Geological storage of CO_2 in sub-seafloor basalt offshore Washington State and British Columbia (CarbonSAFE Cascadia project)

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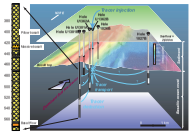
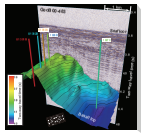
RESERVOIR AND MONITORING

Target Basalt Reservoir





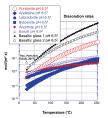
The targeted storage reservoir is located in permeable pillow lavas, fractured and massive flows along a buried basement ridge in the Cascadia Basin (left image, colored surface), between natural inlet-discharge outcrops, Grizzly Bare and Baby Bare, respectively.

Drilled at several existing IODP sites, the subseafloor basalt reservoir is highly fractured, channelized, and porous (10-15%) (Fisher et al. (2011)). Multi-year tracer experiments indicate that the reservoir, sealed to the seafloor (left image, green surface) above by impermeable fine-grained turbidites and hemipelagic clay sediments, is permeable with focused northward fluid flow. A seismic image of the basement-sediment contact shows well locations on the basement ridge with an exaggerated vertical scale (right image, colored surface).

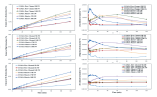
Laboratory Studies

Laboratory experiments are underway using representative ocean basalt samples from the Cascadia Basin and other locations. Measured dissolution rates of basalt indicate that flow channels are much more reactive than the massive basalts, with Ca ion extraction efficiencies reaching ~11-12% at low pH. Compared with kinetic data in basalts from the literature, preliminary tests indicate more rapid dissolution in shallow ocean basalts.

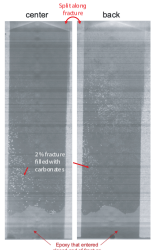
SEM images for surface/altered, glassy, and non-glassy basalt samples from Cascadia Basin cores.



Ca dissolution rates of basaltic rocks. Data from this study; Palandri & Kharaka (2004); Schaef & McGrail (2009).



Cation extraction rates in flow channel and massive basalt samples from IODP Site U1362, Cascadia Basin (E. Hsu, Columbia Univ., unpubl. data).

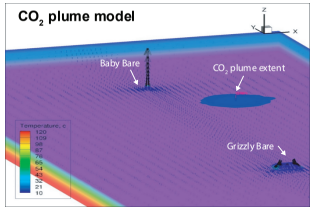


Batch experiments in ocean basalt dredge sample with an engineered (saw cut) fracture. CO_2 injection incurs Mg- and Fe-rich carbonate precipitation after 31 weeks (D. Giammar, Washington Univ., unpubl. data).

Reservoir Modeling

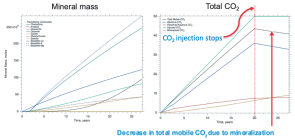
Preliminary numerical simulations investigated the injectivity of 50 MMT CO_2 in the Cascadia basalt reservoir, the impact of natural hydrothermal circulation on the migration behavior of CO_2 plumes and dissolved CO_2 plumes, and the anticipated conversion rates to carbonate minerals. All numerical simulations were conducted using the *STOMP-CO$_2$* numerical simulator with *ECKEChem* and *GeoMech* modules (developed at PNNL).

CO_2 plume model



Simulation results at 70 years after 20 years of CO_2 injection at 2.5 MMT/yr at a location east of the inter-outcrop centerline and 12.5 km from the northern discharge outcrop, Baby Bare. Gas saturation iso-surface is shown at the 0.01 level and indicates lateral and vertical containment in the basalt reservoir and minimal deformation of the gaseous CO_2 plume toward Baby Bare.

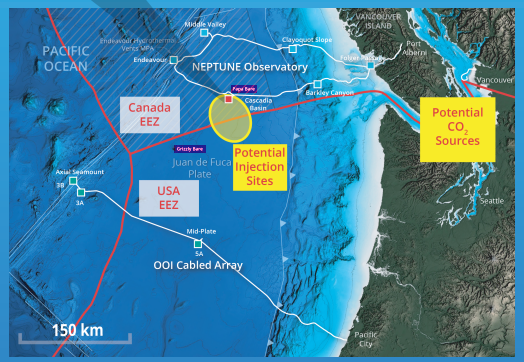
Geochemical model



Simulation results after 20 years of CO_2 injection using conversion rates for secondary carbonate mineral precipitation. Decreases in total mobile CO_2 after injection stops correspond to complete fixation of 50 MMT CO_2 in 135 years, based on the reaction network from onshore studies in the Columbia River Basalt. Inferred results from the significantly more rapid dissolution rates observed in Cascadia ocean basalt samples suggest that this predicted mineralization period is likely to be overestimated.

