CO_2 Multi-Phase Sequestration

– Quantifying Fluid Phase Transition, Gas Migration, Supercritical CO_2 Injection, and Carbon Cycle Information from Dewatering and Exploration of the Potential for Extended Use of Multiple Non-Standard "Campus" Sites at Homestake DUSEL

Drafted Revision by Joe Wang for the

CHEERS Collaboration[1]

To DEDC 20080502

Abstract:

Carbon dioxide (CO_2) is a greenhouse gas responsible for the global warming. Carbon dioxide concentration in the atmosphere has raise above the pre-industrial value with its radiative forcing, a measure of global heating, increased by 20% within the last decade 1995-2005. This greenhouse gas increase is attributed to the use of fossil fuel as well as to change in land use (ICPP 2007). Homestake DUSEL can contribute to fundamental understanding at relevant field scales for CO_2 sequestration, a solution to global warming.

We propose to use existing infrastructure (levels, "sand-holes", drain-holes, etc.) at Homestake, South Dakota to systematically evaluate the sequestration potential of earth materials in transforming and retaining injected CO_2. The main technical activity of conducting controlled field experiment (Activity 2) is supplemented by Activity 1 focusing on gaseous dispersion through the upper levels to the atmosphere and by Activity 3 on carbon and other traced elements dissolved in water at depths. The main activity will focus on two fundamental processes: (1) the upward movement and phase transitions of injected CO_2 that are likely escaped back to the atmosphere, and (2) the absorbed CO_2 on rock grain surfaces left behind. The absorbed CO_2 will likely to interact with solid minerals and slowly, chemically, converted into calcite, thus "sequestered" or imbedded into rock matrix.

Activities 1 and 3 can be conducted now in the Early Implement Phase (EIP), can develop into the DUSEL ISE Phase and are also necessary to address associated environmental and technical challenges to monitor gaseous releases, to evaluate evolution of hydro-chemical-biological-geophysical setting of the Homestake site – a kilometer-scale test bed. Concurrently, we propose to initiate a systematic design of field scale controlled experiments imbedded within this large test bed: the existing "sandline" network used historically for slurry transport for underground stope-filling. The experiments to be designed in this developing S-4 Proposal will initially focus on setups with controlled deposition of rock fragments ("sands") and with controlled releases of fluid sources from selected levels. We envision that a well-designed test sequences at

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[1] **CHEERS** stands for **C**arbon in **H**ydrological **E**nvironment for **E**nhanced **R**etention and **S**equestration, 4/26/2008. See Appendix B for the vision and development of the Collaboration, supports, and interactions with other working groups and communities.

relevant field scales starting at tens of meters toward kilometer scale can address many "Basic Research Needs" identified in CO_2 Sequestration[2].

This pre-proposal is thus aimed for both the Early Implementation Program and for the development of one of the initial suite of experiments (ISEs).The S-4 proposal is aimed to contribute to the establishment of a Multiphase, Multilocation and Multidisciplinary Collaboration – the CHEERS Collaboration - for site evaluation and preliminary design. Since we plan to systematically evaluate existing infrastructures from surface, levels by levels, and follow the dewatering to reach the deeper levels, the CHEERS Collaboration also envisions carrying out Activity 4: locating, exploring and estimating the feasibility of extended uses and targeted research opportunities for not only earth sciences experiments but also other physics investigations and technology developments. These scientific uses would take advantage of the unique features of the Homestake site beyond the "standard campuses" expected to be established at 300L, 4850L and 7400L. CHEERS Collaboration strives to be inter-disciplinary, reaching out to invite industrial and international collaborators.

The first activity on using the 300 Level is related to the DUSEL R&D Proposal submitted on 12/3/2007 (Appendix A). Appendix B presents additional support letters, review comments, and updates of the evolution of the CHEERS Collaboration. Activity 1 is also important from education and outreach prospective, as both the surface and the 300L are amendable for developing activities with direct implications for E&O, such as ecological studies on surface plots and along the stream and channels, displays and lecture halls underground along drifts, demonstration of cosmic ray damping below variable overburden, etc. In addition to interface with public and students, the scientific and technical demonstrations at shallow levels are good starting points or proto-types for more advanced activities at depths.

The second activity on CO_2 sequestration is expanded from the 2006 Letter of Interest (LOI) #85 submitted by Drs. Curt Oldenburg, Sally Benson, Jens Birkholzer, and Joe Wang of LBNL (Lawrence Berkeley National Laboratory, Appendix C). Ongoing field demonstration projects in CO2 Sequestration will help us to articulate the needs for fundamental controlled field experiments. The third activity on dewatering supplements the SDSMT project funded for instrumentation (Appendix D), and we will focus on the carbon cycle modeling aspect. The fourth activity on Extended Uses and Research Opportunities (EURO) is inspired by the white paper on other uses developed by Professor Bob Lanou of Brown University (Appendix E, http://hep.brown.edu/users/lanou/B2-session-draft-v5.pdf).

The CHEERS Collaboration welcomes international participation. Proposal incorporates potential new participants from several institutions who participated in the 2nd International Conference on Underground Science, April 2-4, 2008 at the Low Noise Underground Laboratory, Laboratoire Souterrain à Bas Bruit (LSBB, http://lsbb.unice.fr).

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[2] Basic Research Needs for Geosciences Workshop led by Don dePaolo (February 2007) http://www.sc.doe.gov/bes/reports/files/BRN_workshops.pdf

Relevant information on this conference and and the Keynote talk given by Joe Wang on "Scientific Investigations at Homestake DUSEL" are given in Appendix F.

This S-4 Proposal is for the next 2 years (2009-2010), at approximately 4-5 FTE level annually, to be supplemented by S-5 tasks (2010-2011). We can also start with a few more gathering or workshops to articulate further the scopes. We believe that the sequence of tests and tasks designed in this S-4, S-5 Proposal lead to a meaningful and fundamental, controlled CO_2 multiphase experiment in hydrological environment which contributes to the quantification of enhanced carbon retention and sequestration, one of the ISE to be deployed at Homestake after DUSEL establishment (2012 onward).

