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Northeast BC Geological Carbon Capture and Storage Atlas

Presented by Natalie Sweet, Project Manager, Allison Gibbs, Senior Hydrodynamicist, and John Xie, Senior Engineer

Canadian Discovery Ltd.

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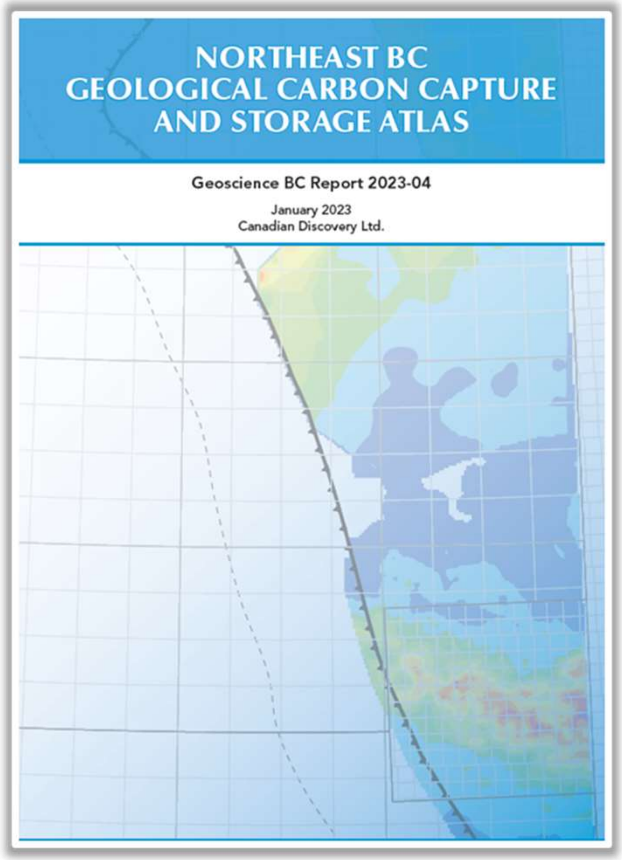
Agenda

- **Atlas Overview**
- **Background – Why and How**
  - » Global Carbon Cycle
  - » Why does CO_2 need to stored?
  - » What is geological CCS?
- **Why is the Atlas Needed?**
  - » How does the atlas help?
- **Atlas Chapter Example**
  - » Belloy Formation
- **Summary of Findings**
  - » CO_2 Storage Potential in NE BC
  - » Maps
  - » Recommendations



Overview of Atlas

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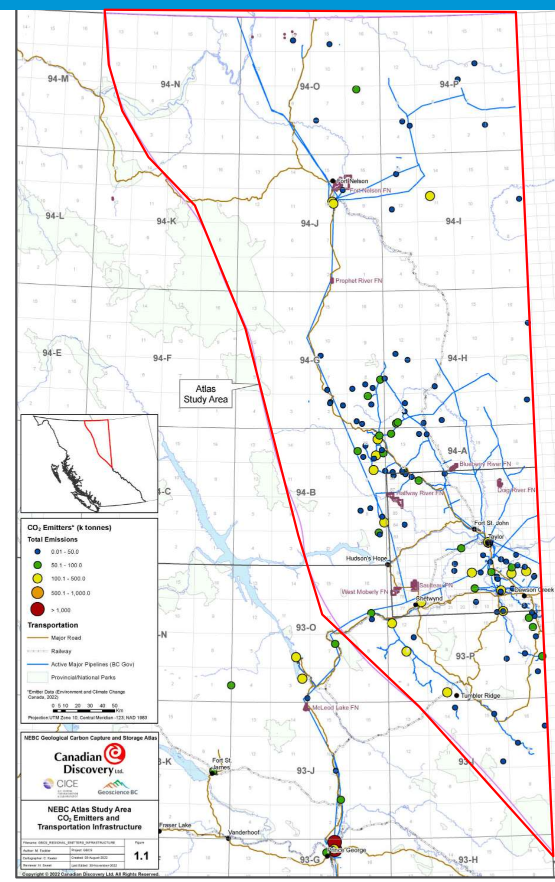
Northeast BC Atlas Background

- Map of study area with locations of stationary CO_2 emitters, cities, towns, First Nations communities, main transportation routes and major pipelines
- Study area encompasses 130, 000 square kilometers
- Favourable area for a CCS study as there are known reservoirs, a large amount of well data, reports and industry knowledge that was used for CCS assessment