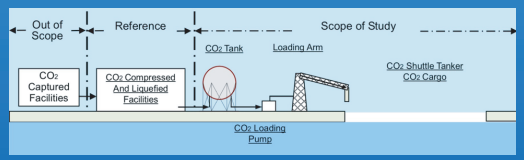
ABSTRACT

Sub-seafloor basalts are widely distributed on Earth and may enable permanent mineralization of injected CO_2 in solid rock form. If feasible and scalable, this sequestration technology promises a means for significant reductions in the atmospheric concentration of greenhouse gases. The CarbonSAFE Cascadia project evaluated both technical and non-technical feasibility of collecting and storing 50 million MT of CO_2 in a safe, ocean basalt reservoir offshore from Washington State and British Columbia. Project goals include evaluating this reservoir as an industrial-scale CO_2 storage complex, developing potential source/transport scenarios, conducting laboratory and modeling studies to determine the potential capacity of the reservoir, determining long-term monitoring options, and assessing economic, regulatory and project risks. Potential scenarios include a variety of industrial sources and transport options in the USA and in Canada. Experimental and modeling results indicate the potential for effective injection and rapid mineralization in sub-seafloor basalt. Regulatory reforms to facilitate offshore CO_2 storage may be needed for development of a future pilot project in the Cascadia Basin and lessons learned at this location may be transferrable elsewhere around the globe.



CO_2 Injection Transport and Monitoring

An active cabled network (NEPTUNE) is in place from Victoria BC to the Cascadia Basin. In situ instrumentation could enable real-time monitoring for seismicity and reservoir properties.



ACCOMPLISHMENTS

- **Contacted potential industry-sourced CO_2 streams in US and Canada and developed different source-transport scenarios**
- **Conducted laboratory studies of CO_2-basalt-water mixtures which indicate variability in reaction rates with potential for complete mineralization**
- **Compiled regional hydrological and petrophysical data that indicate basalt injectivity is high, but likely anisotropic**
- **Modeled CO_2 plume and mineralization potential in the reservoir, indicating long-term containment of injected CO_2**
- **Reviewed regulatory framework for offshore storage in US and Canada; lessons learned may be transferrable elsewhere around the globe**
- **Evaluated cost variables for optimal different source-transport scenarios to this offshore storage location**

References Cited

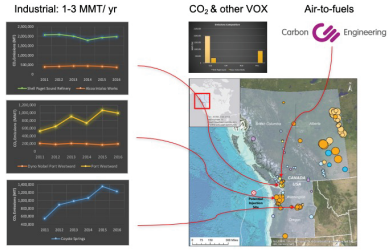
Fisher, A.T., Tsuji, T., Petronotis, K., and Expedition 327 Scientists, 2011. *Proc. IODP, 327*: Tokyo (IODP-MI, Inc.).

Palandri, J.L. and Kharaka, Y., 2004. A Compilation of rate parameters of water-mineral interaction kinetics for application to geochemical modeling, *USGS Open File Report.*

Schaef, T.H. and McGrail P. B., 2009. Dissolution of Columbia River Basalt under mildly acidic conditions as a function of temperature: experimental results relevant to the geological sequestration of carbon dioxide, *Appl. Geochem. 24, 980–987.*

SOURCES AND TRANSPORT

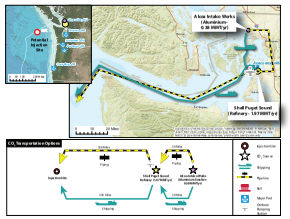
Potential CO_2 Sources Nearby Study Area



Locations in study area of large (>100,000 MT CO_2/year) emitters and annual emissions for five industrial plants. Color and diameter of circles indicate power plants, primarily fueled by natural gas, and the remainder are from other industrial sources, such as refineries, ammonia production operations, and mineral processing plants.

Example Source/Transport Scenarios

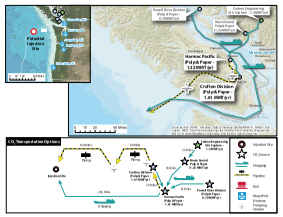
We highlight two scenarios below that are representative of the region, with potentially available transportation options.



Representative CO_2 source and transportation options. Inset map: location of potential offshore injection site (red circle).

Scenario A
Transportation alternatives via ship and via pipeline for multi-source emissions captured from the Alcoa Intalco Works facility and the Shell Puget Sound refinery, and totaling ~2.5 MMT/yr.

A pumping station may be located near the Shell refinery for either pipeline or shipping options to the injection site located ~250 km offshore.



Representative CO_2 source and transportation options. Inset map: location of potential offshore injection site (red circle).

Scenario B
Transportation alternatives via ship and via pipeline for multi-source emissions captured from the Howe Sound, Powell River, Crofton, and Harmac Pacific pulp and paper mills and from the Carbon Engineering air-to-fuels plant. Total emissions from these near tideline sources exceed 6 MMT/yr and are roughly equidistant to the injection site located ~250 km offshore.

If pipeline development is possible over the long term, pumping stations may be located near the Crofton plant and Port Renfrew on the coast.

Levelized Transport Costs

Comparison of levelized costs for shipping and pipeline transport options from facility-specific sources to the offshore reservoir. Although no dedicated CO_2 pipelines exist in the region, offshore transportation options are common for any scenario, and depend upon flow rate and distance to the injection site.