We plan to seek funding from multiple agencies, coordinate academia, national labs, and private industry participation, and evaluate multiple sites for extended uses of unique Homestake facilities. We value inputs, appreciate supports, and welcome participation and endorsement. We continue to reach out and coordinate with leaders and participants of other S-4 Pre-proposals. The framework of this Pre-proposal will evolve accordingly as we develop.. Ultimately, the soundness of the proposal will depend on all of us in the Collaboration collectively.

Main Text:

CO_2 Multi-Phase Sequestration

by the **CHEERS Collaboration**

– Quantifying Fluid Phase Transition, Gas Migration, Supercritical CO_2 Injection, and Dewatering and Exploration of the Potential for Extended Use of Non-Standard "Campus" Sites at Homestake DUSEL

- a Multiphase, Multilocation, and Multidisciplinary Collaboration for site evaluation and preliminary design

List of Potential Participants and Supporters: (Appendix B under development will explicitly describe the interactions and coordination with DEDC, Homestake Scientific Collaboration, Sanford Lab-SDSTA, other Working Leads, industrial partners, foreign visitors, etc. We will continue the Collaboration building during proposal preparation to determine the roles and responsibilities, funding requests, and budget estimates, etc. to explicitly address the S-4 call requirements, focuses on major activities while continuing broaden the Collaboration vision)

In the United States:

LBNL: Joe Wang, Jens Birkholzer, Paul Cook, Stefan Finsterle, Marc Fisher, Barry Freifeld, Susan Hubbard, Tim Kneafsey, Jennifer Lewicki, Hui-Hai Liu, Curt Oldenburg, Rohit Salve, Dmitriy Silin, Eric Sonnenthal, Liviu Tomutsa

SDSMT: Arden Davis, Andy Detwiler, Bill Roggenthen, Larry Stetler, P.V. Sundareshwar

SDSTA: Kathy Hart, Tom Regan, Greg King, Jack Stratton, Susan von Stein

BHSU: Ben Sayler
Brown U.: Bob Lanou
UC Berkeley: Steven Glaser, Kevin Lesko
UC Irvine: Hank Sobel
Columbia: Christen Klose (to be confirmed)
Fermi Lab: Chris Laughton
Georgia Tech.: Leonid Germanovich, Todd Rasmussen (to be confirmed)
New Mexico Tech: Tom Kieft, John Wilson
Oak Ridge: Tommy Phelps
Oglala Lakota College: Jay Roman
U. Penn: Ken Lande
Penn State: Derek Elsworth
Princeton: Tullis Onstott
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U. Tennessee: Susan Pfiffner, Qiang He
U Virginia: George Hornberger

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Géosciences Azu, U. Nice: Yves Guglielmi, Federic Cappa
U. Montpellier: Fredric Boudin
IM2NP: Karine Castellani-Coule
L2MP: Jannie Marfaing
UBC: Mathew Yedlin
Roule Lab: Lionel Tenailleau
U. Avignon: Remi Blancon
U. Comte: Catherine Bertrand
U. Malaga: Bartolome Andreo
U. Napoli: Ruggero Stanga
I. Tech Chime: Gerald Ziegenbalg (to be confirmed)
Dalhousie U.: Dmitry Garagash (to be confirmed)

Overview

The upper levels of the Homestake mine, Lead, South Dakota, are accessible during the early implementation period of Sanford Lab over the next several years. The Sanford Lab of the South Dakota Science and Technology Authority owns the land and currently focuses on safe reentry into all the underground workings. The new collaboration proposed here can start with the following assessment and evaluation activities: (1) releases of CO_2 and noble gases from the 300 ft level (300L campus) and their migration to the ground surface and to the atmosphere; (2) injections of supercritical CO_2 from underground levels, (3) carbon cycle associated with dewatering of the mine to reach deep campuses, and (4) development of extended uses for the infrastructures at Homestake.

Earth science and engineering have intrinsic interests in exploring subsurface environments with extensive spatial coverage. Homestake represents a heterogeneous site with localized flow paths and distinct transitions of geochemical zones (e.g., from sulphur-rich to sulphur-poor conditions). It also offers multiple locations for designing coupled process block experiments, fractured zone experiments, and for research associated with large cavern excavations. The activities of this collaboration will interface with all experiments, including deep life search for biology and sensitive detector housing for physics experiments.

Activities:

The first three activities have in common that they start with existing infrastructures without (or with limited) drilling and excavation: i.e., using existing drifts for Activity 1, semi-vertical and extensive "sandlines" for Activity 2, and existing boreholes from 4850' Level (Middle Campus) for Activity 3. These infrastructure-specific activities are examples for Activity 4: to explore the range of available infrastructures for extended uses. The challenge is for us to develop a coherent approach for a wide range of activities at very different sites. In the following, the abstracts for each activity are first given, and then supplemented by recent field observations and by fast growing information collected during on-going reentry activities.

Activity 1: 300L and Surface Assessment for CHEERS

Abstract of CHEERS-300L:

The 300L, with its horizontal access through multiple drifts to the Kirk Canyon and to the Open Cut, is of interest for early development of physics experiments that require modest shielding, to address safety and environmental issues associated with uses of cryogens (liquid nitrogen, liquid noble gases, dry ice, etc.), to conduct preliminary geotechnical designs of excavations for equipment housing, education and outreach (E&O) accesses and displays. CO_2, with molecular weight of 44 will be evaluated as an analog for Argon (Ar) with atomic weight of 40. There are indications that 300L represents the water table before mine excavation activities de-saturated the subsurface to a depth greater than 2.4 km (8,000 ft). There are also old stopes at 300L that were likely backfilled. Thus, 300L can be relatively quickly developed first as a "Critical Hydrology, Ecology, and Earth Research Site" (CHEERS).

