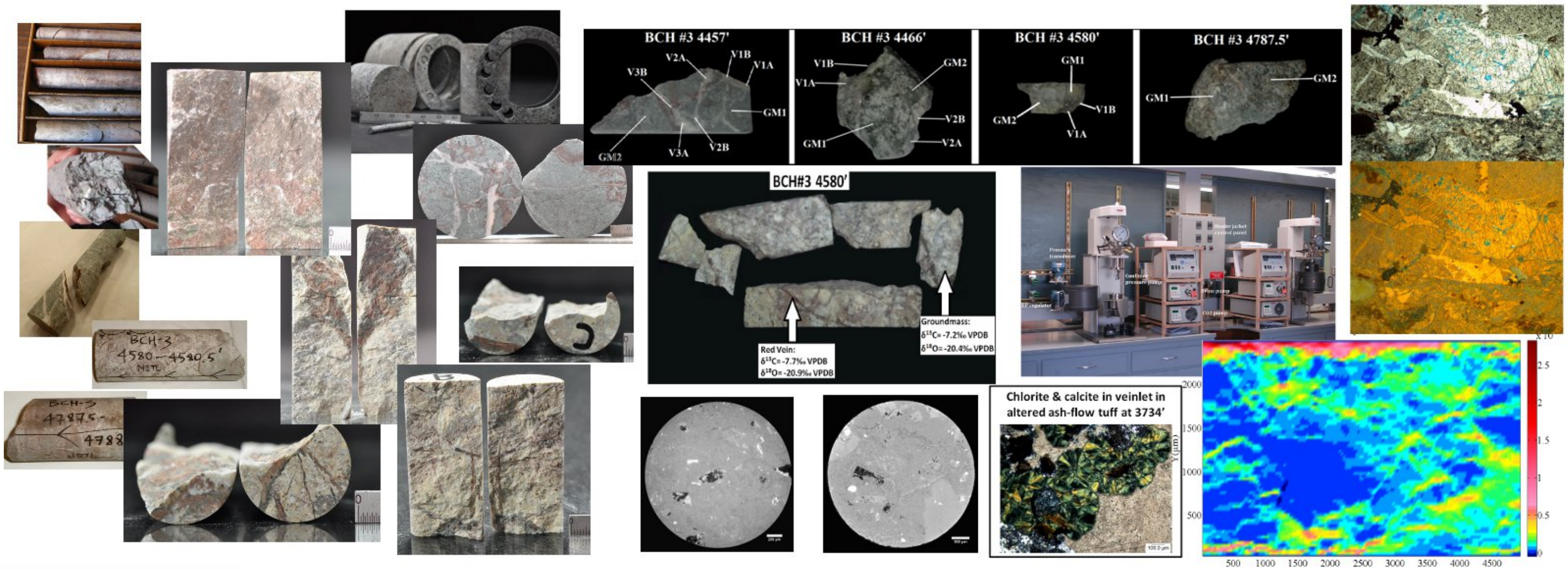



NETL-RUA Regional University Alliance
URS
PENNSTATE
West Virginia University
University of Pittsburgh

# Optimizing parameters for predicting the geochemical behavior and performance of discrete fracture networks in geothermal systems

**Alexandra Hakala (National Energy Technology Laboratory)**

Track 1

Project Officer: Lauren Boyd

Total Project Funding: $995,718

April 25, 2013

# Relevance/Impact of Research

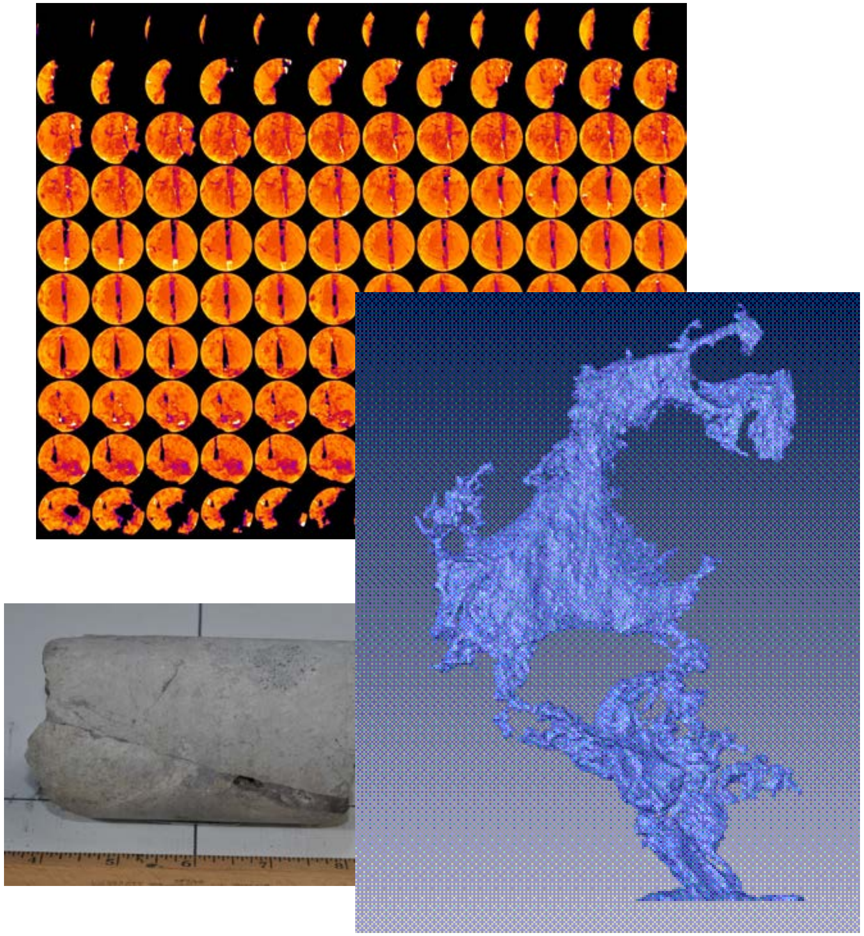


- Fractures – primary pathway for geothermal heat carrier fluids

- Rate of energy extracted depends on
  - Transmissivity of fractures
  - Rate of heat transfer between matrix and fluid within fractures

- Need for predictive modeling and monitoring tools for evaluating changes to fractures during cycling of heat carrier fluids

- **This project:** Goal is to couple fluid-phase monitoring with model-based prediction of fracture behavior



Natural fracture from Brady's core CT images
Depth 4579

# Relevance/Impact of Research

**Project Goal:** **Develop an optimized approach for approximating geochemical evolution of fractures in EGS reservoirs**

