II. PROPOSAL NARRATIVE

Abstract: Carbon capture and storage is a key approach to slow down the CO_2 accumulation in the atmosphere and mitigate global climate change. CO_2 storage requires real-time subsurface monitoring and communications to detect CO_2 leaks. Current solutions require an umbilical, which could impair well integrity and cause leakage. In this proposal, a reliable and cost-effective subsurface wireless communication and sensing system will be established for the real-time long-term monitoring of CO_2 sequestration. The system will deploy an array of toroidal transceivers winding around the highly conductive casing string for wireless data transmission, and utilize energized casing to charge the transceivers and sensors at the surface. A provisional patent has been filed, and an industrial partner has agreed to collaborate on this project. In addition, a team of business students from the Bauer College of Business will help to explore the market potential of this technique in CO_2 storage as well as in oil and gas industry. The potential funding from this program will greatly help us to further validate this technique and explore its full potential in industrial applications. This project will generate a cutting edge underground wireless communication system for real-time monitoring of CO_2 sequestration and help CCME establish a globally recognized carbon management center.

1. Introduction: The sequestrated CO_2 needs to be safely stored in the underground geological structure for at least thousands of years [1]. The leaked CO_2 will affect the environment [2], and endanger human lives [3]. Therefore, measuring and detection of CO_2 leaks at sequestration sites are extremely important [4], [5]. Currently, the deep subsurface monitoring data are sent to surface via an umbilical placed either inside or outside of the well casing. The method requires perforation on the casing and will impair well integrity; the umbilical running up the outside of the casing in the cement annulus can potentially be a pathway to CO_2 leakage [4].

2. Objectives, Significance, and Relevance: In this proposal, we will develop a reliable and cost-effective wireless telemetry system to send real-time monitoring information of CO_2 sequestration to surface. The system will deploy an array of toroidal transceivers around the steel casing string for data transmission, and utilize energized casing to charge the toroidal antennas and subsurface sensors at the surface. This novel wireless communication and sensing system will help maintain well integrity and reduce leakage by eliminating the need for perforated casing or an umbilical in the cement annulus. This project requires collaboration of researchers from engineering, business, and industrial partners.

E Cullen Building · 4302 University Drive, Room 124B · Houston, TX 77204-2040
Office: 713.743.4307 · Fax: 713.743.4323 · uhenergy@uh.edu · www.uh.edu/energy

Significance and the impact: To assure reliable and permanent CO_2 storage, a robust real-time underground communication and monitoring system is extremely important. The success of this project will provide an intelligent, wirelessly connected, and multifunctional communication and sensing system that is capable of transmitting the signal and power for long-term underground monitoring. This system will start a new direction (underground wireless communication and sensing) in CCME that could find many applications in CO_2 storage as well as in oil and gas industry.

Relevance to the mission and vision of CCME: The technique will solve a critical challenge and help CCME to establish a world leading carbon management center for energy by providing a transformative solution for underground communication in CCS and oil & gas industry.

3. Approach: Our approach has two elements. First, develop a reliable and cost-effective wireless telemetry system for real-time data transmission of meaningful measurements between deep subsurface and the surface. Second, develop a wireless power transfer system to charge the downhole antennas and subsurface sensors using energized casing [6]. Figure 1A-C shows the schematic of wireless telemetry for data transmission