Study Area CO_2 Emitters and Transportation Infrastructure



Atlas Components

- Ch. 1: Executive Summary
  - Summary of findings
  - Maps and charts
- Ch. 2: Carbon Capture and Storage Basics
- Ch. 3: Carbon Storage Project Considerations
  - Geological suitability
  - Pressure, temperature and depth requirements
  - Potential risks and risk mitigation
- Ch. 4: Atlas Overview
  - Introduction to the atlas
  - Chapter organization
  - Formation selection and exclusion criteria
  - Carbon storage calculations
- Ch. 5- 16: Individual Formations
  - Summary Page
  - Geological overview and storage complex (reservoir- seal)
  - Porosity-permeability correlations
  - Hydrodynamics
  - Carbon storage calculations
- Ch. 17: Recommendations
  - Next steps
  - Focus areas
  - Proposed future areas of study
- Appendices:
  - A: Regional stratigraphy of NEBC
  - B: Carbon storage calculations
  - C: Depleted pools storage database
  - D: References and resources
  - E: Maps, shapefiles and list of figures

Why is CCS Needed?
What is CCS?
What is Needed for Geological Storage?

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The Global Carbon Cycle and Anthropogenic (Human-Influenced) Excess CO_2

Carbon Capture and Storage (CCS) will permanently remove current emissions and can also remove excess CO_2 from the atmosphere

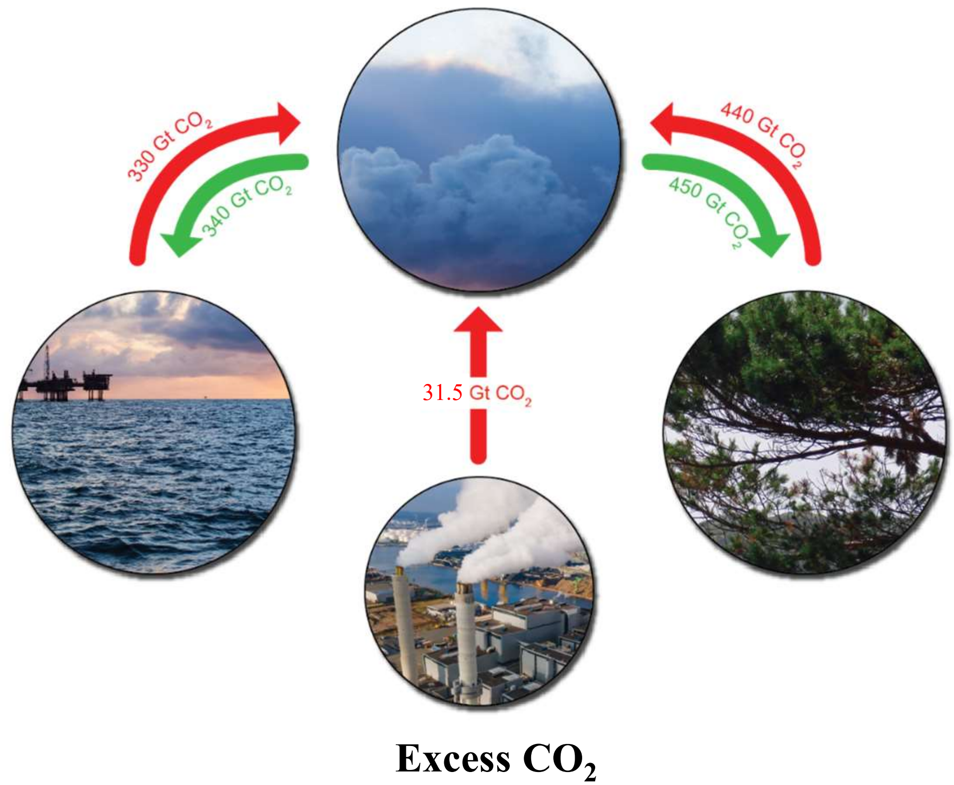
Why is this needed?

- Carbon dioxide (CO_2) is a necessary and naturally occurring gas
- Carbon cycle is a complex system
- Oceans and forests naturally release and capture CO_2 and act to balance CO_2

BUT!

- Too much CO_2 disrupts the natural carbon cycle and acts as a heat trap
- 2021 global estimates
  - 31.5 Gigatonnes (Gt) of excess CO_2

The Global Carbon Cycle



Modified from NASA 2018

What is Geological Carbon **Capture** and Storage (CCS)?