**Primary objectives:**

- Predict changes in fracture transmissivity due to chemical reactions using reactive transport with fracture flow models; verify with laboratory experiments
- Application of specific isotope systems as indicators of fracture flow pathway-specific fluid-rock geochemical reactions

**Anticipated outcomes:**

- Optimized reactive transport model that accounts for
  - Reactive fluid flow
  - Changes in fracture transmissivity due to fluid-rock reactions in EGS reservoir samples
- Demonstrated use of naturally-occurring isotope tracers for characterizing fluid-rock interactions within EGS reservoir fractures

# Relevance/Impact of Research

**GTO R&D Goal: "Temporary sealing of fractures: non-damaging, operation at up to 35 bar pressure differences, up to 300C, operation period of up to 60 days, applicable to fracture openings from 2" to less than 1/16" wide."**

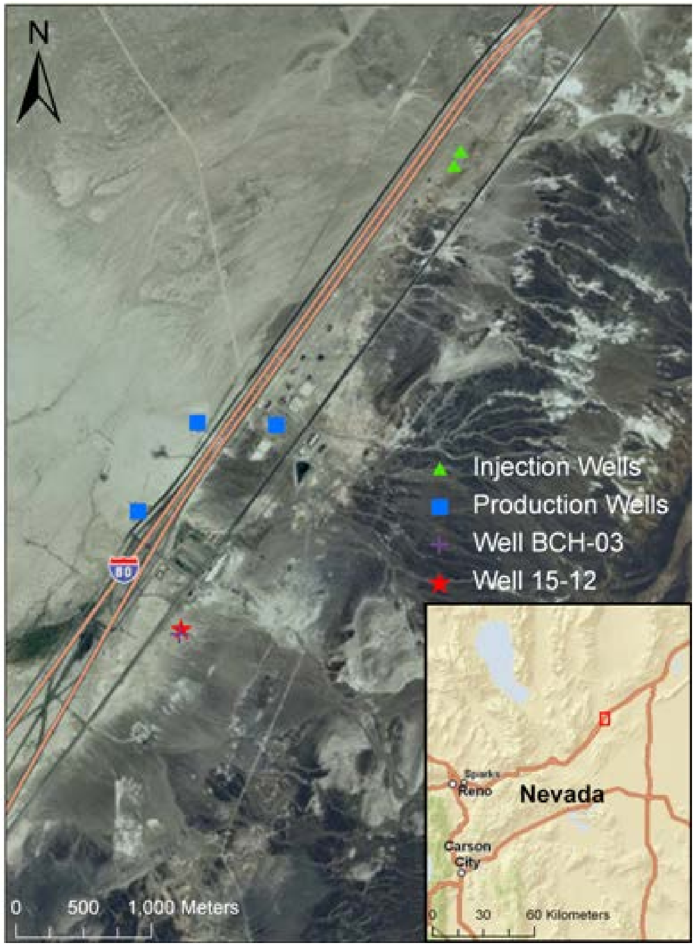
**Our Project Goal: Develop an optimized approach for approximating geochemical evolution of fractures in EGS reservoirs**

- NETL-RUA capability: Coupling high-resolution/non-destructive imaging of fractures with measurements of what mineral material is exchanged with the matrix rock; ability to validate core-scale models
- After core-scale validation, models can be applied with a greater degree of certainty at the field scale to assist with predictive studies of field evolution and energy production.
- Naturally-occurring geochemical tracers measured in produced fluids, such as Sr, C, and O isotopes, may be used to predict reactions that occur in EGS reservoir fractures.

# Brady's Geothermal Field, Nevada



- Brady's Field
  - Field-operated by ORMAT Technologies
  - 80 km (~50 mi) E/NE from Reno, NV
  - Combined flash and binary power plant
  - Reservoir temp ~ 175 to 205ºC at 1-2 km depth
  - Prior concerns with short carrier fluid residence time, excessive draw down, and connectivity between injection and production wells – consideration of EGS
- Prior Study: LANL-NETL ARRA Funded project



# Scientific/Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

| Experimental Team | Imaging Team | Modeling Team | Isotope Team |
|---|---|---|---|

**Dustin Crandall**, **Grant Bromhal** — Fracture Flow and Imaging

**Christina Lopano**, **Barbara Kutchko**, **Corinne Disenhoff** — Mineralogy, Materials Characterization and Imaging

**Kelly Rose** — Core Logging

**Alexandra Hakala (PI)** — Geochemistry

**Yongkoo Seol**, **Eilis Rosenbaum** — Imaging and Modeling

**Li Li, Hang Wen** — Reactive Transport Modeling

**Shikha Sharma, Stephen Henry** — Stable Traditional Isotopes

**Rosemary Capo**, **Brian Stewart** — Non-traditional and Radiogenic Isotopes

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# Scientific/Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

<u>Experimental</u>

Fluid data for bulk chemistry

CT imaging for fracture changes

Petrography, XRD and SEM for solids analysis

<u>Modeling</u>

Reactive transport (predictive and descriptive)

