Integrated Pre-Feasibility Study for CO_2 Geological Storage in the Cascadia Basin, offshore Washington State and British Columbia

DE-FOA-0001584

CarbonSAFE: Phase 1

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National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 1-3, 2017

Outline

1. Project Team and Goals
2. CarbFix and Wallula projects
3. Technical Status: Cascadia offshore basalt
4. Synergies: Injection approaches for mineralization
5. Preliminary Accomplishments
6. Lessons Learned to date
7. Project Summary

CarbonSAFE Project Team

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

Pacific Northwest NATIONAL LABORATORY

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

COLUMBIA LAW SCHOOL

BARNARD
BARNARD COLLEGE · COLUMBIA UNIVERSITY

HÁSKÓLI ÍSLANDS

UNIVERSITY OF CALIFORNIA SANTA CRUZ

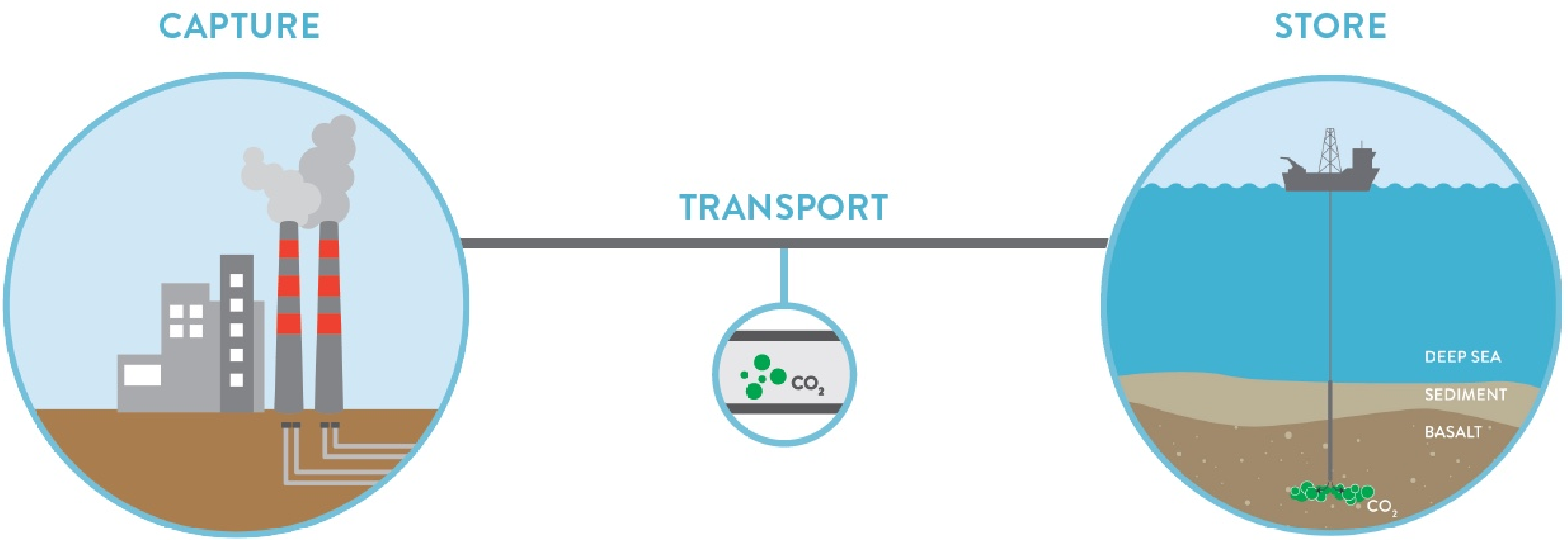
OCEAN NETWORKS CANADA

GHG Underground

<u>Objective</u>:

Integrated pre-feasibility study to characterize an ocean basalt reservoir for safe and permanent storage of 50 MMT of CO_2 in the Cascadia Basin, offshore Washington State and British Columbia

CarbonSAFE Project Goals



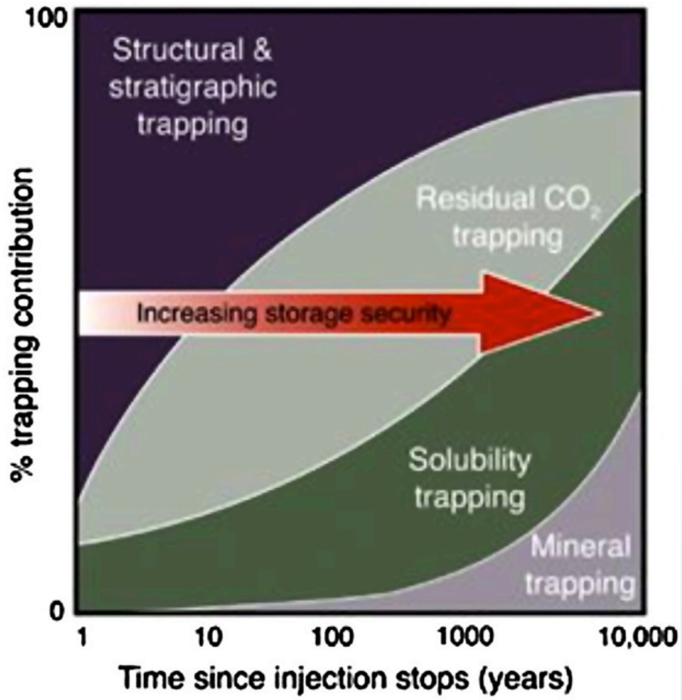
Goal 1: Technical assessment of offshore basalt reservoirs for safe and permanent CO_2 storage (e.g., reservoir characterization, CO_2 sourcing, transport, and monitoring at offshore site)

Goal 2: Non-technical assessment of offshore CO_2 storage site (e.g., regulatory framework, stakeholder engagement, risk assessment, financial needs and long-term liability)