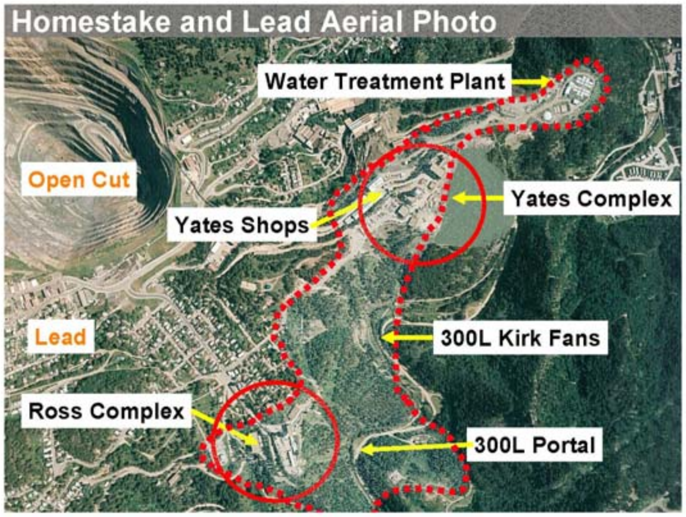
With 300L close to the surface—its overburden ranging from a few meters to over 100 m—and with existing boreholes connected to upper and lower levels and shaft to the surface, we may develop an integrated program for underground processes coupled to traced gas dispersion studies in the atmosphere. Gaseous releases underground need to be vented to the surface for dilution; they act as controlled sources for flux measurements through surface plots and vertically along towers erected in the surface campus.

Observations and Implications – Surface and 300L:

Along the two drifts currently allowed for inspection, we have observed that one drift, the Kirk, seemed to be relatively free of water drips, but with some walls wet covered with “biofilms”, and some ceilings with “calcite-like” precipitates. In comparison, the neighboring drift, the Oro Hondo, had frozen seepages observed during the same visit on 2/20/2008. These “icicles”, distributed at some but not all locations, clearly demonstrated that Oro Hondo Drift has more seepage from the ground surfaces above the drift, with infiltration strong enough to freely enter the drift. There were no (or less) biofilms observed along the Ore Hondo drift as compared to hose observed along the Kirk Drift.

The observed differences could be simply due to the differences in the surface conditions, including the presence or absence of soil covers, rock fractures, topographic reliefs, and local ponding conditions. We thus propose to instrument both drifts and the surface areas directly above, to correlate precipitation (including snow), infiltration, and seepage. We will also construct a local model over both drifts, with topographic variations, soil and tree coverage, mapped fracture networks taken into account to interpret the field observations. Such an exercise or task could contribute to advancement in hill hydrology, mountain front recharge, and many interesting issues associated with watershed water balance modeling. (This is why we have “Critical Hydrology” for our first two letters in the Activity title “CHEERS”)

Another interesting observation from the satellite photo is that we have fewer trees per unit area on the ground surface within the SDSTA property boundary, in comparison with the denser coverage across the Kirk Road on the eastern side of the property. Obviously we have no trees in the township and in the administrative building areas. This satellite photo inspires the proposed task for soil monitoring, with areas within the SDSTA property divided into plots, each with different densities of tree coverage, soil covers, and ecological characteristics. (Now we have “Ecology” for the third letter in “CHEERS”). CO_2 releases (and later argon and others) and sensing at surface and from 300L are planned.



Proposed Tasks:

Now let us propose a few tasks as listed below.

Task 1.1: Dispersion through Soils and Atmosphere above 300L.
Task 1.2: Seepage and Biochemical Alternation along 300L Drifts
Task 1.3: Deformations below Overburdens (to be combined with Suggestion 4.1)
Task 1.4: Drainage below 300L and Accesses to Open Cut
Task 1.5: Geotechnical Designs - Shallow to Deep
Task 1.6: CHEERS-300L

Currently we expect to have SDSMT Atmospheric Sciences to define and lead Task 1.1. The major components are (1) monitoring of weather and vertical concentration/flux profiles from surface to ~ 100 m above ground with a tower similar to the one illustrated above, and (2) measurements through surface plots. The sources range from point releases at ventilation outlets, to areal releases through the bed rocks. These are two types of releases anticipated from accidental gaseous releases. We plan to design experiments specific for different scenarios with controlled releases, to be integrated with Task 6 for the whole site evaluation.

Task 1.2 is aimed to address the field observations of heterogeneous distributions of seepages, biofilms, and precipitates. We expect that the in-drift observations have both spatial and temporal variations. We thus should have cameras and rock surface sensors mounted to continuously monitor (1) inflow seepage associated with precipitations, (2) frozen occurrences in winters, (3) melting in springs, and (4) dry up in summers. It is possible that we can observe the effects of climate changes, with one year wet and the next year dry. This task will need interfaces with many site characterization activities, such as weather measurements in Task 1, results of other mapping exercises, and in-rock measurements from the drift level to the ground surfaces through variable thickness (also part of Task 6).

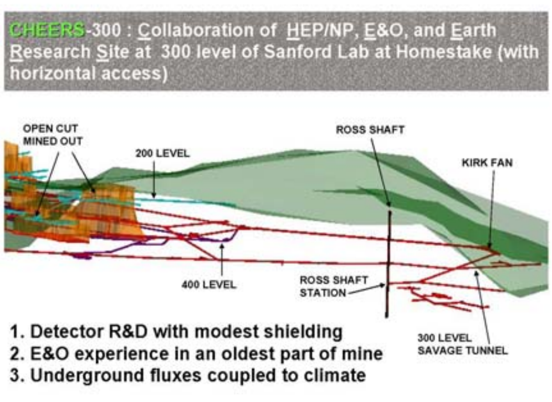
We propose Task 1.3 to identify a ~100 m long drift segment in 300L for controlled deformation measurements: (1) a pressure-pulse experiment, and (2) a long base tiltmeter experiment. Pulse injections into a packed interval below the drift floor will induce deformations both along the borehole and in the shear directions. We can monitor induced pressure and deformations as the fluid pressure overcomes the confining stresses. We can also monitor the tilts induced by the injections, with deployment of long base tiltmeters. Two groups from France plan to carry out this pair of tests 300 m underground at the Low Noise Underground Lab (LSBB). Both groups expressed interests to collaborate with DUSEL scientists and carry out the tests at two depths, one along 100 m at 300L with up to 100 m overburden, and another along 1 km distance at 2000L with 600 m overburden. Our S-4 activity selects test locations, addresses the logistics and EH&S issues, participates in the test design, and collect the data for complimentary modeling and understanding. (Note: this Task will be integrated with Suggestion 4.1).