Geological CCS – is the process of capturing CO_2 and permanently storing it securely underground

- Carbon Capture
  - At Source Capture – separation of CO_2 from other gases at industrial facilities such as coal and natural gas-fired power plants, steel mills and cement plants
    - Higher efficiency because CO_2 is removed before it is released to the atmosphere
  - Direct Air Capture – CO_2 extracted directly from the atmosphere. Location is not emission source dependent and can be located at optimal geological storage sites
    - Lower efficiency as the atmosphere is composed of only 0.04% CO_2
    - Removes excess CO_2

https://www.globalccsinstitute.com/about/what-is-ccs/

Carbon Capture and Storage

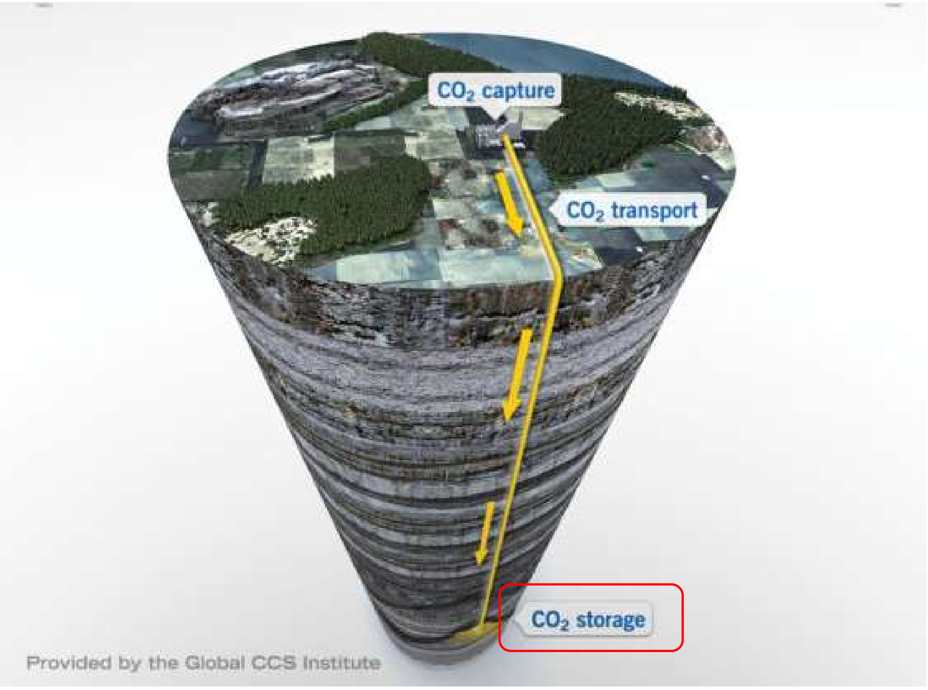
Source: https://www.forbes.com/sites/jamesconca/2019/10/08/carbon-engineering-taking-co_2-right-out-of-the-air-to-make-gasoline/?sh=643d97ec13cc

What is Geological Carbon Capture and **Storage** (CCS)?

- **Transport** – compressed CO_2 is transported via pipelines, trucks and/or rail to suitable geological storage sites
- **Storage** – CO_2 is injected deep into the subsurface and stored in geological formations (reservoirs) safely and permanently