CO_2 storage security and permanence in basalt

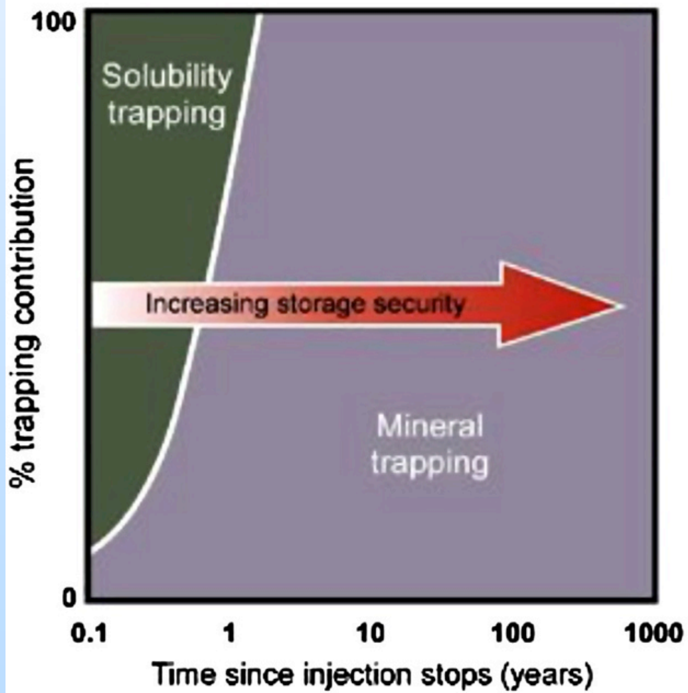
prevailing view in 2005

CO_2 injected into water reservoirs below the surface may be stored through structural, residual solubility and mineral trapping



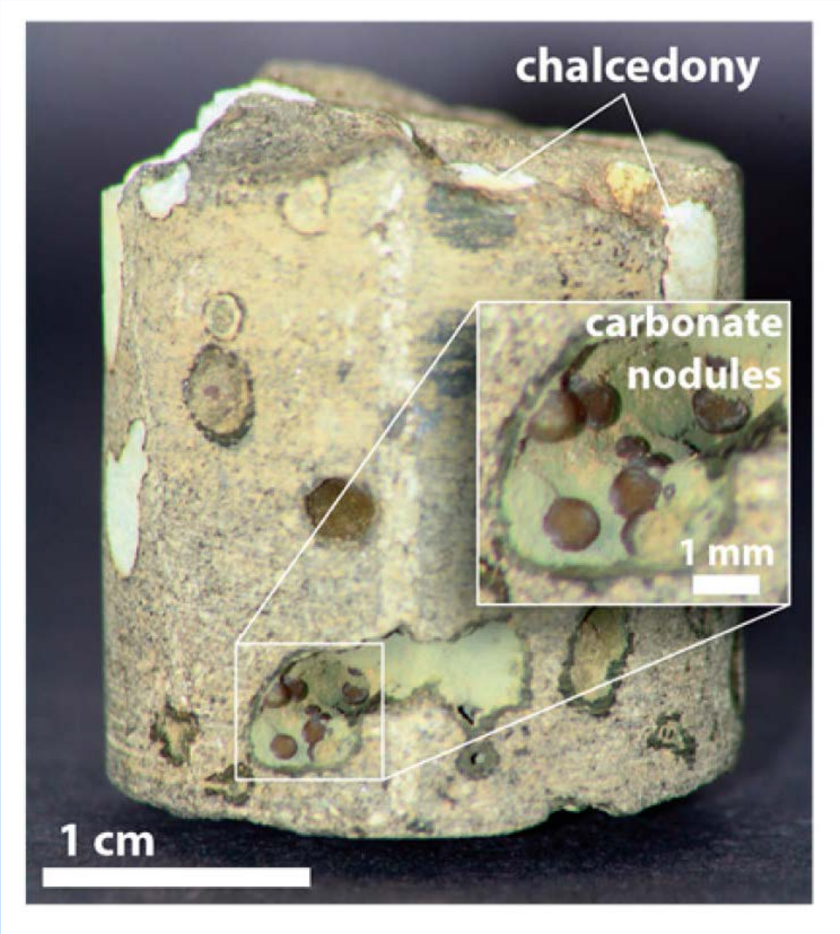
current view in 2016

In situ mineralization via CO_2-fluid-basalt reactions occurs quickly (a few years)



Snæbjörnsdóttir et al., IJGGC, 2017

Wallula, WA Basalt Pilot Project



Visual light imagery

- Injected 1000 tons CO_2 (liquid) into permeable, layered basalt flow tops
- After 2 years, isotopic analysis of sidewall cores chemically distinguishes post-injection ankerite nodules from ambient carbonate
- Progressive enrichment in Fe & Mn over time indicates mineralization of host basalt, not re-precipitated calcite