Task 1.4 will focus on a few locations within 300L, chosen primarily for geotechnical evaluations (Task 1.5). The geotechnical evaluations are driven by users of 300L, either (1) to house a prototype detector, say a 5 kt Liquid Argon detector, a germanium detector, etc., or (2) for rooms needed for E&O classroom, display, and for other equipment fabrications, or (3) for connections to the Yates Complex for E&O tours through raise bore and ramps directly from the Sanford E&O Center. The 300L, with its horizontal accessibility, is a logical place for underground tours, for equipment staging, or for component fabrications protected from direct exposure to sun lights. We have identified so far an interesting location along the Kirk Drift. The Kirk Drift crosses over a Savage Tunnel located 5 m below. Currently we have drain holes from Kirk Drift to the Salvage Tunnel. The field photos at this "intersection" indicate that the Ellison formation rocks at this location is in fairly good conditions, possibly feasible for a new excavation ~5 m in diameter and ~5 m in depth to house a physics detector. Task 1.4 will also explore the extensive drifts towards the Open Cut, with some partially backfilled already. Blocked drifts require extensive rehabilitations to reopen – a challenge for EH&S and an opportunity for ecologists and biochemists to explore one of the oldest parts of the mine. One additional activity for Task 1.5 is to explore options to link 300L with Sanford Education and Outreach Center, currently envisioned to be located across the parking lot of Administrative Building at the Yated Complex. Options may include new drift branching out of existing drifts, new drifts from the Kirk Canyon, dedicated shaft/raise-bore for E&O direct tours to the underground, excavate a new station at Yates shaft, and other configurations which might be more convenient, more economical, or satisfying other project desires and needs.

If the Project do decide to proceed with development of 300L as the Upper Campus for DUSEL early, we need to have a well-defined methodologies established. This Task 1.5 is to be led by Fermi Lab, integrating underground excavation experiences associated with neutrino beam line housing (MINO tunnel), physics experiment hall construction (Soudan mine), and near-surface designs (Nova and Ash River off-axis). The design-and-built procedures, cost estimates, and state-of-art mining advances to be developed at Task 5 will be extremely valuable for similar excavations at greater depths.

Task 1.6 is the integrating task for all 300L monitoring and testing tasks. It will be responsible for designing any gas release experiments driven Task 1.1, interpreting coupling between climate and in-drift seepage and biochemical alternation observed in Task 1.2, coordinating pressure injection tests and deformation monitoring of Task 1.3, characterizing the drainage site and coordinating data collections along backfilled drifts in Task 1.4, and working with engineers, physicists, E&O, EH&S in Task 1.5. Task 1.6's additional focus is on the design and installation of a nest of boreholes to judiciously charactering all processes from 300L through the varying overburdens to the ground surfaces. We believe that all important processes operating over the "critical zone" are present in this system: the CHEERS-300L. If we need to extend the CHEERS to deeper levels, we will recommend the extension based on our 300L findings. From a critical zone viewpoint, we may eventually regard the whole DUSEL facility to 8000L and beyond as one integrated CHEERS.

Task 1.5 and Task 1.6 described in this S-4 proposal are related to the 2 tasks in a DUSEL R&D Proposal submitted 12/3/2007 to DOE Office of Science High Energy Physics (Proposal FY08-004 from LBNL Earth Sciences Division, pending). Please note that we had a different vision for the R&D definition of "CHEERS": with "CHE" standing for Collaboration with High-energy physics/nuclear physics and with Education and outreach. The last three letters "ERS" stand for the same: Earth Research Site as in the early definition of CHEERS (Critical Hydrology, Ecology and Earth Research Site). We retain the same acronym to maintain the continuity in developing 300L from different prospective. Obviously we will not have duplicating efforts and have coordinating efforts for Tasks 5 and 6. (In the final S-4 proposal we will clearly articulate the division and transition from DOE HEP project to NSF S-4 project, each with distinct and discreet emphasis. The details will be further articulated.)



<u>Infrastructure and STSDA Support Needed</u>:

Task 1.1: Erect a 100-m tall pole (the tower itself is available from SDSMT) within the SDSTA property boundary.
Interact with local high schools, Indian tribes, and Sanford E&O Center to develop surface plots for high school projects.

Task 1.2: Mount cameras and sensors on walls, with seepage and moisture measurements and auto-sampling for biochemical evaluations.
Task 1.3: Characterize test sites, drill injection and monitoring boreholes on the drift floor. Mount long base tiltmeters (see Suggestion 4..
Task 1.4: Logistic supports for reentries into old drifts with hydro-bio-chemical sampling.
Task 1.5: Logistic supports for geotechnical evaluations.
Task 1.6: Drill boreholes or raise bores from underground.

Funding:

A request of $500K is pending for CHEERS-300L from DOE Office of Sciences High Energy Physics, supporting LBNL, Fermi Lab, and associated interfaces with physicists, “Transparent Earth”, Sanford E&O, and SDSTA supports. The S-4 funding requests will be determined with SDSMT on Task 1.1, with Fermi Lab on Task 1.5, and with interested parties on other tasks. Tentatively, we include 0.5 FTE led by SDSMT Atmospheric Sciences.

