Development of Multi-Stage Fracturing System and Wellbore Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores/1-2551

- William W. Fleckenstein
- Colorado School of Mines

- Total Project Funding $5.3 million
- October/2021 – September/2024
- September 7th, 2023

This presentation does not contain any proprietary, confidential, or restricted information.

Objectives and Purpose

- Goal 1: To develop and demonstrate the use of low-cost, rapid multistage fracture stimulation technology with cemented casing frac sleeves that eliminates packers used in both conventional stimulation and injection flow control.
- Goal 2: To develop and demonstrate the devices to effectively detect and control the flow of heat-carrier fluid solely from a long-reach injector through the network of induced and existing fractures and produced from an open-hole long-reach well to improve heat recovery.

- Frac sleeves have been successfully cemented and used in oil and gas shale development walls; however, typically with sealing ball receptacles require a telescoping size from large to small (at the far end) with each sleeve that make it impossible to fit tools through them that are needed for injection and production conformance control.
- This project also develops a high temperature downhole tractor for horizontal wells. It will be tested at geothermal conditions in experimental facilities and then in a FORGE well.
- The tractor has fluid flow survey capability to detect “short circuiting” and shifting capability to plug or choke fluid movement through the sleeves based on real time fluid survey data.

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Methods/Approach

- The design approach is flexible and heuristic and is not anchored on any preconceived biases that may interfere with a successful final product. This design approach uses Failure Mode Effects and Criticality Analysis (FMECA) meetings, review, and update schedules as required. This process began before the FOA was announced and has continued throughout the project.
- This design approach is applied to the problem of building an EGS capable of economic power generation. Prior to the FOA, the team considered methods to modify frac sleeves and tractor technology used in the oil and gas industry. Existing methods were examined over a multi-year period and concepts were tested and prototyped through the Mines Senior Capstone Design Program.
- After the FOA was announced, the Mines effort was modified for the higher temperature and higher flowrates needed for a successful EGS system but educated by experience. Existing methods were re-examined considering the new constraints and a pre-proposal and proposal was made with the following basic processes in place.
  - Design and test critical components/subassemblies for the prototype sleeve system, including actuation.
    - Seal drag and collet test fixtures were fabricated and used to test system components.
  - Design and test critical components/subassemblies for the prototype tractor system, including actuation.
    - Critical tractor components passed 225 C No-Go test, using flask technology to extend 175 C components life.
  - Test the prototype casing frac sleeve for actuation by ball and shifting by tractor.

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Methods/Approach

Project Design Approach of the sleeve and tractor design along parallel paths initially proposed:

- Complete Preliminary/Basic Engineering & Component Testing Evaluation
- Detailed Engineering, full scale Prototype Manufacturing, and In-Situ Lab Testing
- Surface testing the integration of sleeve and tractor at temperature and pressure of field test.
- Final Engineering, Field Trial Manufacturing, Field Trial Testing at geothermal conditions

This approach was modified to begin to integrate the sleeve and tractor designs immediately.

Temperature impacts on electronics became apparent, so the wellbore/tractor were modeled to investigate the effectiveness of using flask technology with a heat sink to protect electronics.

Supply chain issues were immediately apparent in ways that were not initially considered during the Proposal Stage. Testing of the sleeve at temperature and pressure, found the original seal system had higher frictional drag forces than specified, and the seal drag testing of the sleeve was lengthened. Utah-FORGE was kept apprised of the successes and failures of the testing and consulted on schedule and budget modifications, with the end goal to complete the project within a FORGE field test window.