Environmental Science & Technology Letters

McGrail et al., ES&TL, 2016

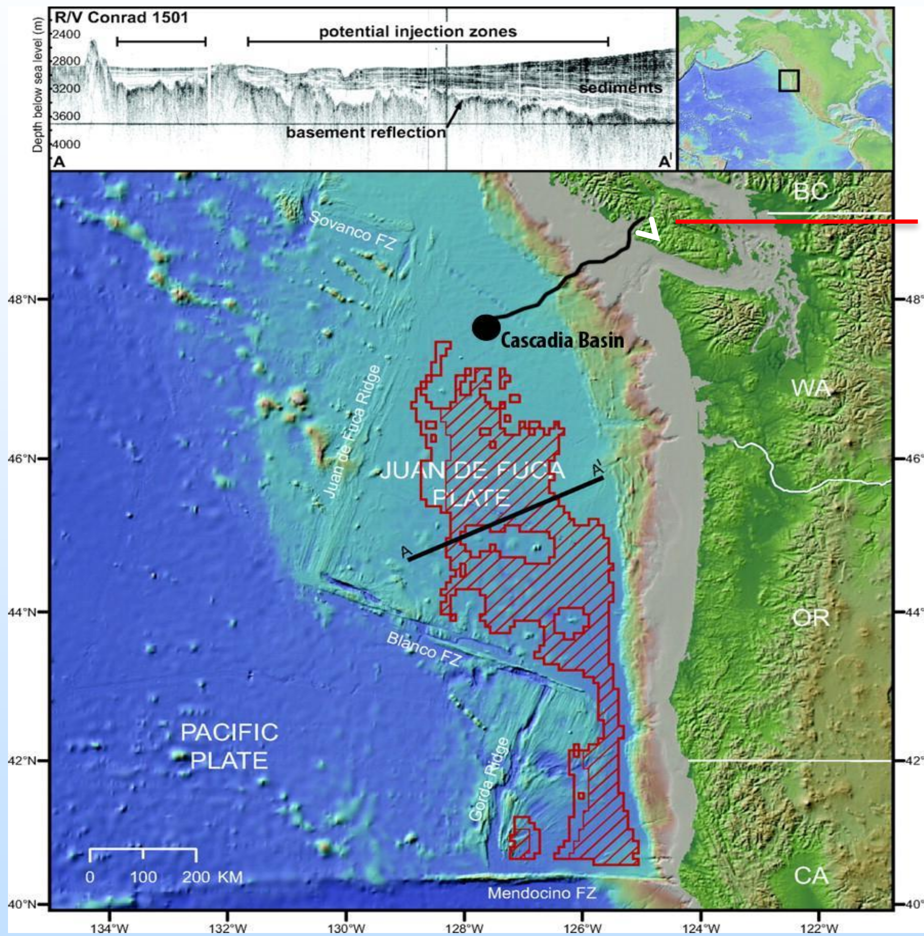
Upscaling questions: in situ mineral carbonation in basalt

- *Do other adequate basalt reservoir sites exist?*
- *What are anticipated in situ reaction rates? Will scCO_2 injection rapidly precipitate carbonates, other minerals?*
- *What is best injection strategy for CO_2 with seawater for large volumes? To optimize mineralization?*
- *What large potential industrial sources of CO_2 could be delivered to the site?*
- *What are best monitoring and volume assessment methods?*

CO_2 storage in the Cascadia Basin

CO_2 injected below sediments may be stored through physical, solubility, and mineral trapping mechanisms –

CarbFIX and Wallula projects show mineralization occurs quickly (a few years)