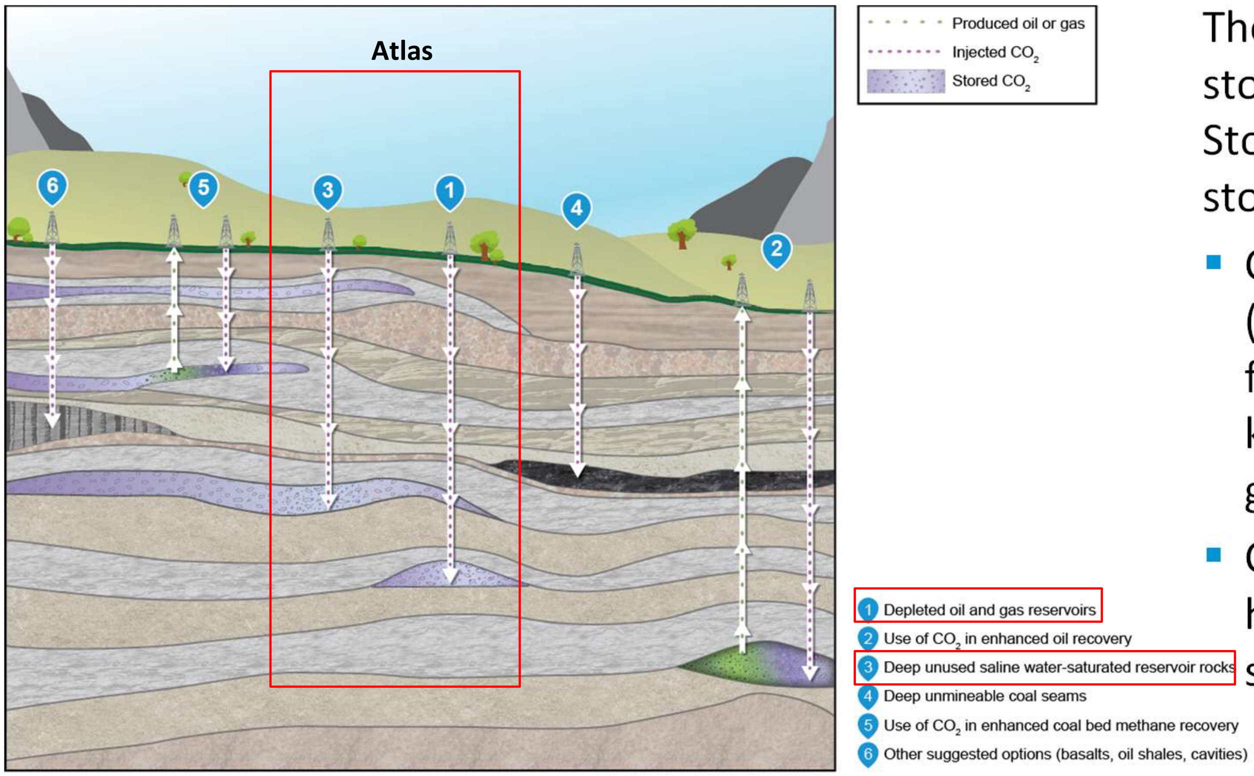
Geological Storage is the focus of the atlas. It is the component of CCS that is geographically fixed so understanding the geology "beneath our feet" is very important.

Carbon Capture and Storage



https://www.globalccsinstitute.com/about/what-is-ccs/

What Types of Geological Storage Options Exist?



Modified from IPCC, 2018, Fig 5.3

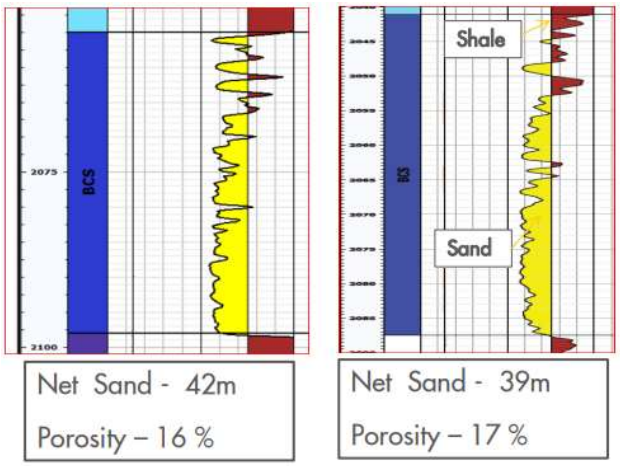
There are six types of geological carbon storage. The NE BC Geological Carbon Storage Atlas addresses two types of storage:

- CO_2 storage in depleted gas reservoirs (Type 1) is inherently suited to store CO_2 for geological time scales because we know hydrocarbons were trapped over geological time frames
- CO_2 permanent storage in saline aquifers has the highest potential for long term storage (Type 3)

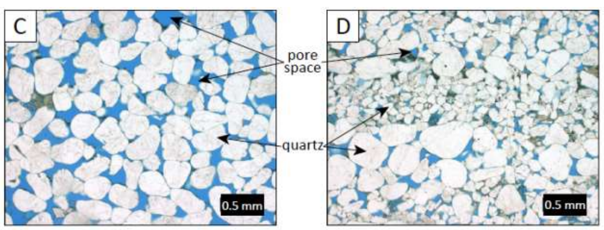
Modified by CDL from IPCC (2018)

What Makes a Good Reservoir for Carbon Storage?

