Microhole Arrays Drilled With Advanced Abrasive Slurry Jet Technology To Efficiently Exploit Enhanced Geothermal Systems

Contract # DE-EE0002783

Microhole Arrays / FLASH

Project Officer : Greg Stillman

Total Project Funding: $3.0 MM / DOE $2.4 MM

Presentation Date: April 24, 2013

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Impact Technologies LLC
Sub-Recipient: LBNL, University of Tulsa

Track Name: Drilling Systems

Collaborations

- **Lawrence Berkeley National Laboratory**

Dr. Stefan Finsterle, Dr. Yingqi Zhang, Dr. Lehua Pan, Dr. Patrick Dobson;

- **The University of Tulsa**

Dr. Ram Mohan, Dr. Ovadia Shoham, Ashwin Padsalgikar (Ph.D. ME program student), Thierry Groga-Bada (MS ME program student);

- Dr. Betty Felber and Dr. Dwight Rychel

Relevance / Impact of Research

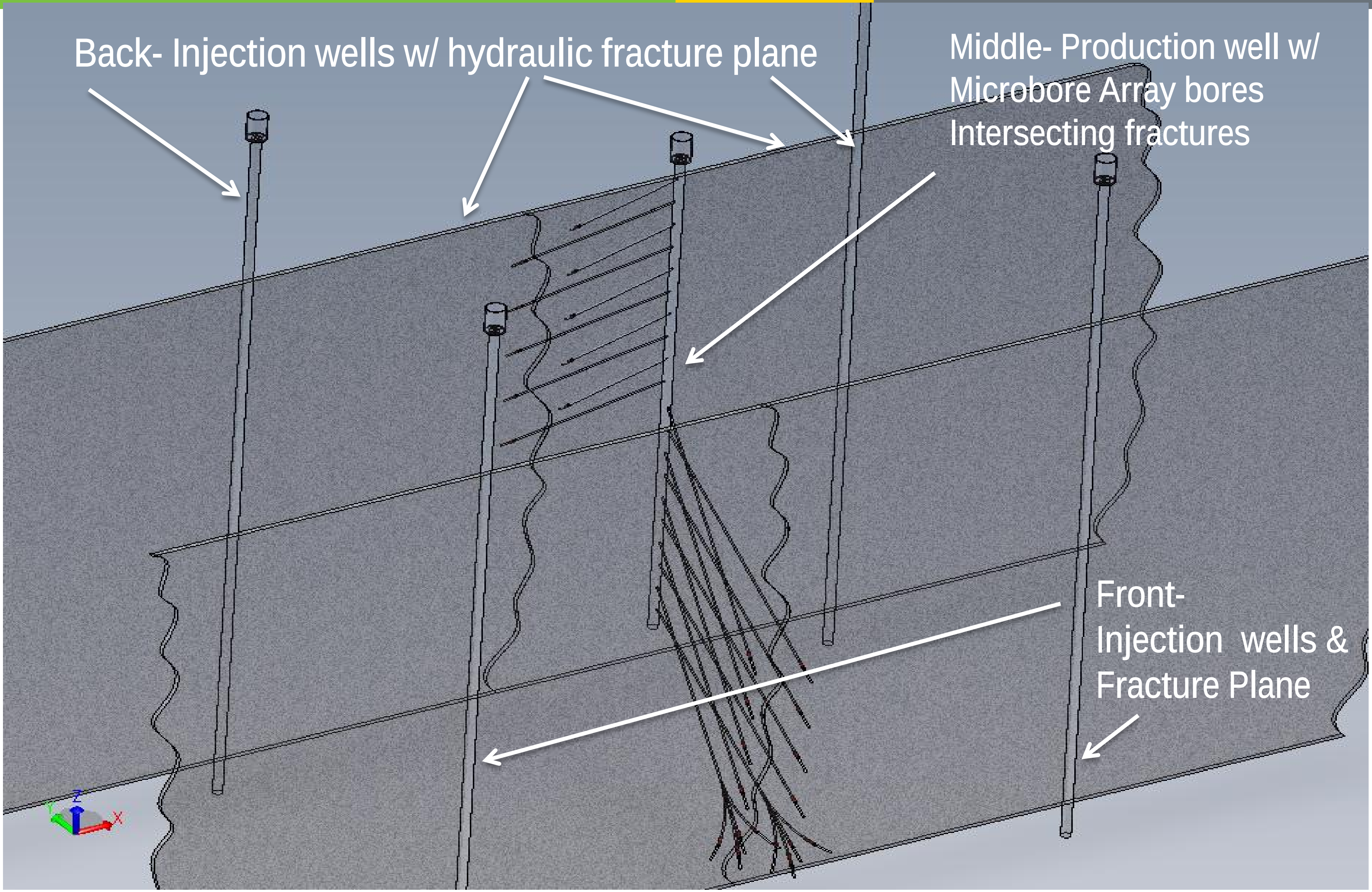
Project Objectives: Demonstrate improved EGS heat mining performance with microhole arrays. Demonstrate microholes drilled with FLASH abrasive slurry jetting.

Concept: Directionally drill multiple (100's for an array) microholes (e.g., bores<4") from a 1st EGS primary wellbore to intersect fracture networks (natural or induced) that are connected to a 2nd EGS wellbore.

Benefits: This project addresses the GTP goals of: improved reservoir rock contact for higher heat transfer / mining creating more efficient EGS projects with fewer vertical large bores and longer lives and thus lower LCOE. Details-

Arrays-Multiple bores increase reservoir contact for higher heat mining, higher chance of encountering fractures for more robust (lower risk) EGS developments and lower LCOE.