Modification of CrunchFlow for complex 3D fracture geometry

<u>Imaging</u>

Industrial and micro-CT imaging of cores

Development of fracture geometry input for CrunchFlow

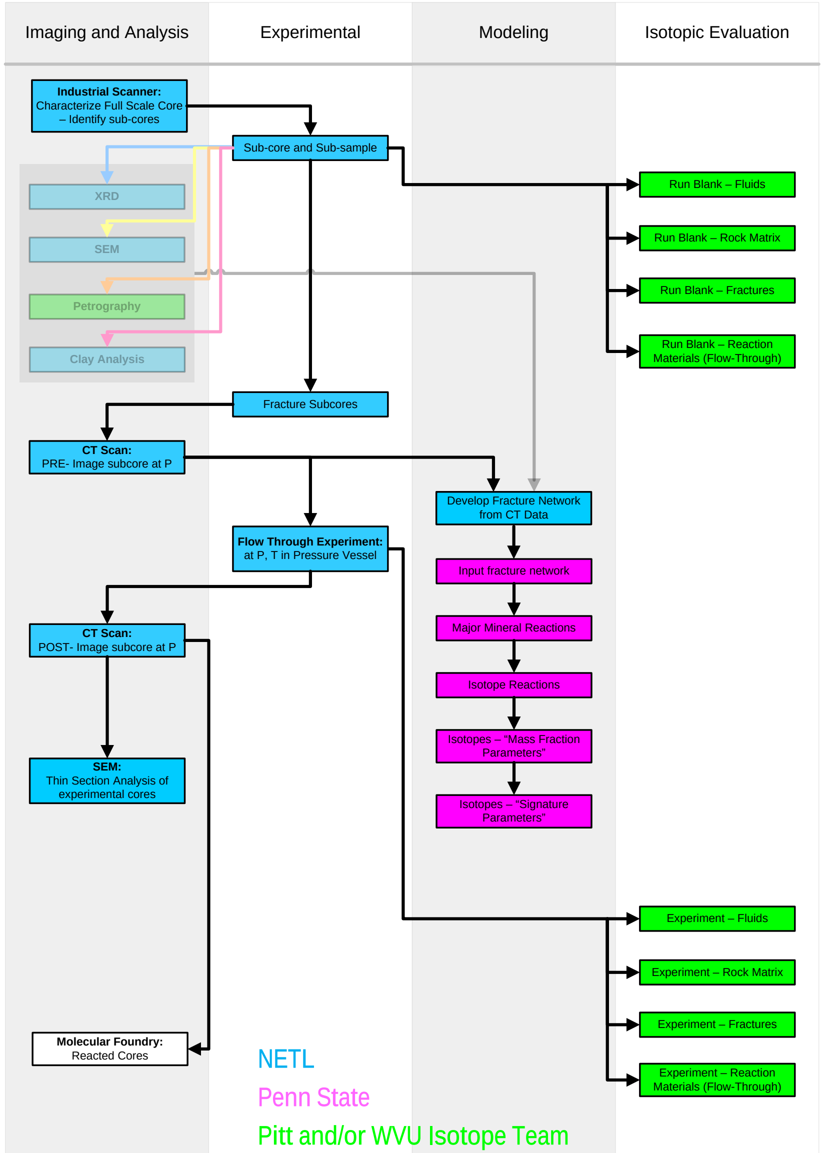
<u>Isotopes</u>

Characterization of experimental cores and fluids

Evaluation of relationship between reacted minerals and observed isotope signature in bulk fluids

# Scientific/Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy




**Task 1:** Coordination of experimental, imaging, modeling and isotopic analysis work.

**Task 2:** Development of reactive transport model coupled with 3D imaging data inputs

**Task 3:** Develop and perform flow-through experiments using Brady field cores

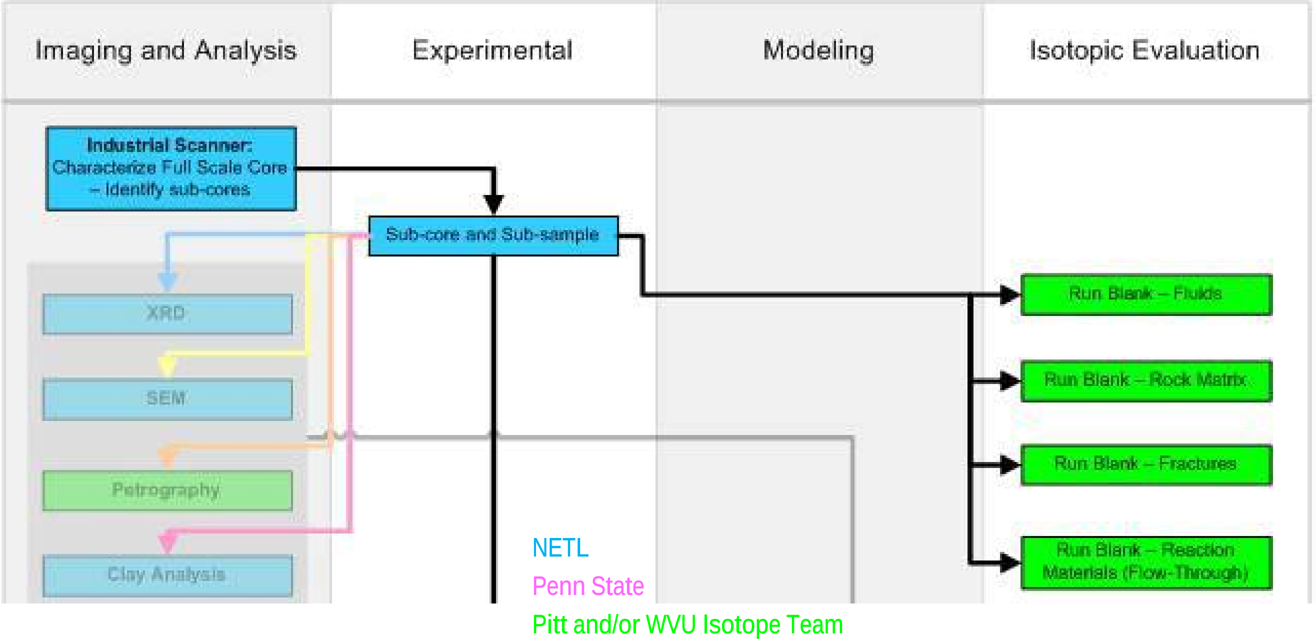
**Task 4:** Reactive transport modeling of fluid-rock reactions

**Task 5:** Isotopic evaluation of fluid-rock reactions

## Pre-Experiment Core Characterization

- Cores from BCH-03 core hole (4457 ft, 4467 ft, 4580 ft, 4788 ft)
- Core analysis: Petrography, Bulk Elemental Composition, Mineralogy*, Clay Analysis*
- Isotopes: C, O, Sr*

(* = still undergoing analysis)




| Original Planned Milestone/ Technical Accomplishment | Date Completed |
|---|---|
| T3: Acquire naturally-fractured cores from Brady's field | 02/02/2012 |
| T1: Select appropriate cores | 9/2012 |
| T1: Finalize suite of isotope systems | 12/2012 |
| T3: Baseline characterization of Brady field cores | Ongoing |
| T5: Initiate baseline isotopic characterization | Ongoing |

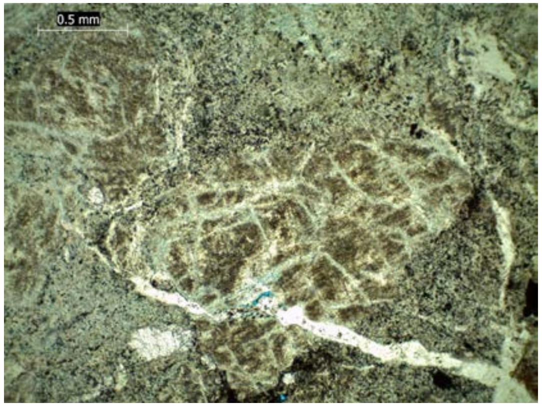
## Sample Pre-Experiment Characterization

