Wireless Microsensors System for Monitoring Deep Subsurface Operations

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Technical Status

- 3-year DOE-NETL project under FOA1998 "Transformational Sensing Systems for Monitoring the Deep Subsurface" (started Feb. 2020)
- Project Objective = Develop a technology for wireless downhole monitoring of subsurface operations via a three-prong approach:

1. Sensor System Development- design and fabricate a fully integrated wireless microsensor-based downhole sensing system to **measure temperature** as the primary indicator of CO_2 presence.

2. Field Deployment/Demonstration- demonstrate system operational feasibility by deploying & testing the sensor system in the casing annulus of two legacy oil & gas wells in Eastern Ohio.

3. Techno-Economic Analysis- establish the technical feasibility & practical utility of the sensing system for reservoir/above zone monitoring in a commercial-scale CO_2 storage complex with numerical multi-phase thermal reservoir simulations and a techno-economic evaluation that benchmarks the total costs, risks and unique benefits.

Result= real time, autonomous monitoring system for accurately tracking/modelling the subsurface movement of CO_2 plumes.



Technical Status

- The project is organized into 5 main technical tasks.
- Currently preparing for field testing task in Sept-Oct 2021.





Technical Status

- Objective = Develop a sensors system for emplacement in CO_2 and/or O&G wells to monitor temperature as proxy for CO_2 .
- 'Sensor ring' concept was adopted to facilitate development of sensors, central data collection & transmitter, wireless charging, energy harvesting, data relay system to surface, encapsulation, retrievable wireless battery charging







Technical Status: Sensor Design

• Challenges to long-term wireless monitoring CO₂ Storage.



• Environmental survivability.

- Significantly moisture-laden downhole environment.
- Pressures/Temperatures encountered during cementing.
- Dimensional restrictions.
- Wireless data telemetry through wellbores.
 - Can you push data through wellbore materials?
 - Can you achieve a meaningful range between relays?
- Wireless power transfer and energy harvesting.
 - Can we transfer a meaningful amount of energy sufficient for all functionalities for 10-30 years?
 - Is the recharging process fast and effective enough?



Technical Status: Sensor Design

• Sensor design completed.

Product	Description
Surface Logger	Receives the data from the wellhead and uploads it into the cloud, from where it may be accessed remotely.
Relay Ring (sonic energy charged)	Communicates with the single nearest rings immediately above and below it.
Sensor Ring (magnetic induction charged)	Communicates with the Battery Module via coil and not LoRa antennas. Otherwise structurally identical to the relay ring.
Wireless Battery Charging Assembly (for sensor rings)	Two-sectioned product. Top section is the battery antenna module, which drives the coiled section below. Entire assembly can be fished out of the well to replace (or recharge) the batteries at the surface, and lowered back in.
Sonic Charging Tool	Essentially a re-purposed Cement Bond Logging (CBL) tool. Sonic Tool is lowered via wireline and dwells around the vicinity of each ring for under an hour.
Encapsulation	Integrated centralizer to protect sensor electronic components running in well and during cementing









Technical Status: Lab Exposure Tests

- A sensor prototype & housing was exposed to supercritical CO₂ in a pressure test cell at temperatures ranging from 20 °C to 50 °C and pressures up to 1,400 psi for 24 hrs.
- The temperature sensor calibrated to measured conditions in the test cell. The resin housing enclosure also protected the electronic components and showed no signs of corrosion.





Technical Status: Bench-Scale Tests

- Data relay ring communication testing was completed in a series of test pipes constructed in lengths of 3', 9', 27', and 120'
- 4 ½" steel tubing centered in 8" outer PVC pipe with resulting annulus filled with oilfield cement to simulate the downhole environment. (Copper foil added to approximate environment in upper well where production casing resides inside surface casing).
- Results demonstrate signal communication through cemented pipe >120 ft with acceptable RSSI attenuation.







Technical Status: Functional Demos

 A series of functional demonstrations were completed to confirm operation of the temperature sensors, wireless charging, sonic energy harvesting, data handling, and surface logging.

