OCEAN NETWORKS CANADA

Integrated Pre-Feasibility Study for CO2 Geological Storage in the Cascadia Basin, offshore Washington State and British Columbia

Phase 1: 1 February 2017 – 31 July 2018

Martin Scherwath, Kate Moran, Martin Heesemann, Cascadia CarbonSAFE team

Ocean Observatory Council Meeting,, 18 April 2018

Cascadia CarbonSAFE Team

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Ocean Networks Canada

GHG Underground

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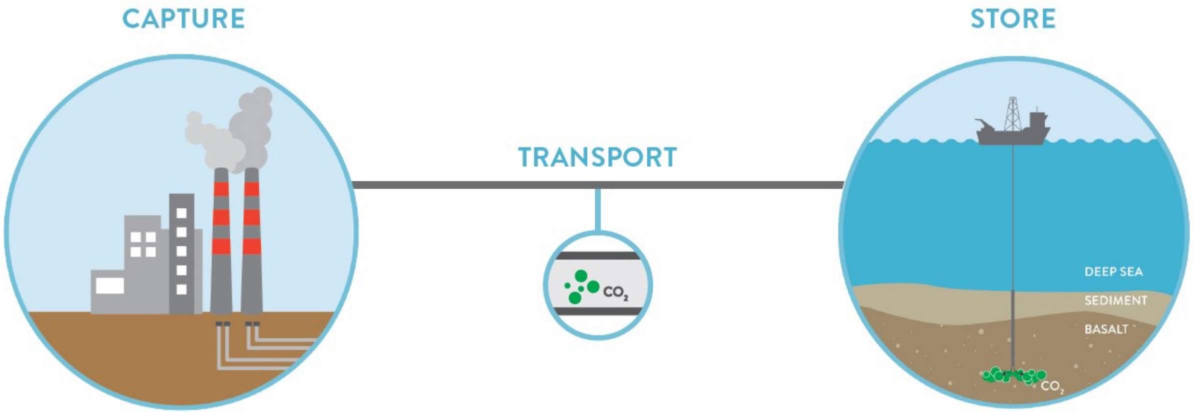
Objective:

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

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)

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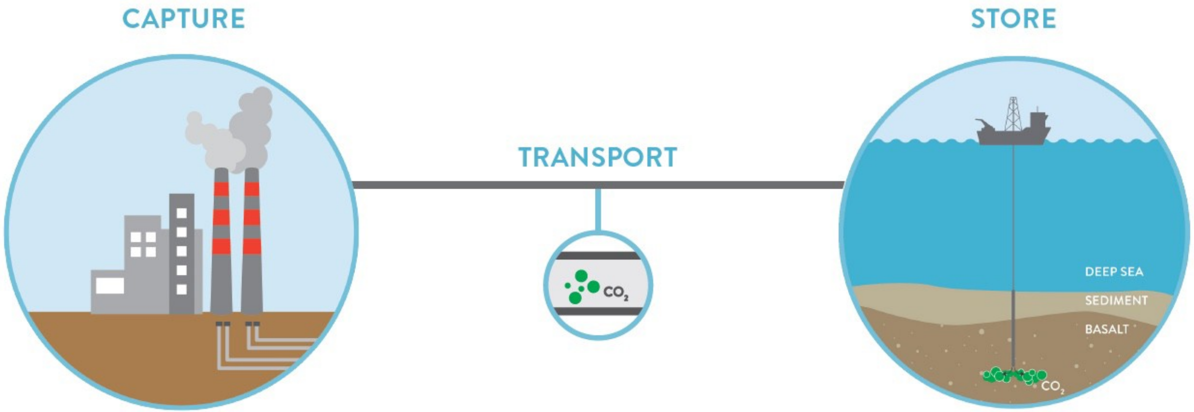