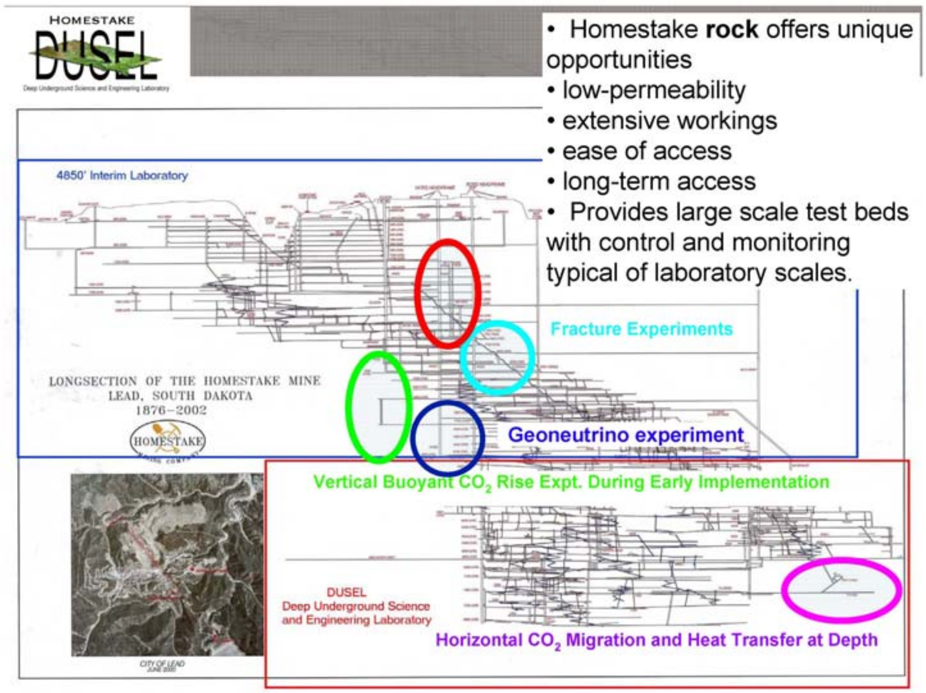
Activity 2: Large Scale Migration for CO_2

Abstract of CO_2 Controlled Sequestration Experiment:

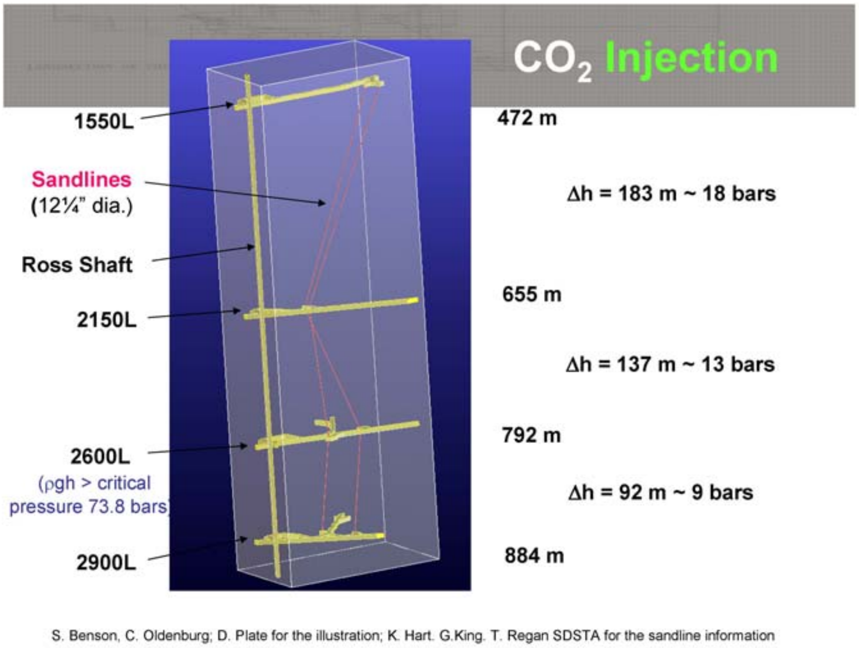
At Homestake, a considerable number of boreholes have been drilled between layers for drainage, ventilation, ore dump, and fluid transport over many years of mining there. We have identified some of the existing infrastructure for potential deployment of field-scale controlled experiments, namely the use of sandlines for CO_2 experiments, which involved the injection of supercritical CO_2—measuring phase transitions and residual CO_2 trapping. Sand-filled columns can be designed with sensors imbedded inside or mounted on the casing of pipe segments (each, say 5m long), to be assembled along ~0.3 m (12 ¼”) diameter sandlines of length ranging from ~50 to 150 m (150 to 450’). These sandlines can be further connected at test stations located at intermediate depths. This activity will also address basic research needs identified for multiphase transport associated with basic energy sciences, with applications to CO_2 geological sequestration. Note that we are not restricted to only pure supercritical CO_2 injections, but also open to other fluid phases and co-injections with multiple species (see Tasks 2.3). As noted in footnote #1, we have redefine CHEERS for Carbon in Hydrologic Environment for Enhanced Retention and Sequestration – our main focus in the S-4 development for CO_2 Multiphase Sequestration as an ISE.

Observations and Implications using “Sandlines”:

During the early years right after Year 2000 when the Homestake was first proposed as a DUSEL site (known as NUSEL then, with N for National, and no E for Engineering), we were looking for sites at grater depths (higher pressures and temperatures), larger diameters (shafts or wintzs with up to 12’, not 12” in diameter), and isolated segments at the end of drifts. However, we are more practical now, with interests on shallower regions, easier to access, etc. We also recognize that one of the most attractive feature at Homestake is its existing infrastructure, with layers ~50 m (150') apart. We should taker advantage of the unique characteristics offered by Homestake, and design controlled experiments not feasible or practical anywhere else.