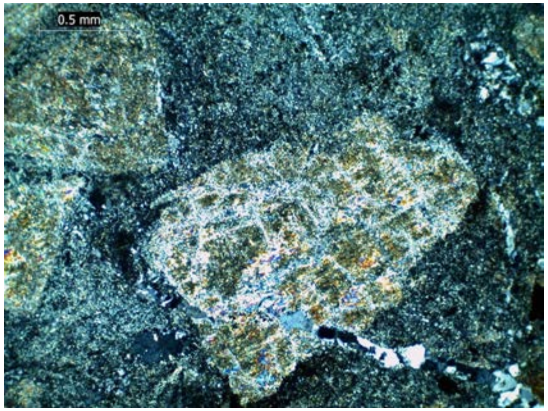
- **Core analysis: Petrography, Bulk Elemental Composition (Multi-Sensor Core Logger from GeoTek)**

**<u>Petrography for 4580 ft core</u>**

- Low porosity
- Mineralogy:
  - Chlorite; quartz and chert; sericite (illite/muscovite); iron oxides (hematite ± magnetite; some specularite); minor carbonate
- Propylitic alteration; serpentinization
  - Clasts and phenocrysts (including plagioclase feldspar) completely altered
  - Veins and fractures generally filled with quartz, clay minerals, chert

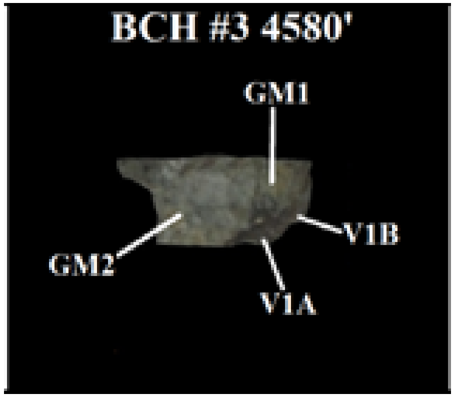
| Core Logger XRF Element Measured, 4580 ft core | % |
|---|---|
| Light Elements (lighter than Mg) | 45.6 |
| Si | 35.4 |
| Al | 7.7 |
| Minor Elements (Ni, Pb, P, S, Ti, V) | 3.0 |
| Cu | 2.9 |
| Fe | 1.9 |
| Ca | 1.9 |
| K | 1.7 |



## Sample Pre-Experiment Characterization

- **Core analysis: Isotopes: C, O**




- Powdered, homogenized samples weighed and analyzed for $\delta^{13}C$ and $\delta^{18}O$ on Gas Bench Device linked to a gas Isotope-Ratio Mass Spectrometer at WVU Stable Isotope Laboratory.


| | $\delta^{13}C$ ‰ VPDB | $\delta^{13}C$ Standard Deviation | $\delta^{18}O$ ‰ VPDB | $\delta^{18}O$ Standard Deviation |
|---|---|---|---|---|
| 4580' Groundmass | -7.03 to -7.07 | 0.03 | -20.17 to -21.27 | 0.78 |
| 4580' Vein 1 | -7.52 to -7.78 | 0.19 | -22.55 to -23.94 | 0.99 |

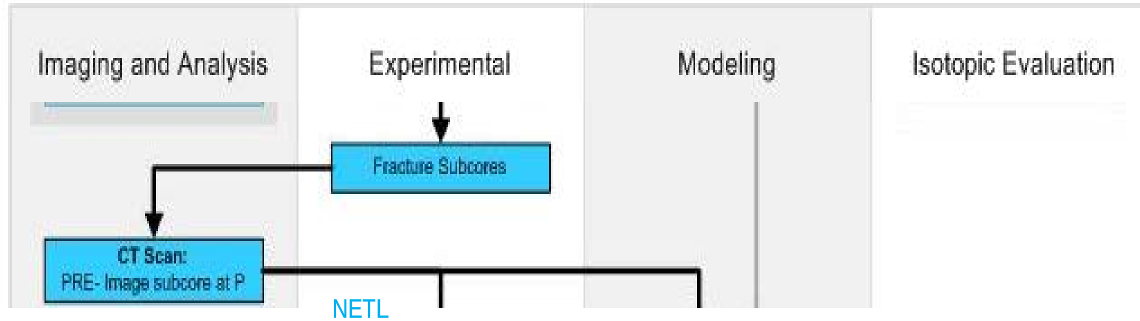
– Isotopic heterogeneity analysis of all cores: ~0.5 -1 ‰ variation in $\delta^{13}C$ and ~0.5 – 2.5 ‰ variation in $\delta^{18}O$ within the same vein and groundmass in samples from different depths.

– Cores used for the flow-through experiments are likely to have different isotopic composition.

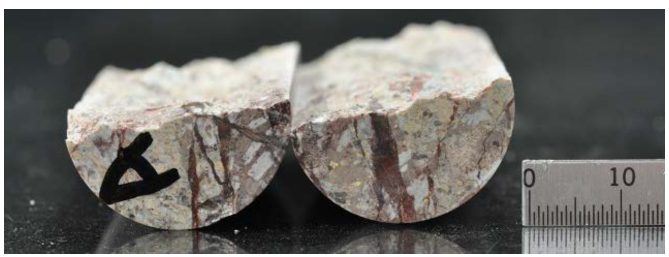
– The high isotopic variability in baseline isotopic signatures necessitates the use of reaction fluid with a very different $\delta^{13}C$ and $\delta^{18}O$ composition compared to the measured values of carbonates.