Microhole Array Concept in an EGS Field



Back- Injection wells w/ hydraulic fracture plane

Middle- Production well w/
Microbore Array bores
Intersecting fractures

Front-
Injection wells &
Fracture Plane

Relevance / Impact of Research- 2

Benefits (continued):

Microholes- Bores< 4" diameter. Lower cost to drill/ install, lower $ risk per bore. More intimate rock contact with more efficient heat transfer. Self-regulating flow between bores, with benefits increasing with smaller bores. These small bores can be drilled only with FLASH ASJ or high energy MMW.

FLASH abrasive slurry jet drilling- use of supercritical nitrogen, carbon dioxide or steam with solids to supersonically erode rocks at 4-20X conventional methods. Considered now as a completion method for EGS systems and NOT for drilling the vertical primary bores. Simple downhole tools, reasonable tool life expectancy for installing short laterals for EGS. Required reduced BHP for high efficiency cutting is problematic, requiring an isolated zone and a downhole pump.

Scientific/Technical Approach

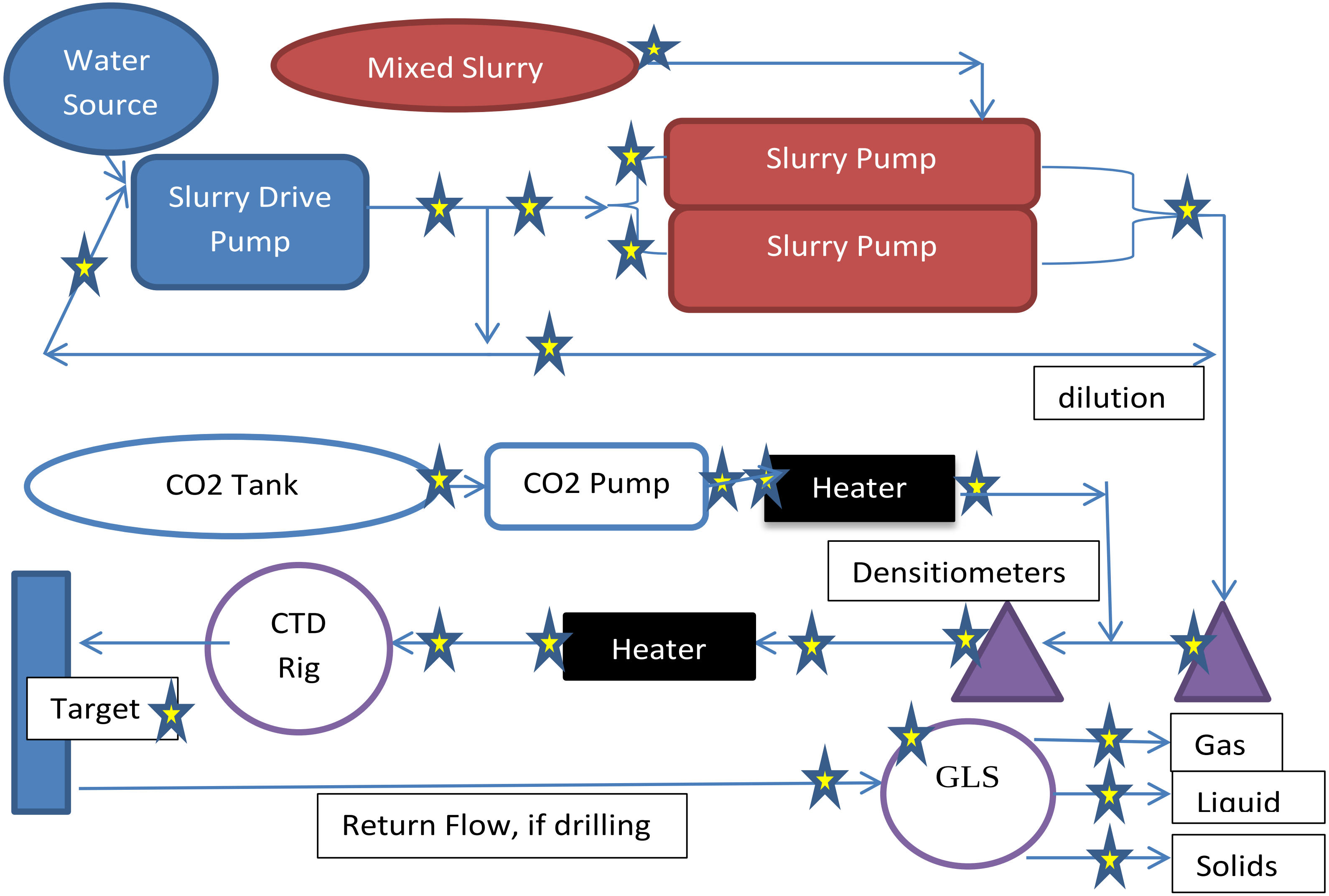
This project had two parallel scientific / technical approaches:

- Investigate and (limited) demonstrate *FLASH ASJ* capabilities to install microholes at EGS depths; and
- Estimate the potential benefits of an installed microbore array on *EGS performance*.