Methods/Approach

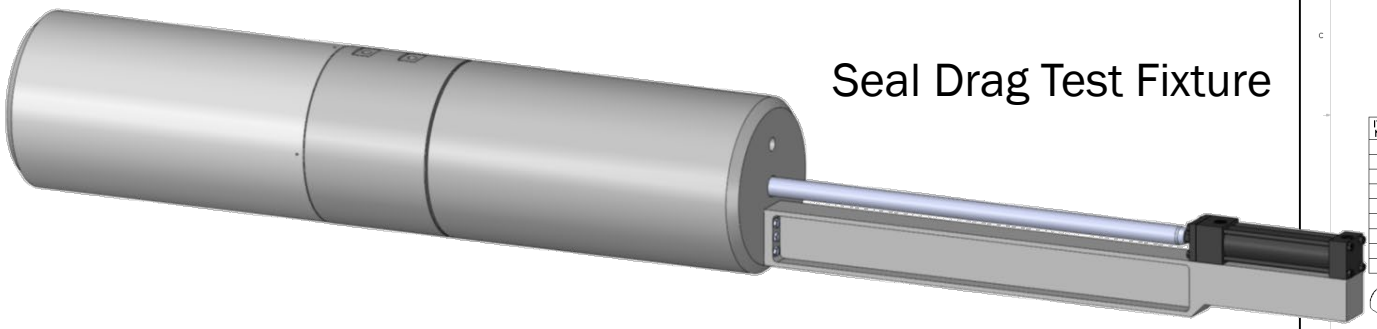
Supply chain issues impacted design choices as lead times for certain components for testing became unrealistic. Component availability and previous testing of an electro-mechanical tractor design by Defiant was available for immediate use. This elevated the chance of success by starting with a wireline tractor that could be modified for use with coiled tubing. This was a combination that was explored by the Mines Capstone Design team as a viable design option prior to the FOA of this project.

The sleeve must work for the project to be successful; and the tractor must support the successful design and operation of the sleeve. The seal drag testing period of the sleeve was lengthened and is giving a much more robust understanding of the sleeve function. The integration of the cooperative functions of both tractor and sleeve will be tested once the sleeve system is performing to at acceptable and predictable friction rates.

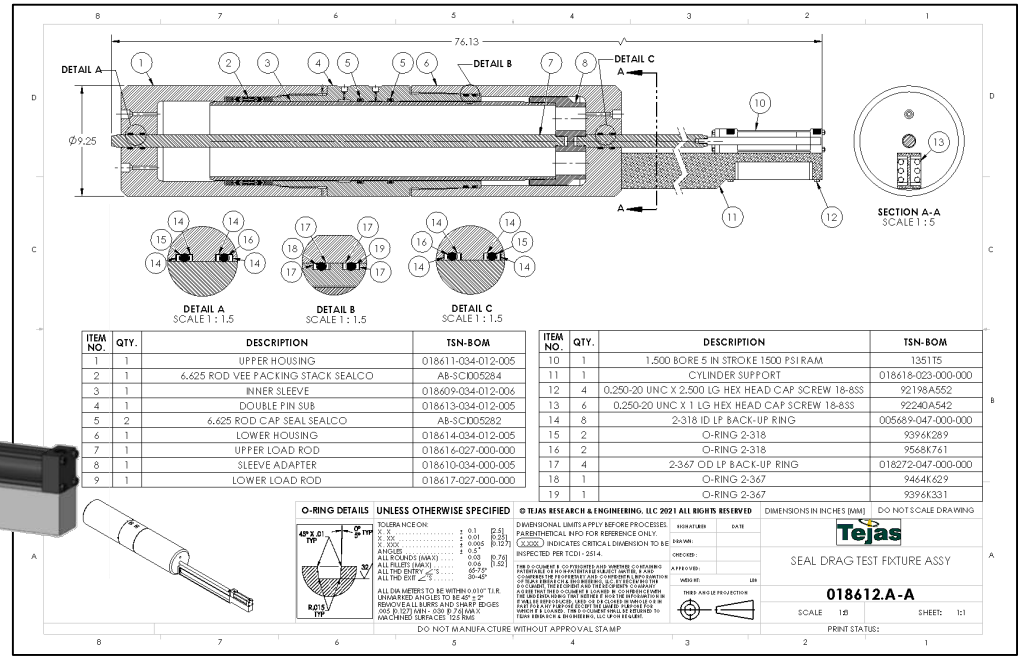
- The tractor initial design period was kept open as the tractor design had to integrate with the sleeve design
- The time for the sleeve testing program was lengthened and modified to include integrating with the tractor.

