FINAL PROJECT REPORT

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Title: **Environmental Responses to Carbon Mitigation through Geological Storage**

Submitted to: DOE Office of Science, Basic Energy Science, Material Science and Engineering Division, EPSCoR
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Period of Performance: September 1, 2008 – August 30, 2013

Montana University Collaborators include:

- **Center for Biofilm Engineering (CBE) Montana State University (MSU)**
  Al Cunningham, Principal Investigator
- **Microbial Ecology Group, Division of Biological Sciences, University of Montana (UM)**
  William Holben, Lead
- **Petroleum Engineering Department, Montana Tech of the University of Montana (MTech)**
  Mary North-Abbott, Lead
- **Departments of Biological Science and Geophysics (MTech)**
  Martha Apple, Lead

Montana University researchers are partnering with scientists from five DOE National Laboratories:

- **Los Alamos National Laboratory (LANL)**
- **Lawrence Berkeley National Laboratory (LBNL)**
- **Pacific Northwest National Laboratory (PNNL)**
- **National Energy Technology Laboratory (NETL)**
- **Lawrence Livermore National Laboratory (LLNL)**

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1.0 INTRODUCTION

This report summarizes research progress on DOE EPSCoR Implementation Grant DE-FG02-08ER46527, entitled **Environmental Responses to Carbon Mitigation through Geological Storage,** for the period September 1, 2008 through August 30, 2013. The report is intended to summarize all relevant project information.

The project concept along with relevance to DOE and the State of Montana are discussed in detail in the text of the proposal**.** In summary, this DOE EPSCoR project is contributing to the study of carbon mitigation through geological storage. Both deep and shallow subsurface research needs are being addressed through research directed at improved understanding of environmental responses associated with large scale injection of CO_2 into geologic formations. The research plan, which represents collaboration between three Montana University system campuses, MSU's Zero Emission Research Technology Center (ZERT), and five DOE National Laboratories (LANL, LBNL, PNNL, NETL and LLNL) has two interrelated research objectives.

- **Objective 1:** *Determine the influence of CO_2-related injection of fluids on pore structure, material properties, and microbial activity in rock cores from potential geological carbon sequestration sites.*
- **Objective 2:** *Determine the Effects of CO_2 leakage on shallow subsurface ecosystems (microbial and plant) using field experiments from an outdoor field testing facility.*

1.1 Research highlights

Highlights from research for Objectives 1 and 2 are summarized below. Detailed discussion of results for each project objective follows in the text of the report.

1) A system for challenging 2.54 cm diameter rock core samples with supercritical CO_2 ($ScCO_2$) and other fluids has been developed at Montana Tech of the University of Montana (MTech). This system, which operates under high pressure (1000 -1500 psi) and controlled temperature conditions, facilitates direct measurement of rock permeability and porosity before and after challenge by $ScCO_2$, brine, and other reservoir fluids.

2) MTech has analyzed rock core samples from geologic formations actively being considered for CO_2 injection. These include the Madison Limestone Formation and the Frontier Sandstone formation in the Powder River basin (Wyoming and Montana).

3) Nuclear Magnetic Resonance Imaging (MRI) methods have been developed at Montana State University (MSU) for imagining rock cores before and after challenging with $ScCO_2$ and brine. This Image capability provides non-destructive estimates of rock properties including porosity, permeability, degree of interconnectivity between pores, and velocity field shifts (Codd et al., 2010). These measurements will help characterize geologic formations relative to their ability to successfully store injected CO_2.

4) MSU researchers have determined that biofilm cultures of *Bacillus mojavensis* are more resistant to exposure to $ScCO_2$ than the same organism growing in suspended culture. After $ScCO_2$ exposure suspended cultures revealed a **3 log10** reduction while biofilm cultures showed a **1 log10** reduction in viable cell numbers (Mitchell et. al, 2008).

5) The MSU research team has also identified an innovative engineered biomineralization process which may enhance CO_2 sequestration in deep geologic formations. This process, which utilizes ureolytic biomineralization to cause the deposition of calcium carbonate minerals, can possibly

enhance CO_2 sequestration in three ways: 1) incorporation of CO_2 directly into the mineral phase thereby enhancing mineral trapping of injected CO_2; 2) raising the solubility limit for CO_2 in brine thereby increasing solubility trapping of CO_2; and 3) long-term sealing of preferential CO_2 leakage pathways which will enhance stratigraphic trapping (Mitchell et al., 2010).

6) The University of Montana (UM) Microbial Response team has developed molecular methods to understand the effect upward CO_2 seepage has on near-surface microbial communities, and specific processes (nitrogen and carbon cycling) controlled by microbes. Specifically these methods assess the response of enzymatic potential (DNA) and activity (RNA) to elevated CO_2. (Morales et al., 2010a; Morales and Holben 2010b). These optimized extraction methods are now being applied to data from the ZERT field site. Results will develop a clearer view of the impact of elevated CO_2 levels on microbially controlled processes with ecosystem level repercussion, and in so doing, test the viability of utilizing microbial communities as early warning systems for detecting CO_2 leakage.

7) The MTech Plant Response team has determined that the appearance of "hotspots" (i.e. visible change in plant leaf wilting and color), along with alterations in hyperspectral signatures at the ZERT site are clear indicators of plant stress and are potentially very useful in detection of leaks of CO_2 from experimental systems, and by extension, of geologically sequestered CO_2 (Lakkaraju et al., 2010: Male et al., 2010). These methods of surface detection can be used to hasten remediation of excessive CO_2.

8) This project has made a substantial commitment to graduate and undergraduate education (Table 1). Over the duration of the project 13 undergraduates, 7 Masters, 4 PhDs, and 2 Post docs have received DOE EPSCoR support.

9) Montana University System (MUS) faculty professional development has been enhanced during this project (see Table 2). Over $3,500,000 has been generated in the form of new research projects which are directly tied to DOE EPSCoR. Another $4,000,000 in grant proposals is currently pending. Also the Project Investigators have published 36 articles in peer reviewed journals and made 51 presentations at conferences and workshops.

2.0 RESEARCH PROGRESS IN DETAIL

The following sections provide detailed discussion of research results by objective and task.

2.1 Research Results for Objective 1, Tasks 1 and 2

Objective 1: *Determine the influence of CO_2-related injection of fluids on pore structure, material properties, and microbial activity in rock cores from potential geological carbon sequestration sites.*

2.1.1 Progress Summary Task 1, Objective 1

Task 1. Develop methods for measuring material and flow properties of rock cores. The long term goal for this task is to develop improved testing methods which will characterize properties of rock core samples important for assessing the potential for geologic formations to successfully store injected CO_2.

High pressure rock core testing system at MTech. Under DOE EPSCoR a novel high pressure core testing system has been built at the MTech Petroleum Engineering Department, under the direction of **Mary North-Abbott**. The system complements existing MTech laboratory equipment which includes a

Boyle's Law helium porosimeter (to measure the porosity of core samples) along with a Ruska gas permeameter and liquid permeameter to measure core permeability. This now gives MTech the capability to conduct comprehensive petrophysical studies of rock core samples and subject them to various $ScCO_2$ and/or brine solution challenges. Specifically this system can measure changes in porosity and permeability of rock cores before and after $ScCO_2$ (or acidic brine) exposure. This core testing system is shown in Figure 1 along with examples of rock types tested to date at MTech.

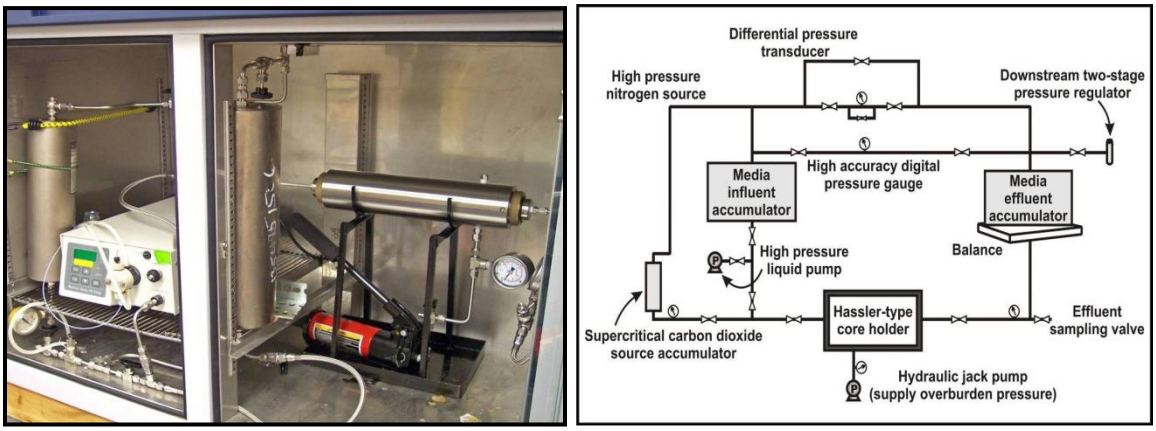


Figure 1-a. *System for testing rock core samples under high pressure and controlled temperature conditions. MTech can produce one-inch diameter cores using their existing core milling facilities in the Petroleum Engineering Department. After the cores are cut and cleaned, attributes such as porosity and permeability can be measured, and a general core description can be provided. These tests can be followed by high pressure (1200 psi, 38 degree C) challenges with various $ScCO_2$ and brine combinations. MTech can then repeat measurements of porosity and permeability on core samples. Permeability and porosity differences before and after $ScCO_2$ will determine whether exposure to $ScCO_2$, brine or other reservoir fluids significantly alters the interior pore structure and material properties (this will be further examined by the MRI experiments at MSU).*

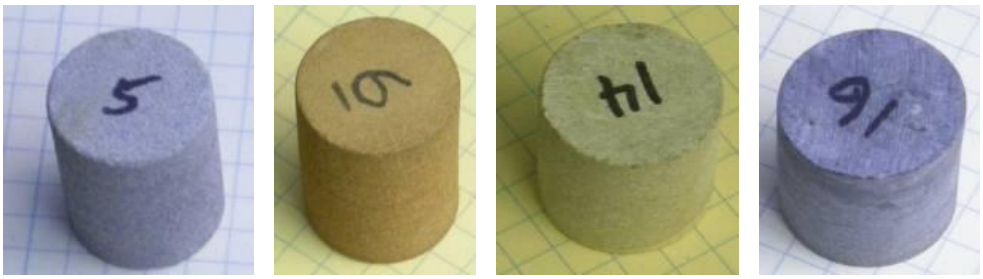


Figure 1-b*. Examples of rock core types currently being tested at MTech include: Berea Sandstone (5), Torrey Buff red sandstone (6), Limestone (14), Dolomite (16). Material properties measured include porosity, permeability, pore volume, grain volume, bulk volume, and bulk density. MTech has begun analyzing rock core samples from geologic formations being considered for CO_2 injection. These formations include the Madison Limestone Formation and the Frontier Sandstone formation in the Powder River basin (Wyoming and Montana).*

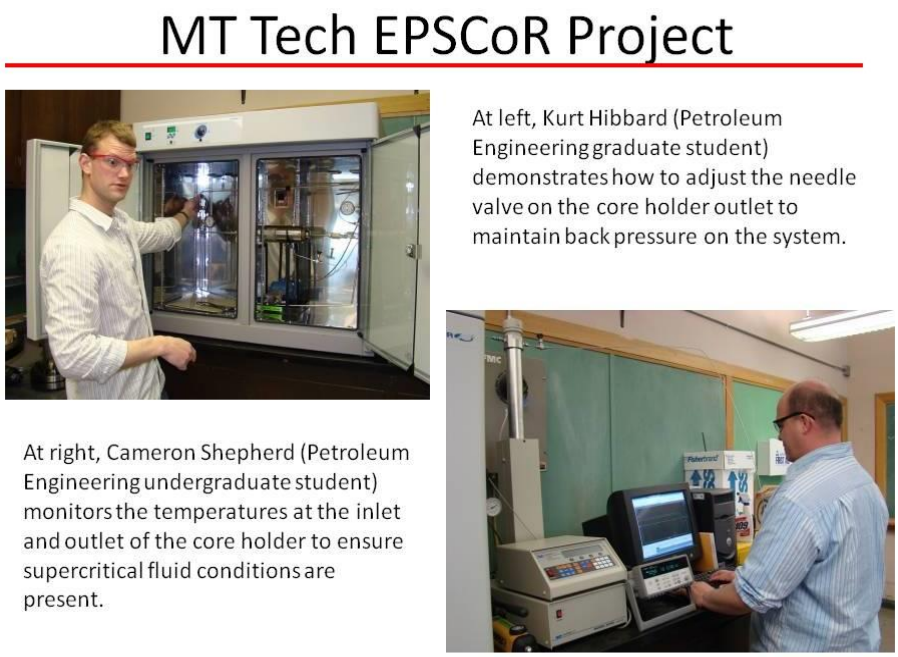


***Figure 1-c**. MTech Graduate students operating high pressure core testing system.*

MTech has begun analyzing rock core samples from actual geologic formations targeted for CO_2 injection. These include the Madison Limestone Formation and the Frontier Sandstone formation in the Powder River basin in Wyoming and Montana. Also MTech core testing capability is being used in combination with the Magnetic Resonance Imaging methods being developed at MSU to provide a comprehensive new way to measure and image the effects of CO_2-related injection of fluids on pore structure and material properties of rock samples from geologic CO_2 sequestration sites.

Magnetic Resonance Imaging at MSU. Under the direction of **Dr. Joe Seymour**, Professor of Chemical and Biological Engineering, and **Dr. Sara Codd**, Associate Professor of Mechanical Engineering, Magnetic Resonance Imaging (MRI) analyses techniques are being developed which provide unique data related to the ability of rock formations to sequester CO_2. The specific MRI method used in our studies is referred to as Proton Nuclear Magnetic Resonance (NMR). NMR detects the presence of hydrogens (protons) in water molecules by subjecting them to a large magnetic field to partially polarize the nuclear spins, then exciting the spins with properly tuned radio frequency radiation, and then detecting weak radio frequency radiation from them as they "relax" from this magnetic interaction. This allows NMR to track the velocity of individual water molecules moving through porous media and, with the aid of image analysis, estimate porous media properties such as porosity, permeability and pore size distribution.

During year 1 MRI was used to investigate pore scale phenomena within bead packs in which a *Bacillus mojavensis* biofilm was grown. This model experiment was conducted to test how well MRI could detect and quantify changes in pore geometry, porosity and permeability due to reduction of free pore space caused by the accumulation of a separate (non-aqueous) material phase. Biofilm was chosen for this purpose because it can be grown relatively easily in bead packs, and provides and NMR signal which is distinctly different form water in the free pore space. After excitation from equilibrium, the NMR signal decays with several different time constants, *T1* (spin-lattice) and *T2* (spin-spin) relaxation. Specifically, *T2* (or spin-spin) relaxation is influenced by the molecular mobility of the nuclei and is hence strongly correlated to fluid viscosity, distance from pore walls in porous samples, nature of those pore walls, and

presence of paramagnetic agents. *T*2 relaxation for biofilm in porous media should yield two populations of *T*2 values – longer values for any water in clean pores and shorter values for any water within biofilm. In Figure 2 it can be seen that the *T2* distribution shifts dramatically as biofilm grows. These MRI methods were later modified and used to analyze pore space distributions in rock cores before and after exposure to supercritical CO_2, as discussed below.

Nuclear Magnetic Resonance Imaging of biofouled beads

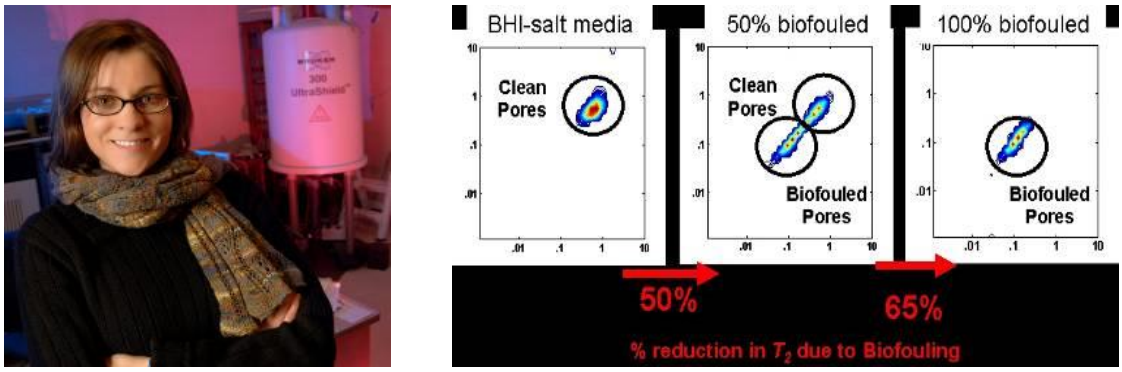


Figure 2. *This project is developing nuclear magnetic resonance (NMR) methods for the characterization of the pore structure and connectivity of geological media in response to biofilm growth (biofilm growth represents a rapid, convenient method for altering pore structure). In this figure three T2-T2 maps for 100 μm borosilicate glass beads in BHI-salt solution media (left), 50% biofouled with Bacillus mojavensis (middle), and 100% biofouled (right). The T2 value for the main diagonal peaks shifts significantly with biofouling—indicating that water originally present in the free pore space is being sequestered inside the biofilm matrix. This indicates that biofilm has substantially reduced free pore space, porosity and permeability. Further research has started to examine rock cores which have been subjected to $ScCO_2$, brine and biomineralization challenges.*

Following the biofouling experiments discussed above, project efforts focused on developing MRI methods for imagining rock cores. In these experiments Berea sandstone and Frontier formation rock cores 6 mm in diameter and 10 to 20 mm in length were saturated with water, challenged with a mixture of $ScCO_2$ and brine, and imaged using MRI. The resulting images (Figure 3) show the locations of larger free pore space (dark red) in relation to the rock matrix (dark blue) as well as how the free pore space changed with $ScCO_2$ exposure.

Images such as these can be analyzed to estimate rock properties including porosity, permeability, and degree of interconnectivity between pores. Relaxation correlation measurements ($T_1 - T_2$ and $T_2 - T_2$) were also carried out to establish a baseline for future measurements and to help assess the image-intensity in pre- and post-CO_2 challenge images.

The image results confirm that MRI methods can be used to analyze rocks of interest in this study. The signal levels and relaxation characteristics will likely vary between rock types but these differences may be very useful for observing changes in the internal structure of rocks between pre- and post-CO_2 challenged states or challenges due to mineral or biofilm deposition. In addition to water density images, relaxation measurements suggest that differences in rock type and water-saturation levels are observable.

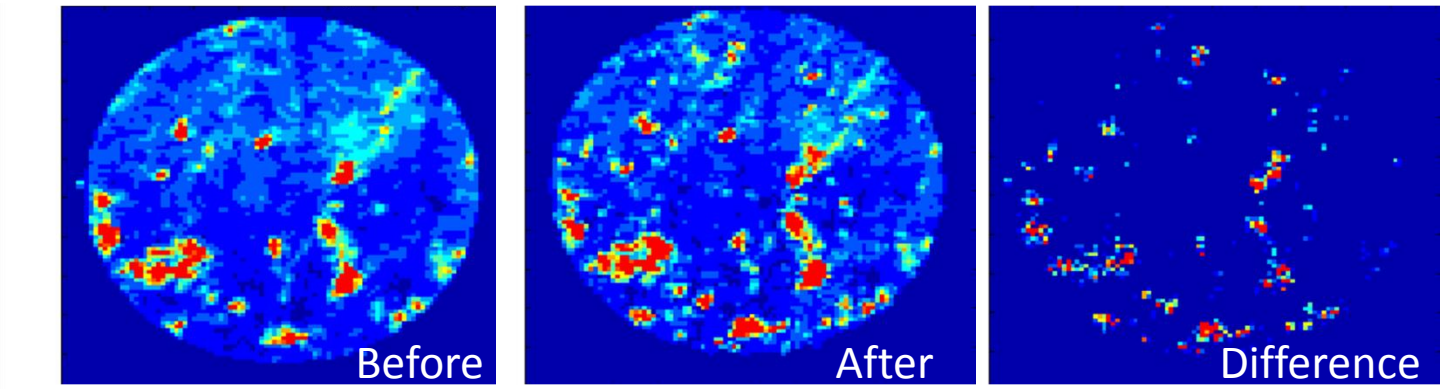


Figure 3 *Preliminary MRI images (1.5 mm slice thickness, 0.27mm x 0.27mm resolution) of a Berea rock core before and after a supercritical CO_2 and brine challenge. Pore density changes indicate the most significant changes are along the backbone flow path.*

Relaxation measurements can thus provide an additional parameter to interpreting measurements in rocks (Codd et al., 2010). MRI measurements can now be made in collaboration with MTech. The same rock cores can be analyzed before and after challenges with $ScCO_2$, brine and other reservoir fluids. MRI results can be compared with permeability and porosity changes observed using the MTech high pressure test system.