The ***FLASH ASJ drilling*** aspect in *Phase I* evaluated key components of fluids, pipes and expected operating conditions from surface down to EGS depths/ conditions. The *Phase II* effort focused on proving its capabilities in bench tests and in field/shop drilling tests. This effort included slurry generation with supercritical fluids at pressures up to 10,000 psig, optimizing slurry mixture content, nozzle design development and testing, and the delivery systems with adequate controls.

Impact Facility
FLASH ASJ Test Bench Flow Chart

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Impact Test Facility Components

Slurry Drive Pump

Pump Slurry Discharge Section

CO_2 Tank & HP Pump

Target , Mover & Dual Heater

Densitometer

Slurry Mix Tank

Directional Tools & Cut Rock Slabs

1.5” holder
3 nozzles

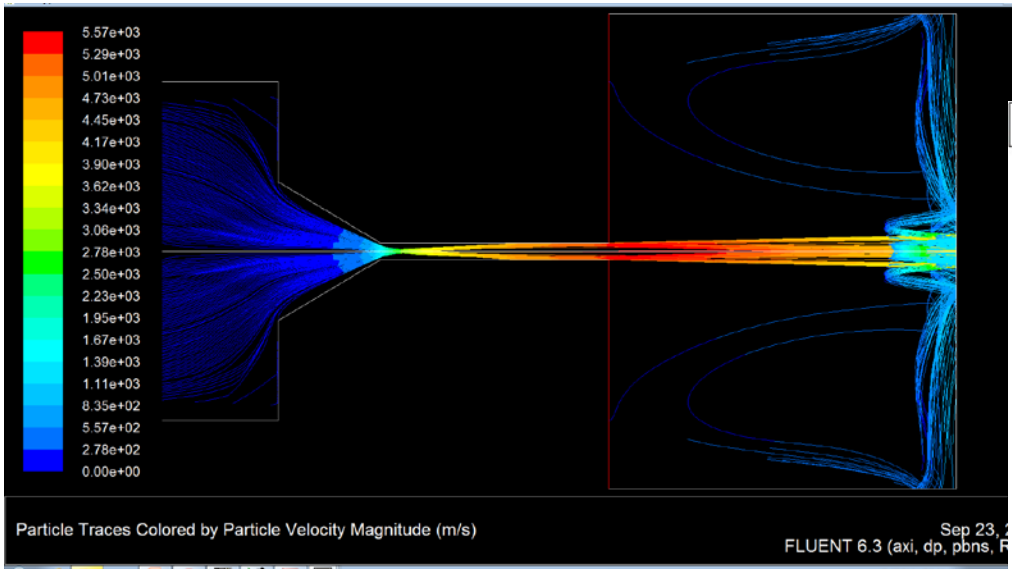
1” holder
1 nozzle

3” holder
4 nozzles

1” holder extension
Straight or bent

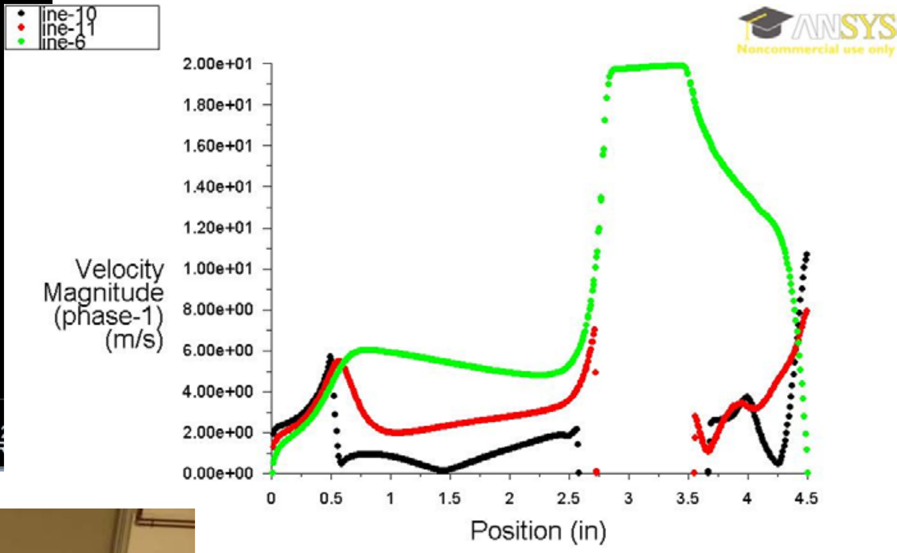
Various nozzle designs

TU Fluent Nozzle Studies & Lab Setup



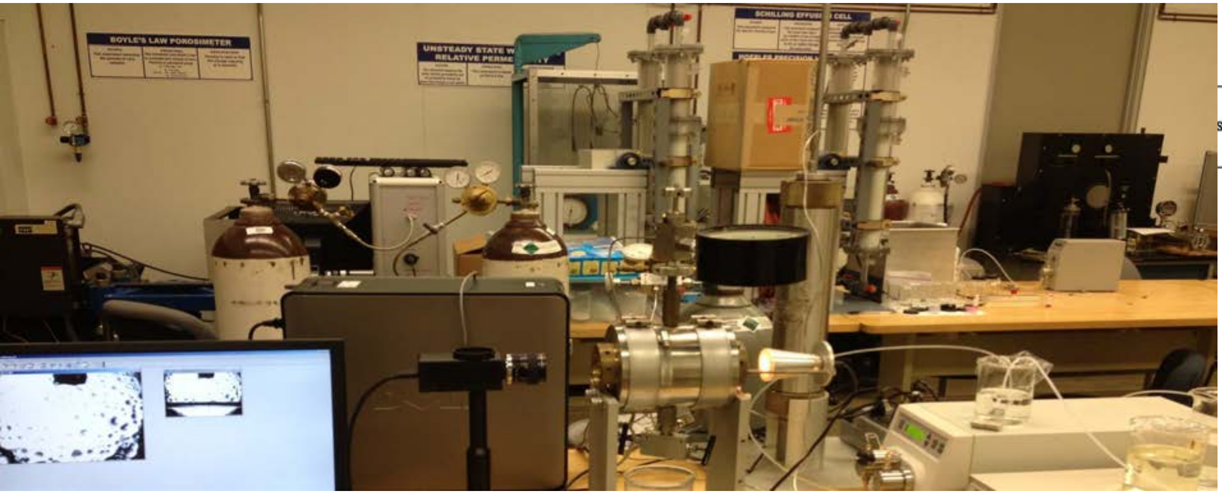
Particle Traces Colored by Particle Velocity Magnitude (m/s)