Porosity/Storage

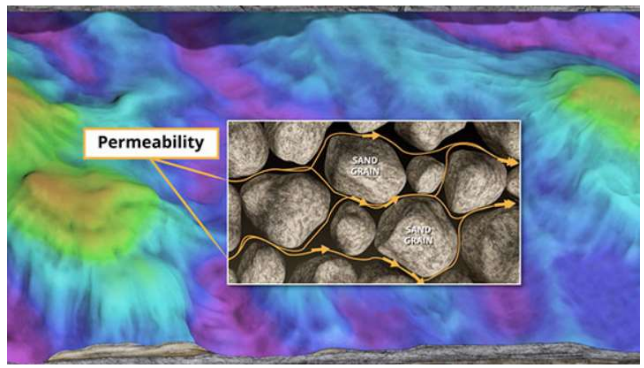


Nb: based on Vsh cut off = 0.35 and Porosity Cut Off = 0.1

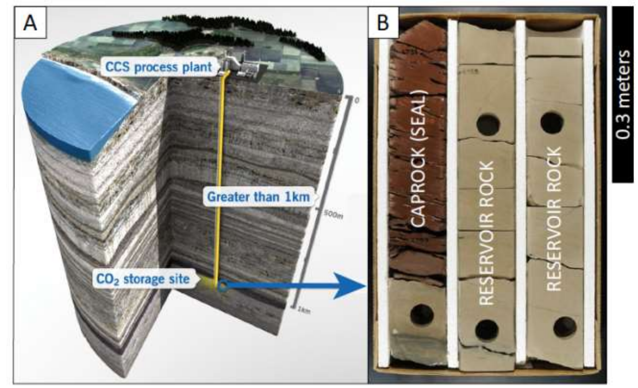


Examples or porosity (blue space)

Permeability/Injectivity



Seals/Containment



- Reservoir (storage unit) needs to have:
  - Good porosity – water/oil/gas-filled space to house CO_2
  - Good permeability – connectivity of the pores is required to move CO_2 into the pore space and away from the well bore
  - Sufficient thickness of reservoir (big enough “container”)
  - Caprock or seal for containment

Shell Quest log data and map from Rock and O’Brien (2016); Image from https://www.geoart.com/what-is-carbon-capture-and-storage/

Why is the Atlas Needed?

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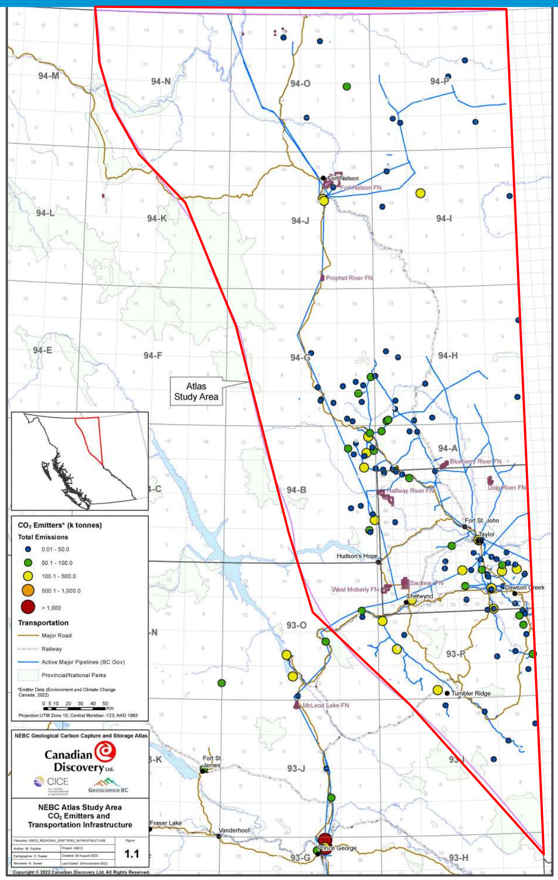
Why is the Atlas Needed?

- It is critical to understand the subsurface to see what geological storage options exist
- Carbon management industry can play a critical role in meeting both B.C.'s climate action and economic development objectives to attain Net Zero 2050 (CleanBC)
- Atlas provides key information to enable improved decision making by policy and regulatory makers, industry, First Nations, communities and others:
  - CCS – Carbon hub model to capture and store large volumes of CO_2 from multiple emitters
  - Industry use – solutions for modest scale emitters; local decisions
  - Green Economy – assist in "low carbon intensity Hydrogen" opportunity assessment and decisions