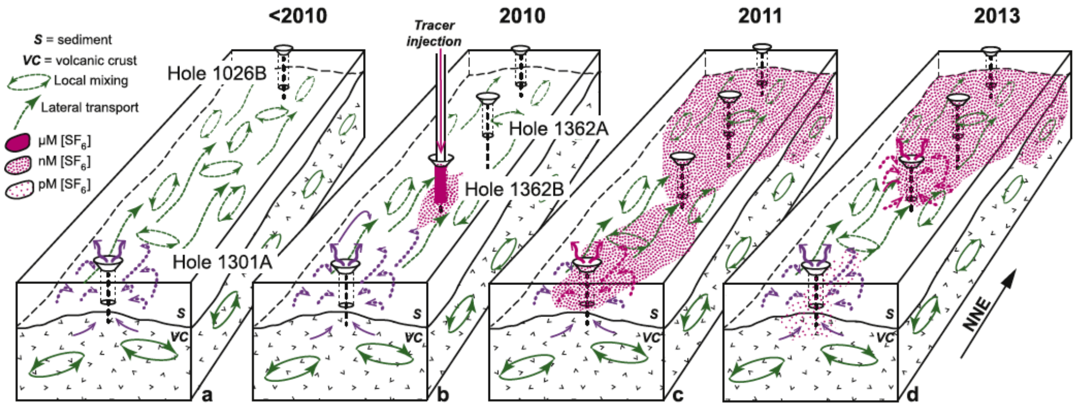


NEPTUNE cabled network

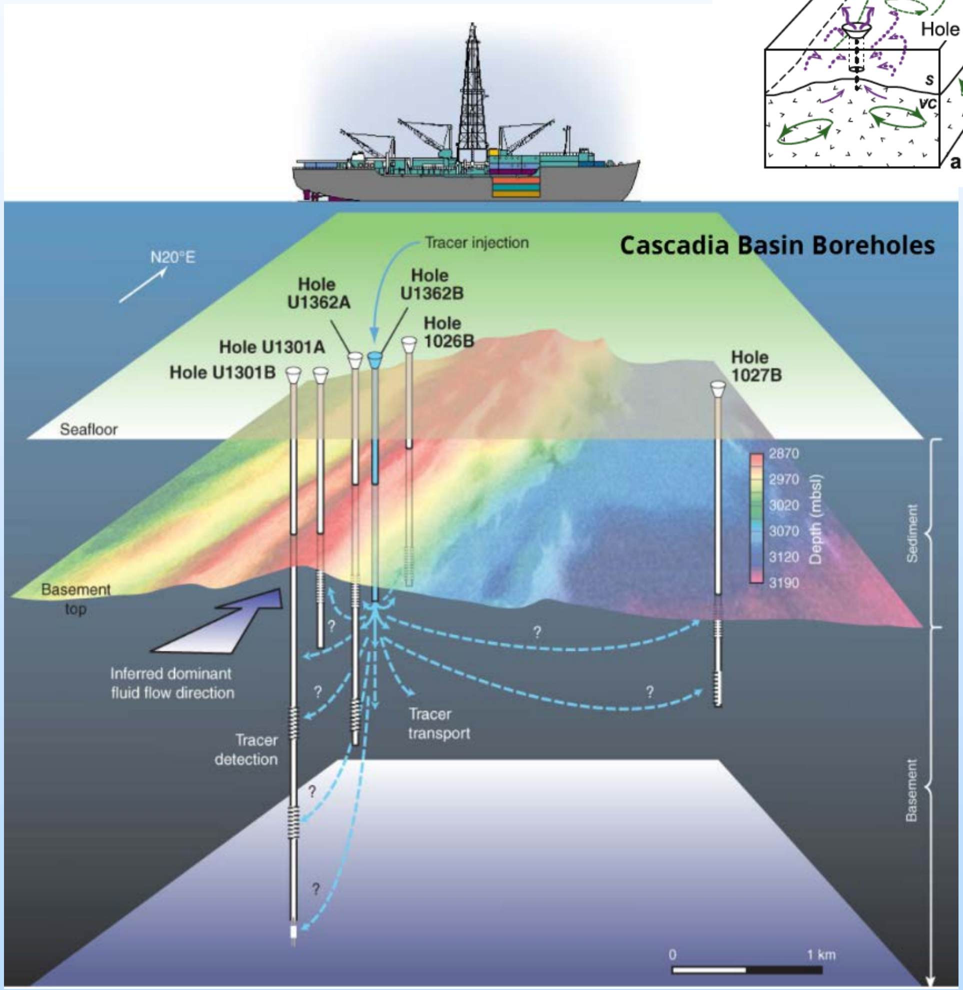
800 km

(after Goldberg et al., 2008)

Existing physical data in Cascadia Basin



(Neira et al, 2013)



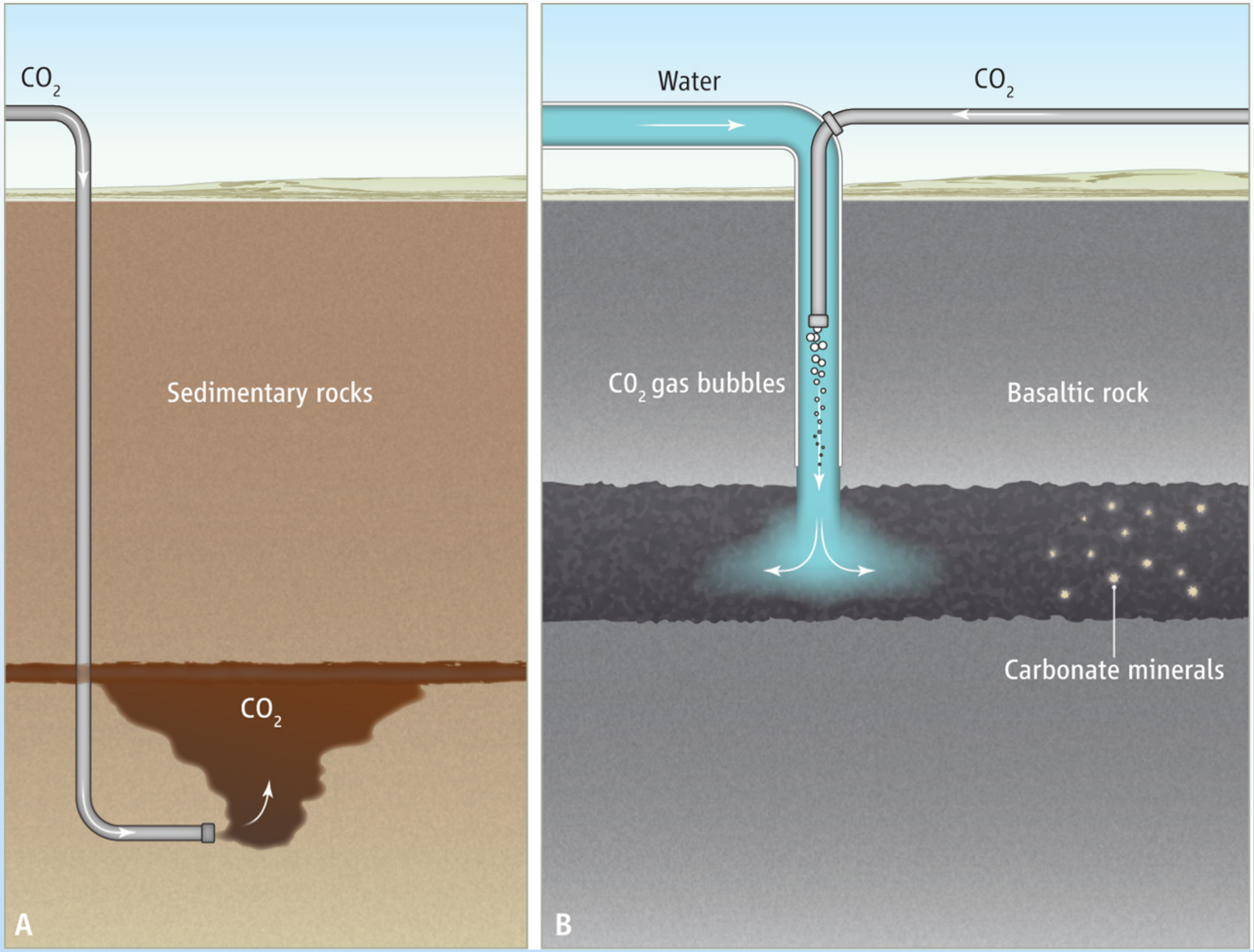
- *Several existing well completions and instrumentation at IODP sites along buried basement ridge*

- *Multi-year tracer experiments through basalt ocean crust indicate focused northward fluid flow*