The SDSTA team was instrumental with the suggestion to use "sandlines" for the CO_2 sequestration experiments. It was pointed out that there are many nearly vertical holes, with relative large diameters on the order of 1', drilled for transporting sand slurries from the surface to "stopes" left behind after ore extraction operations. The wasted rocks, or "sands" after gridding, were mostly disposed by reinjection back to the empty spaces left behind after ore removal. The backfill operations greatly reduced the potential for dangerous collapses. We thus plan to focus on pairs of "sandlines", specifically the ones from 1550L to 2150L, 2150L to 2600L, and 2600L to 2900L. There are many other sandlines continue down throughout the mine. We plan to use the others after we demonstrate in S-4 that we can indeed design and implement controlled experiments, before searching for boreholes and drift ends for deeper, hotter, and potentially higher pressure regions.



Sandlines start and end at "bathtubs" at different levels. The "bathtubs" are located in specially excavated niches or rooms, with half-walls built to form a "basin" for slurry ro depressurize below continuing downward to the next set of "bathtubs" through "sandlines". We propose to convert these "bathtub" stations to "geo-test" stations, not just for CO2 injection experiments, but for many other experiments sharing the common requirements.

Proposed Tasks:

Here we list the S-4 tasks for technical design for this activity to become one of the candidate in the initial suite of experiments:

Task 2.1: Selection of Test Locations.
Task 2.2: Design of Field Implementation Sequences.
Task 2.3: Selection of Fluids, In-filled "Sands" and "Rocks", and Pre-Assembled Test Segments
Task 2.4: EH&S Procedures
Task 2.5: Field Demonstration of Feasibility before Injections
Task 2.6: Test Design and Implementation to Address Basic Research Needs.

We have revisited only one "bathtub" site at 1550L. In the coming months and years, we plan to access more sites to prioritize which are feasible. There are various considerations to be incorporated: the proximity to power, compressed air, water, gas lines, etc. This is only possible if STSTA endorses this experiment. We also need to consult with other experiments to explore the idea of sharing the same "geo-test" beds, perhaps even extending to low background counting, radiation evaluations, mobile biological labs, etc. This is the scope of Task 2.1 envisioned.

Task 2.2 is on the practical constraints on field implementation. Can we indeed ship 5 m long segments of PVC or aluminum tubes, threading through from one bathtub through a sandline to the next level 50 m to 150 m below?

Task 2.3 addresses: What kind of sands, rocks, or a combination of different media? Do we have the medium properties characterized already in the labs? What kind of fluids do we start with: Just water without sand? Compressed air injection? Liquid nitrogen injection? Dry ice as sources of CO_2? Liquified CO_2? Supercritical CO_2? CO_2 with petroleum additives or tracers? Argon or other noble gases?

For the segments, one option we are exploring is whether we should have a uniform design or could have different segments designed by different groups (including potential industrial partners with "smart-well")? Each segment has both in-bore and out-bore sensors for hydro-chemical-biological measurements and for geophysical imaging tools to monitor phase changes and counter flows?

Task 2.4 addresses the critical procedures associated with field implementation. Since we are dealing with fluids other than pure water and air, we need to have sensors deployed around potential leakage points (led by Steven Glaser). This task will work closely with STSTA and DUSEL EH&S teams to make the experiments implementable.

Task 2.5 conducts dry runs with the steps developed in Task 2.2 for readiness assessment before injections. How do we connect the segments in the field without leakage? Do we fill the segments in the field or on the surface in the lab? How to sample residual saturation, with CO_2 stuck on rock surfaces, i.e. assess sequestration potential? *In situ* or direct sampling?

Task 2.6 will embark on the integrated design and interfaces with lab preparation and modeling. We have reviewed some results of lab measurements, and used solutions of counter flows in response to gas injections to initiate the test designs. We have plans to use equation of state packages for supercritical CO_2 injections into sand columns. This Task will systematically use models and lab results to estimate the test durations and locations of the phase transition zones along the sandlines. We have also reviewed the Basic Research Needs from the 2007 DOE BES report to articulate the role of controlled field experiments to address basic questions and technical challenges associated with CO_2 sequestration specifically and multiphase flow processes in general (assessed by Curt Oldenburg). Task 2.6 will be the task to interpret the test results and analyze if key issues are resolved.

Infrastructure and STSDA Support Needed:

Task 2.1: SDSTA Teams will support the selection of sites and determine the constraint to use different "bathtubs' and sandlines.
Task 2.2; The test sequence can be tested and refined with SDSTA field supports.
Task 2.3: Fluids, sands, rock media, tracers are evaluated with Material Safety Data Sheets together with SDSTA.
Task 2.4: Pressure, temperature, fluid releases are monitored with sensors acceptable to STSTA EH&S procedures.
Task 2.5: The readiness dry-runs are conducted with SDSTA.
Task 2.6: Consult SDSTA in adjustments in test designs.

Funding:

1- 1.5 FTE for design effort?. We anticipate that we may need over 5 FTE annually for this activity after proof of concept.

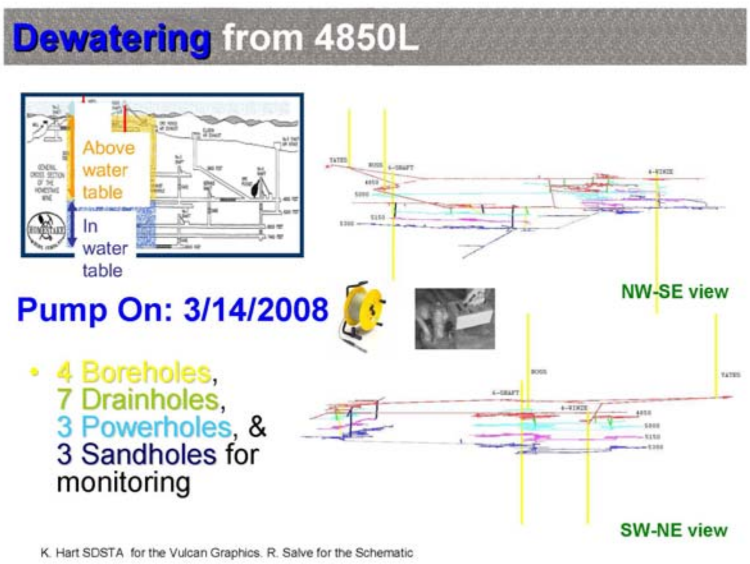
Activity 3: Monitoring of Mine Dewatering and Carbon-Cycle Site Modeling