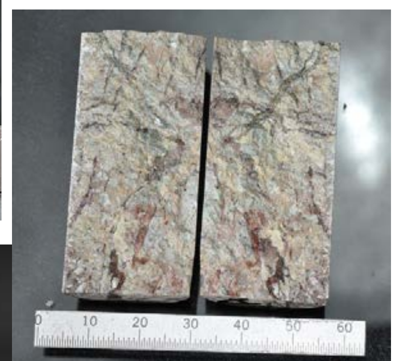
## Pre-Experiment Core Preparation

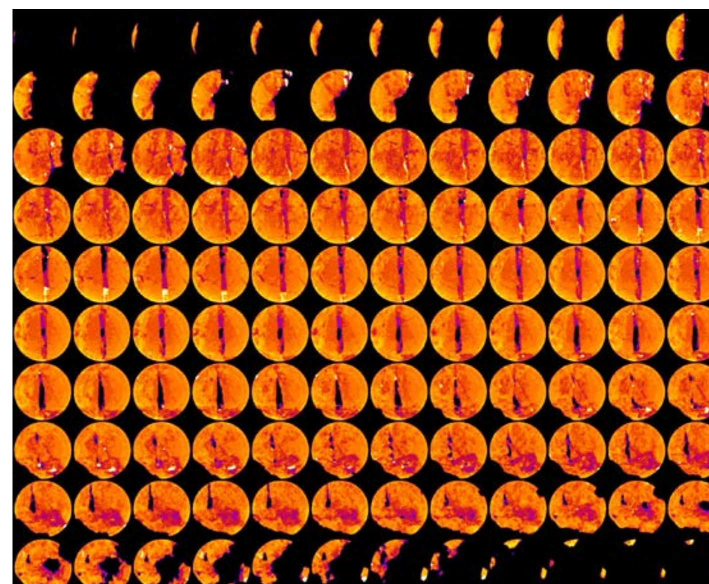
- Cores from BCH-03 core hole (4457 ft, 4467 ft, 4580 ft, 4788 ft)
- Generated synthetic fractures in subcores
- Collect pre-experimental CT scan image




NETL
Penn State
Pitt and/or WVU Isotope Team



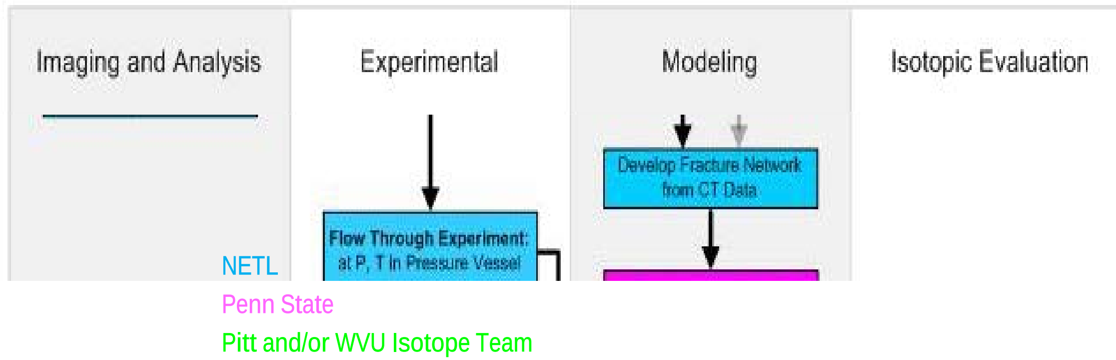




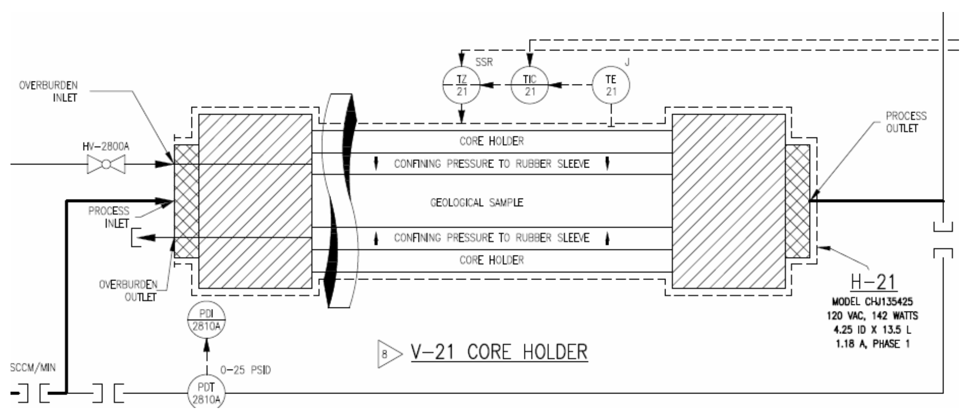
## Setup and testing of flow-through experimental system

- Core holder materials and sample design specified to account for isotope collection needs (up to 149 C temperature – improved temperature control system)


Example of flow-through system configuration

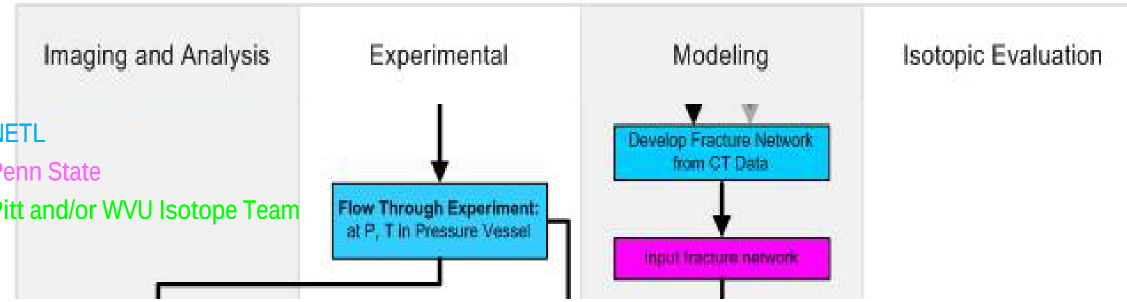



| Original Planned Milestone/ Technical Accomplishment | Date Completed |
|---|---|
| T3: Complete design of flow-through experimental system | 01/30/2013 |