Supply chain issues impacted both the sleeve and tractor schedules of the project and is impacting component supply and machining schedules. The approach of integrating the sleeve and tractor design and testing is allowing the supply chain issues to be compensated for and is keeping the project on track.

Testing Fixtures



Seal Drag Test Fixture



ITEM NO.	QTY.	DESCRIPTION	TSN-BOM
1	1	UPPER HOUSING	018611-034-012-005
2	1	6.625 ROD VEE PACKING STACK SEALCO	AB-SCI005284
3	1	INNER SLEEVE	018609-034-012-006
4	1	DOUBLE PIN SUB	018613-034-012-005
5	2	6.625 ROD CAP SEAL SEALCO	AB-SCI005282
6	1	LOWER HOUSING	018614-034-012-005
7	1	UPPER LOAD ROD	018616-027-000-000
8	1	SLEEVE ADAPTER	018610-034-000-005
9	1	LOWER LOAD ROD	018617-027-000-000

ITEM NO.	QTY.	DESCRIPTION	TSN-BOM
10	1	1,500 BORE 5 IN STROKE 1500 PSI RAM	135175
11	1	CYLINDER SUPPORT	018618-023-000-000
12	4	0.250-20 UNC X 2.500 LG HEX HEAD CAP SCREW 18-8SS	92198A552
13	6	0.250-20 UNC X 1 LG HEX HEAD CAP SCREW 18-8SS	92240A542
14	8	2-318 ID LP BACK-UP RING	005689-047-000-000
15	2	O-RING 2-318	9396K289
16	2	O-RING 2-318	9568K761
17	4	2-367 OD LP BACK-UP RING	018272-047-000-000
18	1	O-RING 2-367	9464K629
19	1	O-RING 2-367	9396K331

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SEAL DRAG TEST FIXTURE ASSY

018612.A-A

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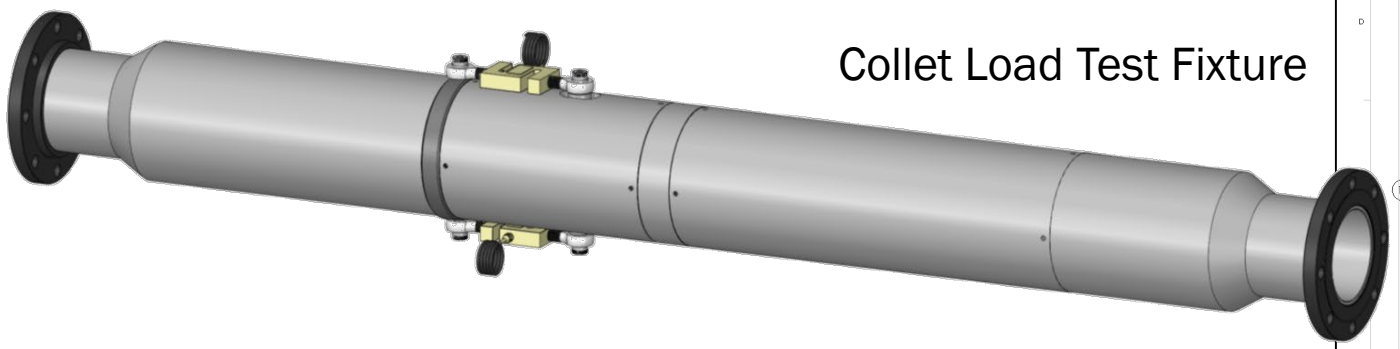
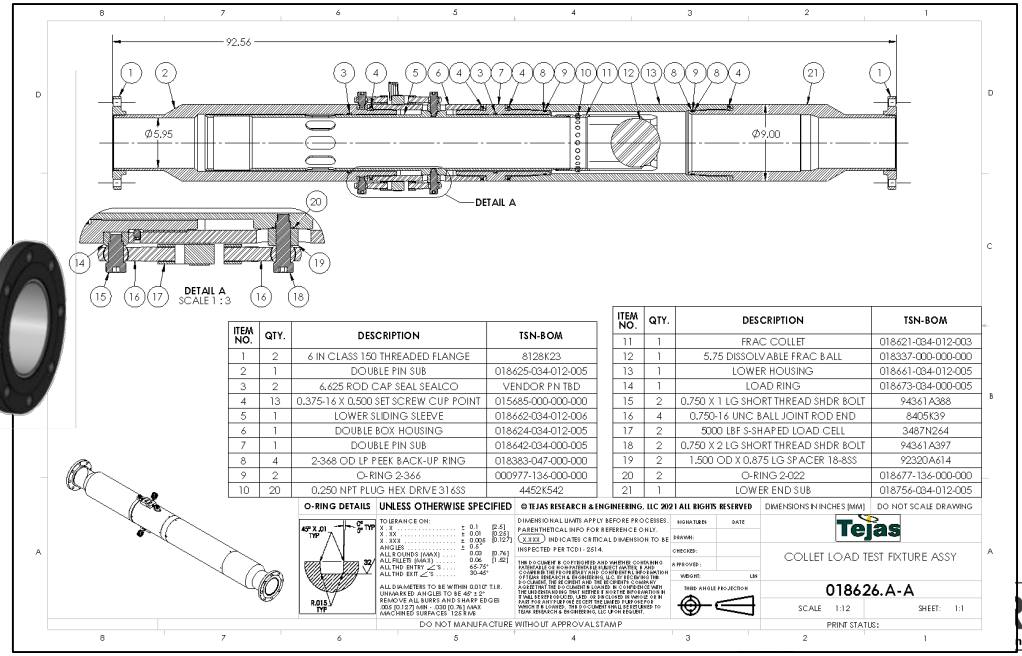