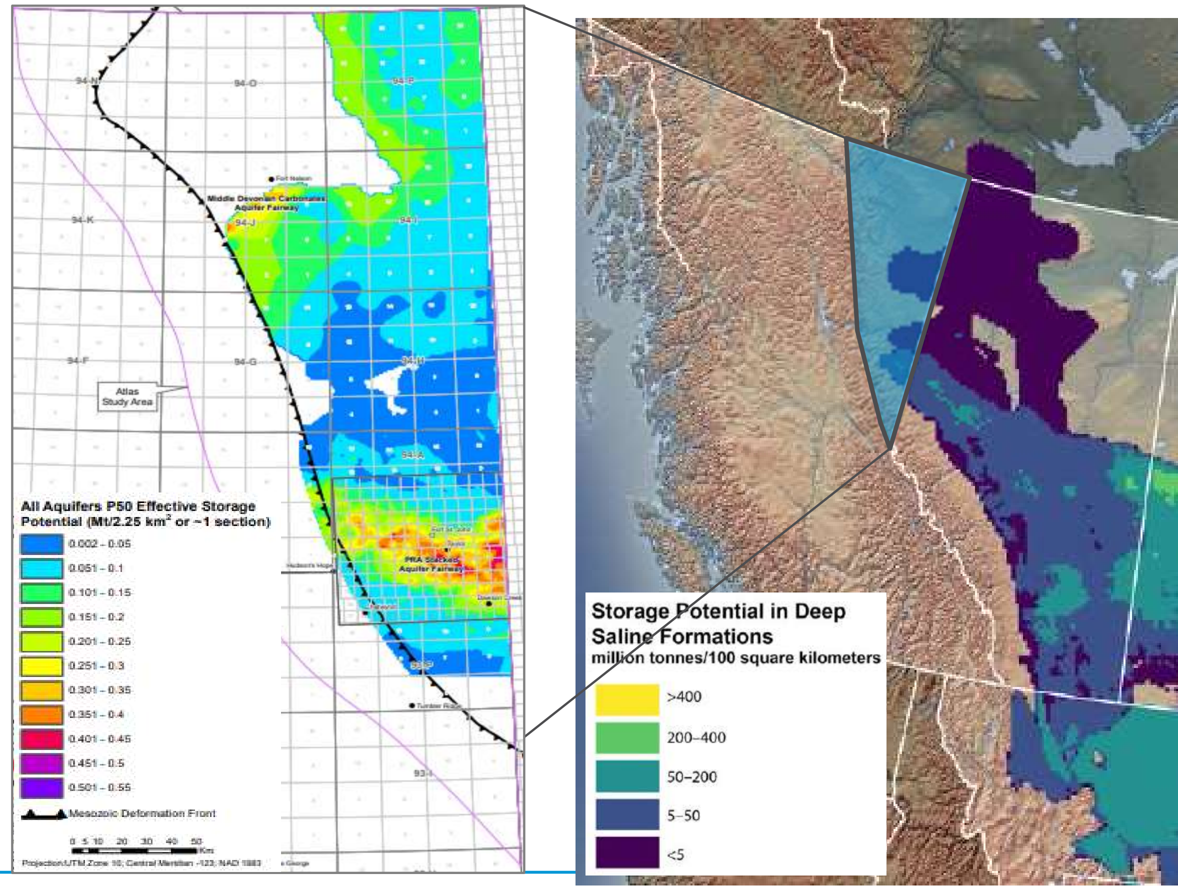
Study Area CO_2 Emitters and Transportation Infrastructure



Atlas Fills a Critical Knowledge Gap

- Previous atlases (e. g. PCOR Partnership Atlas, 2021) did not include much resolution in storage potential of B.C.
- Has collated available public information and studies, combined with additional mapping and research to provide a comprehensive report
- Identifies the most favourable regions for CO_2 storage in NE BC, particularly in areas with CO_2 emissions and access to infrastructure

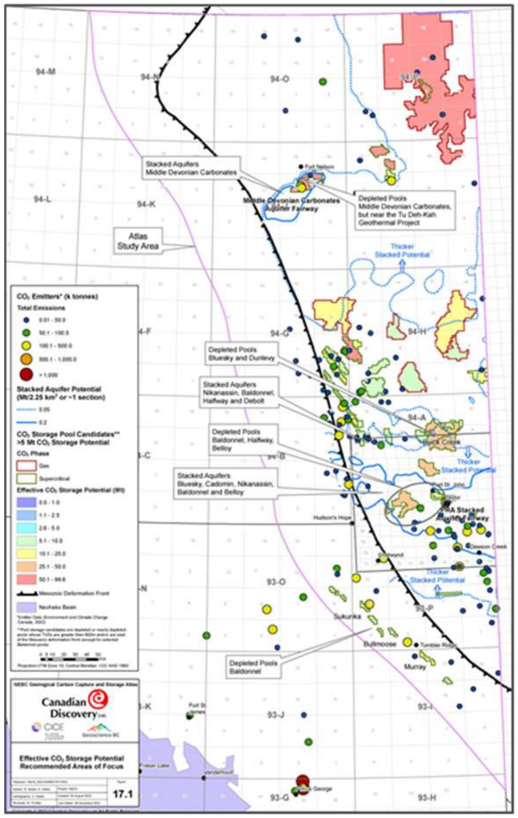
Study Area CO_2 Stacked Aquifer Storage Potential	Storage Potential in Deep Saline Formations (PCOR, 2021)



How Does the Atlas Help?