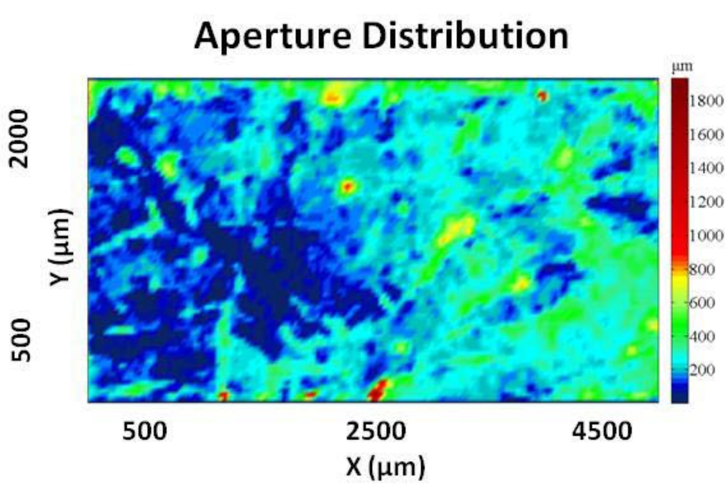


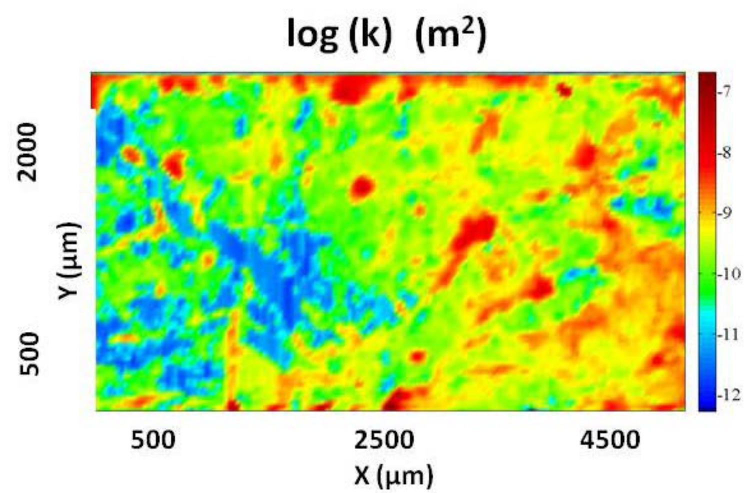
## Converting CT images for reactive transport model

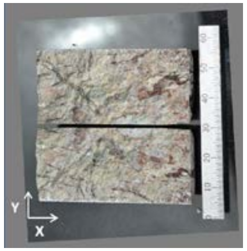
- Industrial CT scan, 31.6 micron resolution
- Convert 3D aperture to 2D aperture map
- Calculate porosity & permeability values from local apertures
- Import k and porosity maps to CrunchFlow, calculate flow




| Original Planned Milestone/ Technical Accomplishment | Date Completed |
|---|---|
| T2: Develop image processing routine | 1/17/2013 |
| T2: Complete setup of framework for 3D image reading | 2/20/2013 |

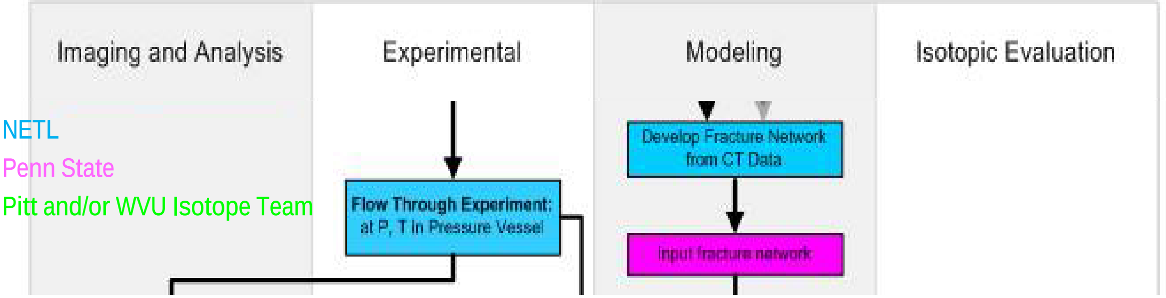


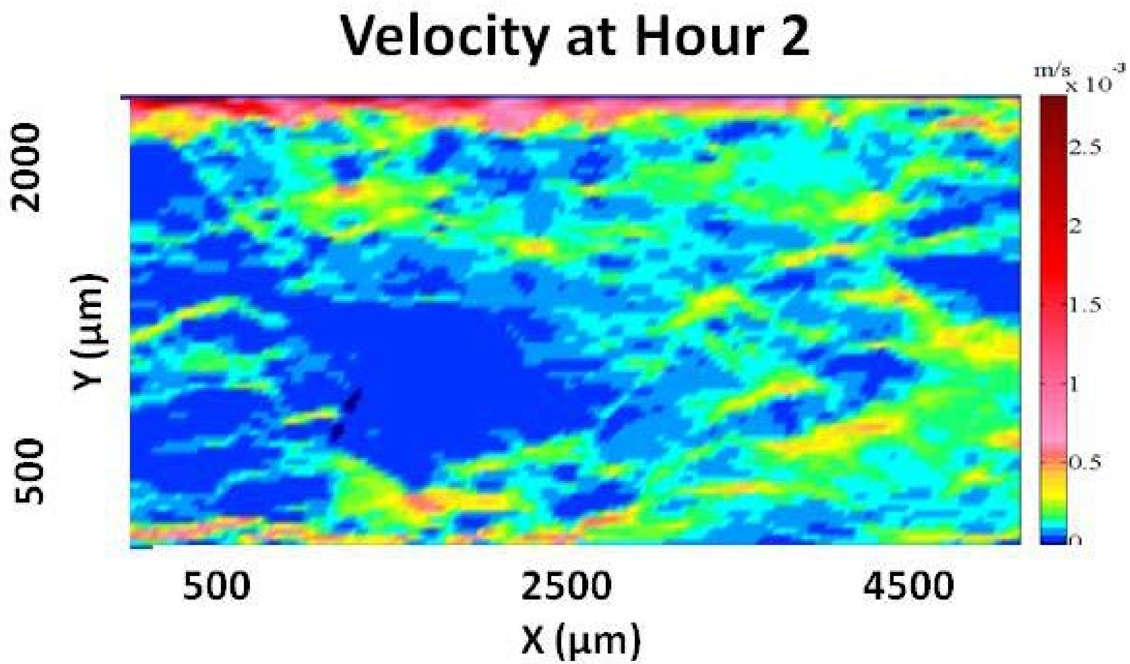



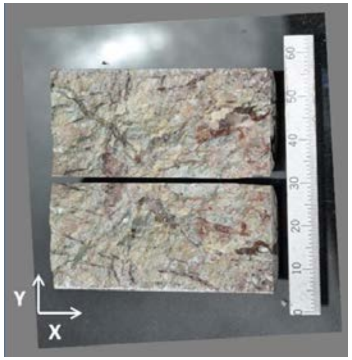
## Calculation of flow rate using CT image input and CrunchFlow

