15) microseismicity shallower than 6 km based on, or extracted from data recorded by, EarthScope TA eastern US array.

3.3. Create maps of risk of activation or reactivation of faults

- **3.3.1.** Create maps of distances to known faults, with uncertainties
- **3.3.2.** Create maps of distances to locations of seismically active faults, with uncertainties
- **3.3.3.** Review the rapidly evolving literature on the relationships between reactivation of faults, reservoir properties, distance to the well site, and categories of fluid management at the well site
- **3.3.4.** As a project team, adopt risk criteria for distances of a geothermal well from a fault with designations as unacceptable risk (Red), intermediate (Yellow), and acceptable risk (Green). The criteria will account for the length of the fault and for properties that are typical for the category of the closest reservoir
- **3.3.5.** Produce maps illustrating areas classified as Green/Yellow/Red

<u>Task 3 Deliverable</u>: Deliver risk map, supporting data according to the Data Management Plan, and related models, for the NY, PA and WV region of the Appalachian Basin for induced or reactivated seismicity, incorporating fault positions and seismicity activity and other information as described in Task 3.

4. **<u>Task 4.0: Utilization Variability</u>:** The purpose of this task is to identify regions in the Appalachian Basin with the capacity to utilize low-grade geothermal heat and the related variability of demand. The result of the task will be utilization maps for the region of the Appalachian Basin in NY, PA and WV and estimates of Levelized Cost of Heat for a small set of communities.

7.4 Develop maps of variable population density and demand for heat.

- **7.4.1** Review of US census data to extract population densities across 3 states;
- **7.4.2** Review of climate or surface temperature data to develop the spatial distribution of seasonal heat demand;
- **7.4.3** Combine population density, heat demand and seasonal demand to develop an index for annual heat demand.

7.5 Use the (GEOthermal energy for Production of Heat and Electricity ("IR") Economically Simulated) model (GEOPHIRES) to conduct parametric analysis of the economics of developing integrated geothermal utilization systems as a function of reservoir performance, demand requirements, and financial factors such as capital costs, and debt and equity rates of return.

- **7.5.1** Update model for inflation and regional effects
- **7.5.2** Integrate current well drilling costs database and infrastructure capital costs
- **7.5.3** After a first draft of a CRS map is created, in anticipation of decision-making based on the finalized CRS map, select two communities in each state, one in a favorable (Green) and one in an unfavorable (Red) area, and for those communities estimate Levelized Cost of Heat (LCOH). The basis for selection of these few communities will depend on the availability of information about i) demand requirements in terms of temperatures, heat flux, and capacity factors, ii) the sub-surface geological features at

those locations, and iii) quality of existing infrastructure for implementing a district network as well as a number of social factors such as community interest.

7.6 Assign ranks to the proximity of a community or other heat consumer to a potential geothermal reservoir.

7.6.1 Use GEOPHIRES to test the sensitivity of the LCOH to the distance of a potential well field to a consumer end point

7.6.2 As a project team, decide upon the thresholds of distance and of heat demand to rank as Green/Yellow/Red

7.6.3 Create a map displaying the Green/Yellow/Red ranks

<u>Task 4 Deliverable</u>: Deliver maps for spatial variability of population and heat demand, and a ranked map for utilization, as described in Task 4, and supporting data according to the Data management Plan, for the NY, PA and WV region of the Appalachian Basin. Deliver estimated Levelized Cost of Heat (LCOH) for two communities in each state.

5. **<u>Task 5.0: Risk Matrix Analysis</u>:** The purpose of this task is to merge the common risk segment maps described above, and to produce a common Risk segment map. This will be the compilation of factors and the most favorable combinations of multiple risk factors from the Risk Factors evaluated in Tasks 1-4. A risk matrix will be applied to combine the four sets of risk factors and will identify up to six "most promising Play Fairways" within the Appalachian Basin in NY, PA and WV.

5.1 Adopt Common Risk Segment (CRS) calculation standard

5.1.1 Examine choices in available software or customize software

5.1.2 Run sensitivity analyses with GEOPHIRES to clarify the relative importance of the four risk factors in the viability of a low-temperature geothermal energy project, and the nature of threshold effects for those factors

5.1.3 As a project team, assign weighting factors for each risk category to develop a simple composite risk value, as well as considering an appropriate range of non-linear total risk functions (including the product of the individual risk factors or their compliments)

5.2 Create maps of individual risk values of each Risk Factor (RF)

5.2.1 Equalize spatial resolution of maps;

5.2.2 Create gridded fields of weighting factor for each of risk categories

5.3 Map spatial variability of geothermal resource from natural reservoirs

5.3.1 Run risk analysis for matrix of risk factors from Tasks 1-4.

5.3.2 Map spatial variability of combined and weighted information on resource, reservoirs, faults, and usage

5.3.3 As a project team, assign thresholds for Green/Yellow/Red ranks

5.3.4 Compare preliminary LCOH estimates for six communities to the current Green/Yellow/Red ranks for consistency.

5.3.5 Run risk analysis calculations for matrix utilizing alternative weightings as appropriate based on expert input.

5.3.6 Identify zones which are the most favorable identified play fairways.

<u>Task 5 Deliverable</u>: Deliver common risk assessment map which delineates more than 6 Play Fairways within the NY, PA and WV region of the Appalachian Basin based upon the compilation of the spatial variability of the risk factors assessed in Tasks 1-4. The models, and available supporting data according to the Data Management Plan, will also be delivered.

Task 6.0: Project Management and Reporting

Task 7.0: Commercialization / Market Transformations