- Easy to use report, maps and database
  - High level summaries with additional technical detail to assist a variety of users
- On a high level – identifies, assesses and ranks the best CCS regions and formations in NEBC
  - Provides areas of focus
- CCS Favourability Map for each formation or groups of formations in relation to emitter locations
- Identifies knowledge gaps and areas for further research
  - Next steps
- Provides a template for research elsewhere in BC
  - Where do other storage opportunities exist?

Effective CO_2 Storage Potential Recommended Areas of Focus (2023 Atlas)



Example Chapter – Belloy

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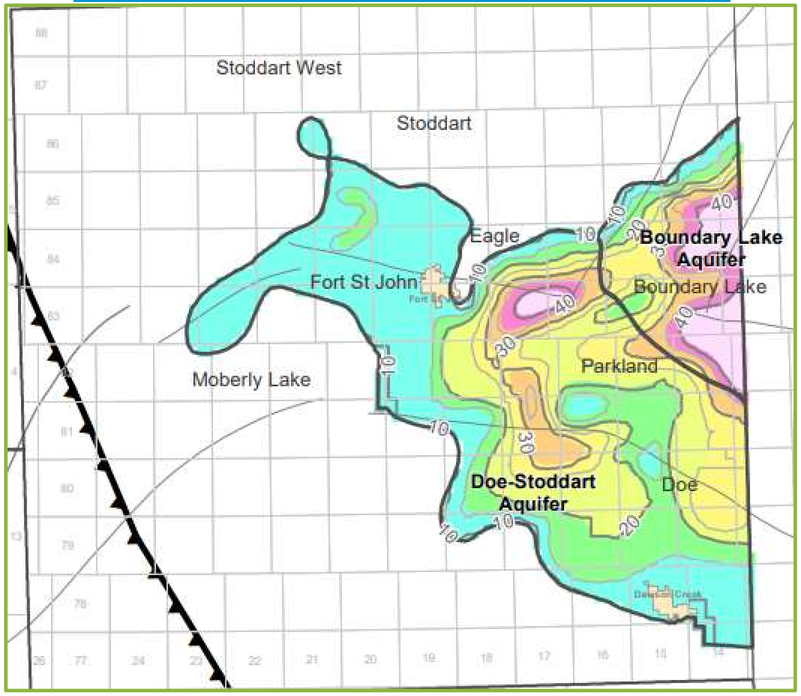
Example Chapter: Deliverables

- Summary page
- Geological, Hydrodynamics and Engineering background
- Table of storage potential for depleted pools and aquifers
- Maps of relevant data – depth, porous reservoir, with critical pressure and temperature lines
- Summary maps to show aerial distribution of storage potential
- Effective CO_2 storage potential calculations
- Appendices of maps, shapefiles and database