– Next step is to add mineral information

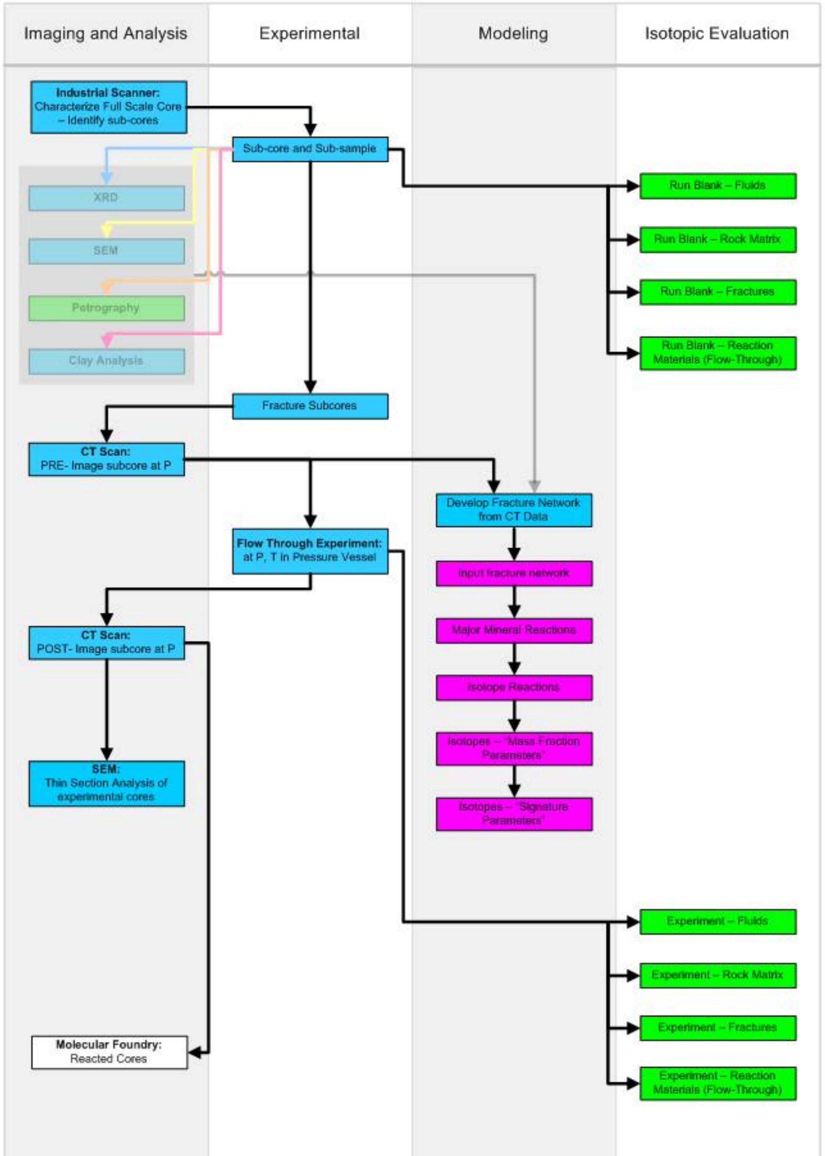



| Original Planned Milestone/ Technical Accomplishment | Date Completed |
|---|---|
| T4: Complete framework for flow and imaging data | 3/12/2013 |



# Future Directions



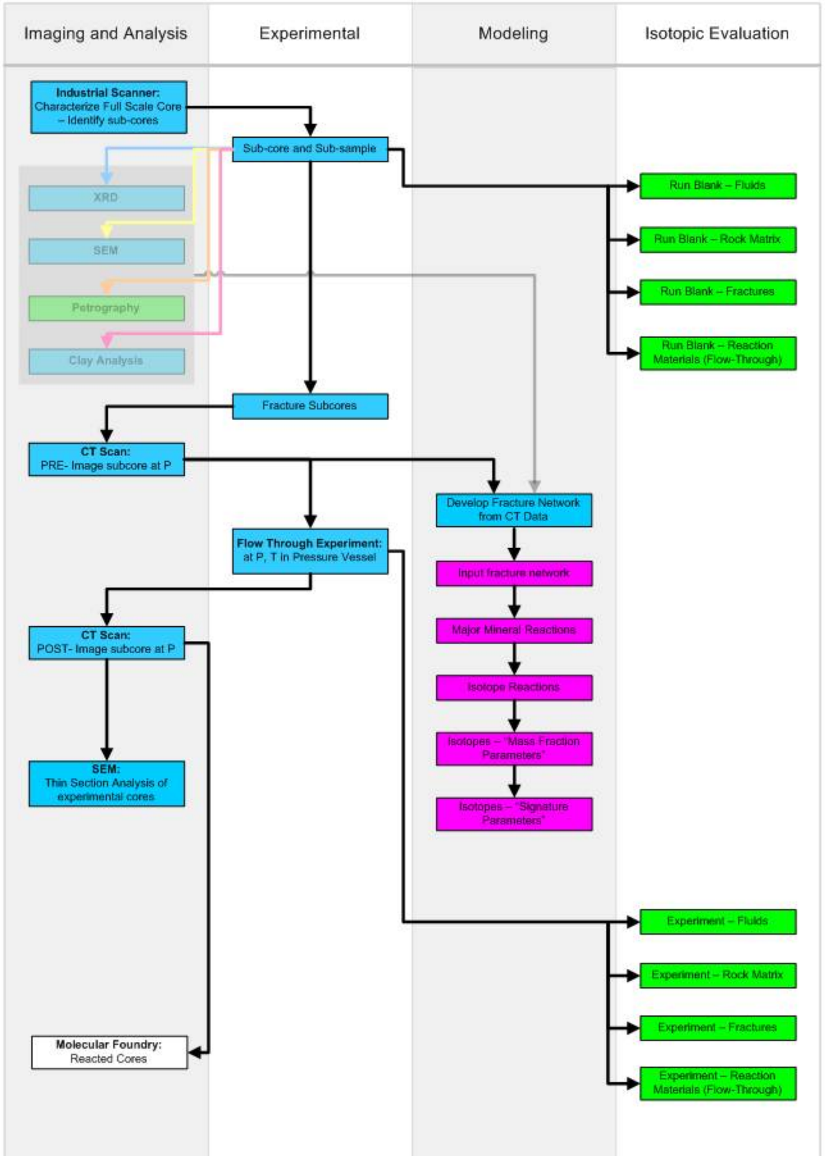

## To be completed prior to initial flow-through experiment

**(* indicates delay in schedule; # indicates delay due to delay with another milestone)**

| Milestone or Go/No-Go | Status & Expected Completion Date |
|---|---|
| #T1: Develop low-blank geochemistry/isotope protocol | Ongoing; Complete 5/2013 |
| *T3: Baseline characterization of Brady field cores | Ongoing; Complete 5/2013 |
| *T4: Develop reaction database | Ongoing; Complete 5/2013 |