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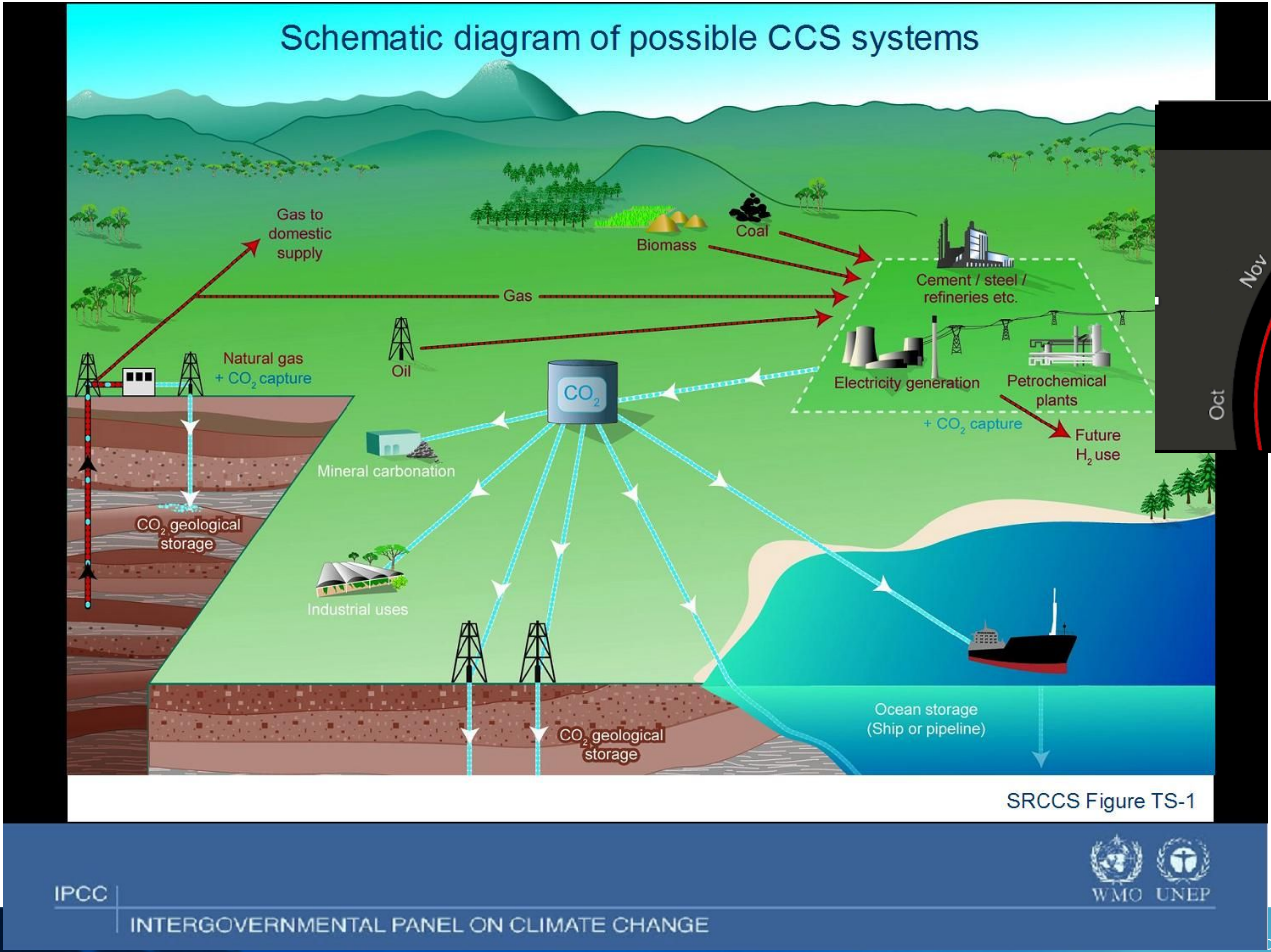
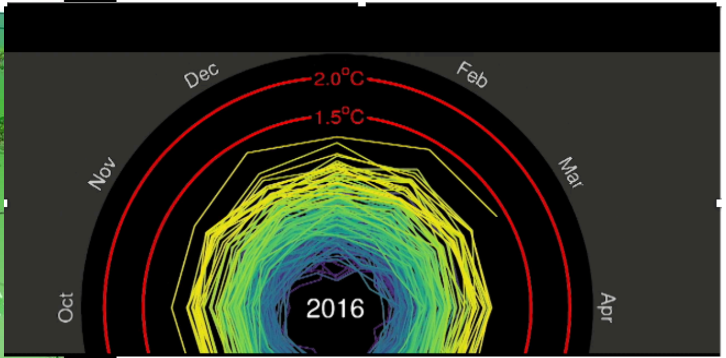
orange: ONC involved; red: ONC led

Carbon Capture and Storage (CCS)





1850-2016

Global CO_2 Capture

By the numbers

Global CCS Institute:

- **37 million tonnes** of CO_2 per year captured from 21 large-scale projects
- Plans for additional **30 million tonnes** of CO_2 per year

- Global emissions **32 billion tonnes** per year
- International Energy Agency estimates that 4 billion tonnes of CO_2 needs to be sequestered annually by 2040 in order to meet the Paris agreement limit, and 11.2 billion tonnes of CO_2 per year by 2060

CCS in Canada

By the numbers

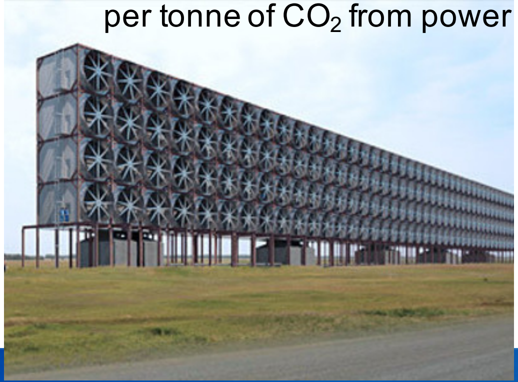
- Alberta Carbon Trunk Line: 2 million tonnes per year (Mtpa) of CO_2 (up to 14.6 Mtpa)
- Quest Canada (Shell): 1 Mtpa of CO_2
- Great Plains Synfuels Plant and Weyburn-Midale 3 Mtpa of CO_2
- Boundary Dam Carbon Capture and Storage 1 Mtpa of CO_2