Temperature Sensor Data Handling







Sonic Harvesting & Wireless Charging





Technical Status: Sensor Fabrication

- Fabrication of sensor components in progress.
- Components were customized to fit in existing well (7" surface casing and 4 ¹/₂" deep casing).
- A total of 100 sensor rings will be fabricated.
- Procurement of oil & gas field services and materials in progress (service rig, cementing, wireline logging, casing, water hauling, excavation)









Technical Status: Field Test Planning

Well A Wireless Data Telemetry

- Sensors and Relays are all rings
- All rings have batteries that depend on sonic based battery charging
- Hot water circulation within 4 ¹/₂" csing to induce a temperature gradient to test sensors.



Cemented 4 ¹/₂" Casing



Well B + Wireless Power Transfer

- Adds to system A.
- Includes a custom battery-module located inside wellbore.
- This module will:
 - Power the sensors
 - Act as a "bridging relay" from the sensors to the first ring-relay.

Future development path for "Sensor-balls"





Technical Status: Field Test Planning

- Field testing plan:
 - #1 Health & Safety!!!! (mostly routine O&G workover effort)
 - plug back 2 existing O&G wells in Guernsey County, Ohio.
 - install sensor system on casing ~3600 ft, cement well to surface.
 - Well A: 2500 ft deep test zone, circulate hot water as poxy for CO₂ to demonstrate sensor function, monitor temperature falloff.
 - Well B: 3800 ft deep test zone, battery module wireless charging, longer term test 2-3 weeks, measure ambient temperatures.







Field Testing of Sensor System

Hickenbottom #1

- Plug-back design completed
- Site access agreement completed with Hopco Ltd. for 3 wells:
 - Dennis #1, Guernsey Co.
 - Hickenbottom #1, Guernsey Co.
 - Hanson #1, Guernsey Co. (Backup well)
- Field testing Sept-Oct 2021.

Dennis #1







Site Prep, Plug-back, Sensor Install

- Site preparations include grading wellpads and access roads, installing culverts, spreading stone, etc.
- Existing perforations in Clinton SS (5,300-5,500 ft.) will be squeezed off with cement.
- 4 ½ inch casing will be shot-off at +/-4,500 ft.
- Composite centralizers containing sensor rings will be installed on 4 ¹/₂" casing and the casing will be run in well and cemented to surface in 2 stages.
- Well A sensors will be installed from ~2,500 ft. to surface.
- Well B sensors will be installed from ~3,600 ft. to surface.