- *Extensive core and measurement data in public archives*

- *Active cabled network (NEPTUNE) for observation and monitoring*

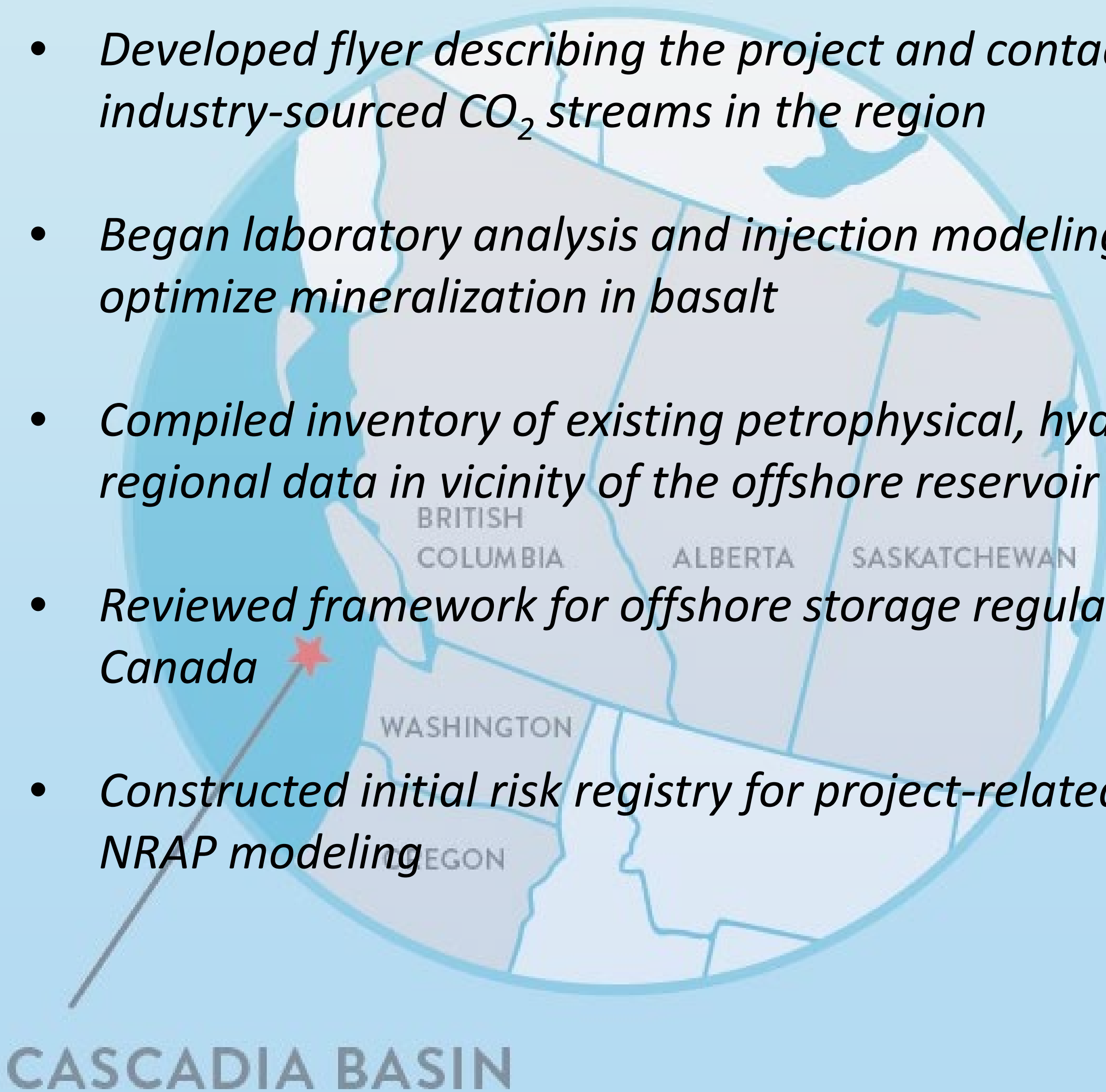
Injection approaches for mineralization: *Synergies with Wallula* and *CarbFix projects*