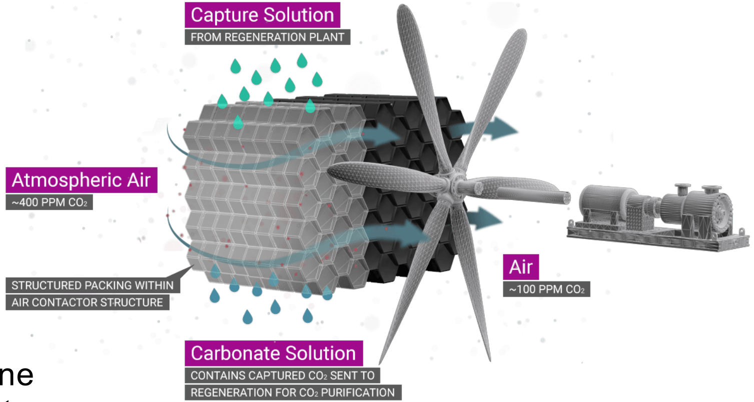
- **Most for Enhanced Oil Recover (EOR)**
- Some as fertilizer
- Some for geological storage

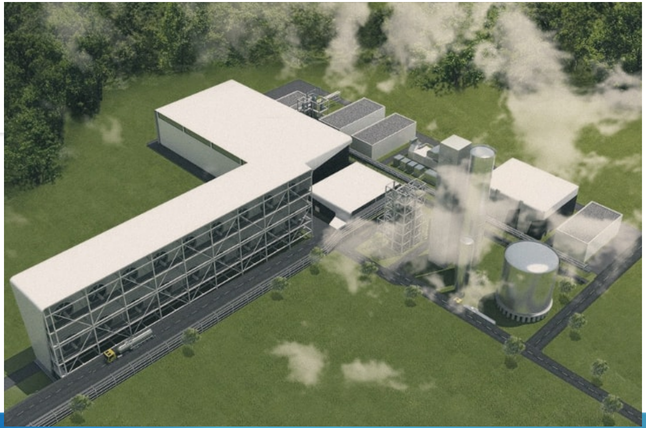
CCS in Canada

Air Capture

- For Utilization (CCU)
- **Carbon Engineering** facility in Squamish, BC
- Plan to capture 1-2 million tonnes of CO_2 per year
- Turn into liquid fuel
- Similar to Climeworks (Zurich, Switzerland) which is for fertilization
- Costs currently US$500-600 per tonne of CO_2; upscaling can ring down costs to US$ 100-200 (compared to US$50 per tonne of CO_2 from power plants)



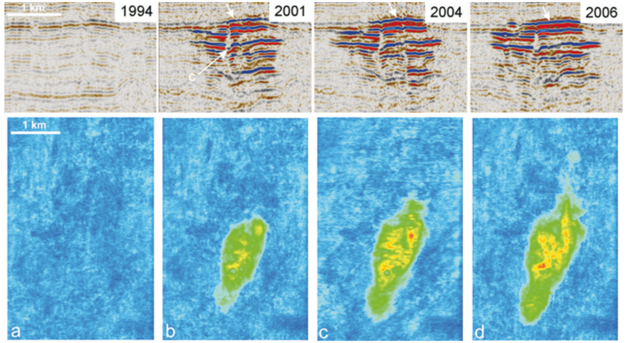


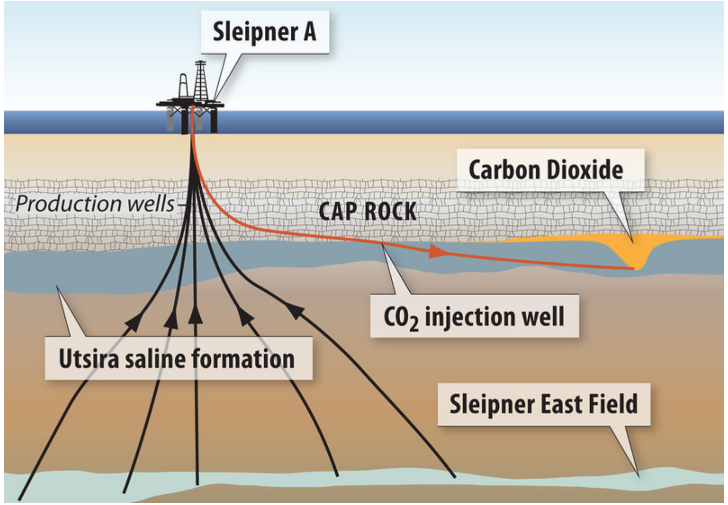


CCS in Rock

Sleipner (Norway) by Stratoil

- Sequestration in North Sea sandstone
- 1 million tonnes of CO_2 annually, 17 million tonnes since 1996
- Long-term monitoring in place
- Will take over millennia for the CO_2 to react with rock to mineralize and be permanently locked