2.1.2 Progress Summary, Task 2, Objective 1

Task 2. Assess microbial community responses to Geologic CO_2 Sequestration. The long term goal of this research task is to examine interactions between anthropogenic CO_2 and microbial communities representative of the deep subsurface environment when geologic sequestration is likely to take place. This task is led by **Dr. Al Cunningham,** MSU Professor of Civil Engineering and **Dr. Robin Gerlach,** Associate Professor of Chemical and Biological Engineering.

Investigation of microbial resistance to $ScCO_2$ exposure. During Phase I our research team completed an investigation of the effects of microbial cells to $ScCO_2$ exposure (Mitchell et. al, 2008). Cells growing in aqueous suspension (i.e. planktonic) and well as in biofilms were investigated. $ScCO_2$ has been shown to act as a disinfectant against microorganisms. These organisms have most often been tested in vegetative or spore form. Since biofilm organisms are typically more resilient to physical, chemical, and biological stresses than the same organisms in planktonic form, they are often considered more difficult to eradicate. Our research was conducted to test the hypothesis that $ScCO_2$ induced inactivation of biofilm organisms would be less effective than against planktonic growth cultures of the same organism.

Bacillus mojavensis was used as a model biofilm organism in this study. It was isolated from a Berea sandstone core used for previous high pressure biofilm experiments at the Center for Biofilm Engineering, Montana State University (MSU), and identified using 16S rDNA sequencing. When grown in a sand support matrix under low flow conditions, *B. mojavensis* forms thick biofilm cultures, which are characterized by a copious EPS matrix. It is a gram-positive organism, a central sporulator, and a nitrate reducer. To generate a suspended culture for subsequent $ScCO_2$ exposure, a frozen stock culture of *B. mojavensis* was inoculated at a ratio of 1:100 into 100mL autoclaved Brain Heart Infusion (BHI) + salt medium [18 g L^{-1} BHI (Oxoid, Lenexa, KS), 0.75 g L^{-1} NH_4Cl; 40 g L^{-1} NaCl, 3 g L^{-1} $NaNO_3$ (Fisher, Pittsburgh, PA)]. The culture was transferred after 24 h into fresh medium by which time a dense planktonic culture of approximately $3.2\times10^8 \pm 0.09\times10^8$ (CFU/mL) had developed. Aliquots of the culture

were decanted into six 10mL $ScCO_2$ extractor cartridges from a SFX 220 Supercritical Fluid Extractor and were capped (Figure A4). Each cartridge comprised of a tube with stainless steel frits (0.5µm pore size) to contain the cartridge's contents while allowing $ScCO_2$ to flow through. In order to promote biofilm growth, *B. mojavensis* was grown under flow conditions in porous media columns housed in an incubator at 30 ℃. The same culturing conditions as described above for planktonic cells were used to generate an inoculum for biofilm growth.

Biofilm and suspended cultures of *B. mojavensis* were exposed to $ScCO_2$ at the Los Alamos National Laboratory (LANL) Supercritical Fluids Facility (Figure 4). Each sample was exposed to $ScCO_2$ at 136 atm and 35℃ for 19 minutes.

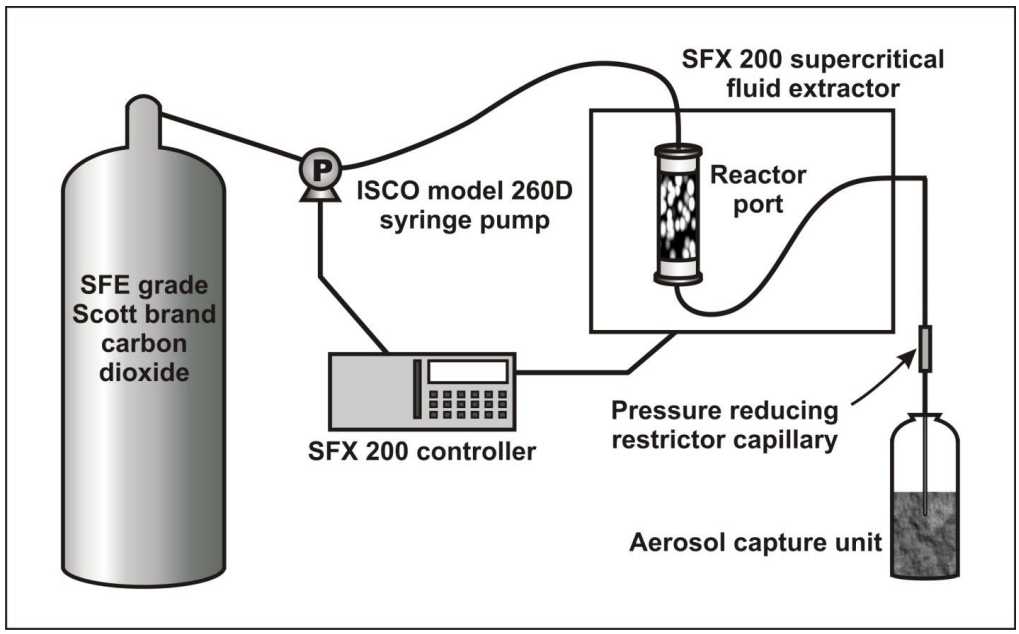


Figure 4. *SFX220 Supercritical Fluid Extractor schematic at the Los Alamos National Laboratory (LANL) Supercritical Fluids Facility. Tests were run in Collaboration with Dr. John Kazuba of LANL.*

After $ScCO_2$ exposure, *B. mojavensis* samples were analyzed for total and viable cells. Suspended cultures revealed a **3 log10** reduction while biofilm cultures showed a **1 log10** reduction in viable cell numbers. These data demonstrate that biofilm cultures of *B. mojavensis* are more resilient to $ScCO_2$ than suspended planktonic communities (Mitchell et al. 2008). It is hypothesized that the small reduction in the viability of biofilm microorganisms reflects the protective effects of extracellular polymeric substances (EPS) which make up the biofilm matrix, and which offer mass transport resistance, and contains a number of functional groups for interaction with and immobilization of CO_2. The resistance of biofilm suggests that higher pressures, longer durations of $ScCO_2$ exposure, and a quicker depressurization rate may be required to eradicate biofilms during the sterilization of heat-sensitive materials in medical and industrial applications. However, the observed resilience of biofilms to $ScCO_2$ is particularly promising for the prospective application of subsurface biofilms in the subsurface geologic sequestration of CO_2.

Biomineralization Studies. During Phase I our DOE EPSCoR research team began investigating the potential for using engineered biofilms to enhance geologic Carbon Capture and Storage (CCS). The primary focus of this inquiry is focused on the use of microbial biofilms to cause the precipitation of mineral deposits in the form of calcium carbonate based on the process of urea hydrolysis. It is well known that ureolytically active microorganisms such as *Sporosarcina pasteurii* (formally *Bacillius*

Pasteruii) are capable of the enzymatic hydrolysis of urea to ammonium (NH_4^+) and bicarbonate (HCO_3^-) (reaction 1), which consumes protons and thus increases the pH in the surrounding environment. The increase in pH and inorganic carbon shifts the carbonic acid system equilibrium towards carbonate (CO_3^2), which in the presence of calcium (or other multi-valent cations) can result in an oversaturation and precipitation of carbonate minerals (reaction 2).

$NH_2CONH_2 + H^+ + 2H_2O \rightarrow 2NH_4^+ + HCO_3^-$ (1)
$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3(s) + CO_2 + H_2O$ (2)

By controlling the supply of Ca^{2+} and HCO_3^- in the subsurface water, injecting or stimulating microbial inocula, growth nutrients and urea, the reactions shown above can be beneficially controlled in a subsurface environment.

Our DOE EPSCoR research team, in collaboration with MSU's Zero Emissions Research and Technology Center (ZERT), has determined that the ureolytic biomineralization process, when properly engineered, can precipitate copious quantities of calcium carbonate into aquifer pores and fractures, thus providing a potential technology for plugging leakage pathways available to injected CO_2. This concept is known as stratigraphic trapping (Cunningham et al., 2008, Cunningham et al., 2010). Our research team also analyzed bacterial hydrolysis of urea (ureolysis) in microcosms containing synthetic brine with variable headspace pressures [p(CO_2)] of $^{13}CO_2$. These experiments demonstrated a net flux of head space $^{13}CO_2$ into the brine and precipitated mineral phases. This result suggests that ureolytic biomineralization may lead to technologies which simultaneously reduce CO_2 leakage from geologic formations, and can trap CO_2 in non-labile mineral and aqueous phases. In other words ureolytic biomineralization is potentially capable of sequestering anthropogenic CO_2 from the gas phase into the mineral phase as $CaCO_3$--thereby facilitating enhanced mineral-trapping of injected CO_2 in the subsurface as well as from waste streams above ground. Of equal importance is that ureolytic biomineralization enhances the capacity of the brine for CO_2 (g) and dissolved carbonate ions, thus increasing the potential for solubility-trapping of injected CO_2 (Mitchell et al., 2010). These concepts for enhancing Carbon Capture and Sequestration (CCS) are shown below in Figure 5.

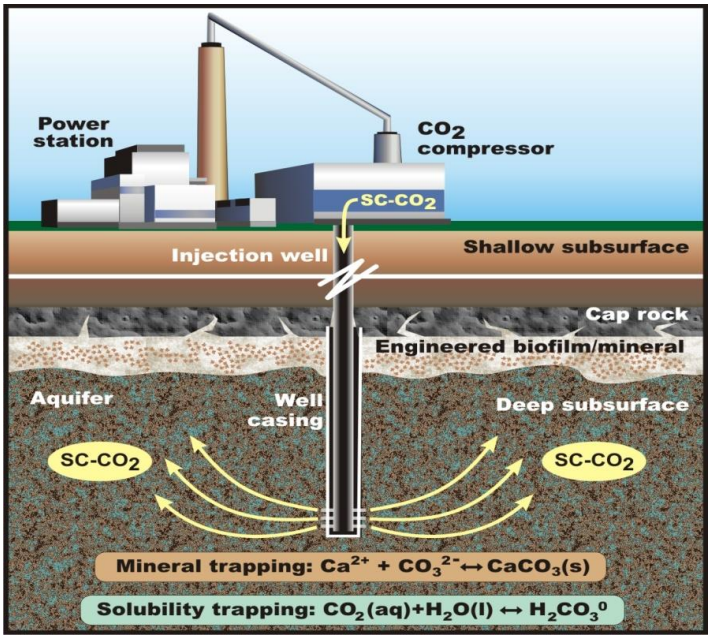


***Figure 5**. Our research program has identified an innovative concept for beneficial CO_2 use based on an engineered biomineralization process. The technologies resulting from this process will enhance the sequestration of carbon dioxide (CO_2) in deep subsurface geologic formations (referred to as Carbon Capture and Sequestration or "CCS") in three ways: 1) incorporation of CO_2 directly into the mineral phase thereby enhancing mineral trapping of injected CO_2; 2) raising the solubility limit for CO_2 in brine thereby increasing solubility trapping of CO_2; and 3) long-term sealing of preferential leakage pathways which will enhance stratigraphic trapping. These concepts are illustrated here.*

The research findings discussed above were the result of experiments which began in 2009 shortly after DOE EPSCoR began. Since that time we have conducted our follow-on research so that there is a clear distinction between research which is supported by DOE EPSCoR and what is supported by ZERT. Specifically we have developed two separate but complimentary lines of inquiry in on-going ureolytic biomineralization and its various applications: (1) (ZERT) research involving one-dimensional packed porous media columns, and (2) (DOE EPSCoR) research involving radial flow, porous media systems. Both lines of inquiry are necessary as we attempt to develop the ureolytic biomineralization process toward field applicable technologies. Journal publications, as well as reporting to DOE (both ZERT and DOE EPSCoR) acknowledge both funding programs as appropriate.

2.2 Research Results for Objective 2, Tasks 1 and 2

Objective 2: *Determine the effects of CO_2 leakage on shallow subsurface ecosystems (microbial and plant) using field experiments from an outdoor field testing facility.*

UM Research Team. Objective 2 has been carried out by a research team composed of faculty from two campuses of the University of Montana (UM) system. The team consists of microbiologists **Dr. William Holben,** Professor and **Dr. Sergio Morales**, Research Assistant Professor, Microbial Ecology Group, Division of Biological Sciences, UM (Missoula campus), and **Dr. Martha Apple,** Associate Professor of Biological Sciences, and **Dr. Xiaobing Zhou,** Associate Professor of Geophysics Montana Tech of The University of Montana (MTech). This team of UM researchers and their students is investigating the effects of controlled CO_2 releases on plants and shallow subsurface microbial communities using data from field experiments performed at the MSU ZERT field test facility (Figure 6a &b).

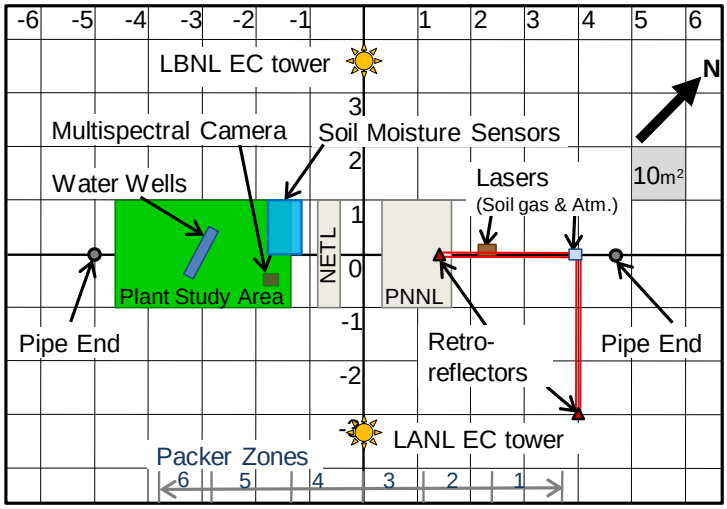
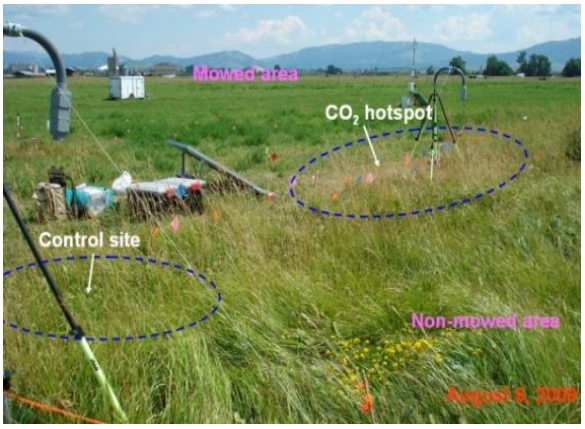


***Figure 6a.** Plan view layout of the MSU ZERT field experiment site. CO_2 is released through packer Zones 1-6 which are located along the centerline of the diagram between the two pipe ends. Plant*

response studies are in the green shaded area soil microbiology samples are taken within various packer zones.

a)

b)



c)

***Figure 6b**. a) Dr. Martha Apple and MTech students installing root zone camera prior to 2009 CO_2 release at ZERT site. b) This figure shows location affected by CO_2 release (hotspots) as well as non-CO_2 impacted control site resulting from the August 2009 release. c) Dr. Sergio Morales and Phillip Drummond, UM Microbiologists, collecting soil samples at ZERT site for the 2009 release.*

The UM research team has participated in controlled CO_2 releases at the ZERT site during summer 2009 and 2010 (and will again in 2011). These controlled CO_2 releases provided opportunities for UM to obtain plant and soil microbe samples before, during and after CO_2 was released. Future ZERT CO_2 releases will provide the opportunity to test hypotheses and methods discussed below. UM findings have been shared routinely with the National Lab and other ZERT partners through white papers and teleconferences.

2.2.1 Progress Summary, Task 1, Objective 2

Task 1. Effect of CO_2 seepage on soil microbial communities: Ecosystem effects and suitability of microbes as sentinels for detecting elevated CO_2. This task, which is studying the effects of elevated CO_2 on soil bacterial community structure and function, is being conducted by the UM Microbiologists **William Holben** and **Sergio Morales**. The long-term goal for this task is to understand the response of soil microbial communities to elevated levels of CO_2 resulting from subsurface seepage and to determine the suitability of microbes as sentinels for unwanted CO_2 leakage at geological sequestration sites.

During 2009, two separate controlled releases of CO_2 were carried out at the ZERT field site. The spring release began June 7, 2009 and lasted until June 14. The sustained release rate was 0.3 tons per day of CO_2 from the horizontal pipe located at a depth of approximate 2.5 meters during this period. A second release (hereafter summer release) of 0.4 tons per day occurred from July 17 through August 4, 2009. The

first release of CO_2 included zones 2, 3, and 4, while the second release was expanded to include zone 5 (zones are shown in Figure A6a). The UM Microbial Ecology Group participated in both CO_2 releases carried out in the 2009 sampling season and collected more than 100 samples for analysis. These samples were collected directly above the horizontal well, at points roughly in the center of Zones 2 & 3 for the June release, and Zones 2 & 5 for the summer release. This strategy allows for a biologically replicated view of CO_2 impact on soil communities, and also for a direct comparison to data collected in the plant study area by other investigators. Additional samples were collected during the 2010 spring release from the vertical injection zone in collaboration with Dr. Martha Apple's plant group. Plant rhizosphere (root-attached soil) samples were gathered in order to investigate the effect of CO_2 seepage at the plant/microbe interface.

Altered genetic expression due to CO_2 exposure. In order to validate our methodology, we focused on 52 samples taken from a single hot spot and the background area for detailed analysis. Samples were collected every 6 hours for 24 hours prior to CO_2 injections, and continued at 6-hour intervals for 24 hours post injection. Samples were processed as detailed in Figure 7. Triplicate nucleic acid extractions (*i.e.* experimental replicates) were performed on each sample and analyzed separately. Both RNA and DNA are analyzed in order to assess both the abundance of targets (gene copies) representing enzymatic potential and transcript numbers (mRNA) representing gene expression levels for multiple carbon (C) and nitrogen (N) cycling genes. To date, 156 extractions have been completed with high quality nucleic acids (DNA and RNA) undergoing analysis by quantitative PCR.

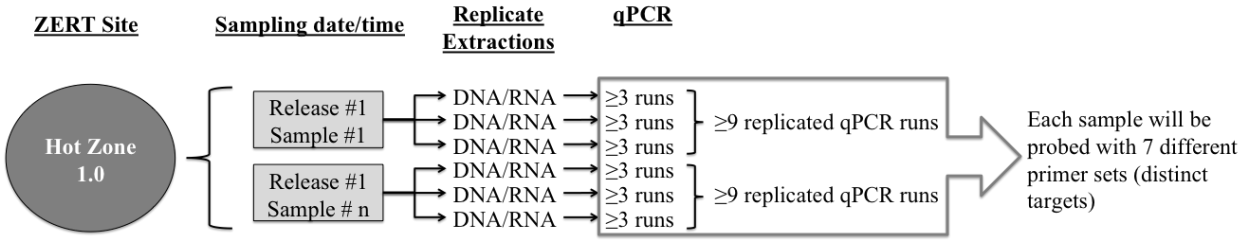


Figure 7. *Typical sample-processing scheme for ZERT site soil samples.*

Preliminary data had led to the hypothesis that CO_2 challenges in the range of the ZERT site releases (or greater) would alter gene expression patterns without significantly perturbing the composition of the community. Current data (Figure 8) measuring gene abundance of nitrogenase (*nifH*, a key enzyme involved in nitrogen fixation) and methyl co-M reductase (*mcrA, encoding a subunit of the enzyme catalyzing the terminal step in biogenic methane production*) have challenged that hypothesis, suggesting that microbial turnover (alterations in gene copy numbers likely due to growth or death of portions of the microbial community) is occurring at rates higher than are typically reported for soils.

This represents a great advance in our understanding of soil community response, and would suggest that microbial communities in soils are as active and dynamic as those found in aquatic systems. Increased CO_2 resulting from the injections resulted in a rapid (peaking at 18 hours) reduction in gene abundance. However, based on field notes, it was noted that inordinately low temperatures at that time may have had a stronger effect on gene abundance than CO_2 levels. Future analyses will specifically include site metadata in statistical tests in order to directly test this suggestion. Current data also suggest that *nifH* (nitrogen cycling) levels were affected more by elevated CO_2 than *mcrA* (carbon cycling), and that those effects lasted longer.