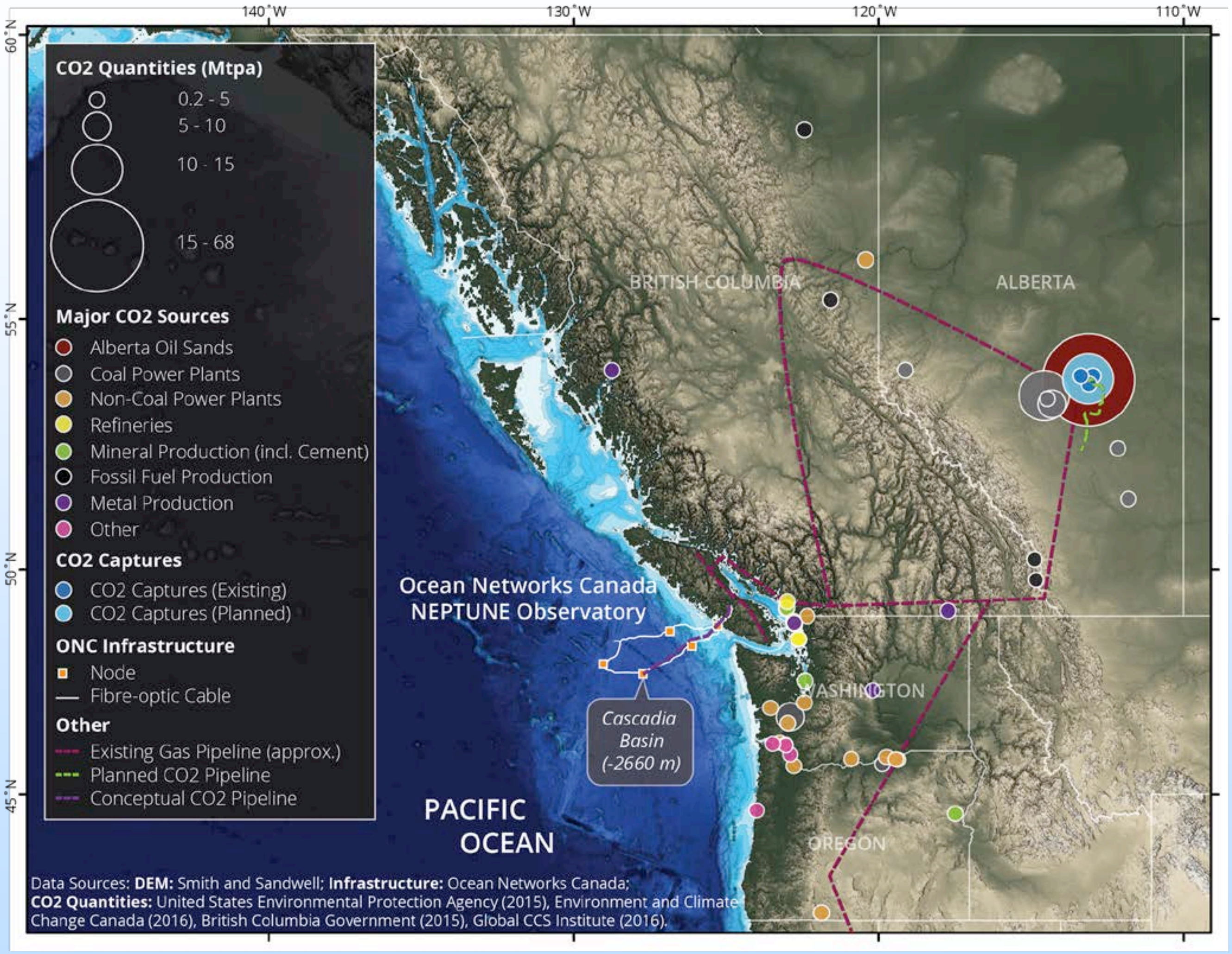
(from Gislason and Oelkers, Science, 2014)

Preliminary accomplishments

- *Developed flyer describing the project and contacted potential industry-sourced CO_2 streams in the region*
- *Began laboratory analysis and injection modeling studies to optimize mineralization in basalt*
- *Compiled inventory of existing petrophysical, hydrological, and regional data in vicinity of the offshore reservoir*
- *Reviewed framework for offshore storage regulations in US and Canada*
- *Constructed initial risk registry for project-related risks and related NRAP modeling*



Potential CO_2 sources near Cascadia area

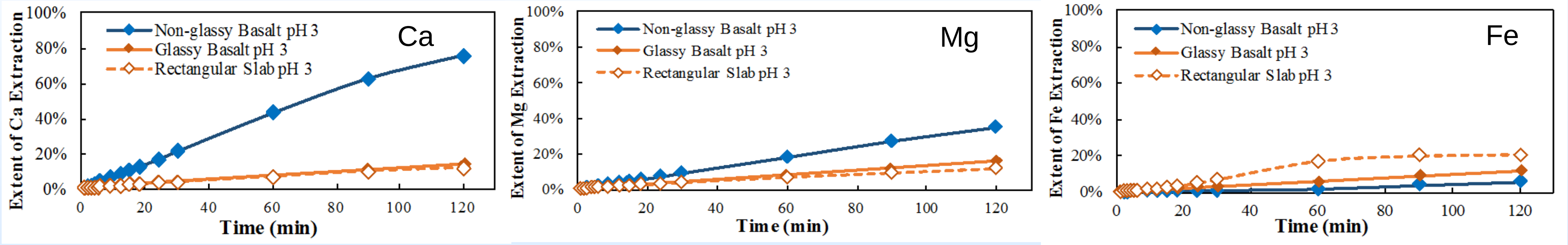


(from M. Scherwath, Ocean Networks Canada, 2016)

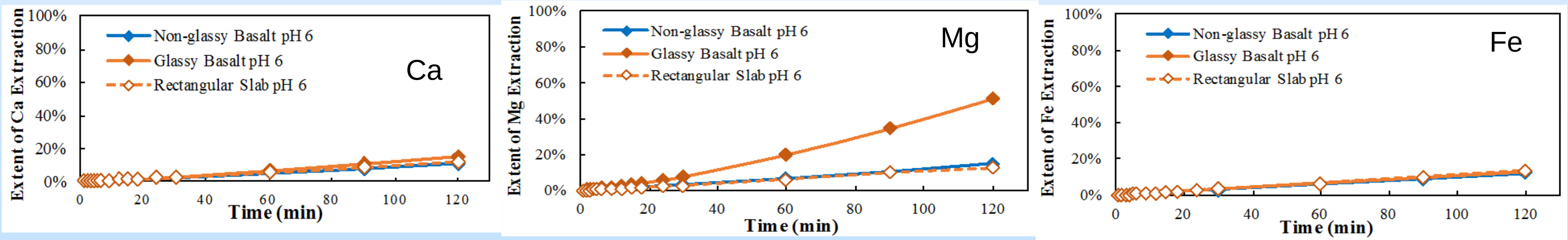
Laboratory results in seafloor samples: CO_2 reaction rates in basalt

Differential Bed Reactor (DBR) Reactivity Experiments (1 bar @ 30°C, far from equilibrium)