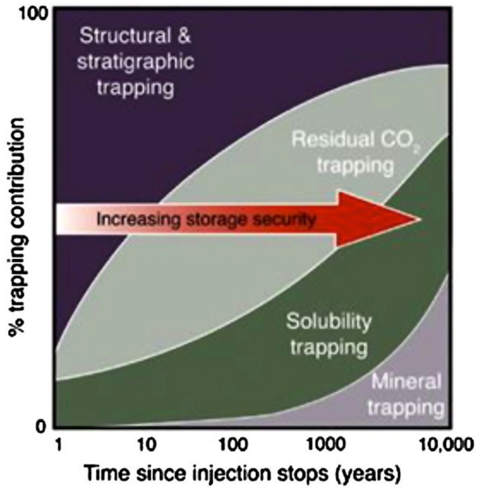




CO_2 storage security and permanence in basalt

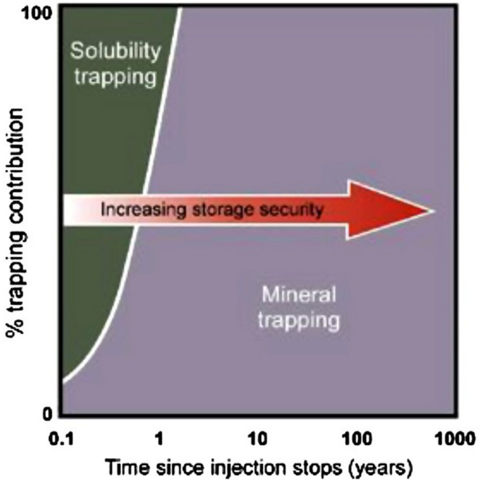
prevailing view in 2005

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



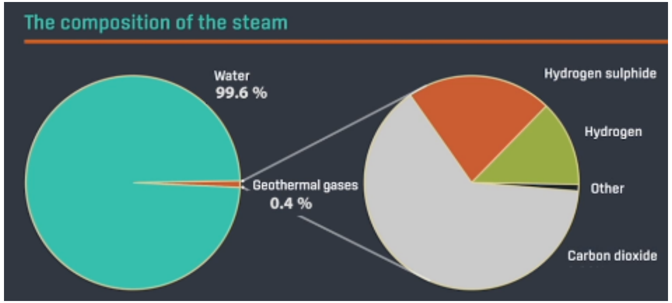
current view in 2016

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



Snæbjörnsdóttr et al., IJGGC, 2017

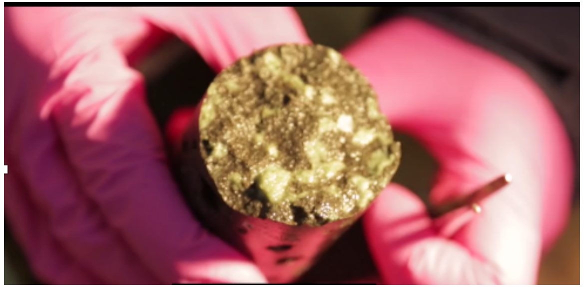
CO_2 storage security and permanence in basalt



CarbFIX by the numbers

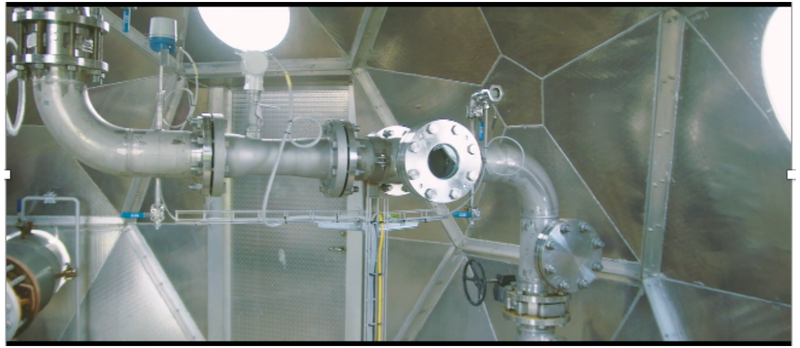
Phase 1 (2007-2017):

- 250 tonnes CO_2 from 2012
- 25 tonnes of water per tonne of CO_2
- **95% solidified in 2 years**

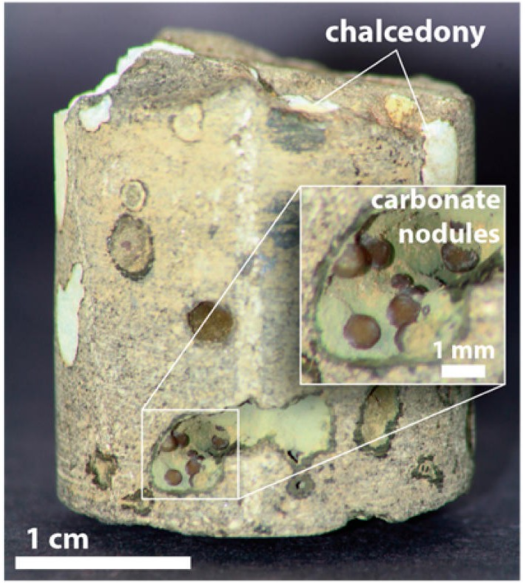


CarbFIX 2: (2017-)

- Air capture
- 50 tonnes of CO_2



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

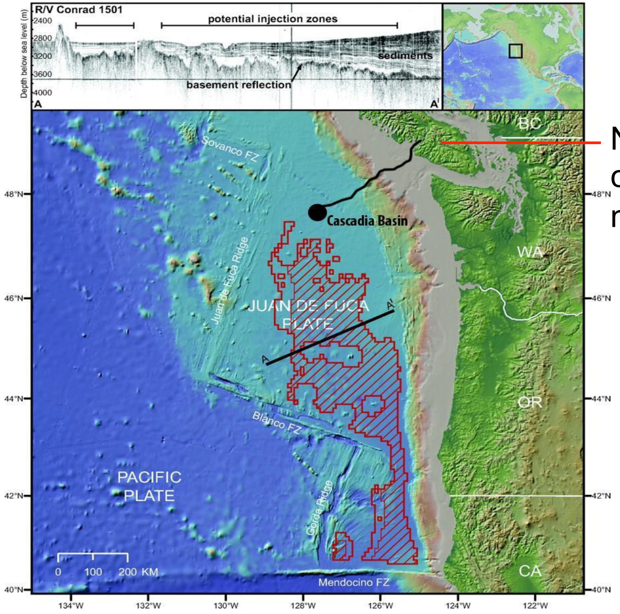
Upscaling questions: in situ mineral carbonation in basalt