Abstract:

The rise of the water table since mine closure in 2003 is the result of localized inflow from the open cut and ground surfaces, as well as from the surrounding groundwater. When the Sanford Lab reclaims the upper levels and conducts the scheduled dewatering operation, we can use the water table changes in shafts and many boreholes to characterize the entire site, to verify that the formation is tight, and to determine how much the water-rock interactions affect the water quality, both locally and regionally. The unique data set can be used to develop and calibrate site models. The effective open space volume (i.e., tunnels, open space in backfill material, and connected pore space in the geologic formation) is not known accurately. The site models can inversely determine this type of parameters, as well as effective hydraulic parameters in the cone of water table depression, from matching the slow rising and subsequent responses to dewatering by pumping. Seeps observed in freshly de-saturated drifts are expected to flow either for a short period determined by the local storage capacity, or for long time periods determined by connected flow paths to the infiltration sources. We can also verify whether localized and/or pressurized water pockets are present at depths, and assess the distances to the water not affected by previous mining activities in the surrounding formations.

Vulcan Survey and Implications:

There are many information and records about 4850L. Since it has not been inspected yet in the reentry operation, we have reviewed the Vulcan database and identified holes in the record from 4850L to lower levels. This information is illustrated to demonstrate the possibility of using the small holes together with large shafts to monitor the planned dewatering operations. With the instruments needed for shaft monitoring recently funded and transducers ordered, we will briefly summarize the potential supplementary deployment of handheld sensors in additional to the shaft monitoring.



Proposed Tasks:

The SDSMT Hydrology Team will be responsible for the shaft sensor installation and data collection. We will consult and coordinate the tasks listed with them:

Task 3.1: Supplementary Data Collection with Handheld Meters.
Task 3.2: Seepage Monitoring during dewatering.
Task 3.3: Synthesis of Water Flow and Quality Data (focusing on carbon-related).
Task 3.4: Site Models Calibrated with Both Flooding and Dewatering Data.
Task 3.5: Assessment of Conceptual Models and Model Uncertainties.
Task 3.6: Comparison of Homestake Hydrology with Other Settings.

Task descriptions will be further developed during the Workshop.

Infrastructure and STSDA Support Needed:

We advocate that the reentry team periodically monitor visually and with handheld meters to collect supplemental data. The dewatering is a one time operation. We lie to confirm that the water table during dewatering is well-defined, with no localized water columns lagging behind the water table declines.

Funding:

TBD. We anticipate that the effort could be 0.5 – 1 FTE for initial modeling effort, from hydrological models to carbon-cycle models.

Activity 4: Extended Use and Research Opportunities (EURO)

Abstract of EURO:

We will collaborate with the physics and biology research communities to explore uses of existing and new infrastructure (drifts, rooms, ramps, boreholes) and to stimulate interdisciplinary activities. Knowledge from ongoing studies associated with reentry operations and funded research will be integrated and presented to new investigators interested in developing new ideas and new applications. We will also assist DUSEL in exchanging information with many underground research laboratories for both physics-detector housing and for coupled-processes evaluations. While each site and each setting is unique, there is knowledge and experience (e.g., in sensors R&D) of mutual benefit to the advancement of underground science and technology. Given that DUSEL represents the U.S. frontier in deep underground science, we can certainly offer the Homestake site as a hub for international collaborations.

Suggestions and Examples:

We are using the findings from a recent trip as examples for further developments in international collaborations. The trip was to the Low Noise Underground Laboratory (LSBB, http://lsbb.unice.fr), at Rustrel-Pays-d'Apt in southern France. LSBB has well-defined infrastructure established within 10 years with focused science and technology activities. The LSBB - Laboratoire Souterrain à Bas Bruit is a horizontal tunnel complex converted from a land-based missile-launch control center into a laboratory dedicated to *interdisciplinary* Underground Science and Technology (*i*-DUST). Since its inception in 1998, LSBB has developed and established international participations with its focus on deploying small and intermediate size experiments for both basic scientific investigations and practical technology testing in low noise background environment.

The experience and findings over the development of LSBB for i-DUST is relevant to the Homestake DUSEL as a successful case study in making direct and smooth transition into a user facility. Furthermore, the "Extended Uses and Research Opportunities" theme in Homestake DUSEL can be further developed realistically by inviting investigators in LSBB *i*-DUST and worldwide to collaborate with us, to conduct R&D on sensitive equipments, to adopt state-of-the-art approaches, and to develop international and inter-disciplinary collaborations.

The current scientific investigations at LSBB include dark matter search at room temperature, superconductivity quantification in low magnetic environment, seismic monitoring with sensitive equipments, seismic to electro-magnetic coupling from epicenters to ion-sphere, borehole-, drift-, to regional scale hydrology, geochemistry, and coupling to rock deformations in the fractured karst rocks, coupling to earth tides and earth rotation, and others. The technologies being tested include reliability of nano-components of electronic devices, calibration of satellite-bound equipments, effects of micro-wave irradiations on biological metabolisms in low noise environment, and others.

Some specific activities envisioned from discussions at this 2nd International Conference on Underground Science are listed.

Suggestion 4.1: Technical Exchange on Seismic Monitoring at Homestake, and LSBB, and Worldwide — The Director of LSBB and his many collaborators are interested in sensitive seismometers (STS2) to map the mountain of LSBB, and to monitor seismic events locally, regionally, and worldwide. The seismic station RUSF is a permanent observation point of international seismic network[3]. The seismic related interests at Géosciences Azur Laboratory, University of Nice – Sophia-Antipolis, include pendulum rotation, rock-fluid interaction, etc. The technical exchanges with Homestake DUSEL will be further developed with investigators of the "Transparent Earth" project of Homestake DUSEL, and with the investigators of the LIGO Project for laser interferometer gravity-wave observatory.