Low pH ~3 *Samples: 11.7% CaO, 7.4% MgO, 10.8% FeO*



High pH ~6 *Samples: 11.7% CaO, 7.4% MgO, 10.8% FeO*

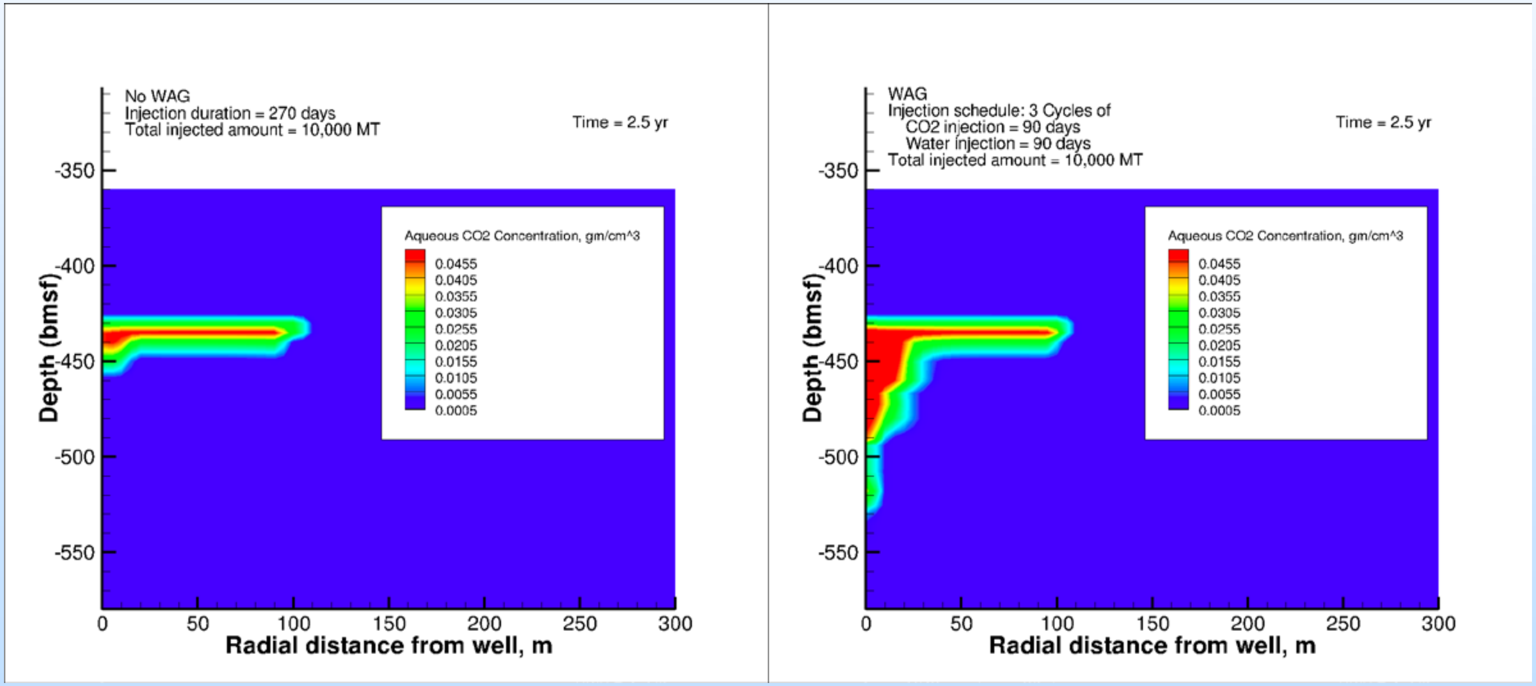


Results show differing behaviors in glassy and non-glassy basalt, especially under low pH conditions

→ ***76% Ca*** **extraction from non-glassy basalt at low pH**

Water Alternating Gas (WAG) miscible flooding for CO_2 mineralization in basalt

Initial 3-cycle model using STOMP-CO2 with ECKEChem to optimize for CO_2 solubility in seawater and mineralization in basalt



(see poster Thursday – **Demirkanli, et al.)**

Data Inventory and Management

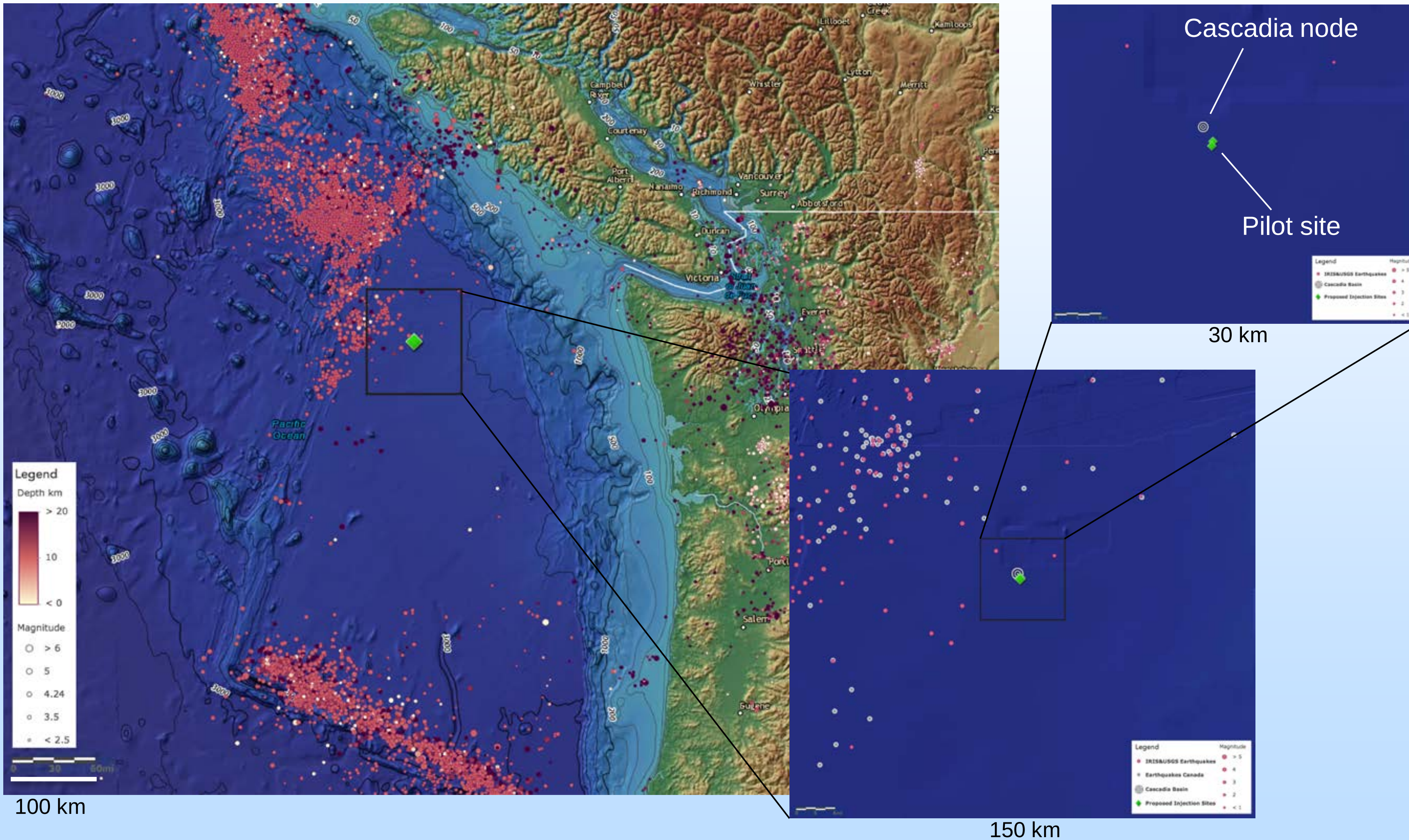
Physical data categories, subtasks and status in inventory