- *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)

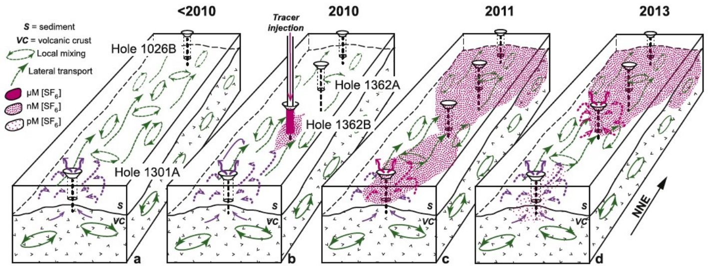


NEPTUNE cabled network

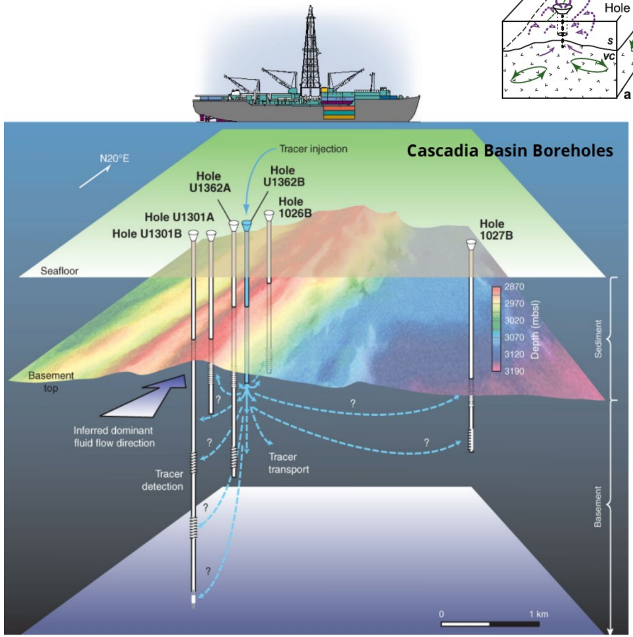
800 km

(after Goldberg et al., 2008)

Existing physical data in Cascadia Basin



(Neira et al, 2013)



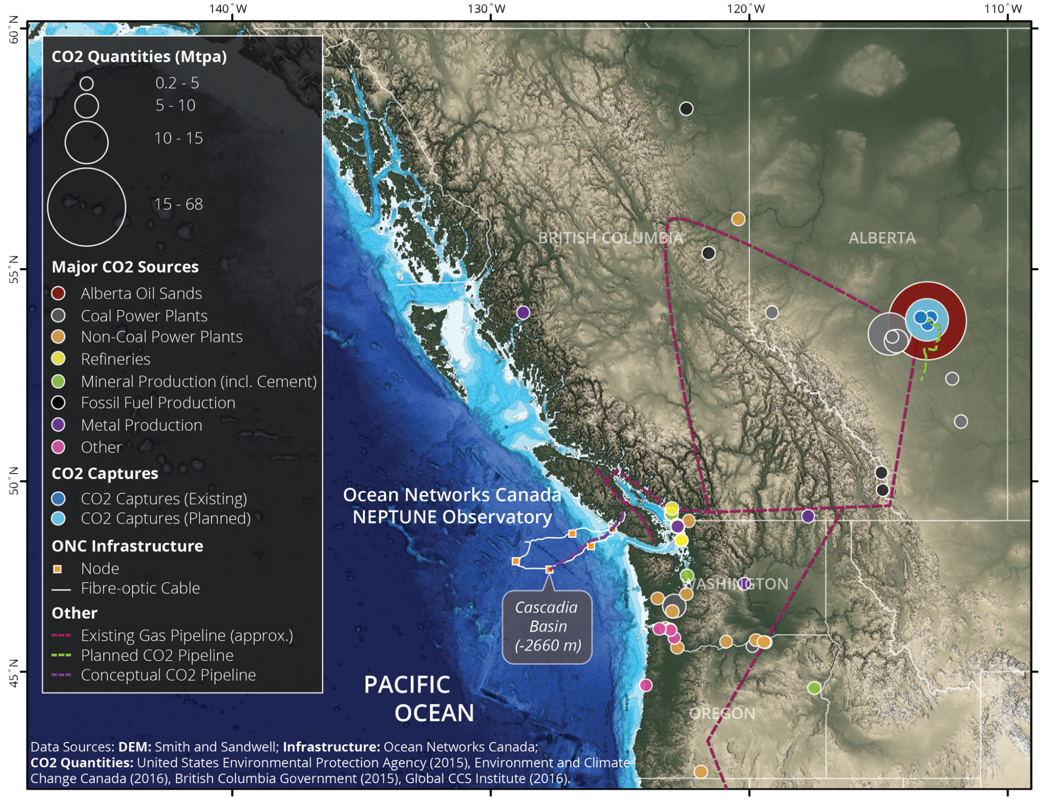
-Several existing well completions and instrumentation at IODP sites along buried basement ridge