Sep 23, 2
FLUENT 6.3 (axi, dp, pbns, R



se-1) (Time=7.8340e-02)

Oct 17, 2012
ANSYS FLUENT 13.0 (2d, pbns, eulerian, rngke, transient)

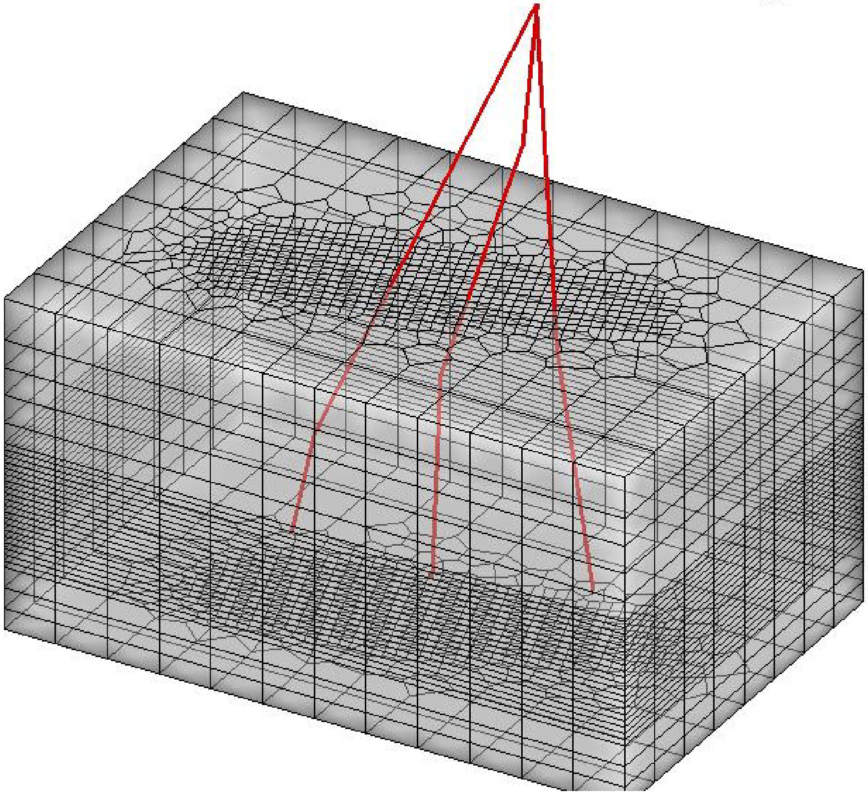


Scientific / Technical Approach - 2

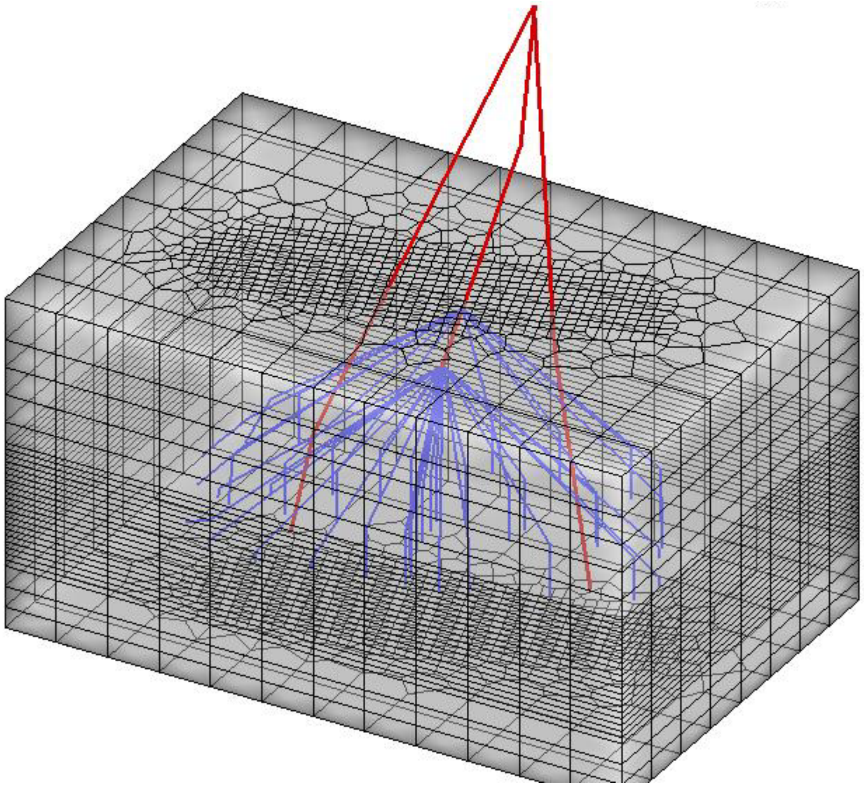
Drilling continued- Bench cutting / boring a 500ºF granite slab at the optimum FLASH conditions is planned. Directional and separation/ safety/ environmental methods and tools were investigated. *Phase III* fills in the data gaps and evaluates the total collected data for the Final Report (*Phase IV*).