Soil population shifts due to elevated CO_2 exposure. An additional aim of this work was to assess whether short-term CO_2 exposure had any detectable effect on heterotrophic microbial population density

in the samples collected from the ZERT site. Initially it was hypothesized that increased concentrations

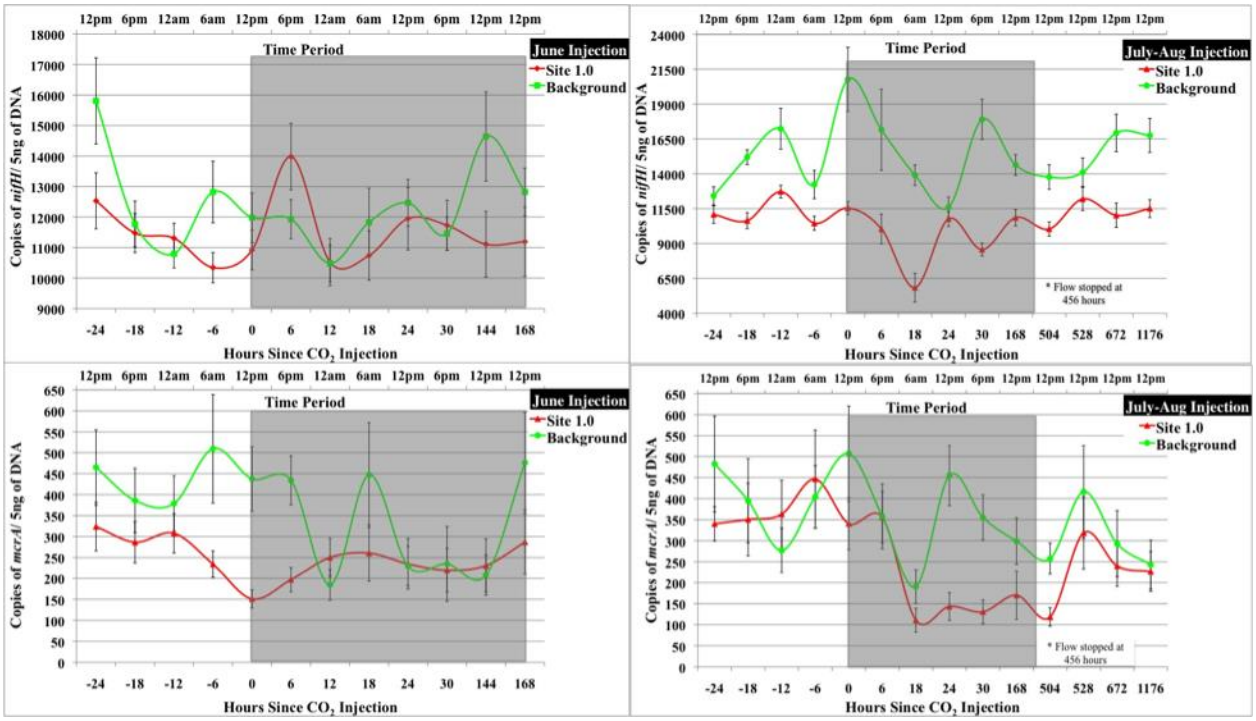


Figure 8. *nifH and mcrA gene abundances in soils before, during and after the June and July-August 2009 CO_2 injections. CO_2 release periods are shaded grey.*

of CO_2 may cause a shift from primarily heterotrophic metabolism to increased autotrophic activity, thereby affecting a change in microbial community composition, respiratory activity and gene expression in near-surface soils. This hypothesis is based on a fundamental difference between heterotrophic and autotrophic bacteria, namely that heterotrophic microbes utilize organic carbon in the soil while autotrophs utilize CO_2 as their main carbon source. By substantially increasing the flux of CO_2 through the soil (due to the controlled release) it was logical to assume that the heterotrophic bacterial population would decrease and that the autotrophic population would increase. Currently, we are converting all our mRNA samples into cDNA in order to quantify gene expression responses to increased CO_2. We have successfully done a preliminary quantification, which indicated low levels of expression (~10-fold lower than DNA levels) in background sites, and even lower in CO_2 exposed sites (Figure 9). Although there

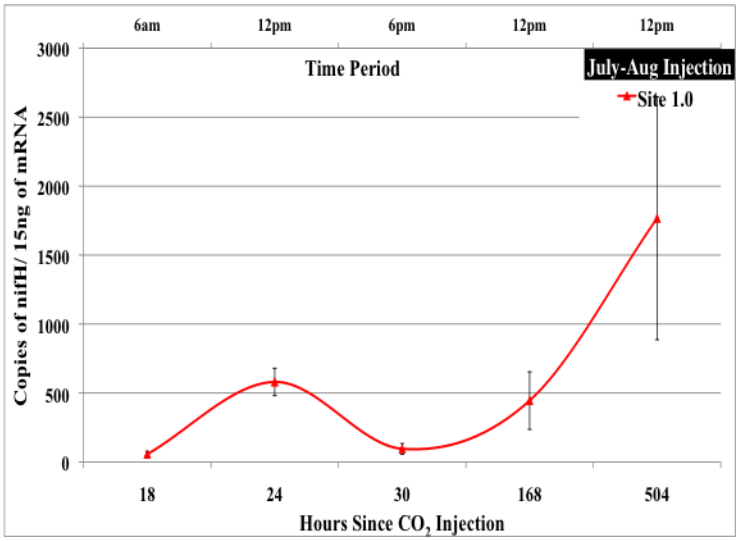


Figure 9. *Gene expression for the nitrogenase (nifH) gene in Zone 2 (Site 1.0).*

is some preliminary indication that the population may be shifting from heterotrophic toward autotrophic more data and analysis are needed to confirm this hypothesis.

Clone Libraries. In addition, the UM microbiology team has completed building clone libraries from ZERT soil bacteria DNA with each set of functional gene primers. This is being done to assess the genetic diversity present for each gene being tracked and to confirm that the qPCR primers we developed are amplifying (quantifying) only the target gene (see Figure 10. for example). We have also participated in a joint sampling effort on the vertical injector zone

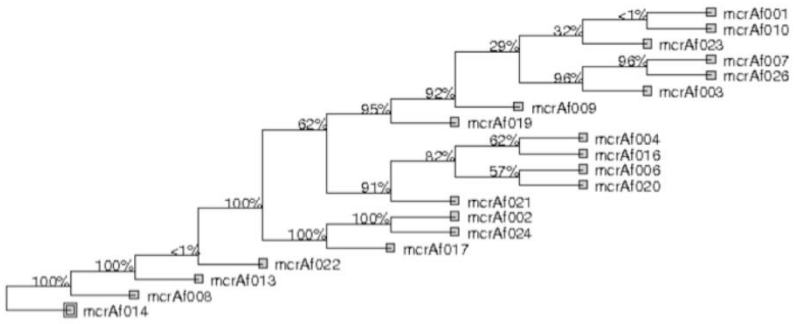


***Figure 10**. Diversity of methyl CoM reductase genes identified from ZERT soil.*

In summary, the optimized RNA/DNA extraction methods and corresponding probes have lead to the development of a solid experimental plan to assess the effects of elevated CO_2 exposure on gene expression. This experimental plan for Phase II is presented in the main text of the renewal proposal.

2.2.2 Progress Summary, Task 2, Objective 2

Task 2. Evaluate plant response to controlled CO_2 seepage through soil. The MTech Plant Response Team, led by **Martha Apple** and **Xiaobing Zhou,** is investigating the effects on plants of deliberate leaks of CO_2 from an experimental carbon sequestration system.

The MTech Plant Responses Research Team measured soil, spectroradiometric, and physiological parameters along a transect extending perpendicularly from a zone of upwelling CO_2 and collected images of roots to a depth of 75-80 cm. The bulk soil electric conductivity (EC), soil moisture, and soil temperature were measured continuously at a CO_2 hotspot (high concentration of soil CO_2) along with soil CO_2 concentration.

Plant identification. The ZERT site is located in a former agricultural field to the west of Montana State University-Bozeman. The vegetation consists of naturally occurring herbaceous plants, none of which were planted expressly for the ZERT project. The MTech Plant Response Team identified the plants and found a mixture of grasses and nitrogen-fixing legumes along with an abundance of dandelions. Plant identification is an important step in characterizing the vegetation, and knowledge of the species-specific responses of plants (including potential differences in survival), to high concentrations of CO_2 is a potentially useful predictive tool in surface detection of leaks from carbon sequestration systems.

Plant stress. The vegetation at ZERT proved to be excellent indicators of surface CO_2 leakage because the above ground parts of the plants died back in circular zones called "hotspots", approximately 3 to 4 meters in diameter, which were clearly visible within two weeks of CO_2 exposure and formed only where concentrations of upwelling CO_2 were the highest (Figure 11).

Leaf Area Index (LAI), (the proportion of ground covered by leaves), decreased markedly in the hotspots. Chlorophyll content decreased significantly and fluorescence increased somewhat in dandelion leaves, which became reddish before turning brown, crumbly, and senescent. The plants then produced very small green leaves. Stomatal conductance was significantly higher in Dandelions than in Orchard Grass (Figure 11).

***Figure 11**. Left to Right. Dandelion and grass leaves, "Hotspots" at the ZERT field site caused by plant die-back resulting from CO_2 released during July 2009.*

Water vapor exits and CO_2 enters through stomata, which generally close with sufficient CO_2 for carbon fixation. It is as yet unknown why the ZERT Dandelions have high stomatal conductance with elevated CO_2. High stomatal conductance may lead to excessive loss of water vapor, possibly explaining leaf dieback in Dandelions.

Alterations in Hyperspectral Signatures are a Measure of Plant Stress. The Mtech plant response team participated in hyperspectral reflectance studies at the ZERT field site during the 2009 and 2010 summer release periods. Hyperspectral reflectance was measured under clear sky conditions at stations along a transect perpendicular to the CO_2 releasing pipe line. Hyperspectral signatures of plants are a product of the interactions of pigments with light. Leaves contain the photosynthetic pigments chlorophyll *a* and *b*, as well as their accessory pigments, xanthophylls and carotenoids. Since photosynthesis hinges on interactions of photosynthetic pigments with light, alterations in these pigments change photochemistry and its corollary, photosynthetic efficiency, and can lead to significant, measurable, plant stress. We detected changes in the visible to near-infrared reflectance spectral signatures of leaves from daily measurements made over the course of 29 days with a spectrometer and with airborne hyperspectral imagery, as shown in Figure 12 (Male et al., 2010).

These changes began to appear within five days after injection of CO_2 and were most pronounced in the zones of leaf dieback known as the hotspots. At least 4-8% CO_2 by volume was necessary to produce altered hyperspectral signatures. Although it is normal for the aboveground parts of herbaceous plants to lose chlorophyll and dieback during the late summer in Montana, the dieback of leaves was pronounced in zones of upwelling CO_2. Leaves in these zones contained significantly less chlorophyll and were thus less green than leaves of plants at ZERT that were not exposed to high CO_2 (Lakkaraju et al., 2010).

Derivative analysis identified two features (minimum and maximum) at 575-580nm and 720-723nm spectral regions in Figure 12. The Normalized-difference first derivative index (NFDI) was defined

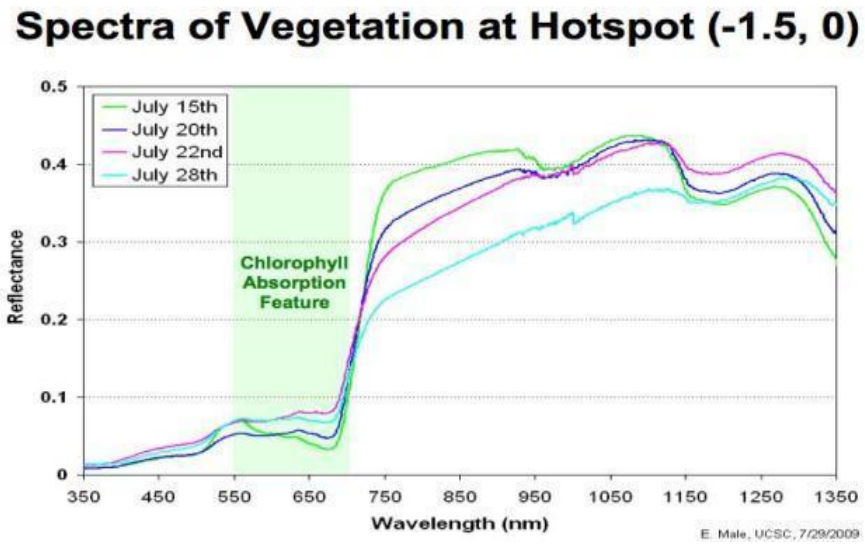


Figure 12. *Graph showing the decrease in reflectance spectra (fraction of incident radiation reflected by plant leaves vs. wavelength) in response to CO_2 exposure during the July-August, 2009 CO_2 release at the ZERT site. Overall plant reflectance decreases with increasing time of exposure to CO_2.*

based on the spectral derivative at the two bands. Four vegetation indices were derived and analyzed with the accumulated soil CO_2 concentration to assess the accumulated impact of high soil concentration on vegetation. Results show that with increased soil CO_2 concentration due to controlled CO_2 leakage: (1) the structural independent pigment index (SIPI) increased, indicating a high carotenoid to chlorophyll ratio; (2) the chlorophyll normalized difference vegetation index (Chl NDI) decreased, suggesting a decrease in chlorophyll content with time; (3) pigment specific simple ratios (both PSSRa and PSSRb, (Figure 13) were reduced for stressed vegetation station compared to that at the control site, indicating a reduction in both chlorophyll a and chlorophyll b; and (4) NFDI was low where plants were stressed. All four indices were found to be sensitive to stress in vegetation induced by high soil CO_2 concentration.

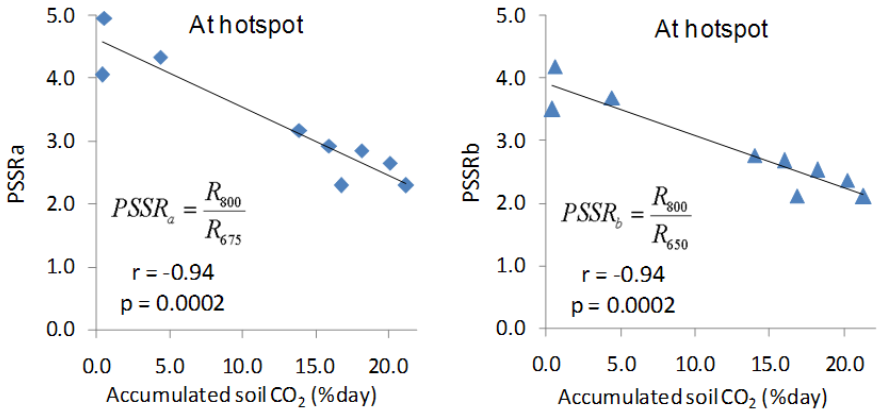


Figure 13. *Decrease of pigment specific simple ratios (PSSRa and PSSRb) derived from hyperspectral reflectance measurement with accumulated soil CO_2 concentration (%day).*

Analysis of soil measurements. Multivariate analyses of the observed time series of the soil bulk EC, soil CO_2 concentration, soil moisture, and soil temperature show that: (1) the slope of the linear relationship between the bulk soil EC and soil moisture increased (from 2.067 to 4.982 dS/m) with

increase in the soil CO_2 concentration due to CO_2 leakage (see Figure 14); and (2) after the CO_2 release, the relationship between soil bulk EC and soil CO_2 concentration observed three modes: gas CO_2 decay mode, dissolved CO_2 decay mode, and natural gas CO_2 mode. Appearance of the dissolved CO_2 mode was due to a sudden increase of soil moisture because of rainstorms. Comparing the two decay modes, we found that the dependence of EC on soil CO_2 concentration was weaker for the gas CO_2 decay mode than the dissolved CO_2 decay mode. Based on these observations, we surmise that it is possible to monitor CO_2 leakage of sequestrated CO_2 using the bulk soil EC method.

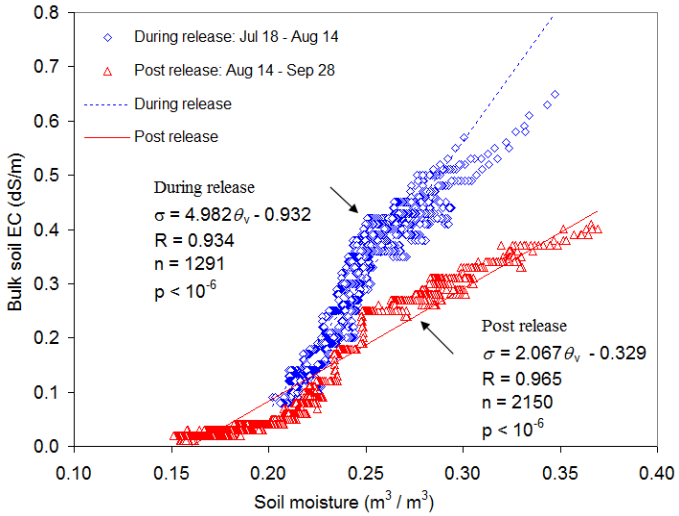


Figure 14. *Soil bulk electrical conductivity (EC) versus volumetric soil moisture from July 18 to September 28, 2009.*

Significance. Sensitive methods to detect possible CO_2 leakage of geologically sequestrated CO_2 are an integral part of geological CO_2 sequestration. Timely detection of possible leakage of CO_2 can provide timely information and remediation. The appearance of hotspots, along with alterations in hyperspectral signatures at the ZERT site, are clear indicators that measure plant stress. Soil EC also appears to be sensitive to the CO_2 leakage. We surmise that both methods can be used to monitor CO_2 leakage of sequestrated CO_2. The Plant Response Team, in collaboration with the UM Microbiologists, is correlating the responses of roots, soil microbes, and soil geophysics/geochemistry to the dramatic changes in the above ground vegetation previously characterized.

3.0 DOE EPSCOR STUDENTS

During Phase I this DOE EPSCoR Implementation project has made a strong commitment to student education. The laboratory-based research associated with Objectives 1 and 2 of this project has offered and continues to offer opportunities for Post docs, PhD and Masters students in areas which include Chemical and Biological Engineering, Environmental Engineering, Petroleum Engineering, and Geophysical Engineering, as well as Science students majoring in Biological Sciences and Microbiology. In addition the CO_2 release experiments at the MSU ZERT field site offer summer Field Assistant opportunities for numerous undergraduate students. Table 1 lists all students receiving full or partial support under DOE EPSCoR.

TABLE 1

DOE EPSCoR Students Montana State University		
Name	**Degree**	**Current Status**
Mitchell, Andrew	Post Doc Biogeochemistry	Faculty member, University of

	(supported by DOE EPSCoR from 09/01/2008 – 07/31/2009)	Aberystwyth, Wales
Hornemann, Jennifer	PhD Chemical and Biological Engineering	Exxon R & D division, Houston TX
Phillips, Adrienne	PhD Environmental Engineering	Graduation 2013
Vogt, Sarah	PhD Chemical and Biological Engineering	Graduation 2013
Parks, Stacy	MS Chemical and Biological Engineering	Graduated spring 2009, working for Bend Research , Bend OR
Schultz, Logan	MS Chemical and Biological Engineering	Graduated Spring 2010, pursuing PhD at University of Copenhagen, Denmark
Bugni, Steve	MS Environmental Engineering (currently receiving half-time stipend support from DOE EPSCoR)	Graduation 2011
Gittins, Ty	BS Chemical and Biological Engineering	Graduation 2011
Harrer, Travis	BS Chemical and Biological Engineering	Graduation 2011
DOE EPSCoR Students – University of Montana and MTech		
Name	**Degree**	**Current Status**
Morales, Sergio	Post Doc Microbiology (UM)	Research Assistant Professor, University of Montana
Jewell, Scott	MS Geophysical Engineering	Graduation 2013
Drummond, Phillip	PhD Microbiology (UM)	On leave
Lakkaraju, Venkata	MS Geophysical Engineering (MTech)	Graduated October 2010
Sharma, Bablu	MS Interdisciplinary Studies (MTech)	Graduation 2011
Hibbard, Kurt	MS Petroleum Engineering (MTech)	Graduated 2010, working for Chesapeake Energy, OK
Overland, Brandon	MS Petroleum Engineering (MTech)	Graduation 2011
Phillips, Russel	BS Petroleum Engineering (MTech)	Graduated 2010, working for Baker Hughes
Shepherd, Cameron	BS Petroleum Engineering (MTech)	Graduated 2010, working for B.P. Alaska
Johnson, Benedict	BS Petroleum Engineering (MTech)	Graduation 2011
Lambson, Roger	BS Petroleum Engineering (MTech)	Graduation 2011
Dorhorst, Carly	BS Environmental Engineering (MTech), Field Assistant, Summer 2009	Graduation 2011
Anderson, Anna	BS Biological Sciences (MTech)	Graduation 2011

	Field Assistant summer 2009-10	
Bradley, Allison	BS Biological Sciences (MTech) Field Assistant summer 2009-10	Graduation 2011
Olson, Jake	BS Biological Sciences (MTech) Field Assistant, Summer 2010	Graduation 2011, plans to attend graduate school
Prince, Josh	BS Biological Sciences (MTech) Field Assistant, Summer 2009-10	Graduation 2011, plans to attend graduate school
Stein, Tara	BS Microbiology, (UM) Field Assistant, Summer 2009-2010	Graduation 2011
Rosario, Maria	BS Microbiology, summer visitor 2009 (UM)	Graduation 2012

Table 1. *Students receiving full or partial support under DOE EPSCoR. Unless otherwise indicated Post docs, PhD students, and Masters students listed in this table received full research stipend support for DOE EPSCoR. Bachelor degree students from MSU and MTech Petroleum Engineering Department typically received hourly support for approximately 10 hours per week from DOE EPSCoR. Bachelors students from UM and MTech Biological Sciences department typically were funded as field assistants during summer months as indicated.*

4.0 FACULTY PROFESSIONAL DEVELOPMENT UNDER DOE EPSCOR

All faculty Principal Investigators participating in this project have benefited in terms of their professional development. Highlights of individual accomplishments are shown in Table 2.