Collet Load Test Fixture



ITEM NO.	QTY.	DESCRIPTION	TSN-BOM
1	2	6 IN CLASS 150 THREADED FLANGE	8128K23
2	1	DOUBLE PIN SUB	018625-034-012-005
3	2	6.625 ROD CAP SEAL SEALCO	VENDOR PN TBD
4	13	0.375-16 X 0.500 SET SCREW CUP POINT	015685-000-000-000
5	1	LOWER SLIDING SLEEVE	018662-034-012-006
6	1	DOUBLE BOX HOUSING	018624-034-012-005
7	1	DOUBLE PIN SUB	018642-034-000-005
8	4	2-368 OD LP PEEK BACK-UP RING	018383-047-000-000
9	2	O-RING 2-366	000977-136-000-000
10	20	0.250 NPT PLUG HEX DRIVE 316SS	4452K542

ITEM NO.	QTY.	DESCRIPTION	TSN-BOM
11	1	FRAC COLLET	018621-034-012-003
12	1	5.75 DISSOLVABLE FRAC BALL	018337-000-000-000
13	1	LOWER HOUSING	018661-034-012-005
14	1	LOAD RING	018673-034-000-005
15	2	0.750 X 1 LG SHORT THREAD SHDR BOLT	94361A388
16	4	0.750-16 UNC BALL JOINT ROD END	8405K39
17	2	5000 LBF S-SHAPED LOAD CELL	3487N264
18	2	0.750 X 2 LG SHORT THREAD SHDR BOLT	94361A397
19	2	1.500 OD X 0.875 LG SPACER 18-8SS	92320A614
20	2	O-RING 2-022	018677-136-000-000
21	1	LOWER END SUB	018756-034-012-005

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COLLET LOAD TEST FIXTURE ASSY

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Technical Accomplishments and Progress - Sleeve

- The sleeve design was successfully built into a Prototype Solidworks model with acceptable Safety Factors for 8,000 psi burst pressures after reducing tool OD to 8.75”.
- Proof of Concept test fixtures were built to test the ball catch mechanism and seal drag, preventing downhole failures.
- 5.75” Balls were successfully tested first using CFD and FEA techniques for a Collet Load Test, then with a mechanical test and a flow test. The ball would always pass at 11-12 BPM, and catch at 8 BPM. The tests were highly repeatable. The collet did not damage the Frac Ball during multiple pump throughs.
- Initial seal stacks had to be machined over, delaying testing. We have performed at least 16 seal drag tests and are working to overcome temperature and pressure limits. We have rearranged the budget for further testing with other seals
- The difference between “vertical” and “horizontal” was negligible during the Seal Drag testing program.