# Future Directions

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

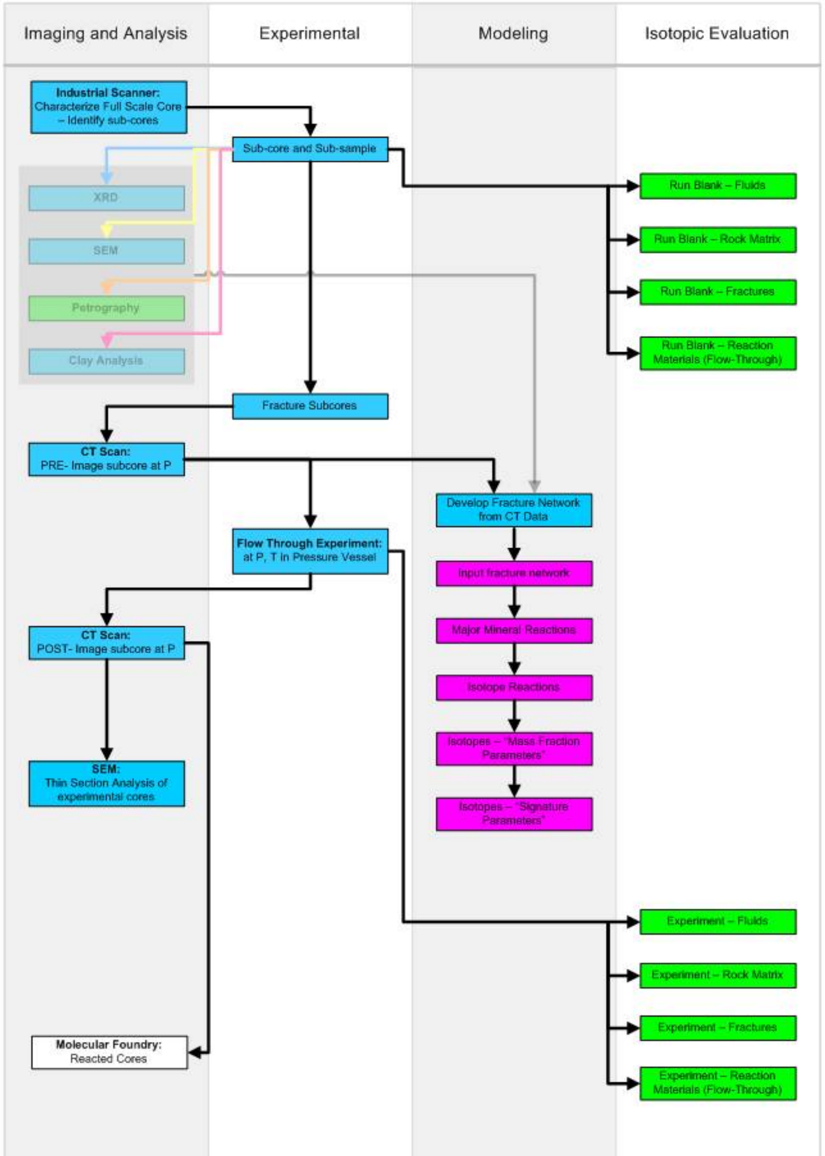



## To be conducted as part of, or in conjunction with, flow-through experiments

**(* indicates delay in schedule; # indicates delay due to delay with another milestone)**

| Milestone or Go/No-Go | Status & Expected Completion Date |
|---|---|
| *T3: Complete first flow-through test | Delay due to lab setup; 7/2013 |
| #T3: Complete flow-through tests | 12/2013 |
| #T5: Isotopic analysis of experimental fluids | Ongoing during experiments (4/2013 through 12/2013) |
| #T5: Identify isotopes for fracture-scale reactions | Ongoing during experiments (4/2013 through 12/2013) |
| #T5: Initiate isotopic analysis of reacted cores | After experiments are complete (7/2013 through 2/2014) |

# Future Directions




## To be conducted as part of, or in conjunction with, flow-through experiments

**(* indicates delay in schedule; # indicates delay due to delay with another milestone)**

| Milestone or Go/No-Go | Status & Expected Completion Date |
|---|---|
| *T2: First micro-scale 3D image data set from flow-through tests | Delay with micro-CT pressure vessel manufacturing; 12/2013 |
| #T2: Complete 2nd micro-scale 3D image data set from flow-through tests | 2/2013 |
| T4: Model for fracture experiments | 11/2013 |
| T4: Predict evolution of fracture structure | 6/2014 |

# Mandatory Summary Slide



- Calculated a flow rate model for fluid flow along a core fracture using CrunchFlow based on geometric inputs from industrial CT scans of synthetically-fractured Brady field cores.
- Positioned to start flow-through experimental work with the Brady field cores in May 2013
  - Geochemical characterization is near completion (including isotope analyses)
  - Blank run testing and shakedown of the flow-through experimental unit will occur during April 2013.
- Next steps for the project involve:
  - Performing flow-through experimental work coupled with bulk geochemical and isotope-specific analyses;
  - Using fractured core geometries coupled with industrial CT scans and baseline geochemistry inputs to predict experimental results with CrunchFlow;
  - Validating modeling results based on experimental data;
  - Further evaluation of finer-scale fracture reactions using the micro-CT scanner;
  - Determining whether isotopes can be used to predict fracture evolution during flow-through of heat carrier fluids.

# Project Management

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Timeline:

| Planned Start Date | Planned End Date | Actual Start Date | Current End Date |
|---|---|---|---|
| November 2011 | October 2013 | June 2012 | June 2014 |

Budget:

| Federal Share | Cost Share | Planned Expenses to Date | Actual Expenses to Date | Value of Work Completed to Date | Funding needed to Complete Work |
|---|---|---|---|---|---|
| $995, 718 | $0 | $929, 829 | $929, 829 | ~$500,000 | $65,889 |

- Experimental work performed with field-relevant samples from Brady's Field
- Leveraging existing resources across the NETL-Regional University Alliance:
  - Industrial CT and micro CT scanners at NETL-Morgantown
  - XRD, XRF analyses at NETL-Morgantown and NETL-Albany
  - Isotope Ratio MS at West Virginia University
  - NETL Multicollector ICP-MS hosted at the University of Pittsburgh
  - Computational capabilities at Penn State University
- Funds for supporting the URS contract (including university subcontracts) have been fully awarded. The difference between "Actual Expenses to Date" and "Value of Work Completed to Date" are funds to support activities by URS and the universities from June 2013 – June 2014.
- "Funding needed to Complete Work" is for NETL Federal salaries, travel, and supplies and materials
- Project is on schedule for completion in June 2014.