TABLE 2

Name	Professional Development under DOE EPSCoR
Al Cunningham and Robin Gerlach (MSU)	Cunningham and Gerlach were awarded a $1,999,374 grant from DOE in July 2010. The 3-year project is entitled "Advanced CO_2 Leakage Mitigation using Engineered Biomineralization Sealing Technologies" and stems directly from DOE EPSCoR activities. Cunningham and Gerlach received a second DOE grant in 2012 entitled "Field Test and Evaluation of Engineered Biomineralization Technology for Sealing Existing Wells". This grant is for 2 years at a funding level of $1,020,000.
Joe Seymour and Sara Codd (MSU)	During October 2010, Seymour and Codd were awarded a $51,775 Equipment grant from DOE to upgrade their NMR spectrometer to image flow of supercritical fluids. This equipment grant enhanced the NMR capability and resulted in Seymour/Codd being awarded a 2-year, $200,000 DOE SBIR grant entitled "NMR Technologies for Monitoring of Biological and Geochemical Processes in the Subsurface". Seymour and Codd received promotions in 2010 (Seymour: Professor, Codd: Associate Professor)
Bill Holben (UM)	Holben was awarded a sabbatical Leave during spring 2010 with the Geological Survey of Denmark and Greenland, working with Carsten Jacobsen and Jacob Bælum, who are world leaders in mRNA extraction and analysis from surface and subsurface soils. This experience enhanced the UM microbiology team's DOE EPSCoR research.
Sergio Morales (UM)	In 2009 Dr. Morales was promoted to Research Assistant Professor. His major assignment has been DOE EPSCoR.
Martha Apple and Xiaobing Zhou (MTech)	Apple and Zhou have developed expanded research collaborations as a result of DOE EPSCoR. They are co-authors with researchers from National Labs, MSU, UM, and UC Santa Cruz on 4 peer-reviewed publications and 8 conference presentations. They have submitted a $4,000,000 research proposal in collaboration with Brookhaven National Lab. Zhou was promoted to Associate professor in 2009. Apple received tenure in 2012 and has implemented field techniques from the ZERT site in research at

	GLORIA and snowfield alpine research sites.
Mary North-Abbott (MTech)	As a result of building the high pressure core testing facility, North-Abbott and the MTech Petroleum Engineering are receiving requests to analyze rock cores from geologic formations targeted for future CO_2 injection.
DOE EPSCoR Publications and Conference Presentations	The DOE EPSCoR Research team has published 36 articles in refereed journals. In addition the research team has collectively made 51 DOE EPSCoR-related presentations at conferences and workshops. A complete list of all Publications and Presentations which acknowledge DOE EPSCoR can be found in Appendix 3.

Table 2. *Professional development accomplishments for all Principal Investigators. Over $3,500,000 has been generated during Phase I in the form of successful follow-on research proposals which are directly tied to DOE EPSCoR. Another $4,000,000 in grant proposals is currently pending. The Principal Investigators have published 36 journal articles and made 51 conference/workshop presentations.*

As Table 2 indicates all Montana University Principal Investigators have demonstrated professional development which is related to their involvement in DOE EPSCoR. The research area of Geologic Carbon Sequestration is relatively recent and holds the potential for continued growth and professional development in the future.

5.0 DOE CRITERIA FOR SUCCESS OR EFFECTIVENESS OF IMPLEMENTATION AWARDS

Listed below in *italics* are the DOE criteria for Success or Effectiveness of Implementation Awards as presented in The DOE EPSCoR annual meeting held July 22-23, 2009 at Brookhaven National Laboratory. We have provided a response to each of these criteria based progress under DOE EPSCoR. The responses are in bullet format, however it should be noted that more detailed information is contained in relevant sections of this project report.

a) *Does the proposer have a plan to or has the awardee made competitive faculty hires and retained outstanding faculty within the scope of the implementation award?*

- DOE EPSCoR has provided opportunities for senior faculty (Cunningham, Bromenshenk, Holben) and junior faculty (Codd, Seymour, Gerlach, Apple, Zhou) to develop a new research topic.
- DOE EPSCoR has facilitated the hiring of two new research faculty, Morales (UM) and Phillips (MSU), with full or partial support from the project.
- All faculty who started this project have been retained, and four have been promoted (Zhou: Associate Professor, Morales: Research Assistant Professor, Codd: Associate Professor, Seymour: Professor). Bill Holben was awarded a sabbatical leave.

b) Does the proposer have a plan to attract or has the awardee attracted outstanding graduate students and post docs?

- Table 1 lists all students supported by DOE EPSCoR (2 post Docs, 4 PhD, 7 Masters, 13 bachelors degree students). This represents a healthy education program at both UM and MSU.
- It is noteworthy that four graduating students have taken jobs in the energy field (Hornemann: EXXON R&D Huston TX (MSU), Shepherd: BP Alaska, Phillips: Baker Hughes, Hibbard: Chesapeake Energy, OK (MTech)).

c) Does the proposer have plans to develop or have they developed as part of the implementation award unique infrastructure capabilities that are critical to the advancement of science or technology? Alternatively, are they planning to or making unique contributions to DOE oriented capabilities (e.g., building or developing unique capabilities for a DOE experiment or facility)?

- DOE EPSCoR has significantly enhanced the ZERT CO_2 field site at MSU.

- DOE EPSCoR has expanded and upgraded the MRI facilities at MSU. This facility now has biogeochemical and geophysical capability.
- DOE EPSCoR funding has build a novel high pressure rock core testing system located at the Petroleum Engineering Department of MTech.

d) Does the proposer have plans to be or are the grantees on track to a sustained leadership position in their discipline(s)?

- CCS research has become a major pursuit for all investigators.
- Co-authorship with other disciplines and National labs (Cunningham, Gerlach, Apple, Zhou, Seymour, Codd, Morales, Holben).
- Invitations to serve a reviewer on Geologic Carbon Sequestration papers and proposals (Cunningham, Gerlach, Seymour, Codd).
- International short courses, workshops, and conference participation related to geologic carbon sequestration (Cunningham, Gerlach, Holben).
- Holben Sabbatical leave 2010.
- Bromenshenk (International Lecture Series New Zealand, Australia, Chile.
- Major DOE funding: Cunningham and Gerlach, $1,999,374, 3-year DOE project awarded. A second DOE grant, $1,020,000 was awarded in 2012. Apple and Zhou, $4,000,000 DOE proposal (with Brookhaven), Pending. Both related to DOE EPSCoR activities.

e) *Does the proposer have plans to or are the grantees effectively leveraging DOE funding and capabilities with local and regional resources? How has the State or Territory EPSCoR Committee planned to and what actions have they taken to maximize the long-term impact of the award?*

In the future this DOE EPSCoR project, in addition to continuing to work with ZERT collaborators, will actively collaborate with other projects and opportunities within the state and region. These include: submitting research proposals (for both private and federal support) in the area of Coal bed CO_2 storage and methane production. Leveraging funding with the Big Sky Carbon Sequestration Project and working with private energy companies to develop research and other collaborative opportunities .

- The Montana University System Science and Technology Committee (MUS-STAC) has outlined steps they are taking to maximize the long term impact of this award. These include: Developing a statewide Science and Technology Plan which includes "energy sciences and engineering" as one of it five major areas. Specifically this plan call for research that <u>focuses on reducing the environmental impact of burning fossil fuels.</u> Our DOE EPSCoR project clearly fits in this plan and our renewal application is being enthusiastically supported by MUS-STAC. A supporting letter states that "*…results from your research potentially could serve both Montana's desire to support its minerals industry and its need to protect its pristine environment. Economic impact of this research could be very positive for our state."*

APPENDIX 1 **BIOGRAPHICAL SKETCHES**

This appendix contains 2-page biographical sketches for the Project Principal Investigator, Project Administrator and all senior Project Personnel. The biographical sketches appear in alphabetical order.

Biographical Sketch

Martha E. Apple
Department of Biological Sciences
Montana Tech of the University of Montana
Butte, Montana 59701
406-496-4575 mapple@mtech.edu

Education and Training

University of Montana, Missoula, Montana. B. A., Botany, 1981
University of Montana, Missoula, Montana. B.A., Geography, 1981
University of Montana, Missoula, Montana. M.A., Botany, 1985
University of Rhode Island, Kingston, Rhode Island. Biology, Ph.D., 1994

Postdoctoral Training

NRC, US EPA, Western Ecology Division, Corvallis, Oregon 1995-1998
University of Nevada, Reno, 2001-2003

Research and Professional Experience

Montana Tech of the University of Montana, Butte, Montana
Associate Professor, Biological Sciences, 2006- present
Assistant Professor, Biological Sciences, 2003-2006.

Publications

Lakkaraju, V. R., Zhou X., Apple, M. E., Cunningham, A.B., Dobeck, L. M., Gullickson, K., and L. H. Spangler. 2010. Studying the vegetation response to simulated leakage of sequestrated CO_2 using vegetation indices. Ecological Informatics 5:379:389.

Apple, M. E. 2010. Aspects of Mycorrhizae in Desert Plants, Chapter 6, IN Desert Plants: Biology and Biotechnology. Edited by R. K. Ramawat, Springer, Berlin. pp.121-134. Invited.

Clark, N. M., Apple, M. E., Nowak, R. S. 2010. The effects of elevated CO_2 on root respiration rates of two Mojave Desert shrubs. Global Change Biology 16:1566-1575.

Male, E. J., Pickles, W. L., Silver, E. A., Hoffmann, G. D., Lewicki, J., Apple, M., Repasky, K., Burton, E. A. 2010. Using hyperspectral plant signatures for CO_2 leak detection during the 2008 ZERT CO_2 sequestration field experiment in Bozeman, Montana. Environmental Earth Science 60 (2):251-261.

Shayanmehr, F., Jalali, S. G., Ghanati, F., Kartoolinejad, D., Apple, M. E. 2009. Two new morphotypes of *Pinus eldarica*: Discrimination by macromorphological and anatomical traits. Dendrobiology. Vol 61:27-36.

Apple, M., C. Thee, V. Smith-Longozo, C. Cogar, C. Wells and R. Nowak. 2005. Arbuscular Mycorrhizal Colonization of *Larrea tridentata* and *Ambrosia dumosa* Roots Varies with Precipitation and Season in the Mojave Desert. Symbiosis 39:131-136.

Olszyk, D., M. Apple, B. Gartner, R. Spicer, C. Wise, E. Buckner, A. Benson-Scott and D. Tingey. 2005. Xeromorphy increases in shoots of *Pseudotsuga menziesii* (Mirb.) Franco seedlings with exposure to elevated temperature but not elevated CO_2. Trees 19:552-563.

Apple, M., K. Tiekotter, M. Snow, J. Young, D. Tingey, A. Soeldner, and B.J. Bond. 2002. Needle Anatomy Varies with Increasing Tree Age in Douglas fir. Special Issue: Age-Related Change in

Structure and Function of Trees and Forests in the Pacific Northwest. Tree Physiology 22:181-189

Apple, M. E., D. P. Ormrod, J. D. Lewis, D. M. Southworth, D. M. Olszyk, and D. T. Tingey. 2000. Morphology and stomatal function of Douglas-fir needles exposed to climate change: elevated CO_2 and temperature. International Journal of Plant Sciences 161:127-132.

Apple, M. E., Lucash, M. S., D. M. Olszyk, and D. T. Tingey. 1998. Morphogenesis of *Pseudotsuga menziesii* buds is altered at elevated temperature but not at elevated $C0_2$. Environmental and Experimental Botany 40:159-172.

Synergistic Activities

- Mountain Research Institute Workshop, Berkeley, CA. December, 2010. Presentation of research summary on GLORIA and ZERT activities. Research summary to be included in the Mountain Research Institute's Research Catalog. 2010.
- GLOCHAMORE and GLORIA Conferences, Perth, Scotland. September, 2010. Platform presentations on the Phenology of Plants at the Southwestern Montana GLORIA site.
- Establishment of a Global Research Initiative in Alpine Environments (GLORIA) site in Southwestern Montana. 2008. The Southwestern Montana GLORIA site is part of an international network of alpine research sites established as long-term monitoring facilities for alpine plants and temperatures in the context of climate change in alpine environments. Baseline data and photo-documentation for the Southwestern Montana GLORIA site submitted and published to the GLORIA database. 2009.
- IPCC 4th Synthesis Report, Invited Expert Reviewer. 2007.
- Member, American Geophysical Union. 2006-2010.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-editors:
Apple, C., Portland Community College, Bradley, A., Montana Tech of the University of Montana
Burton, E. A., Lawrence Livermore National Laboratory, Clark, N. M., University of California, Davis
Cunningham, A.B., Montana State University, Dobeck, L. M., Montana State University
Escurra, C., Universidad del Comahue, Argentina, Fernandez, N., Universidad del Comahue, Argentina
Fontenla, S., Universidad del Comahue, Argentina, Gallagher, J.H., OPeNDAP, Inc.
Ghanati, F., Tarbiat Modares University, Iran, Gullickson, K., Montana State University
Hoffmann, G.D., University of California, Santa Cruz., Jalali, S. G., Tarbiat Modares University, Iran
Jennings, G., United States Geological Survey, Kartoolinejad, D., Tarbiat Modares University, Iran
Koch, G. Northern Arizona University, Lakkaraju, V. R., Montana Tech of the University of Montana
Lewicki, J., Lawrence Berkeley National Laboratory, Male, E. J., University of California, Santa Cruz
Mitman, G. G., Montana Tech of the University of Montana, Morales, S., University of Montana
Nowak, R. S., University of Nevada, Reno , Pickles, W. L., University of California, Santa Cruz
Prince, J.B., Montana Tech of the University of Montana, Pullman, T. Y., Montana Tech of the University of Montana, Repasky, K., Montana State University, Sharma, B. Montana Tech of the University of Montana,Shayanmehr, F., Tarbiat Modares University, Iran, Sillett, S., Humboldt State University, Silver, E. A., University of California, Santa Cruz, Spangler, L. H., Montana State University
Thordsen, J., United States Geological Survey, Warden, J.E., Montana Tech of the University of Montana
Zhou X., Montana Tech of the University of Montana

Graduate and Postdoctoral Advisors and Advisees:
Nandi, S., Stratus Environmental, Inc., Cameron Park, California
Lakkaraju, V. Montana Tech of the University of Montana
Sharma, B. Montana Tech of the University of Montana

Biographical Sketch

Jerry J. Bromenshenk, Ph.D.
Office Telephone: (406) 243-5648; Cell Phone (406) 544-9007
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Education and Training

B.S. Montana State University, 1968
Ph.D., with Honors, Montana State University, 1973

Research and Professional Experience

Research Professor, Division of Biological Sciences	1974 - present
Director MT DOE/EPSCoR	1993 - Present
CEO, Bee Alert Technologies, Inc.	2003-present

Publications most closely related to proposed project

Bromenshenk J.J., Henderson C.B., Wick CH, Stanford M.F., Zulich A.W., Jabbour, R.E., Deshpande, S.V., McCubbin, P.E., Seccomb, R.A., Welch, P.W., Williams, T, Firth, D.R., Skowronski, E., Lehmann, M.M., Bilimoria, S.L., Gress, J., Wanner, K.W., Cramer, R.A., Jr. 2010. Iridovirus and Microsporidian Linked to Honey Bee Colony Decline. *PLoS ONE* 5(10): e13181. doi:10.1371/journal.pone.0013181

Bromenshenk J.J. 2007. *ABC & XYZ of Bee Culture*. 41st Edition. Shimanuki, H., Flottum, K., Harman, A., editors; Medina, OH. A.I. Root Company. 911 pp.

Bromenshenk J.J, 2007. U.S. National Bee Colony Loss Survey. *American Bee Journal* 147(5): 381-384.

Joseph Shaw, Nathan Seldomridge, Dustin Dunkle, Paul Nugent, Lee Spangler, Jerry Bromenshenk, Colin Henderson, James Churnside, and James Wilson. 2005. Polarization lidar measurements of honey bees in flight for locating land mines. *Optics Express* 13(15): 5853-5863.

Bromenshenk *et al.* 2003. Can Honey Bees Assist in Area Reduction and Landmine Detection? *Journal Mine Action* 7.3 (December).

Bromenshenk, J.J., C.B. Henderson, and G.C. Smith. 2003. Biological Systems (Paper II), Appendix S. In: *Alternatives for Landmine Detection*, J. MacDonald *et. al.., eds.* RAND Science and Technology Institute for Office of Science and Technology Policy, Arlington, VA.

Smith, G.C., Bromenshenk, J.J., Jones, D.C., and G.H. Alnasser. 2002. Volatile and Semi-Volatile Organic Compounds in Beehive Atmospheres. In: *Honey Bees: Estimating the Environmental Impact of Chemicals*, J. DeVillers and M-H. Pham-Delegue, eds. Taylor and Francis, London, Chapter 2:12-41.

Barisic, D., Bromenshenk, J.J., N. Kezic, and A. Vertacnik. 2002. The Role of Honey Bees in Environmental Monitoring in Croatia. In: *Honey Bees: Estimating the Environmental Impact of Chemicals*, J. DeVillers and M-H. Pham-Delegue, eds. Taylor and Francis, London, Chapter10:160-185.

Bromenshenk, J.J., G.C. Smith, B.E. King, R.A. Seccomb, D.C. Jones, Michelle A. Taylor, C.B. Henderson, and C.L. Wrobel. 2002. New and Improved Methods for Monitoring Air Quality and the Terrestrial Environment: Applications at Aberdeen Proving Ground-Edgewood Area. Peer-reviewed Annual Report, U.S. Army Center for Environmental Health Research, Ref. Number DAMD17-95-C5072. 115 pp.

Patents/Copyrights

Patents: Smart Hives for Distance Management of Bees, Honey Bee Conditioning Methods for

Explosives Detection. Pending: Hand-held acoustic scanner for honey bee pest and disease detection.

Synergistic Activities In addition to Directing the Montana DOE EPSCoR program, Dr. Bromenshenk:

- Directs a team of 15 scientists and 16 students from The University of Montana, Montana State University, and S&K Electronics (a Native American owned manufacturing company) working on bees and lasers for detection of landmines, dead bodies and meth labs under DoD funding.

- Coordinates a team of 17 senior scientists and students working on colony collapse disorder (CCD) from The U of M, MSU, Texas Tech University, Instituto de Ecologia AC, Xalapa, Veracruz, Mexico, the US Army Edgewood Chemical and Biological Command, Maryland.

- Serves as a member of the National Colony Collapse Working Group that is addressing CCD, a disorder that has resulted in sudden and severe losses of many of the nation's honey bees.

- Serves on the Board of an NSF TCUP award to Chief Dull Knife College in eastern Montana, to improve college instruction in mathematics and science at Native American Tribal Colleges.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers
Collaborators and Co-Editors

Shan L. Bilimoria, *Department of Biological Sciences, Texas Tech University, Lubbock, Texas*
John L. Carlsten, *Department of Physics, Montana State University, Bozeman, Montana*
Robert A. Cramer Jr., *Department of Veterinary Molecular Biology, Montana State University*
Scott Debnam, *Division of Biological Sciences, the University of Montana, Missoula, Montana*
Kim Flottum, *Editor, Bee Culture, Medina, Ohio,*
Joanna Gress, *Department of Plant Sciences and Plant Pathology, Montana State University*
Margaret M. Lehmann, *Department of Veterinary Molecular Biology, Montana State University*
Kevin Repasky, *Department of Physics, Montana State University, Bozeman, Montana*
Robert A. Seccomb, *Division of Biological Sciences, The University of Montana, Missoula, Montana, and Bee Alert Technology, Inc., Missoula, Montana*
Joseph A. Shaw, *Optical Technology Center, Montana State University, Bozeman, Montana*
Evan Skowronski, *US Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, Edgewood Area, Maryland*
Lee H. Spangler, *Associate Vice-President for Research, Montana State University, Bozeman, Montana*
Michael F. Stanford, *US Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, Edgewood Area*
Phillip M. Welch, *Division of Biological Sciences, The University of Montana, Missoula, Montana, Bee Alert Technology, Inc., Missoula, Montana*
Kevin W. Wanner, *Department of Plant Sciences and Plant Pathology, Montana State University*
Charles H. Wick, *US Army Edgewood Chemical Biological Center,Edgewood Area, Maryland*
David Westervelt, *Florida Dpartment of Agriculture and Consumer Services, Gainesville, Florida*
Trevor Williams, *Instituto de Ecologia AC, Xalapa, Veracruz, Mexico,*
Alan W. Zulich, *US Army Edgewood Chemical Biological Center, Edgewood Area, Maryland*

Graduate and Postdoctoral Advisors and Advisees:
Dr. Bromenshenk's research focuses on advising and providing practical, hands on research experience to undergraduate students, many of whom represent minority groups, including women and Native Americans. Graduate and Postdoctoral Students for DOE EPSCoR are listed with their primary advisors.