The ***EGS performance*** aspect of using microhole arrays initially focused (*Phase I*) on identifying various possible configurations, making programming modifications (effort moved from *Phase II*) in TOUGH2. In *Phase II* the effort shifted to modeling (partial, 40 bore) microhole array configurations to compare to conventional EGS configurations. A dual-K and a Soultz-based models were developed and used for this comparison. In *Phase III* the influence of multiple directional bores within a fracture network was evaluated also using a Soultz based fracture model.

Dual-K Model Comparison- with and without microbore array

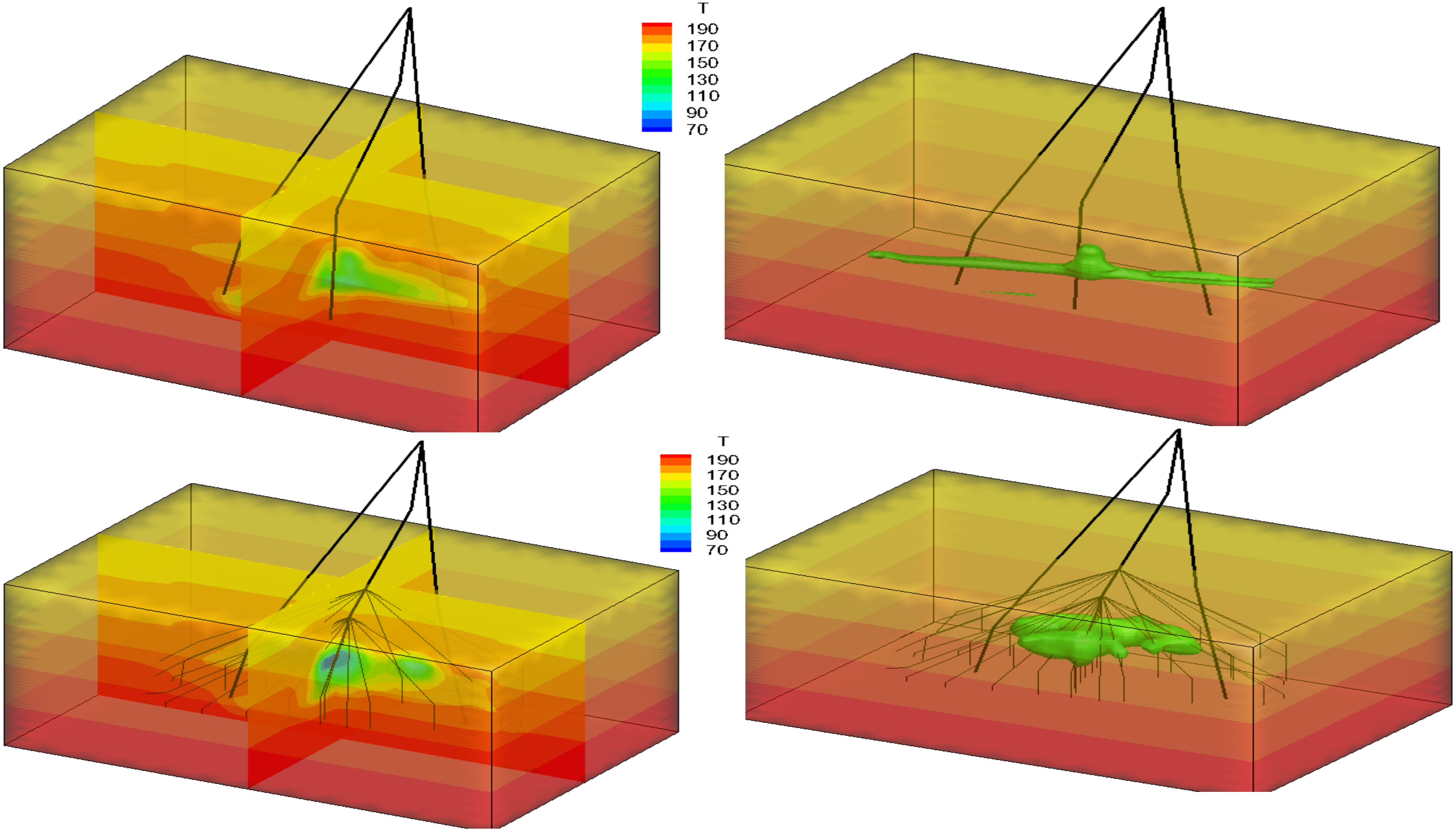


- Conventional Design



Microhole Configuration

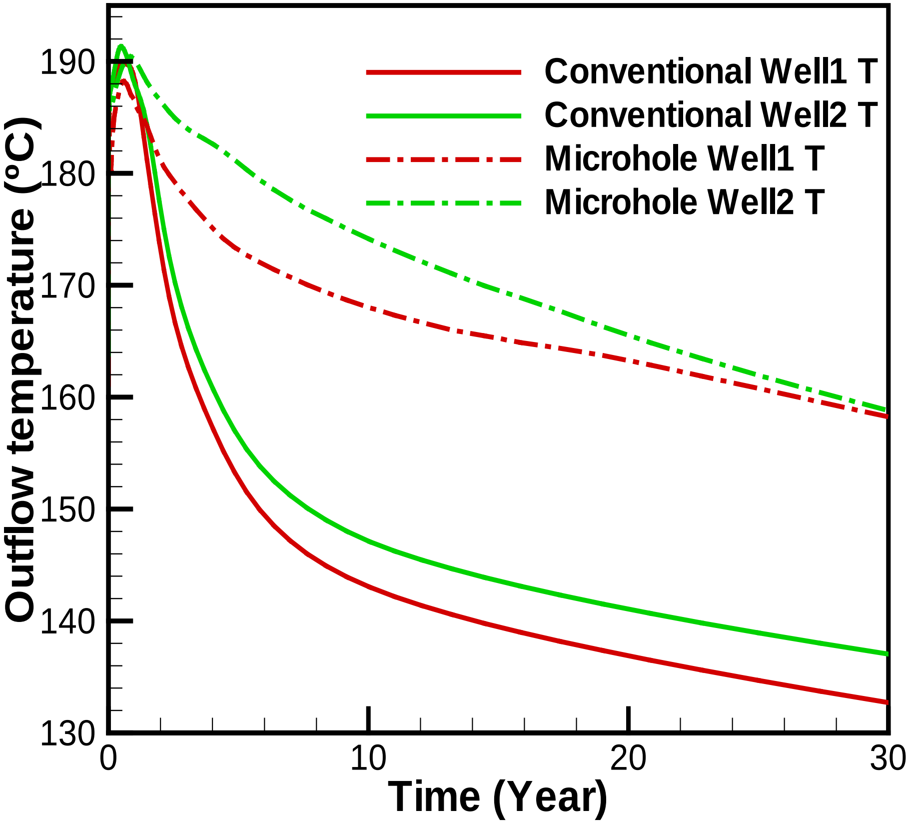
Dual-K Model without (top)/ with Microhole Arrays- 10Yr Temperatures