	Data Categories								
Tasks	Bathymetry	Chemistry	CO2 Source and Transport	Heat Flow, Temperature and Pressure	Geologic Model	Physical Properties	Seismics	Seismicity	Site/Hole Info
5.1: CO_2 Source Availibilty			●○▯						
5.2: CO_2 Transportation to Offshore Storage Site			●○▯						●
5.3: Evaluation of Storage Reservoir	●▯	●○		●○▯	●○	●○		●○	●
5.4: Long-term Monitoring of CO_2 Storage		▯		●○▯	▯	●○			
5.5: Risk Assesment of CO_2 Storage		●○			●○	●○	●○▯	●○	

Available	●
To be Produced	○
Known and Missing	▯
Needed but Nonexistent	▯

(as of 24 July 2017)

Natural Seismicity: Juan de Fuca tectonic plate



Data sources: *IRIS Interactive Earthquake Browser; USGS Earthquake Catalog; Natural Resources Canada Earthquake Database; Ocean Networks Canada Cascadia Basin*

Preliminary Project Risk Registry

Tally of identified project risks from the comprehensiveness analysis

Responsible Actor	R Tally	Component	C Tally	Time/Phase	T Tally	Location	L Tally	Goal	G Tally	Activity	A Tally
R01) Operator	16	C01) Management	7	T01) pre-FEED	1	L01) Capture plant	6	G01) Assess risks via ROMs	1	A01) Mission & Scoping	5
R02) Funder	3	C02) Staff	0	T02) FEED	11	L02) Transit route	6	G02) Build integrated project	19	A02) Design	4
R03) Insurer	2	C03) Finance	2	T03) Pilot-Demo	16	L03) Inj site surface	0	G03) Prove engrd system	3	A03) Teambuilding	4
R04) Chief Engr	10	C04) Permits	17	T04) Build	0	L04) Resv Near Injector	11	G04) Execute On Schedule	2	A04) Characterize Site Geolo	3
R05) Chief Geosci	8	C05) Reservoir	4	T05) Operate	8	L05) Resv Far Field	8	G05) Execute On Budget	5	A05) Envt Bsln Monitoring	0
R06) Permits-Compliance	10	C06) Confining zone	1	T06) Close operations	1	L06) Non-localized	13	G06) Monitor & control	5	A06) Permits & Compliance	9
R07) Builder	1	C07) Static geologic mo	0	T07) Post-Closure/PISC	1			G07) Prove injectivity	4	A07) Communications	5
R08) Driller	1	C08) CO2 source	7					G08) Prove seal	2	A08) Surface construction	1
R09) Sfc Monitor	3	C09) Transport	6					G09) Prove capacity	1	A09) Drill & Complete	0
R10) Subsfc Monitor	7	C10) Injectors	2					G10) Inform public	5	A10) Capture ops	1
R11) Communications	10	C11) Monitoring sfc	3					G11) Plan next steps after pil	0	A11) Transmission ops	2
		C12) Monitoring subsfc	6					G12) No envt damage	2	A12) Injection ops	6
		C13) Dynamic model	3					G13) No one hurt	2	A13) Monitor & Model	6
		C14) Operations	1							A14) Finance & Control	3
		C15) Eco protection	2							A15) Management ongoing	0
		C16) Public consent	3							A16) Decommission	1

(as of 5 July 2017)

Lessons Learned to date

- Large potential sources of anthropogenic CO_2 exist in the region
- Existing regulations appear to restrict CO_2 transport across national boundaries (e.g., between US and Canada)
- Compiled hydrological data indicate basalt injectivity is high but likely anisotropic
- Laboratory studies of CO_2–basalt–water mixtures indicate large variability in reaction rates
- Real-time injection monitoring is feasible using NEPTUNE

Project Summary

- Objective: Integrated pre-feasibility study to characterize an ocean basalt reservoir for safe and permanent storage of 50 MMT of CO_2 in the Cascadia Basin, offshore Washington State and British Columbia

- Accomplishments: Technical and non-technical tasks for assessment of this storage option are on track for the anticipated project schedule

- Next steps: Project workshop, 3-5 October 2017

Thank you