Biographical Sketch

Sarah L. Codd
Associate Professor, Department of Mechanical and Industrial Engineering
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Education and Training.

Alexander von Humboldt Post-Doc Research Fellowship, Universität Ulm, Germany			2000-2001.
FoRST Post-Doc Fellowship, Massey University, New Zealand			1996-1999
Ph D.	Physics	University of Kent at Canterbury, UK	1996
B.Sc (Hons)	Physics	Massey University, New Zealand	1993

Research and Professional Experience:

Associate Professor of Mechanical Engineering	2009-current
Assistant Professor of Mechanical Engineering	2005-2009
Research Asst. Prof. Chemical Engineering Dept., MSU.	2002-2005
Research Fellow, New Mexico Resonance, Albuquerque, NM	2001-2002
Research Fellow, Universität Ulm, Germany	2000
Research Fellow, Massey University, New Zealand	1996-1999
Asst. Lecturer, Physics, Massey University, New Zealand	1993

Publications

P.T. Callaghan and S.L. Codd. (2001) "Flow coherence in a bead pack observed using Frequency Domain Modulated Gradient NMR." *Phys. Fluids* 13: 421-427.

J.D. Seymour, J.P. Gage, Sarah L. Codd and R. Gerlach,(2004) "Anomalous fluid transport in porous media induced by biofilm growth." *Physical Review Letters*, 93: 198103.

J.D. Seymour, J.P. Gage, S.L. Codd, R. Gerlach. (2007)"Magnetic Resonance Microscopy of Biofouling Induced Scale Dependent Transport in Porous Media" *Advances in Water Resources*, 30(6-7):1408-1420.

J.R. Brown, J.D. Seymour, S.L. Codd, E.O. Fridjonsson, G.R. Cokelet, and M.Nyden, (2007). "Dynamics of the Solid and Liquid Phases in Dilute Sheared Brownian Suspensions: Irreversibility and Particle Migration" *Phys. Rev. Lett.* 99, 240602

J.A. Hornemann, A. A. Lysova, S. L. Codd, J. D. Seymour, J. R. Brown, P. S. Stewart , S.C. Busse,(2008) "Biopolymer and water dynamics in microbial biofilm extracellular polymeric substance" *Biomacromolecules* 9, 2223-2228.

J.A. Hornemann, Codd, S.L., Seymour, J.D., Romanenko, K.V.(2009) Magnetic Resonance Microscopy application to Biofouling in Porous Media. *Diffusion Fundamentals* 10 1.1 - 1.3.

J.R. Brown, E.O. Fridjonsson, J.D. Seymour and S.L. Codd, (2009)"NMR measurement of shear-induced particle migration in Brownian suspensions", Physics of Fluids 21(9) 093301.

T.R. Brosten, S.L. Codd, R.S. Maier, and J.D. Seymour,(2009) "Dynamic length scale characterization and nonequilibrium statistical mechanics of transport in open cell foams". Physical Review Letters 103, 218001.

T.R. Brosten, E.O. Fridjonsson, S.L. Codd, and J.D. Seymour,(2010) "Transport of colloidal particles in a porous open cell foam." DOI: 10.1016/j.jcis.2010.04.050 Journal of Colloid and Interface Science.

E.O. Fridjonsson, J.D. Seymour, L.N. Schultz, R. Gerlach, A.B. Cunningham and S.L. Codd, (2010)"NMR measurement of hydrodynamic dispersion in porous media subject to biofilm mediated precipitation reactions", (accepted) Journal of Contaminant Hydrology.

Synergistic Activities

Reviewer for Journal of Physical Chemistry, Journal of magnetic Resonance, Biotechnology and Bioengineering, Concepts in Magnetic Resonance and Journal of Materials Science.

Annually present an MRI lab activity for the Native American MAP outreach program (see http://hughes.montana.edu/) and the engineering freshmen program at MSU and a Granular Materials lab activity for the high school girls EYH outreach program (Expanding Your Horizons) and engineering freshmen program at MSU

Mentor for MSU Society of Women Engineers student chapter and active faculty participant in the Engineering Minority centre (Empower) and faculty mentor for all female Mechanical Engineering students to improve retention.

Involve undergraduate students from the Montana INBRE Program (IDeA Networks of Biomedical Research Excellence) in research experiences for undergraduates.

Executive Committee of Division of Spatially Resolved Magnetic Resonance of the AMPERE Society and conference chair of 10th International Congress on Magnetic Resonance Microscopy in 2009.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators (Co-Authors and Co-PIs from last five years)

Steve Altobelli (New Mexico Resonance, NM), Diana Bernin (Chalmers, Sweden), Giles Cokelet (Chem. E., Montana State University), Mike Franklin (Microbiology, Montana State University), Gill G. Geesey (Microbiology, Montana State University), Robin Gerlach (Chem.E., Montana State University),Russ Hertzog (INEEL), D.G. Koehler-King (Bend Research, OR),S Konagurthu (Bend Research, OR), Igor Koptyug (Novosibirsk, Russia), K.A. Lightley (Bend Research, OR), Anna Lysova (Novosibirsk, Russia), James Maneval (Bucknell University, PA), Bob Meier(U.S. Army Engineer Research and Development Center, Vicksburg, MS), Magnus Nyden (Chalmers, Sweden), Joseph Seymour(Chem.E., Montana State University), Tim Scheibe (Pacific Northwest National Laboratory), Hugo Schmidt (Physics, Montana State University), Stephen Sofie (Mech. E., Montana State University),Phil Stewart (CBE, Montana State University), A.M. Tartakovsky (PNNL), Brian Wood (Oregon State University), Peter Suci (Montana State University).

Graduate and Postdoctoral Advisors and Advisees

Completed: Tyler Brosten(U.S. Army Engineer Research and Development Center, Vicksburg, MS), Jennifer Brown (Montana State University, MT), Einar Fridjonsson (Cambridge University, UK), Erica Gjersing (UC Davis), Jennifer Hornemann (Exxon, TX), Dan Howe (PNNL), Konstantin Romanenko (University of New Brunswick, Canada),

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Education and Training

University of Nevada, Reno NV,	B.S. Civil Engineering	1970
Montana State University, Bozeman MT,	M.S. Civil Engineering	1971
University of Nevada, Reno NV	Ph. D. Hydrology	1977

Research and Professional Experience

Montana State University

Research Development Coordinator, Center for Biofilm Engineering	1992-present
Professor of Civil Engineering	1987-present
Associate Professor, Civil Engineering	1982-1987
Assistant Professor, Civil Engineering	1977-1982

University of Nevada, Reno

Research Associate, Water Resources Center, Desert Research Institute	1972-1977

Publications

Gerlach, R.; Cunningham, A.B. (2010): Influence of Biofilms on Porous Media Hydrodynamics. Vafai, K. (ed.), Porous Media: Applications in Biological Systems and Biotechnology. Taylor Francis. pp. 173-230.

Cunningham ,A.B., R. Gerlach, L. Spangler, A.C. Mitchell, S. Parks, and A. Phillips (In Review). Reducing the risk of well bore leakage of CO_2 using engineered biomineralization barriers. Submitted September 2010 to Energy Procedia.

Fridjonsson, E.O.; Seymour, J.D.; Schultz, L.N.; Gerlach, R; Cunningham, A.B.; Codd, S.L. (2010): NMR Measurement of Hydrodynamic Dispersion in Porous Media Subject to Biofilm Mediated Precipitation Reactions. Journal of Contaminant Hydrology. Accepted. doi:10.1016/j.jconhyd.2010.07.009

Gerlach, R.; Cunningham, A.B. (2010): Influence of Microbial Biofilms on Reactive Transport in Porous Media. Proceedings of the Third International Conference on Porous Media and its Applications in Science, Engineering and Industry. Montecatini, Italy. June 20-25, 2010.

Mitchell A.C., K. Dideriksen, L.H. Spangler, A. B. Cunningham, R. Gerlach (2010). Microbially enhanced carbon capture and storage by mineral-trapping and solubility-trapping. Environ. Sci. Technol., 44(13):5270-5276. doi: 10.1021/es903270w

Ebigbo, A., R. Helmig, A.B. Cunningham, H. Class, and R. Gerlach (2010). Modelling biofilm growth in the presence of carbon dioxide and water flow in the subsurface. *Advances in Water Resources*, Volume 33, Issue 7, 762-781, doi: 10.1016/j.advwatres.2010.04.004

Mitchell, A.C., A. Phillips, R. Hiebert, R. Gerlach, and A.B. Cunningham. (2009). Biofilm enhanced subsurface sequestration of supercritical CO_2, *International Journal Greenhouse Gas Control*, Vol (3), No1, 90-99. doi:10.1016/j.ijggc.2008.05.002

Cunningham, A.B., R. Gerlach, L. Spangler, L. Schultz and A.C. Mitchell. (2008). Microbially Enhanced Geologic Containment of Sequestered Supercritical CO_2. Proceedings, 9th International

Conference on Greenhouse Gas Technologies, November, 2008. Available through Energy Procedia at http://www.sciencedirect.com/science/journal/18766102.
Mitchell , A.C, A. Phillips, M. Hamilton, R. Gerlach, J.Kuszuba, and A.B. Cunningham. (2008) Resilience of planktonic and biofilm communities to supercritical CO_2. *Journal of Supercritical Fluids*. Vol 47, Issue 2, 318-325.
Mitchell, AC, A. Phillips, J. Kaszuba, H.K. Hollis, R. Gerlach, A.B. Cunningham, **(**2008)Microbially enhanced carbonate mineralization and containment of CO_2.*Geochimica et Cosmochimica Acta.* 72 (12), A636.

Patents/Copyrights

Co-Editor for "Biofilms—The Hypertextbook": A web-based teaching and learning resource.

Synergistic Activities

- Co-Editor for "Biofilms--The Hypertextbook". A web-based teaching and learning resource.
- Co-organizer, short course on Multiphase Flow, Transport and Bioremediation, University of Stuttgart, Germany Taught annually 2000 – present.
- Member, Editorial Review Board of Biodegradation 2006-2008
- Member, Idaho National Laboratory (INL) Subsurface Science Advisory Board, 2000 – 2004.
- Associate Director, Inland Northwest Research Alliance (INRA) 2000-2002.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-Editors
Montana State University: Dr. Lee Spangler, Dr. Robin Gerlach, Dr. Anne Camper, Dr. Brent Peyton, Dr. Sarah Codd, Dr Joe Seymour, Dr. Phil Stewart, Dr. Rocky Ross (Co-editor)
University of Montana: Dr. Bill Holben, Dr Sergio Morales, Dr. Martha Apple, Dr. Xiaobing Zhou, Mary North-Abbott
University of Alabama Birmingham: Dr. Peter Walsh
Manhattan College: Dr. Robert Sharp
Penn State Altoona: Dr. John Lennox (Co-Editor)
*University of Stuttgart, Germany***:** Dr. Rainer Helmig, Dr. Anozie Ebigbo
Aberystwyth University, Whales: Dr. Andrew Mitchell

Graduate and Post Doctoral Advisors (None) and Advisees.
PhD Students (last 5 years)

University of Stuttgart: Anozie Ebigbo, Andreas Bielinski, Yvonne Reinhardt

Montana State University: Paul Sturman, Darla Goeres,

Masters students
Montana State University: Elliott Barnhart, Logan Schultz, Stacy parks, Laura Wheeler

Biographical sketch
Robin Gerlach

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Education and Training

Ph.D. Environmental Engineering, Center for Biofilm Engineering, Montana State University - Bozeman, 2001
M.S. Environmental Science and Engineering (Diplomingenieur Technischer Umweltschutz), Technical University Berlin, 1996
Summer Course in Microbial Diversity, Marine Biological Laboratory, Woods Hole, MA, 2001
Summer School in Synchrotron Radiation Center of Advanced Microstructure and Devices, Louisiana State University Marine Biological Laboratory, Baton Rouge, LA, 2002
Certificate in Radiochemistry ("Fachkunde im Strahlenschutz" Fachkundegruppen 2.3, 4.2 und 4.3); radiation safety training, permission to work with open and encapsulated radionuclides without activity limit in Germany

Research and Professional Experience
Associate Professor, Chemical and Biological Engineering, Center for Biofilm Engineering, Thermal Biology Institute, Montana State University, Bozeman, MT, August 2006–present
Assistant Research Professor, Center for Biofilm Engineering, Montana State University, Bozeman, MT, April 2003– August 2006
Postdoctoral Researcher/Research Engineer, Center for Biofilm Engineering, Montana State University, Bozeman, MT, May 2001–April 2003
Research and Teaching Assistant, Center for Biofilm Engineering, Montana State University, Bozeman, MT, 1996-2001, Dept. of Environmental Science and Engineering, Rice University, Houston, TX, 1994-1995, Dept. of Environmental Microbiology and Technical Hygiene, Technical University of Berlin, 1992-1996

Publications
1. SCHULTZ, L.; PITTS, B.; MITCHELL, A.C.; CUNNINGHAM, A.B.; GERLACH, R. Imaging Biologically-Induced Mineralization in Fully Hydrated Flow Systems. *Microscopy Today*. Accepted. To appear March 2011 with cover image feature.
2. GERLACH, R.; CUNNINGHAM, A.B. (2010): Influence of Biofilms on Porous Media Hydrodynamics. Vafai, K. (ed.), Porous Media: Applications in Biological Systems and Biotechnology. Taylor Francis. pp. 173-230.
3. EBIGBO A.; HELMIG, R.; CUNNINGHAM, A.B.; CLASS, H.; GERLACH, R. (2010) Modelling biofilm growth in the presence of carbon dioxide and water flow in the subsurface. Advances in *Water Resources*. 33:762–781. doi: 10.1016/j.advwatres.2010.04.004
4. FRIDJONSSON, E.O.; SEYMOUR, J.D.; SCHULTZ, L.N.; GERLACH, R; CUNNINGHAM, A.B.; CODD, S.L. (2010): NMR Measurement of Hydrodynamic Dispersion in Porous Media Subject to Biofilm Mediated Precipitation Reactions. Journal of Contaminant Hydrology. Accepted. doi:10.1016/j.jconhyd.2010.07.009
5. MITCHELL, A.C.; DIDERIKSEN, K.; SPANGLER, L.H.; CUNNINGHAM, A.B.; GERLACH, R. (2010): Microbially enhanced carbon capture and storage by mineral-trapping and solubility-trapping. *Environmental Science and Technology*. 44(13):5270-5276. doi: 10.1021/es903270w
6. MITCHELL, A.C.; PHILLIPS, A.J.; HIEBERT, R.; GERLACH, R.; SPANGLER, L.; CUNNINGHAM, A.B. (2009): Biofilm enhanced geologic sequestration of supercritical CO_2. The *International Journal on Greenhouse Gas Control*. 3:90-99. doi:10.1016/j.ijggc.2008.05.002

7. CUNNINGHAM, A.B.; GERLACH, R.; SPANGLER, L.; MITCHELL, A.C. (2009): Microbially enhanced geologic containment of sequestered supercritical CO_2. *Energy Procedia*. 1(1):3245-3252. doi: 10.1016/j.egypro.2009.02.109
8. MITCHELL, A.C.; PHILLIPS, A.J.; HAMILTON, M.A.; GERLACH, R.; HOLLIS, K.; KASZUBA, J.P.; CUNNINGHAM, A.B. (2008): Resilience of planktonic and biofilm cultures to supercritical CO_2. *The Journal of Supercritical Fluids.* 47(2):318-325. doi:10.1016/j.supflu.2008.07.005
9. CUNNINGHAM, A.B.; SHARP, R.S.; CACCAVO JR, F.; GERLACH, R. (2007): Effects of Starvation on Bacterial Transport Through Porous Media. *Advances in Water Resources*. 30(6-7):1583-1592.
10. SEYMOUR, J.D.; GAGE, J.P.; CODD, S.L.; GERLACH, R. (2004): Anomalous Fluid Transport in Porous Media Induced by Biofilm Growth. *Physical Review Letters*. 93(19):8101-8104.

Synergistic Activities

- Session Chair "Biotransport in Porous Media". Third International Conference on Porous Media and its Applications in Science, Engineering and Industry. Montecatini, Italy. June 20-25, 2010

- Invited presentations: i) Third International Conference on Porous Media and its Applications in Science, Engineering and Industry. Montecatini, Italy. June 20-25, 2010; ii) PNNL CCS Workshop. Richland, WA. June 04, 2010; iii) EGU General Assembly 2010. Vienna, Austria, 02–07 May 2010; iv) Pittcon 2008. New Orleans, LA. March 03, 2008.

- Reviewer Environmental Science and Technology, Biotechnology Bioengineering, Environmental Engineering Science, Biodegradation, Journal of Hazardous Materials, Journal of Microscopy, Book "Porous Media: Applications in Biological Systems and Biotechnology", Biofouling

- Reviewer Stanford Synchrotron Radiation Lightsource (SSRL). User Proposals. (2009)

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-editors

Amonette, J.E. – Pacific Northwest National Laboratory; Apel W.A. - Idaho National Laboratory; Apple, M. – University of Montana; Ballor, N.R. - California Institute of Technology; Biederman, J.A. - Suffield Academy, CT; Borch T. - Colorado State University; Butterfield, P.W. - Washington State University; Camper, A.K. – Montana State University; Characklis, G. – U of North Carolina; Class, H. – University of Stuttgart; Codd S.L. - Montana State University; Colwell, R. – Oregon State University; Cunningham A.B. - Montana State University; Dohnalkova, A. - Pacific Northwest National Laboratory; Dideriksen, K. – University of Copenhagen; D'Imperio, S – Novozymes; Ebigbo, A. – University of Stuttgart; Fields, M. – Montana State University; Fridjonsson, E.O. – Montana State University; Gage, J. – unknown; Gibbons, H. – Department of Defense; Hamilton, M. – Montana State University; Harwood, J. – Chemical Industry, OK; Heath, L. – University of Montana; Helmig, R. – University of Stuttgart; Hiebert, R. – MSE Technologies Applications; Holben, W. – University of Montana; Hollis, K. - Los Alamos National Laboratory; Inskeep W.P. - Montana State University; James G. - Montana State University; Kaszuba, J. - Los Alamos National Laboratory; Klapper, I. – Montana State University; Lee B. - Idaho National Laboratory; Lozhkin, A.P. - Kaszan State University; Mitchell, A. - Montana State University; Magnuson, T. – Idaho State University; Matheson L. - Center for Innovation, Butte (MT); Miller, A.R – Idaho National Laboratory; Miller, S. – University of Montana; Menicucci, J. – CTW Energy, Bozeman, MT; Naumenko, E. - Kaszan State University; Naumov, A. - Montana State University; Naumova, R. - Kaszan State University; North-Abbot, M. – University of Montana; Petersen J. - Washington State University; Peyton B. - Montana State University; Phillips, A. – Montana State U; Redden, G. – Idaho National Laboratory; Reichard, D. – University of Montana; R. Ruan – U of Minnesota; Sani, R. - South

Dakota School of Mines and Technology; Schultz, L.N. – University of Copenhagen; Sears, J. – Consultant, Bozeman, MT; Seymour J. - Montana State University; Silkin, N.I. - Kaszan State University; Sivaswamy, V. - Geomatrix, Inc.; Spangler, L. - Montana State University; Stoodley, P. - Allegheny-Singer Research Institute; Suvorova, E.S. - Kaszan State University; Viamajala S. - Utah State University; Wildenschild, D. – Oregon State University; Wood, B. – Oregon State University; Zhang, T. – Montana State University; Zhou, X. – University of Montana; Ziganshin, A. - Kaszan State University;

Graduate and Postdoctoral Advisors and Advisees
M.S. Advisors: Dr. Martin Steiof, Berlin Technological University; Dr. Wolfgang Dott RWTH Aachen; Dr. Joseph Hughes, Georgia Tech
Ph.D. and Postdoc Advisor: Dr. Al Cunningham, Montana State University

Thesis Advisor and Postgraduate-Scholar Sponsor
Current Graduated Students: Erin Field (Ph.D. student), Steve Bugni (M.S.); James Connolly (Ph.D.)
Graduated: Logan Schultz (M.S. 2010); Andy Pannier (M.S. 2009); Stacy Biebel (M.S. 2008); Laura Wheeler (M.S. 2008)
Postgraduates advised: Post Graduate Advisor for Adrienne Phillips (current), Howard Christiansen (unknown), Stacy Parks (Biebel) (Bent Research), Andrew Mitchell (U of Aberystwyth)

Biographical Sketch

WILLIAM E. HOLBEN

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Education and Training

State University of New York at Fredonia, Fredonia, NY.	B.S. Biology,	1978
State University of New York at Buffalo, Buffalo, NY.	M.A. Cell & Molec Bio	1983
State University of New York at Buffalo, NY.	Ph.D. Cell & Molec Bio	1985
Michigan State University, E. Lansing, MI, Post-Doc, Molecular Tools for Microbial Ecology		1985-88

Research and Professional Experience

5/01-present Professor, Division of Biological Sciences, The University of Montana, Missoula, MT.
8/95-5/01 Associate Prof., Division of Biological Sciences, The University of Montana, Missoula, MT.
8/93-8/95 Research Scientist, Dept. of Environ. Microbiology, The Agouron Institute, La Jolla, CA.
12/88-8/93 Research Assistant Prof. and co-Group Leader of CME-JRDC Joint Research Project on Molecular Evolution of Catabolic Pathways. Ctr. for Microb. Ecol., Michigan State Univ.