Suggestion 4.2: Field Testing of Hydro-Mechanical Equipments and Coupling —The High Pulse Poroelasticity Protocole (HPPP) developed at Géosciences Azur Laboratory, and the Long Base Tiltmeter (LBT) developed at Géosciences Montpellier are two examples of sensitive equipment to be deployed along a 250-m long LSBB gallery with on average 300-m overburden. It is feasible to test these equipments also at Homestake DUSEL in the 300-ft (100-m), the 2000-ft (600-m depth with lateral extent up to 4 km), and other levels for additional meso-scale evaluations. This suggestion is also given above in Activity 1, Task 3.

[3] Wansand, G. 2006. "The low noise underground laboratory of Rustrel-Pays-d'Apt". J. Physics: Conference Series 39, 157-159. The article is available at http://lsbb.unice.fr. The article also provides overview of the low noise conditions and unique environmental and technical characteristics in terms of anisotropic activity. seismological noise, gravity, and electromagnetic shielding at LSBB.

Suggestion 4.3 : Multi-Scale Coupling of Electromangetic and Seismic Waves — With its unique room shielded from magnetic field[4], LSBB is the site for tests of digital SQUID magnetometers led by Univ. Savoie. Early observations of the correlation between seismicity and superconductivity at LSBB has led to great enthusiasm about the coupling of electromagnetic waves with seismic waves. Other significant studies include the imagings with microwave antenna of Univ. British Columbia, the irradiation of microwave on plants planned by the Univ. Avignon, and the coupling of seismic signals to ionosphere study led by CNRS-Orleans. The EM waves travel faster than the seismic waves. It is likely that further development at underground labs worldwide on this coupling could open up new predictive methodologies and new fields.

Suggestion 4.4 : Comparison between Karstic Aquifers and Metamorphic Rocks — We can use such a comparison to test (1) the hypothesis that local saturated condition near the tip of rock surface is responsible for seepage in man-make galleries (LSBB) and natural caves (observed by investigators in Chrono-Environnement - Besançon, EMMAH – Avignon - France, U. Magala - Spain), and (2) the hypothesis that regionally in karstic formations, mountains are unsaturated above water table due to its highly permeable and complex characteristics, while water tables follow the topographic variations in many other rock types. At Homestake, the permeability may be very low locally and water-table may be ill-defined. These are examples that comparative hydrological studies at both sites may shed light on fundamental understanding of hydrology at different formations.

Suggestion 4.5 : Radiative Characterization — The planned radiative characterization at LSBB in 2008, the radioactivity survey assessment at French Navy's Roule underground laboratory (Cherbourg-France), and the intense interests at Homestake DUSEL to establish multi-user Low Background Counting Facility have many approaches and techniques in common. We can also include in this suggested collaboration the interests in tracer studies with dissolved organic matter or CO_2 (EMMAH – Avignon, CNRS-Grenoble), and other geochemical measurements in bio-chemical samplings.

Suggestion 4.6: Extended Uses and Research Opportunities (EURO) — LSBB with its low noise environment has attracted a long term testing program on self error rates in electronic chips (IM2NP – Marselle, Principal Engineer from San Jose, USA, LSBB, XILINX), on an electric force microscope for metal-semiconductor-insulator interface layers (U. Cezanne – Marseille),

[4] *Ibid.:* The main experimental area of LSBB is the old control room at 500 m depth, which was built as a Faraday cage isolated from mechanical vibrations, thus the shielding reduces the magnetic field. This EM shielded, mechanically isolated room (100 m^2 floor) has magnetic field less than 6 μT, a long time stability of better than 20 nT and fluctuations below 2.5 fT/√Hz.

on a double torsion pendulum for testing LISA (a space interferometric antenna for gravitational waves) Gravitational Reference Sensor on the ground (U. Firenze - Italy), for a ring laser gyroscopes for Earth's absolute rotation rate (EOST-U. Strasbourg - France, Tech. U. Munich, U. Munich - Germany), and others. We could collaborate with LSBB to articulate Homestake DUSEL main characteristics – extensive infrastructure, heterogeneous rock formations, well-defined flow, benign geochemistry, and seismic quietness – to fully utilize our space and potential for underground science, engineering, and innovative technologies.

While the technical suggestions listed above are mainly on earth related investigations, the "EURO" suggestion should also include astrophysics and other physics experiments. During the call for Letters of Interest (LOI) in 2006 for the Early Implementation Program (EIP) at Sanford Lab there were a number (~10) LOI's acted on favorably by the Program Advisory Committee (PAC) but which did not fit neatly into the standard disciplinary categorization. Nor did they necessarily require the full facilities of any of the various "campuses" envisioned for DUSEL. Rather, they more often wished to take advantages of spaces/features truly unique to Homestake relative to other underground facilities. Often they did not require extended occupancy for completion of the experimental program envisioned or in some cases they represented exploratory experimentation in the service of a broader future program on important science. Because of these LOI interests a group of us were charged by the S-1 organizers of the November 2007 Washington DUSEL Workshop to investigate "How to foster the science represented by these other uses." As a result of that Workshop some mechanisms were proposed to foster these ideas and to provide them with access to process and due consideration. Of what these processes might consist is presented in the White Paper on Other Uses requested by S-1 and which is contained here as Appendix E (http://hep.brown.edu/users/lanou/B2-session-draft-v5.pdf). Support is requested here for Activity 4 to initiate and implement this process and to insure that the mechanisms merge smoothly into the future DUSEL management structure for support of the experimental program.

Funding Request:

TBD. 0.5-1 FTE effort for coordination and some travel supports? i.e. 0.1-0.2 FTE effort to support and coordinate with each of 5-10 groups per year?

Note: Appendices A-E will be included in the final S-4 submittal. Appendix B under development will discuss funding, responsibilities of participants, etc. in more details.