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

-Extensive core and measurement data in public archives

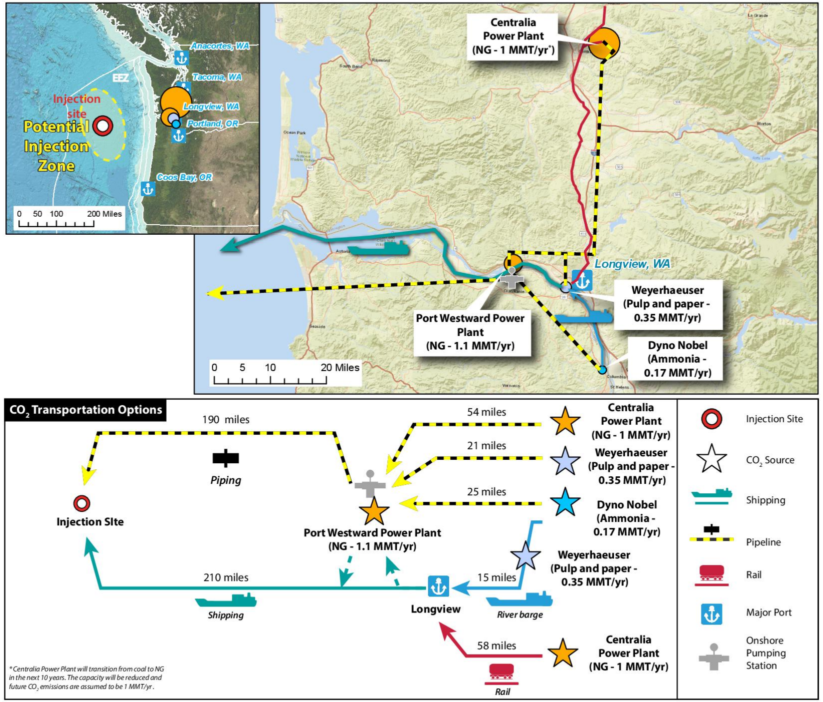
-Active cabled network (NEPTUNE) for observation and monitoring

Potential CO_2 sources near Cascadia area



(from proposal)

CarbonSAFE Cascadia Case Scenarios



Case #2 – Power Plants plus Mix

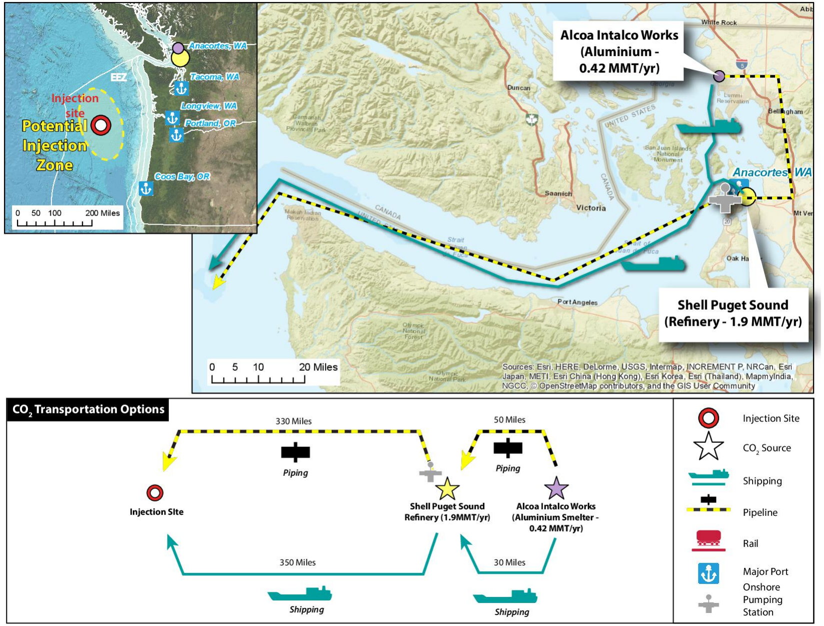
Sources:

- Power Plants: 2.5 Mtpa
  - Centralia Power Plant, 1 Mtpa
  - Port Westward Power Plant, 1.1 Mtpa
- Other: 0.52 Mtpa

Transport:

- Rail, Ship and/or Pipeline

CarbonSAFE Cascadia Case Scenarios



Case #3 – North Washington Coastal Mix

Sources:

- Shell Puget Sound Refinery, 1.9 Mtpa
- Alcoa Intalco Work Aluminium Plant, 0.4 Mtpa

Transport:

- Ship and/or Pipeline 380 miles to Cascadia Basin

CarbonSAFE Cascadia Case Scenarios

Case #4 – Largest BC fossil fuel CO2 Emitters

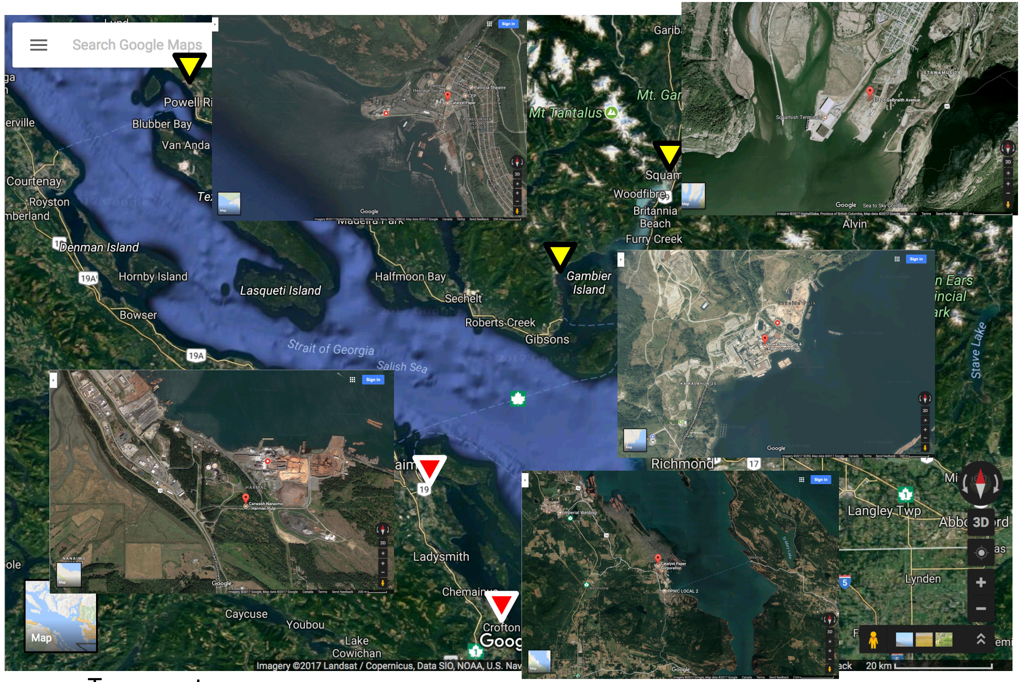
Sources:

- Main Sources: 1.551 MMT/yr ▼
  - Richmond Cement Plant, 0.797 MMT/yr
  - Delta Plant, 0.754 MMT/yr

Transport:

- Ship or Offshore Pipeline: 300 miles from Richmond and Delta Plants to Cascadia Basin ONC Node

CarbonSAFE Cascadia Case Scenarios



Case #5 – Carbon-negative scenario: Largest BC CO_2 Emitters incl. Biomass, plus Air Capture

Sources:

- Main Sources: 2.9 MMT/yr ▼
  - Crofton Division, 1.6 MMT/yr
  - Harmac Pacific Operations, 1.3 MMT/yr
- Maybe add: 2.2 MMT/yr ▼
  - Howe Sound Pulp and Paper Mill, 1.5 MMT/yr
  - Powell River Division, 0.7 MMT/yr
  - Carbon Engineering, 1-2 MMT/yr, CO_2 Air Capture

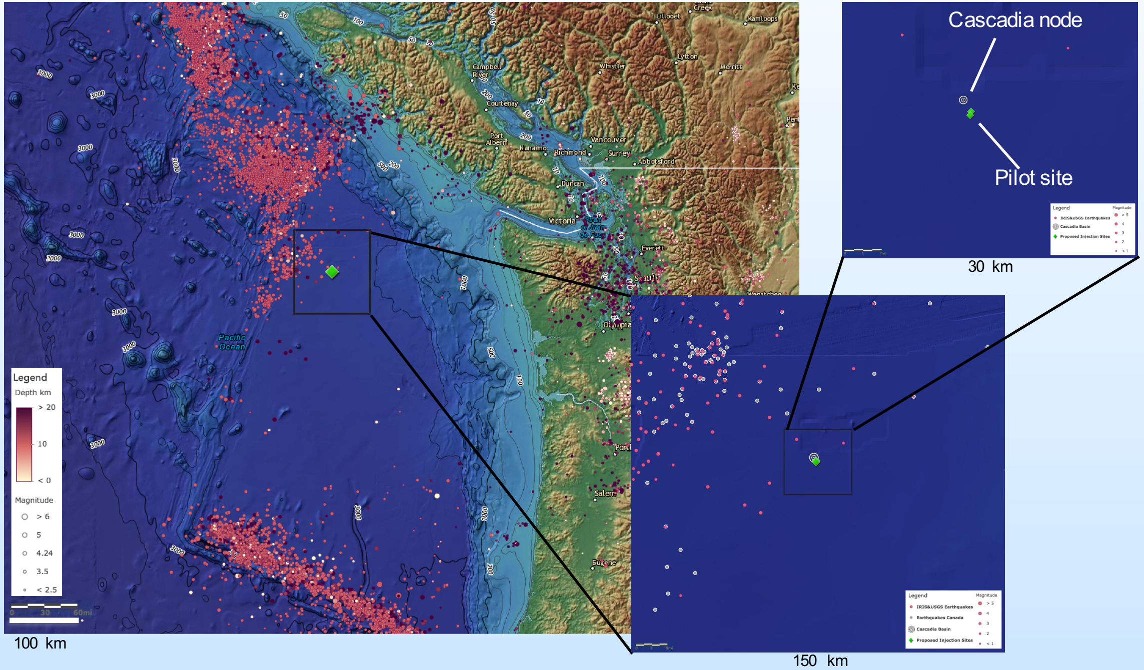
Transport:

- Pipeline for main sources:
  - Land (new route along Highway): 80 miles to Port Renfrew
  - Offshore: 160 miles from Port Renfrew to Cascadia Basin ONC Node
- Ship from Harmac via Crofton to Cascadia Basin ONC Node: 290 miles

Phase I accomplishments to date

- *Developed contact list and approached 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 and engaged regulators (April 2018 Workshop)*
- *Constructed risk registry for project-related risks and related NRAP modeling*
- *Compiled list for common and other potential environmental monitoring parameters*

Natural Seismicity: Juan de Fuca tectonic plate



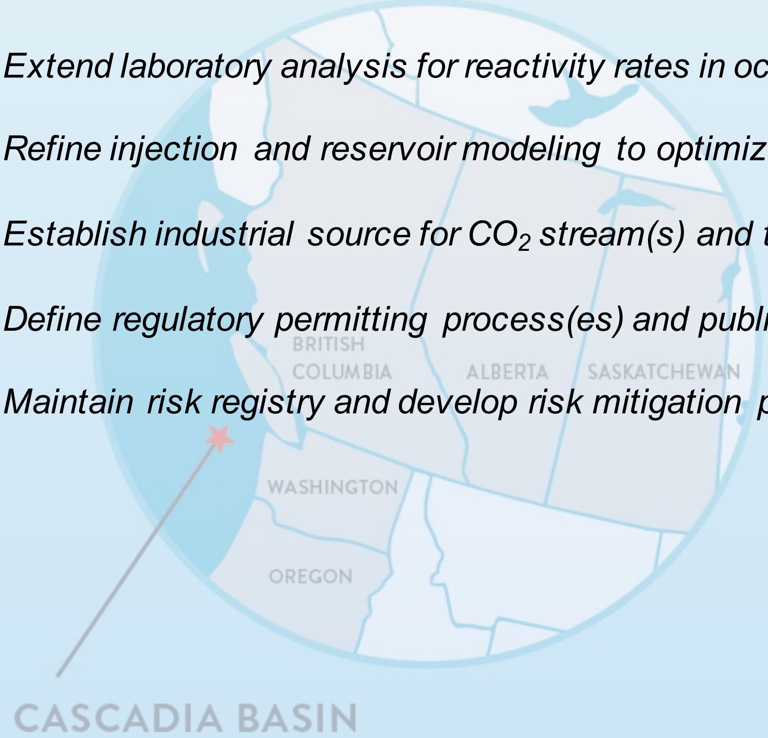
Data sources: *IRIS Interactive Earthquake Browser; USGS Earthquake Catalog; Natural Resources Canada Earthquake Database; Ocean Networks Canada Cascadia Basin*

Lessons Learned to date

- Large potential sources of anthropogenic CO_2 exist in the region
- Existing regulations appear to restrict offshore CO_2 disposal across national boundaries (e.g., Canada to U.S.)
- 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

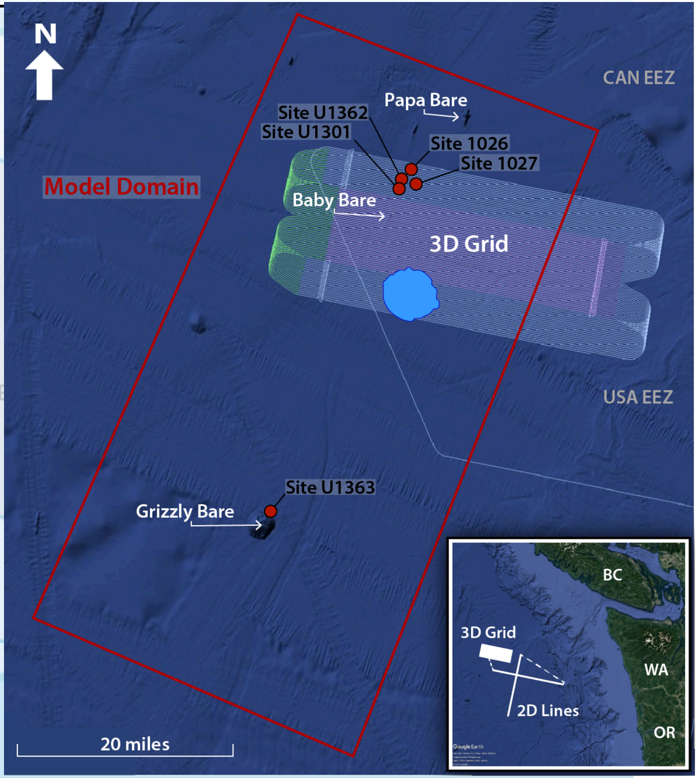
Phase I plans

- *Extend laboratory analysis for reactivity rates in ocean basalt*
- *Refine injection and reservoir modeling to optimize mineralization*
- *Establish industrial source for CO_2 stream(s) and transport options*
- *Define regulatory permitting process(es) and public outreach plan*
- *Maintain risk registry and develop risk mitigation plan*



Phase II-IV plans

- *Next Phase II* ***proposal submitted*** *in February 2018, on Storage Complex Feasibility (for 2 years)*
  - *Lab and Field Studies (incl. 2D/3D seismics over target area) and modelling, regulatory engagement and public outreach*
- *Phase III: Site Characterization needed to meet storage permit requirements, and address rights of way (2 years)*
- *Phase IV: Permitting and Construction (3.5 years)*



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THANK YOU!

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