Ten Relevant Publications (last 5 years only)

Ball, P.N., M.D. MacKenzie, T.H. DeLuca, and W.E. Holben. 2010. Wildfire and charcoal cnhance nitrification and ammonium-oxidizing bacterial abundance in dry montane forest soils. J. Environ. Qual. 39:1243-1253 doi:10.2134/jeq2009.0082.

Morales, S.E., T. Cosart, and W. Holben. 2010. Bacterial gene abundances as indicators of greenhouse gas emission in soils. ISME J. 4, 799–808; doi:10.1038/ismej.2010.8.

Lowell, J.L., N. Gordon, D. Engstrom, J.A. Stanford, W.E. Holben and J.E. Gannon. 2009. Habitat heterogeneity and associated microbial community structure in a small-scale floodplain hyporheic flow path. Microb. Ecol. 58:611–620.

Feris, K.P., P.W. Ramsey, S.M. Gibbons, M.C. Rillig, J.N. Moore, J.E. Gannon, and W.E. Holben. 2009. Hyporheic microbial community development is a sensitive indicator of metal contamination. Environ. Sci. Technol. DOI: 10.1021/es9005465.

Morales, S.E., T.F. Cosart, J.V. Johnson and W.E. Holben. 2009. Extensive phylogenetic analysis of a soil bacterial community illustrates extreme taxon evenness and the effects of amplicon length, degree of coverage, and DNA fractionation on classification and ecological parameters. Appl. Environ. Microbiol. 75: 668-675.

Ramamoorthy S., J.S. Piotrowski, H.W. Langner, W.E. Holben, M.J. Morra, and R.F. Rosenzweig. 2009. Ecology of sulfate-reducing bacteria in an iron-dominated, mining-impacted freshwater sediment. J. Environ. Qual. 38:675-84.

Bælum, J. M.H. Nicolaisen, W.E. Holben, B.W. Strobel, J. Sørensen and C.S. Jacobsen. 2008. Direct analysis of *tfdA* gene expression by indigenous bacteria in phenoxy acid amended agricultural soil. ISME J. 2:677-687.

Mummey, D., W. Holben, J. Six, and P. Stahl. 2006. Spatial stratification of soil bacterial populations in aggregates of diverse soils. Microb. Ecol. 51:404-411.

DeLuca, T.H., M. D. MacKenzie, M. J. Gundale, and W. E. Holben. 2006. Wildfire-produced charcoal directly influences nitrogen cycling in Ponderosa Pine forests. Soil Sci. Soc. Am. J. 70:448–453.

Kovacik, W.P. Jr., K. Takai, M.R. Mormile, J.P. McKinley, F.J. Brockman, J.K. Fredrickson and W.E. Holben. 2006. Molecular analysis of deep subsurface cretaceous rock indicates abundant Fe(III)- and So-reducing bacteria in a sulfate-rich environment. Environ. Microbiol. 1:141-155.

.

Synergistic Activities Relevant to this Proposal

- Local Organizing Committee Member, 13th Int'l Symposium on Microbial Ecology; Aug. 2010, Seattle, WA.
- Instructor in international collaborative workshops for multi-national research training and collaboration: Egypt 1995, Egypt 2001, Spain 2003, Denmark 2010.
- Director, Office of Research and Educational Opportunities for Students at the University of Montana.
- Director, Montana—Ecology of Infectious Diseases (M—EID) Program; a National Science Foundation-Integrative Graduate Education and Research Traineeship Program.
- Director, Montana Integrative Learning Experience for Students (MILES) Program; A Howard Hughes Medical Institute Undergraduate Science Education Program.
- Multi-national research collaborations with the Geological Survey of Denmark and Greenland; Chuo University, Japan; and a commercial microbial research company, Alimetrics, in Helsinki, Finland.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-Editors

Aaron Adams (U of Wisconsin), Sandra Adams (U of Wisconsin), Martha Apple (U of Montana), Jacob Baelum (Denmark), Ragan Callaway (U of Montana), Frans DeBruijn (France), Sale Engstrom (U of Montana), James Gannon (U of Montana), Robin Gerlach (Montana State Univ.), Nathan Gordon (U of Montana), Carsten Jacobsen (Denmark), Thomas DeLuca (Wales), Anu Kettunen (Finland), Hannu Kettunen (Finland), Brita Maki (Finland), Derek MacKenzie (U of Alberta), Johnnie Moore (U of Montana), Markku Mutanen (Finland), Mary North-Abbott (U of Montana), Pekka Nurminen (Finland), Philip Ramsey (U of Montana), Matthias Rillig (Germany), Lee Spangler (Montana State Univ.), Jack Stanford (U of Montana), Giles Thelen (U of Montana),Yuichi Suwa (Japan), William Woessner (U of Montana), Xiaobing Zhou (U of Montana).

Graduate and Postdoctoral Advisors

Graduate Advisor: Edward A. Morgan
Postdoctoral Advisors: James M. Tiedje and Barry K. Chelm (deceased)

Thesis Advisor (All Persons) and Postdoctoral Scholars Sponsored (Past 5 Years)

Graduate students:

William Kovacik, Ph.D. 2002; Bacterial transport through oxic and anoxic aquifers,
Kevin Feris, Ph.D. 2003; Heavy metal effects on microbial community structure and function
Sandra Adams, M.S. 2006; Microbes, Stoneflies, and Fish: Trophic Interactions in Aquatic Ecosystems
Jarrod Pollock, Ph.D. 2010
Margie Kinnersley, Ph.D. 2010
Ellen Lark, (current Ph.D. student)
Marnie Rout, co-mentor with plant ecologist (current Ph.D. student)
Theodore Cosart, co-mentor with computer scientist (current Ph.D. student)

Postdoctoral Scholars Sponsored:

Timothy C. Gsell; present position at Governors State University, Illinois
Patrick N. Ball; present position at University of Oregon, Bend Campus
Daniel L. Mummey: Postdoctoral Scholar (Research Assistant Professor)
Jennifer L. Lowell; current Postdoctoral Fellow
Sergio E. Morales; Postdoctoral Scholar (Research Assistant Professor); PI of current proposal

Biographical Sketch

Sergio E. Morales Vicente, Ph.D.
Microbial Ecology Program, Division of Biological Sciences, The University of Montana Missoula, Montana 59812-1002 Phone: (406) 214-4131, FAX: (406) 243-4184, E-mail: sergio.morales@mso.umt.edu

Education and Training

Ph.D. Microbiology and Molecular Genetics, University of Vermont. 2006
B.S. Magna Cum Laude, Biology, University of Puerto Rico-Mayagüez. 2001
Exchange Student, Biology, State University of New York at Plattsburgh. 2000

Research and Professional Experience

2009-2010, Curriculum Coordinator, Office of Research and Educational Opportunities for Students, University of Montana, Missoula, MT
2009-present, Adjunct Faculty, Chief Dull Knife College, Lame Deer, MT
2008-present, Lecturer Chief Dull Knife College, Lame Deer, MT
2008-present, Adjunct Faculty, College of Agricultural Sciences, University of Puerto Rico, Mayagüez, PR
2007-present, Research Assistant Professor, Division of Biological Sciences, The University of Montana, Missoula, MT
2006-2007, Postdoctoral Research Associate, Division of Biological Sciences, The University of Montana, Missoula, MT
2001-2006, Research Assistant, Department of Microbiology and Molecular Genetics, University of Vermont, Burlington, Vermont
2002-2003, 2005 Teaching Assistant, Department of Microbiology and Molecular Genetics, University of Vermont, Burlington, Vermont

Publications

Morales SE and WE Holben. 2011. Linking bacterial identities and ecosystem processes: Can 'omic' analyses be more than the sum of their parts?. FEMS Microbiol. Ecol. Jan;75(1):2-16

Mouser PJ, Rizzo D.M, O'Grady P, Morales SE, Stevens L, Druschel G and N Hayden. 2010. The Use of Microbial Community Profiles for Improving Detection of Groundwater Contamination from Leaking Waste Disposal Sites. Water Resources Res. 46, W12506, doi:10.1029/2010WR009459, 2010

Gibbons SM, Feris K, Ramsey PW, McGuirl MA, Morales SE, Hynninen A, and JE Gannon.(2010). Microcalorimetry demonstrates the costs and benefits of *Pseudomonas putida* strain KT2440 metal tolerance genes. Appl. Env. Microbiol. doi:10.1128/AEM.01187-1

Morales SE, Cosart T, and WE Holben. 2010. Bacterial populations as indicators of greenhouse gas emission in soils. ISME J. 4: 799-808.

Morales SE and WE Holben. 2009. Empirical testing of 16S PCR primer pairs reveals variance in target specificity and efficacy not suggested by *in silico* analysis. Appl. Env. Microbiol. 75(9): 2677-2683.

Morales SE, Cosart T, Johnson J and WE Holben. 2009. Extensive phylogenetic analysis of a soil bacterial community illustrates extreme taxon evenness and the effects of amplicon length, degree of coverage, and DNA fractionation on classification and ecological parameters. Appl. Env. Microbiol. 75(3):668-675.

Morales SE, Cosart T, Johnson J and WE Holben. 2008.Supplemental programs for enhanced recovery of data from the DOTUR application. J. Microb. Methods. 75(3):572-575.

Gotelli NJ, Mouser PJ, Hudman SP, Morales SE, Ross D, and AM Ellison. 2008.Geographic variation in nutrient availability, stoichiometry, and metal concentrations of plants and pore-water in ombrotrophic bogs in New England, USA. Wetlands. 28(3):827.

Morales SE and TA Lewis.2006.Transcriptional regulation of the *pdt* gene cluster of *Pseudomonas stutzeri* KC involves an AraC/XylS family transcriptional activator (PdtC) and the cognate siderophore pyridine-2,6-bis(thiocarboxylic acid). Appl. Env. Microbiol. 72: 6994-7002

Morales SE, Mouser PJ, Ward N, Hudman SP, Ross DS, Gotelli NJ and TA Lewis.2006. Comparison of bacterial composition and diversity in New England *Sphagnum* bogs using terminal restriction fragment length polymorphism (T-RFLP). Microb. Ecol. 52:34-44.

Synergistic Activities

Grant Reviewer for NSF:

Division of Environmental Biology-Ecosystems Science
Division of Antarctic Science- Antarctic Organisms and Ecosystems
Division of Biological Infrastructure- Undergraduate Research and Mentoring in the Biological Sciences

Reviewer for the following peer-reviewed journals:

Applied and Environmental Microbiology Journal
ISME (International Society for Microbial Ecology) Journal
Microbial Ecology Journal
Antonie van Leeuwenhoek International Journal
Pedosphere Journal
Molecular Phylogenetics and Evolution Journal

Mentor for:

Students at Chief Dull Knife College
The University of Montana (UM) Introductory Multicultural Summer Undergraduate Research Experience (IM-SURE) Program at UM
The University of Montana Research Experiences for Undergraduates (REU) Program
The Montana Integrative Learning Experience for Students (MILES) Program

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-editors (last 48months):

William E. Holben (University of Montana), James E. Gannon (University of Montana), Theodore Cosart (University of Montana), Jesse V. Johnson (University of Montana), Jon M. Graham (University of Montana), Philip J. Ramsey (University of Montana), Tyron Venn (University of Montana), Eric Linder (University of Texas-Brownsville), Paula Mouser (University of Ohio), Donna M. Rizzo (University of Vermont), Patrick O'Grady, (UC Berkeley), Gregory K. Druschel (University of Vermont),Nancy Hayden (University of Vermont), Lori Stevens (University of Vermont), Sean M Gobbons (University of Montana), Kevin Feris (Boise State University), Michelle A. McGuirl (University of Montana), Anu Hynninen (University of Helsinki), Stephen P. Hudman (Truman State University), Aaron M Ellison (Harvard), Jacob Baelum (Geological Survey of Denmark and Greenland), Bo Elberling (University of Copenhagen), Carsten S. Jacobsen (Geological Survey of Denmark and Greenland), Peter Kuhry (Stockholm University), Gustaf Hugelius (Stockholm University)

Graduate and Postdoctoral Advisors:

William E. Holben (University of Montana), Donald S. Ross (University of Vermont), Nicholas J. Gotelli (University of Vermont), Thomas A. Lewis (Montana State University), Keith P. Mintz (University of Vermont) and Douglas I. Johnson (University of Vermont).

Biographical Sketch

Mary A. North-Abbott
Petroleum Engineering Department, Montana Tech of the University of Montana
1300 West Park Street, Butte, MT 59701
Phone (406) 496 4810
Fax (406) 496 4417
E-mail NorthAbbott, Mary [MNorthAbbott@mtech.edu]

Education and Training

Bachelor of Science in Petroleum Engineering, Montana Tech of the University of Montana, 1985

Master of Project Engineering and Management, Joint degree from Montana Tech of the University of Montana and Montana State University-Bozeman, 2000

Licensed Professional Engineer (Petroleum) in the State of Montana

Research and Professional Experience

Montana Tech of the University of Montana: Assistant Professor in the Petroleum Engineering Department, teach graduate and undergraduate courses, August 2004 to present

MSE Technology Applications, Inc.: Project Manager/Senior Petroleum Engineer, Butte, MT, 10/98-9/04; Petroleum Engineer/Project Manager, Butte, MT, 4/95-10/98; Training Director, Butte, MT, 4/91-4/95; Scientist, Evaluation, Science, & Materials, Butte, MT, 10/89-4/91

Conoco, Inc.: Operator, Condensate Unit, Billings, MT, 4/87-6/89; Maintenance Operator, Production Field Office, Odessa, TX, 7/85-4/87

Publications

North-Abbott, M.A, (2010). Core Sample Flow Property Changes due to Supercritical CO_2 Exposure. Presentation at the AAPG Geoscience Technology Workshop "Carbon Capture and Sequestration: New Developments and Applications, Case Studies, Lessons Learned" August 10^{th}-12^{th}, 2010 Golden, CO.

North-Abbott, M.A.and Phillips, R. (2010). Reservoir Rock Flow Property Alteration Due to Carbon Dioxide Flooding, Montana Tech Undergraduate Research Project presentation.

Flow Property Alterations in Sandstone, Limestone, and Dolomite due to $ScCO_2$ Exposure, Masters thesis for Kurt Hibbard (Montana Tech Petroleum Engineering), May 2009.

North-Abbott, M.A (submitted/declined). Effects Of Supercritical Carbon Dioxide On The Wettability Of Carbonate Rocks, 2010 SPE International Conference on CO2 Capture, Storage, & Utilization, in New Orleans, LA, November 2010.

Synergistic Activities

- Session chair at the AAPG Geoscience Technology Workshop "Carbon Capture and Sequestration: New Developments and Applications, Case Studies, Lessons Learned" August 10^{th}-12^{th} in Golden, CO.

- Advisor for undergraduate student in support of their Undergraduate Research Project, which is in support of the DOE EPSCoR project
- Advisor for one graduate student for his thesis project, which was supported by the DOE EPSCoR project
- Development of the Coalbed Methane (CBM) Petroleum Engineering Research Program at Montana Tech - Funded by Montana Tech Seed Grant Program to collect and test coal cores to determine modulus of elasticity and Poisson's ratio to support stimulation of CBM wells.
- Coal Core Testing Project - Montana Tech, Instructor/Advisor to student in (two-credit) Special Projects Course, PET 4910, to support the triaxial testing of coal cores for coalbed methane research.
- Low-Permeability Gas Sand Fracture Stimulation Study – Funded by Halliburton to study the effects of sand fracture stimulation in low permeability, shallow, low pressure gas sands, principally in northern and eastern MT. The objective of the current study is to develop methods for improving stimulation outcomes.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-editors
Kurt Hibbard (Former Montana Tech graduate student), David Reichhardt (Montana Tech),

Dr. Burt Todd (Montana Tech),

Russell Phillips, Montana Tech undergraduate student.

Cameron Shepherd (Montana Tech undergraduate student.

Graduate Advisor
Dr. Kumar Ganesan, Montana Tech of the University of Montana

Thesis Advisor
Kurt Hibbard, M.S. in Petroleum Engineering from Montana Tech, 2009. Currently employed by Chesapeake Energy, Oklahoma City, OK.

Biographical Sketch
Joseph D. Seymour

Professor, Department of Chemical and Biological Engineering
306 Cobleigh Hall Montana State University Bozeman, Montana 59717
Telephone (406) 994-6853; fax (406) 994-5308 email jseymour@coe.montana.edu

Education and Training

Florida State University	Chemical Engineering	B.S. 1990
University of California, Davis	Chemical Engineering	Ph.D. 1994
Massey University, New Zealand	Physics, Post-doctoral	1995-1996
The Lovelace Institute	Biomedical, Post doctoral	1997

Research and Professional Experience

Professor Dept. of Chem. and Biolog. Eng. Montana State University	2010-Current
Associate Professor Dept. of Chem. and Biolog. Eng. Montana State University	2005-2010
Assistant Professor Dept. of Chem. and Biolog. Eng. Montana State University	2001-2005
Staff Scientist, New Mexico Resonance, Albuquerque, NM	1998-2001
Alexander von Humboldt Fellow, Universität Ulm, Germany	2000

Publications

E.R. Rassi, S.L. Codd and J.D. Seymour, "Nuclear magnetic resonance characterization of the stationary dynamics of partially saturated media during steady-state infiltration flow" in press *New Journal of Physics* 2010.

E.O. Fridjonsson, J.D. Seymour, L.N. Schultz, R. Gerlach, A.B. Cunningham and S.L. Codd, "NMR measurement of hydrodynamic dispersion in porous media subject to biofilm mediated precipitation reactions", in press *Journal of Contaminant Hydrology*. 2010.

T.R. Brosten, E.O. Fridjonsson, S.L. Codd, and J.D. Seymour, "Transport of colloidal particles in a porous open cell foam." *Journal of Colloid and Interface Science* **349**(1). 384-391. 2010.

T.R. Brosten, S.L. Codd, R.S. Maier, and J.D. Seymour, "Dynamic length scale characterization and nonequilibrium statistical mechanics of transport in open cell foams". *Physical Review Letters* **103** 218001 2009.

J.A. Hornemann, S.L. Codd, R. Fell, P.S. Stewart and J.D. Seymour, "Secondary Flow Mixing due to Biofilm Growth in Capillaries of Varying Dimensions", *Biotechnology and Bioengineering* **103**(2): 353-360. 2009.

S.L. Codd, J.D. Seymour, Editors. Magnetic Resonance Microscopy: Spatially Resolved NMR Techniques and Applications, Wiley-VCH, Weinheim, Germany, 2009.

R.S. Maier, M.R. Schure, J.P. Gage, J.D. Seymour, "Sensitivity of pore-scale dispersion to the construction of random bead packs." *Water Resources Research* **44**(6): W06S03. 2008.

J.R. Brown, J.D. Seymour, S.L. Codd, E.O. Fridjonsson, G.R. Cokelet and M. Nyden, "Dynamics of the solid and liquid phases in dilute sheared Brownian suspensions: Irreversibility and particle migration", *Physical Review Letters* **99**: 240602. 2007.

J.D. Seymour, J.P. Gage, S.L. Codd and R. Gerlach, "Magnetic resonance microscopy of biofouling induced scale dependent transport in porous media", *Advances in Water Resources*, **30**: 1408-1420. 2007.

E.L. Gjersing, S.L. Codd, J.D. Seymour and P.S. Stewart, "Magnetic resonance microscopy analysis of advective transport in a biofilm reactor." *Biotechnology and Bioengineering*, **89**(7): 822-834. 2005.