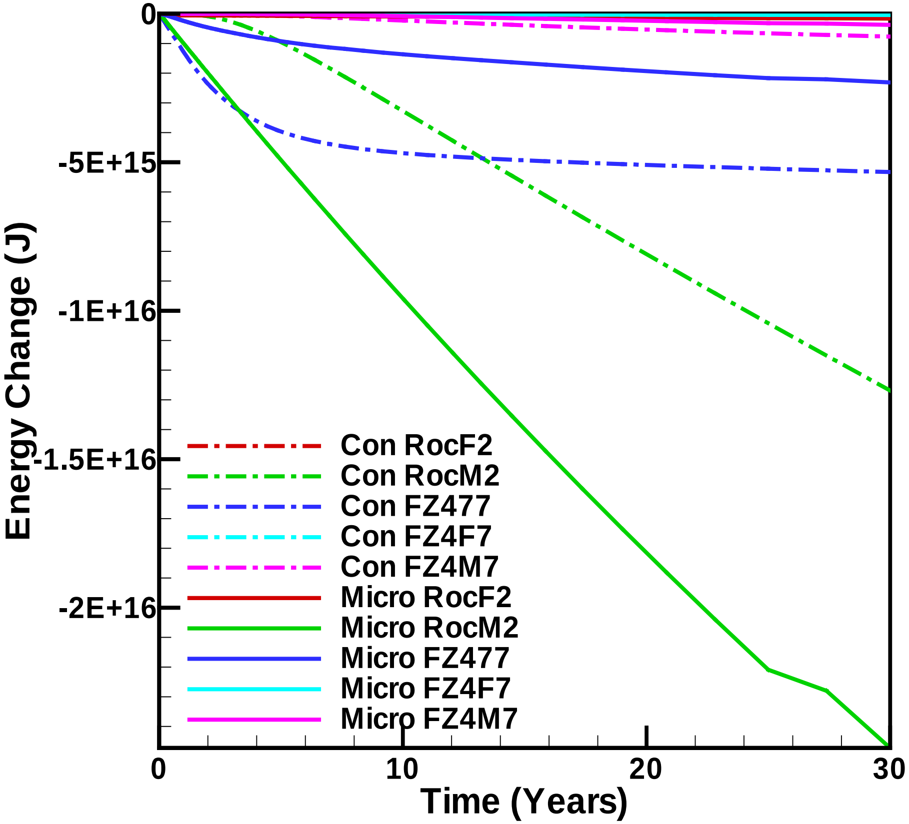


Temperature distribution

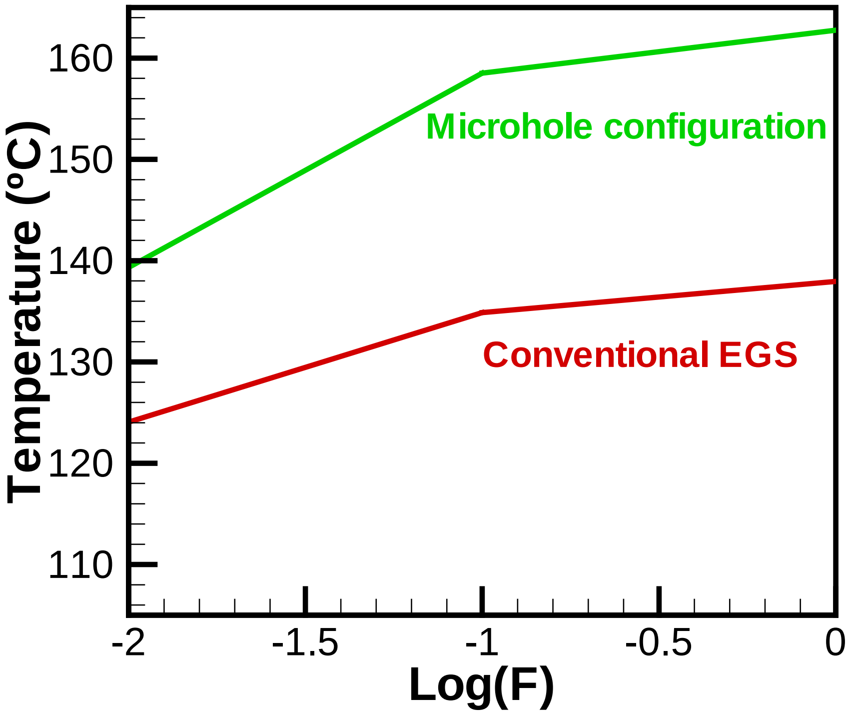
130ºC iso-surface

Dual-K Model Simulation Results





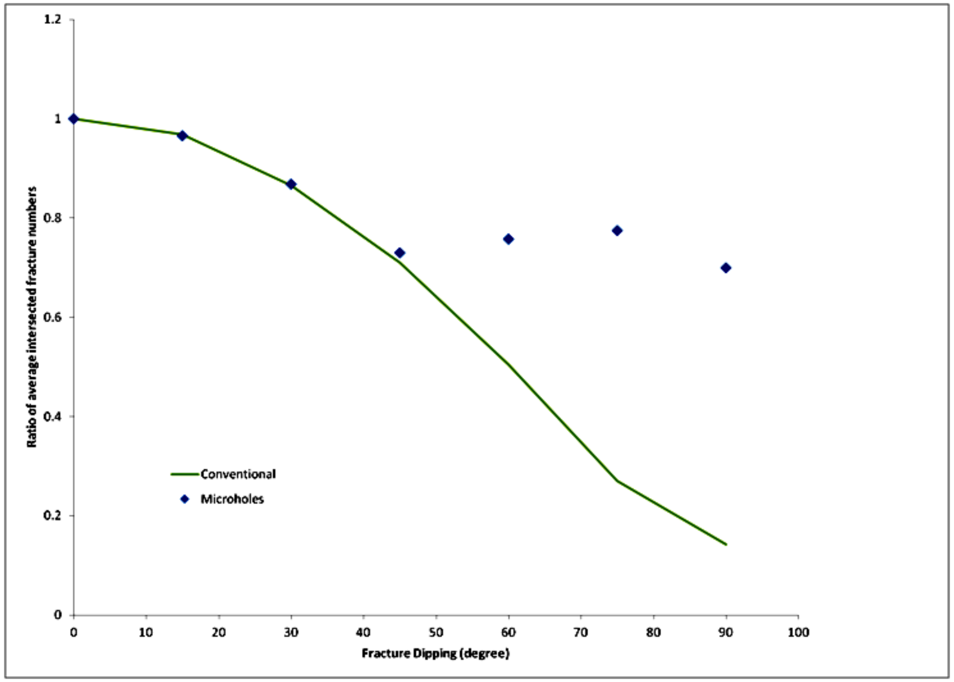
Dual-K Model Influence Fracture-Matrix Area and Fracture Network Model Results



F - fracture matrix interface area reduction factor

Fracture Network Model

Relative Number of Intersecting Fractures vs Dipping Angle



Accomplishments, Results and Progress

FLASH ASJ Drilling-

- Multiple FLASH fluids were identified and evaluated including water/ steam, CO_2, N_2 and flue gas. CO_2 & steam have been bench tested.
- Drilling simulations using SPT's WellFlo program showed specific fluids were optimal for different depths. CO_2 works best <10,000 feet, N_2 >10,000+ feet. Both can form hydrates / ice.
- Now bench testing 3rd generation multiphase nozzles on granites & sandstones. TU is simulating a new 4th generation nozzle design for optimizing FLASH performance. Over 100 hours of cutting life has been obtained on selected nozzles with advanced materials.
- Slurry generation is now with a 4th generation pump. TU is designing a 5th generation induction version slurry pump, Weatherford aiding.
- Bench tested FLASH ASJ drilling at low (5000 psig) pressures on many granites and sandstones for nozzle optimization designing.
- Modified 1" coiled tubing rig for FLASH ASJ drilling. Prepared rig for jointed pipe use for shallow drill tests.
- TU graduate students made 3+ presentations to industry groups,

Accomplishments, Results and Progress

EGS Performance Simulation Efforts -

- Four microhole array configurations were identified and modeled-
  - a single bore concentric/ counter flow heat exchange model,
  - a doublet model,
  - a sophisticated dual permeability (Dual-K) model adapted from Soultz conditions- with /without microhole arrays and semi-analytical wellbore heat exchange.
  - a Soultz-based fracture network model for estimating microbore fracture intersection probabilities.
- Results of the Dual-K model show that ***microhole arrays can make a significant impact on long term heat transfer efficiency of EGS***.
- Results from the Fracture Network model showed that ***microhole arrays can provide robustness (lower risk) in fractured systems***.
- Prepared and presented 3 papers on this work. One to be published in *Geothermics*, "Microhole arrays for improved heat mining from enhanced geothermal systems".