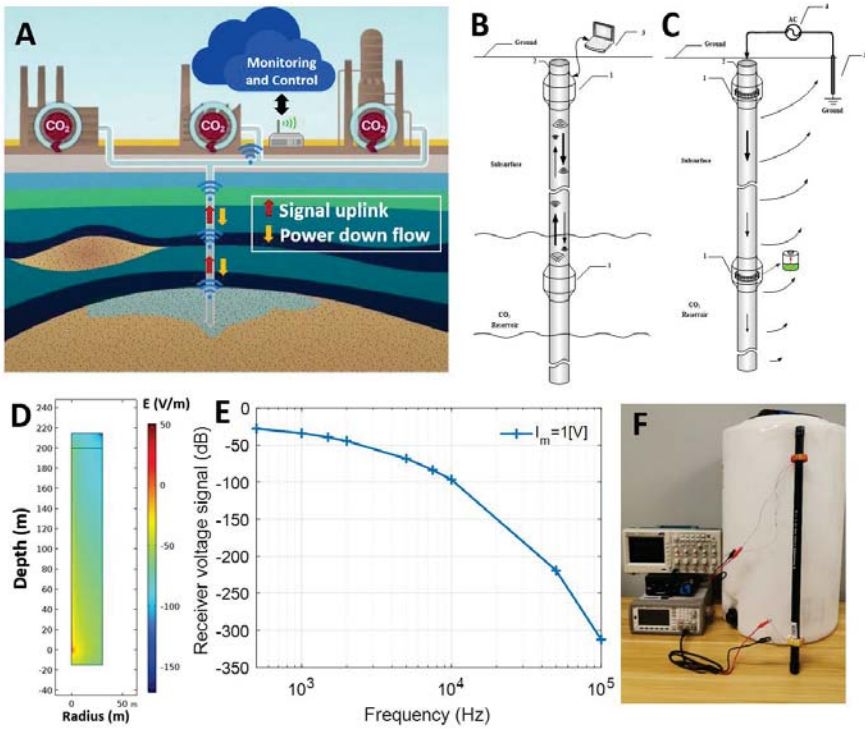

Figure 1: Schematics and preliminary data. (**A**) Real-time subsurface wireless communication and sensing system. (**B**) Schematics of wireless data transmission using toroidal antennas. (**C**) Schematic of Wireless power transfer from surface to subsurface. (**D**) COMSOL simulation results. (**E**) Frequency responses show the channel capacity can be up to 50 kbps. (**F**) Scale down system for lab tests.

E Cullen Building • 4302 University Drive, Room 124B • Houston, TX 77204-2040
Office: 713.743.4307 • Fax: 713.743.4323 • uhenergy@uh.edu • www.uh.edu/energy

between the underground sensors and the surface. A toroidal antenna is a winding of loops of conductive wire around a ring of material with a high value of magnetic permeability such as ferrite or mu-metal. When working, the toroidal antenna will stimulate electric currents in the casing string. The current carrying information will gradually leak into underground formation while flowing along the casing string. The measurable signal can be picked up by a voltmeter on the surface with one of its two terminals connected to the casing, and the other terminal to an earth antenna as a metal stake driven into the ground with a certain distance away from the well, or by another toroidal antenna winding around the casing at a shallow depth near the surface (Fig. 1B). To enhance the data transmission rate for long distance communication in lossy media, the multi-hop wireless communication technique can be used with several relay antennas deployed along the long casing.

Since no direct cable link exists between the surface and the downhole devices, a wireless power transfer system is necessary for long-time monitoring. Figure 1C shows the schematic of the energized casing technique to wirelessly charge the downhole transceivers and sensors. The casing is energized at the surface by a strong oscillating current source and a fraction of current can be transmitted to the casing bottom since the high conducting casing acts as good guidance for current flow. Using efficient energy harvesting devices, the transceivers and sensors in the deep subsurface can be charged.

4. Outcomes and Time Frame: The project will result in an intelligent, wirelessly connected, and multifunctional communication and sensing system that is capable of transmitting signal and power for long term underground monitoring. The timeline of the project is shown below.

Task	Task Description	Q1	Q2	Q3	Q4	Q5	Q6
T1	Design & analysis of toroidal antenna	x	x				
T2	Multi-hope wireless communication		x	x	x		
T3	Power transfer by energized casing			x	x	x	
T4	Lab experiments			x	x	x	x
T5	Final report and future proposals preparation					x	x

E Cullen Building • 4302 University Drive, Room 124B • Houston, TX 77204-2040
Office: 713.743.4307 • Fax: 713.743.4323 • uhenergy@uh.edu • www.uh.edu/energy

5. Progress and Management Reporting: We will provide short quarterly written progress reports, half-yearly oral presentations, and a final report at the end of the project term.

6. Equipment and Facilities: We have sufficient equipment and facilities for conducting this project. Detailed information is included in the appendix.

7. Internal and External Funding: The team are conducting two DOE projects related to this area: "Deep Learning Enhanced Joint Inversion for High-Resolution CO_2 Plume Monitoring" ($120,000, 06/29/20-06/28/21) and "A Web-based Turnkey Solution for Fast 3D Simulations of Electromagnetic Telemetry in Oilfield and Geothermal Drilling" ($120,000, 02/18/20-02/17/21).

8. Future Proposal Submissions: We will submit proposals to the DOE SubTER or SBIR/STTR (teaming up with a high-tech small company) programs by the end of the project. We will also actively contact potential industry sponsors (e.g. Shell, Chevron, Schlumberger, Halliburton) starting from Summer 2021. Besides, we plan to apply for the NSF I-Corps program in Fall 2020 or Spring 2021 to conduct market study of downhole wireless telemetry and power transfer in the areas of CO_2 storage, oil and gas, nuclear waste disposal, and geothermal exploration.

9. Research Team: Jiefu Chen is an expert in well logging and applied electromagnetics with 5 years of experience in the oil and gas industry, Xiaonan Shan has expertise in underground sensing, and Miao Pan's research focuses on wireless communication.

10. Industrial Collaboration: APS Technology, a leading downhole measurement solution provider, is willing to collaborate with us on this project (please see the attached support letter).

11. Business Development Plan: A provisional patent has been submitted (application number 62938601, field on 11/21/19). A team of five students from the C. T. Bauer College of Business Wolff Center For Entrepreneurship will explore the market and customers for this technology and create a business plan around the invention (please see the appended letter of support).

E Cullen Building • 4302 University Drive, Room 124B • Houston, TX 77204-2040
Office: 713.743.4307 • Fax: 713.743.4323 • uhenergy@uh.edu • www.uh.edu/energy