Synergistic Activities

Journal Reviewer: *Physical Review Letters, Journal of Magnetic Resonance, AIChE Journal, Biotechnology and Bioengineering, Journal of Membrane Science, Geophysics, Physical Review E, Applied Magnetic Resonance, Journal of Applied Physics, Biorheology, Journal of Physical Chemistry, Vadose Zone, Biofouling*

Invited Lectures: American Geophysical Union Fall Meeting, San Francisco, CA, December 13-17, 2010. American Geophysical Union Fall Meeting, San Francisco, CA, December 15-19, 2008. 9th Annual Conference on Magnetic Resonance in Porous Media, Cambridge, MA July 13-17 2008. Department of Chemical Engineering and Magnetic Resonance Research Center, Cambridge University, Cambridge UK, June 26 2008. EUCHEM Conference Structure Dynamics in Soft Condensed Matter, Fiskebäckskil (Göteborg), Sweden, August 20-22, 2007. Department of Chemical Engineering, Columbia University, New York, New York, September 19, 2006.

Plenary Lecture at the 8th International Conference on Magnetic Resonance Microscopy, Utsunomiya, Japan, August 22-26, 2005.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-editors: Sarah L. Codd (Montana State Univ.), Giles R. Cokelet (Montana State Univ.), Al B. Cunningham (Montana State Univ.), Robin Gerlach (Montana State Univ.), Robert S. Maier (Army Engineering Research Center, Vicksburg), Magnus Nyden (Chalmers University, Sweden)

Graduate Advisees: Jennifer R. Brown Ph.D. 2007 (Asst. Prof Montana State University), Jennifer A. Hornemann, Ph.D. 2009 (Exxon), Tyler R. Brosten Ph.D. 2009 9Army Engineering Research Center Vicksburg), Einar Orn Fridjonsson Ph.D. 2010 (MRRC/ChE Cambridge University, UK), Amber L. Broadbent, Ph.D. candidate 2010, Sarah J. Vogt Ph.D. candidate 2012, Erik M. Rassi Ph.D. candidate 2011, Alexis Sanderlin, Ph.D. candidate 2014, Erica L. Gjersing M.S. 2003 (NREL), Daniel T. Howe, M.S. 2004 (PNNL)

Biographical Sketch

Xiaobing Zhou
Department of Geophysical Engineering
Montana Tech of the University of Montana
Butte, MT 59701
Tel: 406-496-4350 Email: xzhou@mtech.edu;
website: http://www.mtech.edu/mines/geophysical/xzhou/.

Education and Training

Ph.D. 2002	Geophysics (remote sensing)	University of Alaska Fairbanks, USA
M.S. 1989	Theoretical Physics	Sichuan University, China
B.S. 1986	Physics	Hunan Normal University, China

Research and Professional Experience

- 8/2009 to present, Associate Professor, Department of Geophysical Engineering, Montana Tech, Butte, Montana
- 8/2005 to 5/2009, Assistant Professor, Department of Geophysical Engineering, Montana Tech, Butte, Montana
- 8/2002 to 8/2005, Research Assistant Professor of Hydrology, Department of Earth and Environmental Science, New Mexico Tech, Socorro, New Mexico
- 1/1998 to 8/1998, Visiting scientist, Geophysical Institute, University of Alaska Fairbanks, Alaska.
- 7/1997 to 1/1998, Visiting scientist, University of California San Diego, California

Publications

Song, K., X. Zhou, and Y. Fan, (2010)Retrieval of soil moisture content from microwave backscattering using a modified IEM model, *Progress in Electromagnetics Research* B, 26, 383-39.

Lakkaraju, V. R., X. Zhou, M. Apple, A. Cunningham, L. M. Dobeck, K. Gullickson, L. H. Spangler,(2010) Studying the vegetation response to the simulated leakage of sequestered CO_2 using spectral vegetation indices, Ecological Informatics, 5, 379-389.

Zhou, X.,(2010) Analytical solution of gravity anomaly of irregular two-dimensional (2D) masses with density contrast varying as a 2D polynomial function, Geophysics, 75 (2), I11-I19.

Zhou, X., (2009) Three-dimensional (3D) vector gravity potential and line integrals for the gravity anomaly of a rectangular prism with 3D variable density contrast, Geophysics, 74 (6), I43-I53.

Song, K., X. Zhou, Y. Fan,(2009). Empirically adopted IEM for retrieval of soil moisture from radar backscattering coefficients, *IEEE Transactions on Geoscience and Remote Sensing*, 47(6), 1662-1672.

Zhou, X., H. Guan, H. Xie, and J. L. Wilson,(2009), Analysis and Optimization of NDVI Definitions and Areal Fraction Models in Remote Sensing of Vegetation, *International Journal of Remote Sensing*, 30(3), 721-751.

Zhou, X., N.-B. Chang, S. Li,(2009) Applications of SAR Interferometry in Earth and Environmental Science Research, *Sensors*, 9, 1876-1912.

Zhou, X.,(2009) General line integrals for gravity anomalies of irregular two-dimensional (2D) masses with horizontally- and vertically-dependent density contrast, *Geophysics*, 74(2), I1-I7.

Zhou, X., (2008) 2D vector gravity potential and line integrals for the gravity anomaly caused by a 2D mass of depth-dependent density contrast, *Geophysics*, 73 (6), I43-I50.

Zhou, X., N.-B. Chang, and S. Li,(2007) Detection of Coastal Region Sea Ice Decay from Orthorectified RADARSAT-1 ScanSAR Imagery: A Case Study of Bering Strait and Norton Sound, Alaska, *Journal of Environmental Informatics*, 10(1), 37-46.

Synergistic Activities

Member, American Geophysical Union, Society of Exploration Geophysicists, Remote Sensing and Photogrammetry, International Association of Hydrological Sciences.

Proposal reviewer, National Science Foundation, National Oceanic & Atmospheric Administration, PostDoctoral Research Fellowship of NSF; NASA Postdoctoral Program; Georgia National Science Foundation.

Member, Research Advisory Committee (2005-), Instructional Improvement Committee (2005-), Library Committee (2005-), Montana Tech; Large River Ecosystems Advisory Committee, Montana NSF EPSCoR program (2007-), NASA/Montana Space Grant Consortium representative of Montana Tech, AmericaView/ MontanaView representative of Montana Tech.

Journal manuscript reviewer, *Advances in Space Research; Ecological Informatics; Environmental Modeling and Assessment; Exploration Geophysics; Geophysics; Hydrological Processes; International Journal of Remote Sensing; Journal of Applied Remote Sensing; Journal of Hydrology; Remote Sensing of Environment; and Water Resources Research*

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Collaborators and Co-Editors

Curtis Link (Montana Tech), Martha Apple (Montana Tech), Harold Millegan (Montana Tech), Al Cunningham (MSU), Joe Shaw (MSU), Lee Spangler (MSU), Laura Dobeck (MSU), Lucian Wielopolski (BNL), Tom Patton (MBMG), Knut Stamnes (Stevens Institute), Martin Jeffries (U of Alaska Fairbanks), Kim Morris (U of Alaska Fairbanks), Hongjie Xie (U of Texas San Antonio), Jan Hendrickx (New Mexico Tech), John Wilson (New Mexico Tech), Enrique Vivoni (Arizona State U), Rick Donavan (Michigan Tech), Ni-Bin Chang (U of Central Florida), Zong-Liang Yang (U of Texas Austin), Williams Woessner (U of Montana).

Graduate and Post Doctoral Advisors and Advisees.

PhD Advisor: Shusun Li (University of Alaska Fairbanks)

Graduate student advisees: Christopher Kellogg, Venkata Lakkaraju, Bablu Sharma, Zhanibek Katrenov, Prasenjit Debnath, Aaron V. Wandle, Geoffrey Marshall, Sungho Hung, Kathy Fleming, Jianhui Zhang.

PostDoc advisee: Kaijun Song

APPENDIX 2 CURRENT AND PENDING SUPPORT

This is a list of all federal and non-federal support for all DOE EPSCoR Project personnel for ongoing and proposed projects. Personnel are either Principal or Co-Principal Investigators on these projects/proposals. The list is in alphabetical order.

Investigator **Martha E. Apple (MTech)**

Support:	Current
Project/Proposal Title:	RAPT: Researching Alpine Plant Traits
Source of Support:	European Union INTERACT/TRANSACT Access Grant
Total Award Amount:	$5200
Total Award Period:	06/01/13 - 12/01/13
Person-Months Per Year:	Cal: 0.5, Acad: 0.0 Summer: 1.0

Support:	Current
Project/Proposal Title:	Arctic-Alpine Plants On Edges of Vanishing Snowfields and Glaciers at Glacier National Park
Source of Support:	RM-CESU NPS
Total Award Amount:	$10,000
Total Award Period:	6/1/12 – 10/1/13
Person-Months Per Year:	Cal: 1.0, Acad: 0.0 Summer: 1.0

Support:	Current
Project/Proposal Title:	Environmental Responses to Geologic CO_2 Sequestration
Source of Support:	DOE-EPSCoR program
Total Award Amount:	$460,820 (Montana Tech share, including match)
Total Award Period:	09/01/08 – 08/31/11
Person-Months Per Year:	Cal: 0.5, Acad: 0.0 Summer: 0.5

Support:	Current
Project/Proposal Title:	A survey of *Streptomyces* Bacteria at the Zero Emission Research and Technology Center.
Source of Support:	Montana Tech Undergraduate Research Program
Total Award Amount:	$2,010
Total Award Period Covered:	11/01/10 – 05/01/11
Person-Months Per Year:	Cal: 0.0, Acad: 0.0 Summer: 0.0

Support:	Pending
Project/Proposal Title:	A New Approach for Long-Term Monitoring of Leaks from Geologic Sequestration
Source of Support:	US Department of Energy, National Energy Technology Laboratory
Total Award Amount:	$4,000,000
Total Award Period Covered:	09/01/11 – 08/31/15
Location of Project:	Brookhaven National Laboratory, U. of Montana, Montana Tech.
Person-Months Per year:	Cal: 0.0, Acad: 0.0 Summer: 0.0

Investigator **Jerry Bromenshenk (Project Administrator, UM)**

Support: Current

Project/Proposal Title: Applied Research using Honey Bees for Stand Off Detection of Landmines and Improvised Explosive Devices (IEDs
Source of Support: Honey Bee Biological Sensors Program, U.S. Army Night Vision and Electronics Directorate
Total Award Amount: $5,300,000
Total award period: September 29, 2006 extended to September 28, 2011,
Person-Months Per Year: Cal: 5.0

Support: Current (Principle Investigator)
Project/Proposal Title: Environmental Responses to Geologic CO_2 Sequestrations
Source of Support: DOE-EPSCoR program
Total Award Amount: $1,200,000
Total Award Period: 09/01/08 – 08/31/11
Person-Months Per Year: Cal: 1.0

Support: Current
Project/Proposal Title: Environmental Responses to Geologic CO_2 Sequestrations
Source of Support: DOE-EPSCoR program
Total Award Amount: $1,400,000
Total Award Period: 09/01/08 – 08/31/11
Person-Months Per Year: Cal: 2.0

Support Pending
Project/Proposal Title: Confirmatory Investigation of a Pathogen-Twin Interaction as a Marker/Cause of Honey Bee Colony Collapse.
Source of Support: USDA Agriculture and Food Research Initiative
Total Award Amount: $500,000
Total award period: 10/1/10 -09/30/11
Person-Months Per Year: Cal. 1.0

Investigator: Sarah Codd (MSU)

Support: Current
Project/Proposal Title: NMR Imaging and Pore-Scale Simulation of Electrokinetic Transport in Cementitious Materials (PI)
Source of Support: U.S. Army Engineer Research and Development Center
Award Amount: $320,000
Total Award Period: 04/10 - 04/13 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Support: Current
Project/Proposal Title: Low Cost In-Situ NMR Technologies for monitoring Biological and Geochemical Processes in the Subsurface (MSU PI)
Source of Support: US DOE SBIR (Phase II)
Award Amount: $200,000 (MSU)
Total Award Period: 10/01/12-09/31/14 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Support: Current
Project/Proposal Title: Spectrometer upgrade for magnetic resonance microscopy facility (co-PI)
Source of Support: Murdock Foundation
Award Amount: $475,000
Total Award Period: 07/01/12-07/01/15 Location of Project: MSU
Person-Months Per Year Committed to the Project: 0.0

Support: Current
Project/Proposal Title: Magnetic Resonance and Spray Drying Model (co-PI)
Source of Support: Bend Research Inc
Award Amount: $160 000
Total Award Period: 09/01/12 - 09/01/14 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Support: Current
Project/Proposal Title: Environmental Responses to Geologic CO_2 Sequestration
Source of Support: DOE-EPSCoR program
Total Award Amount: $1,400,000
Total Award Period: 09/01/08 – 08/31/13
Person-Months Per Year: Cal: 1.0

Support Current
Project/Proposal Title: NMR Imaging and Pore-Scale Simulation of Electrokinetic Transport in Cementitious Materials
Source of Support: U.S. Army Engineer Research and Development Center
Total Award Amount: $320,000
Total award period: 10/2010 – 09/2013
Person-Months Per Year: Cal: 1.0

Support Pending
Project/Proposal Title: Magnatic resonance of supercritical fluids in porous media(PI)
Source of Support: NSF CBET
Funds Requested: $306 000
Total Award Period: 9/1/13 – 8/31/16 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Investigator **Alfred Cunningham (Principal Investigator, MSU)**

Support: Current
Project/Proposal Title: Impact of Mineral Precipitating Biofilms on the Physical and Chemical Characteristics of Porous Media
Source of Support: National Science Foundation Division of Mathematical Sciences
Award Amount: $750,000
Total Award Period Covered: 10/01/09 – 9/30/13
Person-Months Per Year: Cal: 0.5 Acad: 0.0 Sumr: 0.0

Support:	Current
Project/Proposal Title:	Basic Science of Retention Issues, Risk Assessment & Measurement, Monitoring & Verification for Geologic CO2 Sequestration
Source of Support:	U.S. Department of Energy
Award Amount:	$1,206,878
Total Award Period Covered:	10/01/04 – 9/30/2014
Person-Months Per Year:	Cal: 2.0 Acad: 0.0 Sumr: 0.0

Support:	Current
Project/Proposal Title:	Environmental Responses to Geologic CO_2 Sequestration
Source of Support:	DOE EPSCoR
Award Amount:	$1,400,000
Total Award Period Covered:	9/1/2008 – 8/31/2013
Person-Months Per Year;	Cal: 2.0 Acad: 0.0 Sumr: 0.0

Support	Current
Project/proposal title:	Advanced CO_2 Leakage Mitigation using Engineered Biomineralization Sealing Technologies
Source of Support:	U.S. Department of Energy
Award Amount:	$ 1,999,374
Total Award Period:	10/1/2010 – 9/30/2014
Person-Months Per Year:	Cal: 2.0 Acad: 0.0 Sumr: 0.0

Support:	Current
Project/Proposal Title:	Field Test and Evaluation of Engineered Biomineralization Technology for Sealing Existing Wells
Source of Support:	DOE-NETL
Award Amount:	$1,020,000
Total Award Period Covered:	11/12-10/14
Person-Months Per Year;	Cal: 0.0 Acad: 2.0 Sumr: 0.0

Support:	Current
Project/Proposal Title:	Environmental Responses to Geologic CO_2 Sequestration
Source of Support:	DOE-EPSCoR program
Total Award Amount:	$1,400,000
Total Award Period:	09/01/08 – 08/31/13
Person-Months Per Year:	Cal: 1.0

Investigator **Robin Gerlach (MSU)**

Support:	Current
Project/Proposal Title:	Impact of Mineral Precipitating Biofilms on the Physical and Chemical Characteristics of Porous Media
Source of Support:	National Science Foundation Division of Mathematical Sciences
Award Amount:	$750,000
Total Award Period Covered:	10/01/09 – 9/30/13
Person-Months Per Year:	Cal: 0. Acad: 0.0 Sumr: 1.0

Support	Current
Project/proposal title:	Advanced CO_2 Leakage Mitigation using Engineered Biomineralization Sealing Technologies
Source of Support:	U.S. Department of Energy
Award Amount:	$ 1,999,374
Total Award Period:	10/1/2010 – 9/30/2014
Person-Months Per Year:	Cal: 0.0 Acad: 1.0 Sumr: 0.0

Support:	Current
Project/Proposal Title:	Basic Science of Retention Issues, Risk Assessment & Measurement, Monitoring & Verification for Geologic CO2 Sequestration
Source of Support:	U.S. Department of Energy
Award Amount:	$1,206,878
Total Award Period Covered:	10/01/04 – 9/30/2014
Person-Months Per Year:	Cal: 0 .0 Acad: 0.0 Sumr: 1.0

Support:	Current
Project/Proposal Title:	Environmental Responses to Geologic CO_2 Sequestration
Source of Support:	DOE EPSCoR
Award Amount:	$1,400,000
Total Award Period Covered:	9/1/2008 – 8/31/2013
Person-Months Per Year;	Cal: 2.0 Acad: 0.0 Sumr: 0.0

Support:	Current
Project/Proposal Title:	Field Test and Evaluation of Engineered Biomineralization Technology for Sealing Existing Wells
Source of Support:	DOE-NETL
Award Amount:	$1,020,000
Total Award Period Covered:	11/12-10/14
Person-Months Per Year;	Cal: 0.0 Acad: 1.33 Sumr: 0.0

Support:	Current
Project/Proposal Title:	Microbial Activity and Precipitation at Solution-Solution Mixing Zones in Porous Media
Source of Support:	DOE-NETL
Award Amount:	$1,348,780
Total Award Period Covered:	11/10-10/13.
Person-Months Per Year;	Cal: 0.0 Acad: 01.0 Sumr: 0.0

Support	Pending
Project/Proposal Title:	Visualizing the Influence of Microscale Changes Induced by Biogeochemical Processes on Reactive Transport in Porous Media
Source of Support:	DOE
Award Amount:	$998,690
Total Award Period Covered:	10/10-09/13;
Person-Months Per Year;	Cal: 0.0 Acad: 01.0 Sumr: 0.0

Investigator **William E. Holben (UM)**

Support:	Current
Project/Proposal Title:	Environmental Responses to Geologic CO_2 Sequestration
Source of Support:	DOE EPSCoR
Award Amount:	$1,400,000
Total Award Period Covered:	9/1/2008 – 8/31/2011
Person-Months Per Year;	Cal: 0.0 Acad: 0.0 Sumr: 1.0

Support	Current
Project/Proposal Title:	IM-SURE, Introductory Multicultural Summer Undergraduate Research Experience in Environmental Biology.
Source of Support:	NSF-REU
Award Amount:	$312,511
Total Award Period Covered:	4/15/08-4/14/11
Person-Months Per Year;	Cal: 0.0 Acad: 0.0 Sumr: 0.0

Support	Current
Project/Proposal Title:	Montana Ecology of Infectious Diseases (M-EID): Integrative Graduate Training in Multi-Scalar Computational, Mathematical and Empirical Approaches to Complex Problems.
Source of Support:	NSF-IGERT
Award Amount:	$3,126,729
Total Award Period Covered:	4/15/08-4/14/14
Person-Months Per Year;	Cal: 1.0 Acad: 0.0 Sumr: 0.0

Support	Current
Project/Proposal Title:	MILES—Montana Integrative Learning Experience for Students at the University of Montana.
Source of Support:	Howard Hughes Medical Institute Undergraduate Science Education Program
Award Amount:	$1,500,000.
Total Award Period Covered:	9/06 – 8/11
Person-Months Per Year;	Cal: 0.0 Acad: 0.0 Sumr: 1.0

Support	Current
Project/Proposal Title:	Nyack Microbial Observatory Project.
Source of Support:	NSF Microbial Observatories Program:
Award Amount:	$1,307,312
Total Award Period Covered:	05/01/04-04/30/10 (Extended)
Person-Months Per Year;	Cal: 0.0 Acad: 0.0 Sumr: 1.0

No **Pending** proposals except for DOE EPSCoR Renewal Proposal

Investigator **Joe Seymour (MSU)**

Support:	Current
Project/Proposal Title:	NMR Imaging and Pore-Scale Simulation of Electrokinetic Transport in Cementitious Materials (PI)
Source of Support:	U.S. Army Engineer Research and Development Center
Award Amount:	$320,000

Total Award Period: 04/10 - 04/13 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Support: Current
Project/Proposal Title: Low Cost In-Situ NMR Technologies for monitoring Biological and Geochemical Processes in the Subsurface (MSU PI)
Source of Support: US DOE SBIR (Phase II)
Award Amount: $200,000 (MSU)
Total Award Period: 10/01/12-09/31/14 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Support: Current
Project/Proposal Title: Spectrometer upgrade for magnetic resonance microscopy facility (co-PI)
Source of Support: Murdock Foundation
Award Amount: $475,000
Total Award Period: 07/01/12-07/01/15 Location of Project: MSU
Person-Months Per Year Committed to the Project: 0.0