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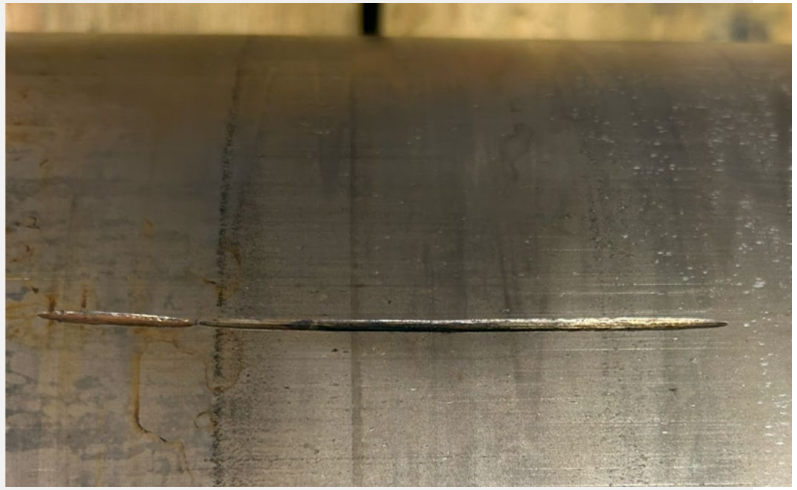
Test 15 - Santos Configuration

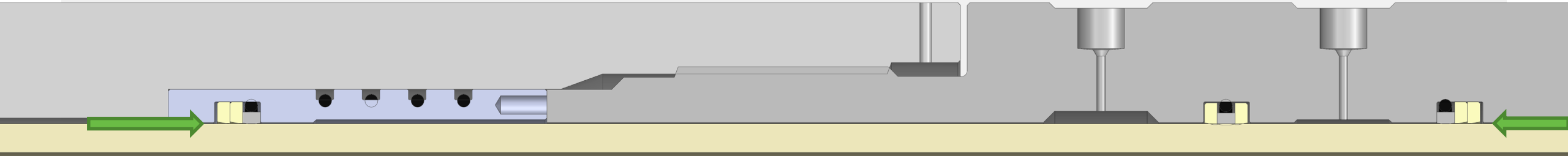
Moved both Backup Rings to the non-pressure side of the gland…to eliminate potential PEEK backup drag

Lower Ambient Seal Drag

Initial forces were 50% lower with the configuration change…

When the Lower Rod seals failed (cycling at 5,000 psi), side load
from the expanding water to gas galled the Lower Rod within the Test Fixture.
The sleeve had “grooves” that were flow-cut by the steam





Technical Accomplishments and Progress - Tractor

Assessed of existing tractor proto-types and other tractors and chose a electromechanical/hydraulic tractor design with available components without coiled tubing.

Completed Go/No-Go #1 – Critical Tractor Components Tested to 225°C at 12 hour duty cycle with some components tested to 175°C, using flask modeling for 225°C at 12 hour duty cycle qualification.

The actuator design was segmented out to operate independent of tractor. This allows use of pump down and coiled tubing deployment with or without a tractor.

Completed manufacturing key components such as the full latch anchor assembly and solenoid bodies.

Completed layout of electronics chassis and tool wire routing. Started assembly of latch bodies for testing. Completed design of the high temperature swivel.