Future Directions

- The end of this project in 4 months. Funds are also growing short.
- By the end of this project-
  - FLASH ASJ drilling should be fully bench tested and optimized with 3rd generation nozzles. 4th generation nozzles should be final designed.
  - Several 500ºF granite slabs will be cut, sliced and bored with FLASH ASJ using supercritical CO_2 to evaluate impact of rock temperature on ASJ drilling.
  - The induction slurry pump version will be final designed, built and tested.
  - Ceramic liner will be installed into the GLS separator for erosion protection.
  - FLASH ASJ using CO_2 will be used to drill a shallow vertical hole with jointed and the CTD rig.
  - The Final Report will be submitted by the end of September 2013.
- Hopefully, from this study DOE will see the benefits of small bore arrays for developing EGS reservoirs. This will lead to further development of technologies that can install such small bore at EGS/ geothermal conditions.
- Impact is committed to developing FLASH ASJ drilling to commercial levels. The long term outcome of this project will be a proven and commercial FLASH ASJ drilling system initially used for drilling shallow vertical applications (VSPs and GSHPs), then going deeper and directional with experience to EGS.

Mandatory Summary Slide

- Microhole Arrays can provide robustness (lower risk) and sustainability (longer productive life) to an EGS project by-
  - Contacting a larger rock volume with more flow paths,
  - Reduces the risk of a failed design by increased probability of intersecting flowing fractures,
  - Self regulate flow between microholes reduces ‘short circuiting’ of working fluids within the connected EGS rock system.
- Microhole systems & hydraulics for FLASH ASJ drilling appear possible, at even 30,000 ft, by selectively using- CO_2, N_2, steam and flue gas. Target application is EGS completions not primary vertical bores.
- FLASH ASJ has (bench test) proven capable of drilling all rocks efficiently- even basalt. Additional demonstrations are needed via bench and field drilling tests. Low BHPs are needed for efficient cutting. New 4th generation nozzle, holder and tools indicate reasonable life under abrasive conditions.

Project Management

- PI’s job was coordinating efforts. Minimized travel expenses with phone calls, conference calls and emails with subcontractors.
- LBNL and Dr. Felber, Dr. Rychel efforts are finished, except final report.
- Tulsa University’s efforts are behind schedule due to-
  - Late start with conversion from initial subcontractor to TU. Needed DOE approval. TU needed time for contracting and getting students
- Impact’s efforts are behind schedule and over budget due to-
  - Took 9 months off project in 2012 due to funding concerns
  - Slurry generation problems necessitating 4 pump versions
  - Sourcing CO2 source was difficult (1 year) and more costly than anticipated (multi-year tank rental contract required).
  - Tried renting, unsuccessfully, a high pressure pump for CO2. Required purchasing one at great expense to budget.
  - Optimizing the FLAH ASJ system proved harder than anticipated.

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
1 Feb 2010	31 Jan2013	26 Feb 2010	30June2013

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$2,400,000	$600,000	100%	97.5%	Not all accomplished	$200,000

Phases/ Tasks/ SubTasks- 1 of 3

Phase 1: Technology and System Feasibility Study

- Task 1: Evaluation of Microhole ASJ Technology
  - Subtask 1:Evaluate and Identify FLASH Fluids
  - Subtask 2:Evaluate and Identify Piping Sizing & Configurations
  - Subtask 3:Evaluate Heat Transfer and Hydraulics
- Task 1: Demonstration of Increased EGS Performance Using Microhole Technology
  - Subtask 1:Define Drilling and Production Scenarios
  - Subtask 2:Develop Geothermal Reservoir Models
  - Subtask 3:Compare Fluid Flow and Heat Transfer for Different Scenarios

Phases/Tasks/SubTasks- 2 / 3

Phase 2: Microhole Technology Development for EGS

- Task 1: Development of Microhole ASJ Drilling Technology for EGS Conditions
  - Subtask 1: Research and Testing of the Pipe
  - Subtask 2: Research and Testing of the FLASH Fluids
  - Subtask 3: Research the FLASH ASJ Characteristics of 300ºC Rocks
  - Subtask 4: Expand the Directional Capabilities of Microholes
  - Subtask 5: Safety and Control Issues
- Task 2: Development of Simulation Capabilities for Microhole Technology
  - Subtask 1: Development of Non-Isothermal Wellbore Simulator for Supercritical Fluids
  - Subtask 2: Coupling of Wellbore Simulator to Reservoir Simulator

Phases/ Tasks/ SubTasks- 3 / 3

Phase 3: Design and Optimization of Microhole Array Deployment for EGS

- Task 1: Operational Plan for Drilling and Completion of EGS Microhole Arrays
  - Subtask 1: Microhole ASJ Drilling Operational Plan for EGS
  - Subtask 2: Microhole ASJ Directional Drilling Operational Plan
  - Subtask 3: Safety & Environmental Assessment & Mitigation Plan
- Task 2: Optimized EGS Performance Using Microhole Technology
  - Subtask 1: Evaluate Intersection Probability of Microholes with Fracture Network
  - Subtask 2: Develop Integrated EGS Approach Using MHT

Phase 4: Final Reporting and Technology Transfer

- Task 1: Project Management and Reporting
  - Subtask 1: Final Report & Technology Transfer