Support: Current
Project/Proposal Title: Magnetic Resonance and Spray Drying Model (co-PI)
Source of Support: Bend Research Inc
Award Amount: $160 000
Total Award Period: 09/01/12 - 09/01/14 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Support: Current
Project/Proposal Title: Environmental Responses to Geologic CO_2 Sequestration
Source of Support: DOE-EPSCoR program
Total Award Amount: $1,400,000
Total Award Period: 09/01/08 – 08/31/13
Person-Months Per Year: Cal: 1.0

Support Current
Project/Proposal Title: NMR Imaging and Pore-Scale Simulation of Electrokinetic Transport in Cementitious Materials
Source of Support: U.S. Army Engineer Research and Development Center
Total Award Amount: $320,000
Total award period: 10/2010 – 09/2013
Person-Months Per Year: Cal: 1.0

Support Pending
Project/Proposal Title: Magnatic resonance of supercritical fluids in porous media(PI)
Source of Support: NSF CBET
Funds Requested: $306 000
Total Award Period: 9/1/13 – 8/31/16 Location of Project: MSU
Person-Months Per Year Committed to the Project: 1.0 (Summer)

Support: Pending
Project/Proposal Title: Visualizing the Influence of Microscale Changes Induced by Biogeochemical Processes on Reactive Transport in Porous Media

Source of Support: U.S. Department of Energy Office of Science (BER)
Award Amount: $240,000
Total Award Period Covered: 04/2011-04/2014
Person-Months Per Year; Cal: 1.0 Acad: 0.0 Sumr: 0.0

Investigator **Xiaobing Zhou**

Support: Current
Project/Proposal Title: Infrastructure via Science- and Technology-Enhanced Partnerships (INSTEP)
Source of Support: National Science Foundation (NSF)
Total Award Amount: $ 50,000
Total Award Period Covered: 05/01/10 - 04/30/11
Person-Months Per Year Cal: 0.0 Acad: 0.0 Sumr: 0.0

Support: Current
Project/Proposal Title: Space Grant Fellowship: Christopher Hannen Kellogg
Source of Support: NASA/Montana Space Grant Consortium
Total Award Amount: $11,000
Total Award Period Covered: 01/01/11 - 05/31/11
Person-Months Per Year: Cal: 0.0 Acad: 0.0 Sumr: 0.0

Support: Current
Project/Proposal Title: Derivation of Soil Moisture and Snow Liquid Water Content for Soil and Snow in Montana Using RADARSAR-1 SAR Imagery
Source of Support: Alaska Satellite Facility / NASA Headquarters
Total Award Amount: $7,530 (data credits)
Total Award Period Covered: 04/01/08 - 03/31/11
Person-Months Per Year: Cal: 0.0 Acad: 0.0 Sumr: 0.0

Support: Current
Project/Proposal Title: Environmental Response to Geologic CO2 Sequestrations
Source of Support: DOE EPSCoR program
Total Award Amount: $460,820.00 (Montana Tech share, including match)
Total Award Period Covered: 09/01/08 - 08/31/11
Person-Months Per Year: Cal: 0.0 Acad: 0.0 Sumr: 0.5

Support: Pending
Project/Proposal Title: The design of a roadway LIDAR system for micro DEM mapping
Source of Support: Department of Transportation
Total Award Amount: $500,000
Total Award Period Covered: 10/01/2011-9/30/2014
Person-Months Per Year: Cal: 0.0 Acad: 0.0 Sumr: 0.5

APPENDIX 3 BIBLIOGRAPHY AND REFERRENCES CITED

NOTE! This appendix also contains a complete listing of all DOE EPSCoR Supported Publications and Presentations.

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APPENDIX 4 FACILITIES AND OTHER RESOURCES

This DOE EPSCoR proposal will leverage heavily on existing facilities and equipment as described below.

MSU FACILITIES AND OTHER RESOURCES

ZERT Field Site. This outdoor experimental facility is located on MSU Agricultural land and became fully operational in June 2007. The facility consists of a 4-inch steel horizontal well approximately 210 feet in length and buried at a depth of approximately 8 feet below pasture land consisting of alfalfa and native prairie grass. The horizontal well allows CO_2 from a storage tank to be pumped underground and released along the axis of the well—thereby providing a linear source of CO_2 flux which rises up through the overlying soil. Key measurements which can be made include CO_2 flux (using eddy covariance, free space LIDAR, and portable soil flux chambers), tracer and stable isotope studies, ground water chemistry, and LIDAR measurements of the soil gas in the shallow subsurface (see Table 3 in main body of proposal for details).

Center for Biofilm Engineering. Montana State University's Center for Biofilm Engineering (CBE) offers an ideal setting for the interdisciplinary, collaborative research that is the basis for its worldwide reputation in the field of biofilms. The CBE is located in MSU's Engineering/Physical Sciences and occupies >20,000 ft^2 including offices and conference rooms, two computer laboratories, and thirteen state-of-the-art research laboratories. The CBE Technical Operations Manager oversees the research laboratories, provides one-on-one training for students, ensures safe laboratory practices, and maintains equipment. State-of-the-art instruments and equipment are available for use by all CBE faculty, staff, and students.

CBE Facilities and equipment relevant to DOE EPSCoR proposal include: 1) a high pressure rock core testing system [Cunningham et al., 2005] capable of performing flow-through studies on one inch diameter rock core samples using brine, CO_2, and other fluids under high pressure (70-80 atmospheres) and in the presence/absence of microbial biofilms and mineralization deposits (a similar system will be built at the MTech Petroleum Engineering Department under this grant); 2) a Magnetic Resonance Laboratory (MR) which has recently developed the capability to image biotic and abiotic rock core samples with water, brine, or $ScCO_2$ as the fluid of interest; 3) Microscope facilities; 4) Computer facilities; and 5) the MSU ICAL facility. Details are given below.

- **MSU MR Facilities**

MR Preparation Laboratory

The MRM preparation laboratory in the Engineering College at MSU has space for set-up and preparation of samples. This laboratory is approximately 600 sq ft and its preparation facilities include a fumehood and several wet lab areas with natural gas and deionised water outlets. There is also computer and desk space for up to 8 graduate student participants and office space for the facility manager and several post-docs.

MR Spectrometer Laboratory

This 600 sq ft laboratory is adjacent to the MR preparation lab. The lab houses two MR spectrometers and the earths field spectrometer. Dr Busse is the MRM facilities manager and handles instrument booking schedules and routine software and hardware maintenance and cryogen filling. He is also the manager of the Chemistry NMR facility.

Spectrometer 1: Bruker narrow bore magnet and DRX250 console with a Micro5 imaging insert providing 3000 mT/m in three directions over a sample size of 10 mm diameter.

Spectrometer 2: Bruker Super Wide Bore Magnet and AVANCE 300 Imaging System. The available bore space for samples is 64 mm diameter with 3-D magnetic field gradient coils capable of 300 mT/M gradients in all directions. A Micro2.5 imaging insert reduces the available sample space to 25 mm diameter but provides gradients of 1000 mT/m for higher resolution imaging work.
Bruker Rheo-NMR Inser: Both systems have a Rheo-NMR insert. The Bruker Rheo-NMR Insert is a device designed to place standard rheometric devices inside the NMR detection coil of a vertical bore magnet. Cone and plate, couette cell and four-mill rolls are available in a variety of sizes. The couette devices are capable of rotation rates in the range 0.08-4.24 Hz, which can yield shear rates up to 500 Hz.
Earths Field Imaging Spectrometer: This instrument allows 3D imaging of large objects upto 50 mm diameter for teaching demonstrations and graduate training. The instrument is portable, located on a cart and often used outside or in our rooms for outreach programs.

- **MSU CBE Microscope Facilities**

The **microscopy facilities** are coordinated by the Microscopy Facilities Manager who trains and assists research staff and students in capturing images via optical microscopy and fluorescent confocal microscopy, and maintains the equipment. The microscopy facilities include three separate laboratories—the **Optical Microscopy Lab**, the **Confocal Microscopy Lab**, and the **Microscope Resource Room and Digital Imaging Lab**. These facilities will be used to examine porous media and rock core samples subjected to ScCO2 and with biofilm and biomineralization deposits.

- **MSU CBE Computer Facilities**

CBE staff and students have access to personal computers connected to the MSU College of Engineering computer network. A student computer laboratory offers twelve state of the art PCs along with scanning and printing services. In addition, the CBE maintains computational PCs, and three computational servers for data manipulation, mathematical modeling, and graphic image analysis.

- **MSU ICAL Laboratory**

The Image and Chemical Analysis Laboratory (ICAL) in the Physics Department at Montana State University is located on the 3rd floor of the EPS Building, adjacent to the Center for Biofilm Engineering. ICAL MSU was established in order to promote interdisciplinary collaboration in research, education, and industry, and to strengthen existing cooperation between the physical, biological, and engineering sciences by providing critically needed analytical facilities. These facilities are open to academic researchers. The ICAL currently contains seven complimentary microanalytical systems:

Atomic Force Microscope (AFM), Auger Scanning Electron Microprobe (Auger), Field Emission Scanning Electron Microscope (FESEM), Scanning Electron Microscope (SEM), and Time of Flight Secondary Ion Mass Spectrometer (SIMS).

The SEM and AFM will be used extensively in examining rock core samples under DOE EPSCoR.

MTECH FACILITIES AND OTHER RESOURCES

MTech Facilities –Petroleum Engineering Department. The core laboratory, which is located on the main floor of the MT Tech Petroleum Engineering building, will be used for this project. The majority of the equipment needed to complete the petrophysical studies is located in that laboratory and it will likely house the high pressure rock core system constructed to support this project. Current and newly purchased

MTech Petroleum Engineering Department laboratory equipment will be used to conduct the core testing; including Boyle's Law helium porosimeter to find the porosity of the core samples, and the Ruska gas permeameter and liquid permeameter to measure the permeability of the core samples both before and after being subjected to the $ScCO_2$ injection. There is also an engineering laboratory available on campus to conduct compressive strength testing of core samples

MTech Facilities – Plant Responses Team. The Apple laboratory in the Department of Biological Sciences at Montana Tech has available bench space and is equipped with fluorescence microscopy and other instruments suitable for research in plant ecology, plant cell biology, and plant physiology. This laboratory, as well as the accompanying office, is supported by the Information Technology, Physical Plant, Clerical, and Research Branches of Montana Tech. The lab has a laptop computer that can be taken to the ZERT site. Samples collected at the ZERT site can be easily transported to the Apple laboratory for analysis.

The Spectroscopy and Remote Sensing Lab (PI: Xiaobing Zhou) in Geophysical Engineering Department of Montana Tech has one portable spectroradiometer, two infrared radiometers and accessories, two desktop computers, and two laptop computers available for this project. The spectroradiometer and infrared radiometers will be to monitor the hyperspectral signature and emissivity change of vegetation in response to various emission rates of soil CO_2 controllable at the ZERT facility. The two Time Domain Reflectometry (TDR) sensors and a multi-channel datalogger to be purchased from this project for soil moisture profile monitoring and the two infrared radiometers will be installed at the sites for continuous measurement and data collection. Soil samples taken from both test site and control site at regular interval (every two weeks) will be analyzed in MSE Laboratory (Butte, Montana) to monitor the change of Al^{+3} concentration. The laptop computers in the lab can be used for field data collection of data download from the datalogger. The desktop computers in the lab can be used for data analysis.

Equipment already available at MTech for this project includes the following items:

Li-Cor 2000 – Device for measuring Leaf Area Index (LAI), Hansatech Fluorimeter, Hansatech Chlorophyll Content Meter, Hansatech Oxytherm Oxygen Electrode, Refrigerator for Sample Storage, Plant-Drying Oven, Sartori Balance, Dell Laptop Computers, CID Root Imaging System, CID Leaf Area Meter,Olympus Dissecting Microscope, Nikon Fluorescence Microscope with Image Capture Device and Monitor, Image-J Image Analysis Software, Canon Digital Camera, ASD FieldSpec Pro Spectroradiometer and accessories, Heitronics Infrared Radiation Pyrometers and accessories. All except the refrigerator, plant-drying oven and fluorescence microscope are portable.

UNIVERSITY OF MONTANA FACILITIES AND OTHER RESOURCES

The UM investigators have ~2400 ft^2 of dedicated research space available in support of this project. Facilities and Equipment at University of Montana which will be utilized in the DOE EPSCoR project include the following:

Computers and IT

Ethernet, wi-fi and LAN network
Mobile computer lab and permanent computer labs equipped with modern Macintosh and PC laptop and desktop computers
High resolution, networked laser and color printers
Large-format color printer for posters, schematics, flow-charts, etc.
Departmental IT support (full-time FTE with helpers)
Web Design Engineer for web-site construction, instructional tools, assessment, etc.
Technical Writer for assistance with presentations, publications, public relations, etc.

Microbiology

- Microscopes
  - Basic, stereo, compound, phase contrast, fluorescent (with photography)
  - SEM - JEOL 35CF
  - TEM - Hitachi
- Centrifuges
  - Microfuges (4)
  - Sorvall RC5-B Super-Speed Centrifuge
  - Beckman L7-65 Ultracentrifuge (and 5 rotors)
- Incubators
  - Several each of static and shaking benchtop models
  - Two in-lab walk-in cold-rooms (100 sq ft each)
  - Walk-in controlled temperature room
  - Fermentation equipment (to 14 L)
  - Anaerobic chamber and associated facilities
- Refrigerators
- Freezers
- Ultra-low freezers

Molecular Ecology

- 100 sq ft walk-in PCR Clean Room with full UV irradiation
- Bio-Rad iCycler Real Time Quantitative PCR cycler with dedicated PC
- Four thermal cyclers
- (Three) Bio-Rad D-Gene denaturing gradient gel electrophoresis (DGGE) units and software
- Agarose and PAGE electrophoresis equipment
- SSCP capabilities
- Nucleic acid vacuum blotter
- Gradient fractionating equipment
- Ambis radioactive blot analyzer
- Bio-Rad "Gel-Doc" digital image capture and software
- Flat-bed and gel scanning equipment and software
- Digital image analysis, pattern-matching, and database capabilities
  - Includes BioNumerics v. 4.6.1, Molecular Analyst and RFLP-Scan software
- UV/Vis Spectrophotometers
- Liquid scintillation counter
- Hewlett Packard HPLC (high pressure liquid chromatography)
- Hewlett Packard GC (gas chromatography)

Molecular Biology Core Facility

- DNA synthesizer
- DNA sequencer (ABI 3130 capillary unit and ABI 377)

Geochemistry Analytical Laboratory

- TJA IRIS ICAPES with CETAC Ultrasonic nebulzier IC
- Coulometrics Coulometer
- GFAA
- Varian AAS with continuous hydride generator
- Shimatzu DOC/TIC analyzer
- Dionex DX500 IC
- Perkin Elmer HPLC

APPENDIX 5 EQUIPMENT

MONTANA STATE UNIVERSITY EQUIPMENT

ZERT Field Site. Major equipment located at the ZERT field site includes**:** equipment for measuring atmospheric CO_2 flux (Eddy covariance, free space LIDAR, and portable soil flux chambers), and soil gas CO_2 flux using a subsurface LIDAR system.

Center for Biofilm Engineering. Major equipment available at CBE which is relevant to DOE EPSCoR includes**:**1) a high pressure rock core testing system [Cunningham et al., 2005] capable of performing flow-through studies on one inch diameter rock core samples using brine, CO_2, and other fluids under high pressure (70-80 atmospheres) and in the presence/absence of microbial biofilms and mineralization deposits (a similar system will be built at the MTech Petroleum Engineering Department under this grant); 2) a Magnetic Resonance Laboratory (MR) which has recently developed the capability to image biotic and abiotic rock core samples with water, brine, or $ScCO_2$ as the fluid of interest; 3) Microscope facilities which include an Optical Microscope, a Confocal Microscope, an Atomic Force Microscope (AFM), an Auger Scanning Electron Microprobe (Auger), a Field Emission Scanning Electron Microscope (FESEM), a Scanning Electron Microscope (SEM), and a Time of Flight Secondary Ion Mass Spectrometer (SIMS).

Magnetic Resonance Laboratory. The major DOE EPSCoR-related MR equipment includes:

Spectrometer 1: Bruker narrow bore magnet and DRX250 console with a Micro5 imaging insert providing 3000 mT/m in three directions over a sample size of 10 mm diameter.
Spectrometer 2: Bruker Super Wide Bore Magnet and AVANCE 300 Imaging System. The available bore space for samples is 64 mm diameter with 3-D magnetic field gradient coils capable of 300 mT/M gradients in all directions. A Micro2.5 imaging insert reduces the available sample space to 25 mm diameter but provides gradients of 1000 mT/m for higher resolution imaging work.
Bruker Rheo-NMR Inser: Both systems have a Rheo-NMR insert. The Bruker Rheo-NMR Insert is a device designed to place standard rheometric devices inside the NMR detection coil of a vertical bore magnet. Cone and plate, couette cell and four-mill rolls are available in a variety of sizes. The couette devices are capable of rotation rates in the range 0.08-4.24 Hz, which can yield shear rates up to 500 Hz.
Earths Field Imaging Spectrometer: This instrument allows 3D imaging of large objects upto 50 mm diameter for teaching demonstrations and graduate training. The instrument is portable, located on a cart and often used outside or in our rooms for outreach programs.

MTECH EQUIPMENT

MTech Petroleum Engineering Department. The MTech Petroleum Engineering Department is located on the third floor of the newly constructed Natural Resources Building. The core Petroleum Engineering laboratory will continue to be used for this project. The major equipment needed to complete the petrophysical studies is located in that laboratory including the high pressure rock core system constructed to support this project. Additional equipment includes: a Boyle's Law helium porosimeter to find the porosity of the core samples, and the Ruska gas permeameter and liquid permeameter to measure the permeability of the core samples both before and after being subjected to the $ScCO_2$ injection. There is also an engineering laboratory available on campus to conduct compressive strength testing of core samples.

MTech Plant Responses Team. The Apple laboratory in the Department of Biological Sciences at Montana Tech has available bench space and is equipped with fluorescence microscopy and other

instruments suitable for research in plant ecology. Equipment at MTech for this DOE EPSCoR project includes the following items: a Li-Cor 2000 – Device for measuring Leaf Area Index (LAI), a Hansatech Fluorimeter, Hansatech Chlorophyll Content Meter, Hansatech Oxytherm Oxygen Electrode, Refrigerator for Sample Storage, Plant-Drying Oven, Sartori Balance, Dell Laptop Computers, CID Root Imaging System, CID Leaf Area Meter,Olympus Dissecting Microscope, Nikon Fluorescence Microscope with Image Capture Device and Monitor, Image-J Image Analysis Software, Canon Digital Camera, ASD FieldSpec Pro Spectroradiometer and accessories, Heitronics Infrared Radiation Pyrometers and accessories. We have recently acquired two Decagon Leaf Porometers, an Opti-Sciences Anthocyanin Meter, and an Opti-Sciences Fluorescence Ratio Chlorophyll Content Meter for Small Leaves. All except the refrigerator, plant-drying oven and fluorescence microscope are portable.

UNIVERSITY OF MONTANA EQUIPMENT

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Microbiology
Microscopes
Basic, stereo, compound, phase contrast, fluorescent (with photography)
SEM - JEOL 35CF
TEM - Hitachi
Centrifuges
Microfuges (4)
Sorvall RC5-B Super-Speed Centrifuge
Beckman L7-65 Ultracentrifuge (and 5 rotors)
Incubators
Several each of static and shaking benchtop models
Two in-lab walk-in cold-rooms (100 sq ft each)
Walk-in controlled temperature room
Fermentation equipment (to 14 L)
Anaerobic chamber and associated facilities
Refrigerators
Freezers
Ultra-low freezers

Molecular Ecology
100 sq ft walk-in PCR Clean Room with full UV irradiation
Bio-Rad iCycler Real Time Quantitative PCR cycler with dedicated PC
Four thermal cyclers
(Three) Bio-Rad D-Gene denaturing gradient gel electrophoresis (DGGE) units and software
Agarose and PAGE electrophoresis equipment
SSCP capabilities
Nucleic acid vacuum blotter
Gradient fractionating equipment
Ambis radioactive blot analyzer
Bio-Rad "Gel-Doc" digital image capture and software
Flat-bed and gel scanning equipment and software
Digital image analysis, pattern-matching, and database capabilities
Includes BioNumerics v. 4.6.1, Molecular Analyst and RFLP-Scan software
UV/Vis Spectrophotometers

Liquid scintillation counter
Hewlett Packard HPLC (high pressure liquid chromatography)
Hewlett Packard GC (gas chromatography)

Molecular Biology Core Facility
DNA synthesizer
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Varian AAS with continuous hydride generator
Shimatzu DOC/TIC analyzer
Dionex DX500 IC
Perkin Elmer HPLC