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Technical Accomplishments and Progress

Actual Milestone/Technical Accomplishment	Date Completed
Milestone 1.1.1 – Revised PMP was completed Milestone 1.2.1 – Preliminary Engineering for the Frac Sleeve is completed Milestone 1.2.2 – Sleeve Basic Eng. Seal Drag & Collet Load Test Milestone 1.3.1 – Initial Tractor Project Planning Milestone 1.3.2 – Initial Tractor Design Milestone 1.3.3 – Constructed ambient temperature prototype testing system Milestone 1.3.4 - Assessed existing high temperature motors, electronics, and tools * Milestone 1.2.2 completed with exception of the Seal Drag Force Testing	(12/31/2021) (6/31/2022) (In Progress)* (2/28/2022) (8/30/2022) (11/30/2022) (11/30/2022)
GO/NO GO #1: - Test mission critical components of initial prototype.	(11/30/2022)

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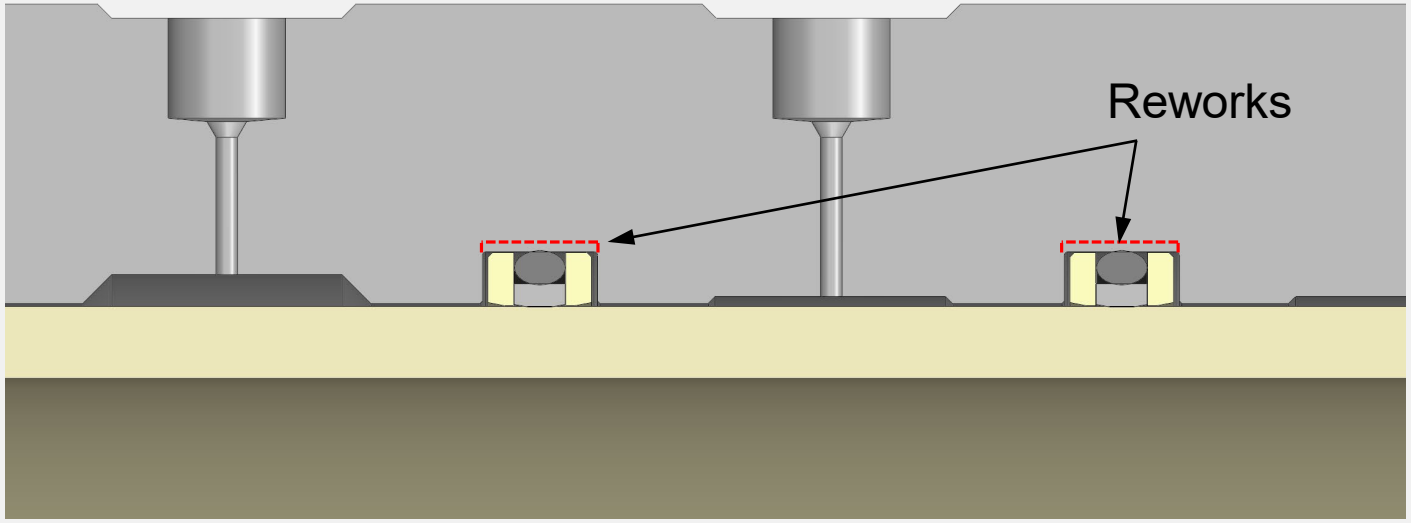
Technological Advancement and Data Dissemination

- The project provides a new generation of frac sleeves which has attracted a great deal of attention with inquiries from operators from Kazakhstan to US shale basins. Videos of the sleeve animation for EGS using horizontal wells are being distributed. Presentations include the combination of geothermal and natural gas for combined power generation that extends the utility of EGS by using the sleeves also for conformance control. Presentations have been made to several CCUS companies. Finally, the system may have induced seismicity prevention benefits.
- Numerous media interviews, presentations to politicians, Venture Capital groups (for example Chevron Ventures). Dr. Fleckenstein was an invited speaker to several utility conferences to discuss future prospects of EGS and gave numerous presentations about how EGS can be facilitated by the sleeve and tractor combination.. Dr. Fleckenstein will be traveling to Washington DC in September to lobby the Colorado Delegations, and numerous other politicians and Administration officials in support of geothermal research appropriations.
- Six technical papers have been or are being written. A Patent Application is currently being prosecuted before the US PTO. Numerous data sets are uploading to the GDR.