Wireless Micro Sensor Project Field Work Schedule									
Assume September 1st start date									
Dennis #1 Well									
Task	Vendor	Start	Finish	Davs	Comments				
Complete Field Work	All	9/1/2021	10/9/2021	39	Field work period of performance				
Prepare Access Road and Location	WolfRun	9/1/2021	9/4/2021	4	Mob in and prepare road and location				
Delive r purchased casing	Berry Well Service	9/2/2021	9/2/2021	1	Deliver purchased casing to the centralizer installation location (Cambridge, OH?)				
Instal I composite centralizers	Maxwell & Engenius	9/3/2021	9/6/2021	4	Install composite casing centriaizers on purchased 4 1/2" casing				
MELLService Bit	Renny Well Service	9/3/2021	10/5/2021	37	AS RECORD				
Spot tanks and haul water	Dow Came mo	9/3/2021	9/4/2021	2	1 #500 Bbl. 1 # 150 Bbl open top, havi water as needed				
Plug Clinton formation	Berry Well Service	9/6/2021	9/7/2021	2	Run 2:3/8" tubing to top Clinton perforation, set cement plug, pull tubing				
Squeeze Clinton Perfs	Petroset	9/6/2021	9/6/2021	1	Spot 400 ft. cement plug through tubing				
Delivercasingw/centriaizers	Berry Well Service	9/7/2021	9/7/2021	1					
Run CBL / Shoot off 4-1/2" casing	Appalach ian Well Surveys	9/7/2021	9/7/2021	1	Run OBL to determine TOC, Shoot 4-1/2" casing, Pull one (t. Casing				
Set casing stub plug	Petroset	9/7/2021	9/7/2021	1	Set 100ft. casing stub plug in 7-7/8" hole w/30 sacks Class A cement				
Circulate hole with gel	Petroset	9/7/2021	9/7/2021	1	Mix gel and circualte hole				
log onen hole	Annalachian Well Surveys	9/9/2021	9/9/2021	1	Calculate hole volume from clainer log for cement fill				
Run 4-1/2' casing in well	Berry Well Service	9/11/2021	9/11/2021	1	Run casing to +/-3800 ft. Run DV tool at +/-2000 ft. Run sensors to +/-2,500 ft.				
Cement 41/2" casing	Petroset	9/10/2021	9/11/2021	2	Cement from 3800 ft. to surface in 2 stages. Circulate 8hours between stages.				
WDC - 72hours	N/A	9/11/2021	9/13/2021	3	Wait on Cement				
Dtll out cement and stage tool	Berry Well Service	9/14/2021	9/16/2021	3	Drill out and chase to bottom and curculate clean. PODH with tubing				
Run Radi al CBL	Appalachian Well Surveys	9/17/2021	9/17/2021	1	Check for coment fill up and bond quality				
Run 2-3/8" tubing in well	Berry Well Service	9/18/2021	9/18/2021	1	Run tubing to +/- 2550 ft.				
RDMO Service Rig	Berry Well Service	9/20/2021	9/20/2021	1	Move to Hicke inbottom wiel				
Circulate bot water in well	Einhhurn Services	9/26/2021	9/24/2021	1	Monitor sensors and minur to confirm bottom hale temperature chapter				
Analyze system performance	Battelle & Engenius	9/24/2021	9/28/2021	5					
MIRU Service Rig	Berry Well Service	10/6/2021	10/6/2021	1					
Haul water and tanks off location	Dow Cameron	10/6/2021	10/8/2021	3	Empty and clean out tanks - dispose of waste water				
Pull tubing	Berry Well Service	10/6/2021	10/6/2021	1					
RDMO Service Rig	Berry Well Service	10/7/2021	10/7/2021	1	Move back to Hickenbottom well				
Reclaim location and lease road	Wolf Run	10/7/2021	10/9/2021	3					
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Well A Testing

- Demonstrate long-range wireless telemetry through cement, 40-80 ft relay spacing.
- Circulate hot water through tubing to record increase in bottom hole temperature and monitor temperature fall-off.





Well B Testing

- Demonstrate repeatability and reliability of the deployment of the wireless system to 3,600 ft depth.
- Extend relay spacing to 120 ft.
- Demonstrate that sonic charging of electronic devices in the annulus is possible.
- Longer term monitoring 2-3 weeks or greater.



Well Schematic - Site: B



Health & Safety

- Health & Safety plan completed for field testing.
- Relatively routine well work.
- Main hazards = heavy machinery, rotating parts, high pressure oil/gas/water, cement materials.









Data Processing/Modeling & Techno-Economic Evaluation

- Data Processing and Numerical Modelling
 - Data processing and QA/QC
 - Numerical modeling of field microsensor data
 - Verify CO₂ plume w/temperature
- Techno-Economic Evaluation for CO₂ Storage Applications
 - Assessment of monitoring integration with existing technologies
 - Benchmarking analysis of microsensor system applications



Example: CO₂ storage system monitoring design





Accomplishments to Date

- Sensor design and lab testing completed for wellbore telemetry, temperature monitoring, wireless charging, energy harvesting, data transfer, and field tests.
- Field testing planned for September-October 2021 in 2 existing oil wells in Guernsey Co., Ohio.

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Schedule

Milestones

Task/ subtask	Milestone Title & Description	Scheduled Completion date	Verification method
1.1	Update project Management Plan	February 12, <u>2020</u>	Electronic Document Submission
2.5, 2.6	Microsensor System Design	December 2020	Sensor Design Memo
2	Decision Point to Move to Field Testing	February 2021	DOE-NETL Approval
2.6	Complete Field Test Unit Construction	March 2021	Sensor System Lab Test Memo
3.0	Confirm wells for field testing	January 2021	Final NEPA Env. Quest.
3.1	Prepare Field Testing Plan (sensor system deployment plan complete)	May 2021	Field Testing Plan Submitted Electronically
3	Decision Point on Final Field Sites	February 2021	DOE-NETL Approval
3.6	Sensor Data Collection (<u>initial</u> sensor data successfully collected)	February 2022	Field Testing Summary Report Submitted Electronically
4.3	Sensor Data Validation (data validated by numerical simulations)	June 2022	Field Data Submitted Electronically to EDX
5.1	Technology Development Plan (techno- economic assessment and methods)	October 2022	Technology Development Plan Submitted Electronically
6.3	Complete Project and Final Report (final DOE submittal)	January 2023	Final Report Submitted Electronically