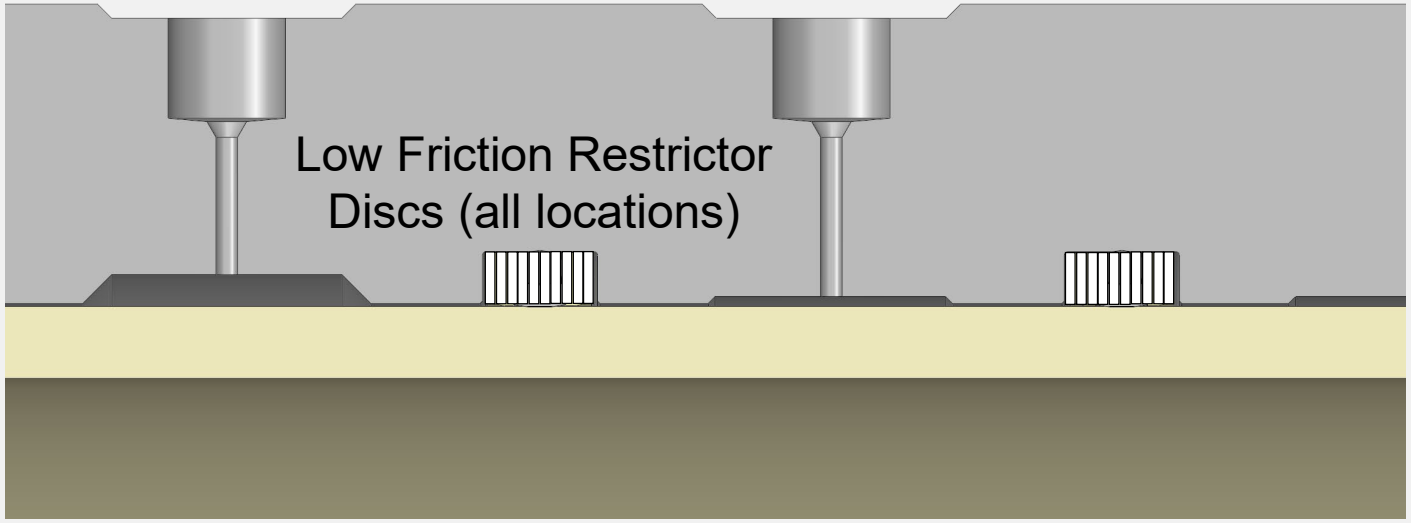
Future Directions

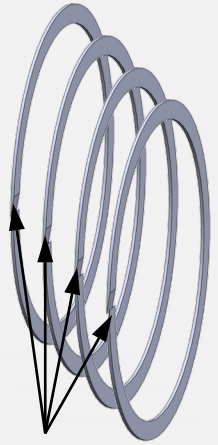
1. Reduce the Squeeze in our current Cap Seal Design (more influenced by pressure than temperature)

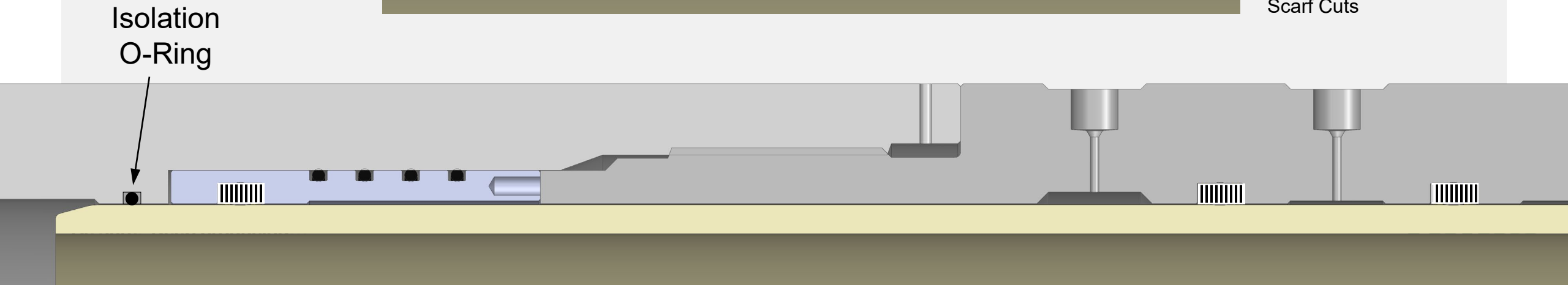


Future Directions

2. New Disc Design – Leaky Disc Seals with a small Isolation O-Ring for FAT and cementing







Milestone Table
1-2551 CSM PI: William Fleckenstein

X	Original Contractual Due Date
⊙	Active R&D
○	Adjusted Milestone Due Date
●	Final (Completed)
	Deliverable (Report required)