Lessons Learned

- There are many challenges to wireless sensors in deep wellbores (depth, cement, casing, pressure, temperature, fluids, install).
- These challenges have resulted in a more developmental process exploring items like data transmission lengths, effect of well materials on data signals, energy harvesting options, wireless charging, and data handling using a sensor ring and relay ring approach.
- A sensor ring approach was adopted to allow for functional technology field testing and accommodate legacy well specifications.
- The project team successfully demonstrated sensor system operation at supercritical conditions lab testing, 120 ft cemented casing data transmission test on surface, and functional bench-scale demos.
- Next step is field testing in two oil wells at depths of 2500 ft and 3600 ft scheduled for September-October 2021.



Project Summary

- Three-prong project approach: 1) develop a wireless downhole sensor system to monitor for CO₂ storage, 2) field test the sensor system in two legacy oil & gas wells, and 3) validate the technology and demonstrate its applicability to monitoring CO₂ in the subsurface.
- Key advancements in generated through this research: distributed wireless microsensor system, wireless telemetry system to transmit data to surface, customized deployment options, and an approach to processing and integrating sensor data to understand CO₂ distribution and track CO₂ plume movement in the subsurface.
- Path Forward
 - Sensor System Component Fabrication of sensor rings, relays, battery module
 - Sensor System Field Testing (September-October 2021)
 - Plug back wells, install sensor system, cement to surface
 - Collect, analyze data for well A and well B deployments
 - Field Test Data Analysis, Modeling, & Techno-Economic Evaluation
 - Model CO₂ temperature indicator for CO₂ storage
 - Techno- economic deployment options for legacy O&G wells, CO₂ wells



Appendix Material

As follows

Benefit to the Program

- Project addresses FOA1998 Area of Interest 1: *Transformational* Sensing System for Monitoring the Deep Subsurface:
- Wireless microsensors system for CO₂ storage applications.
- System deployment options for legacy oil & gas wells.
- Network of real-time monitoring points for CO₂ storage zones without the expense of new wells.
- Real time, autonomous monitoring data for accurately tracking/modelling the subsurface movement of CO₂ plumes.
- The sensor system benefits operators, regulators, and stakeholders associated with diverse CO₂ storage applications:
 - Commercial-scale deep saline CO₂ storage sites,
 - CO₂-EOR operations/optimization,
 - 45Q monitoring/reporting/verification requirements, and
 - USEPA Class 6 UIC requirements for geologic CO_2 storage.

Project Overview- Goals and Objectives

The goal of this project is to develop a technology for wireless downhole monitoring subsurface operations via a three-prong approach:

- Sensor System Development- design and fabricate a fully integrated wireless microsensor-based downhole sensing system to measure temperature as the primary indicator of CO₂ presence.
- 2. Field Deployment/Demonstration- demonstrate system operational feasibility by deploying & testing the system in the casing annulus of two legacy 5000-6000 ft boreholes.
- **3. Techno-Economic Analysis** establish the technical feasibility and practical utility of the sensing system for reservoir and above zone monitoring in a commercial-scale CO₂ storage complex by:
 - integrating this data into a numerical multi-phase thermal reservoir simulator that can predict the location and movement of fluid flow in the subsurface, and
 - a techno-economic evaluation that benchmarks the total costs, risks and unique benefits.

Project Organization Chart



Gantt Chart

Task Name		EY2020 (BP1)			FY2021 (BP1)				FY2022 (BP2)				
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◆ = Deliverable/Milestone F = <u>Final_PMP</u> = Project Management Plan