Budget Year	Year 1						Year 2				Year 3		
Actual Qtr.	Q4 21	Q1 22	Q2 22	Q3 22	Q4 22	Q1 23	Q2 23	Q3 23	Q4 23	Q1 24	Q2 24	Q3 24	Q4 24
Project Qtr.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13

Project Milestones	Deliverable													
Task 1.1 – Project Management and Planning		⊙	⊙	⊙	⊙	⊙	⊙							
Task 1.1.2 – Data Management		⊙	⊙	⊙	⊙	⊙	⊙							
Task 1.2 Frac Sleeve Technology Development Using Single Sized, Dissolvable Ball		⊙	⊙	⊙	⊙	⊙	⊙							
Milestone 1.2.1 - Define project management		●												
Milestone 1.2.2 - Basic engineering complete			⊙	⊙	⊙	⊙	⊙	⊙	○					
Milestone 1.2.3 - Detailed engineering complete					X		○ ⊙	⊙	⊙	○				
Milestone 1.2.4 - Manufacturing Complete - full-scale components, prototype parts and test fixtures fully received, verified, and inspected from manufacturing.						X	○⊙		•	•	○			
Milestone 1.2.5 - Validation Testing Plan Complete								X		•	○			
Milestone 1.2.6-Functional Frac Sleeve –								X		•	○			
Task 1.3 Tractor Design, Build, and Test		⊙	⊙	⊙	⊙	⊙	⊙							
Milestone 1.3.1 - Assessed of existing tractor			●											
Milestone 1.3.2 - Complete listed requirements					●									
Milestone 1.3.3 - Construct testing systems.						●								
Milestone 1.3.4 - GO/NO GO #1:Test mission critical						●								
Milestone 1.3.5 - Complete electronics Package					X					○				
Go/No-Go #2-Achieved a Functional Tractor							X			○				
Task 2.4 Modify Frac Sleeve and Tractor														
Milestone 2.4.1 - Analysis of frac sleeve	NA							X		○				
Milestone 2.4.2 - These components will be combined with the hydraulic tractor	NA								X		○			
Go/No-Go #4-Flow conformance control									X		○			
Milestone 2.4.3 -Submit an EQ (Group B,									X		○			
Go/No-Go #5-Submit an EQ (Group B									X		○			
Task 3.5 Technology Testing and Evaluation														
Milestone 3.5.1 - Complete Utah FORGE field testing											X			
Task 3.5.2 Project closeout														
Milestone 3.5.2 - Engineering documentation														X

Schedule

Current Plan

Functional
Sleeves & Tractor

Q1 - 2024.

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Summary

- Successful completion of this project provides the tools needed for the construction of a subsurface heat exchanger by developing and demonstrating the use of low-cost, rapid multistage fracture stimulation technology with cemented casing frac sleeves that eliminates packers used in both conventional stimulation and injection flow control.
- Successful completion of this project provides the devices to effectively detect and control the flow of heat-carrier fluid in an ESG system through the network of induced and existing fractures and produced from an open-hole long-reach wells to improve heat recovery. A stochastic economic analysis has quantified the importance of thermal decline to the NPV of an EGS project.
- Discussions with multiple operators contemplating, or designing EGS pilot projects has indicated the need for a sleeve system, which can be modified to provide choke capabilities as well.
- The tools provided by this project can limit both induced seismicity risk and water associated with stimulation methods for EGS wells.
- This project can provide the multi-stage stimulation tools needed to lower EGS costs in a similar manner to shale development cost improvements.