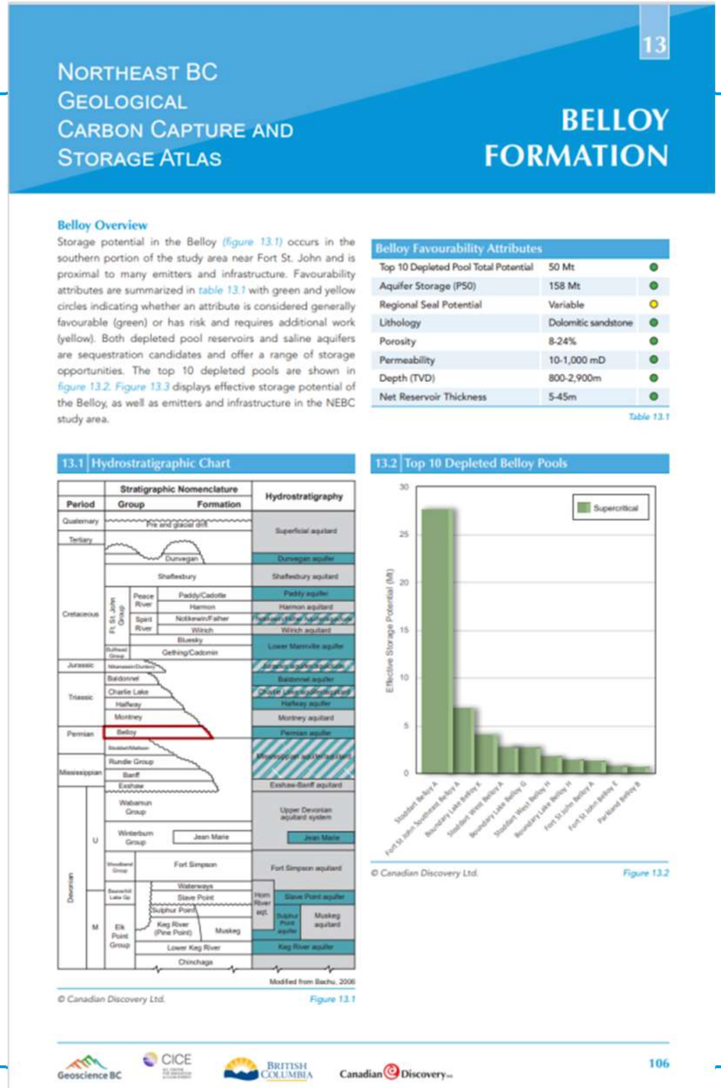
Belloy Aquifer Net Reservoir Thickness



Belloy Example: Summary Page

- Summary page provides a quick look at each formation
- Useful for comparing formations

Belloy Favourability Attributes		
Top 10 Depleted Pool Total Potential	50 Mt	●
Aquifer Storage (P50)	158 Mt	●
Regional Seal Potential	Variable	●
Lithology	Dolomitic sandstone	●
Porosity	8-24%	●
Permeability	10-1,000 mD	●
Depth (TVD)	800-2,900m	●
Net Reservoir Thickness	5-45m	●


Northeast BC Geological Carbon Capture and Storage Atlas

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BELLOY FORMATION

Belloy Overview

Storage potential in the Belloy (figure 13.1) occurs in the southern portion of the study area near Fort St. John and is proximal to many emitters and infrastructure. Favourability attributes are summarized in table 13.1 with green and yellow circles indicating whether an attribute is considered generally favourable (green) or has risk and requires additional work (yellow). Both depleted pool reservoirs and saline aquifers are sequestration candidates and offer a range of storage opportunities. The top 10 depleted pools are shown in figure 13.2. Figure 13.3 displays effective storage potential of the Belloy, as well as emitters and infrastructure in the NEBC study area.

Belloy Favourability Attributes		
Top 10 Depleted Pool Total Potential	50 Mt	●
Aquifer Storage (P50)	158 Mt	●
Regional Seal Potential	Variable	●
Lithology	Dolomitic sandstone	●
Porosity	8-24%	●
Permeability	10-1,000 mD	●
Depth (TVD)	800-2,900m	●
Net Reservoir Thickness	5-45m	●

Table 13.1

13.1 Hydrostratigraphic Chart

© Canadian Discovery Ltd. Figure 13.1

13.2 Top 10 Depleted Belloy Pools

© Canadian Discovery Ltd. Figure 13.2

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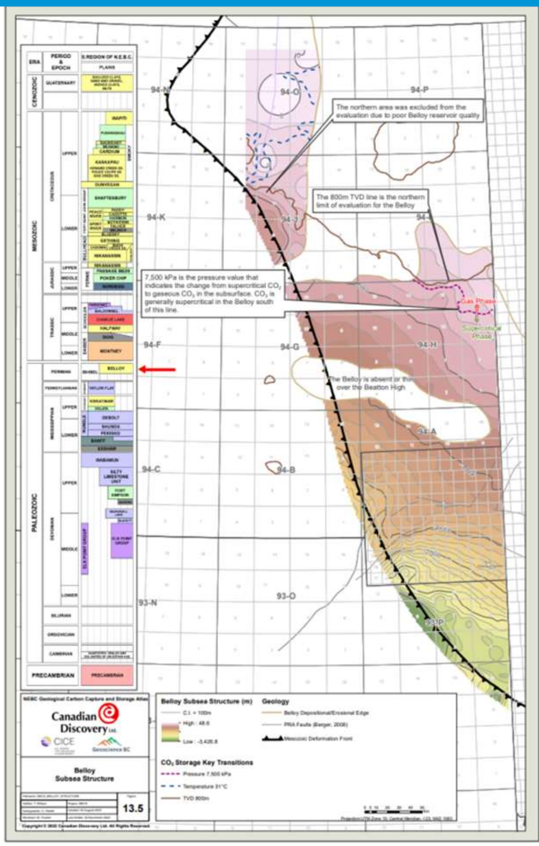
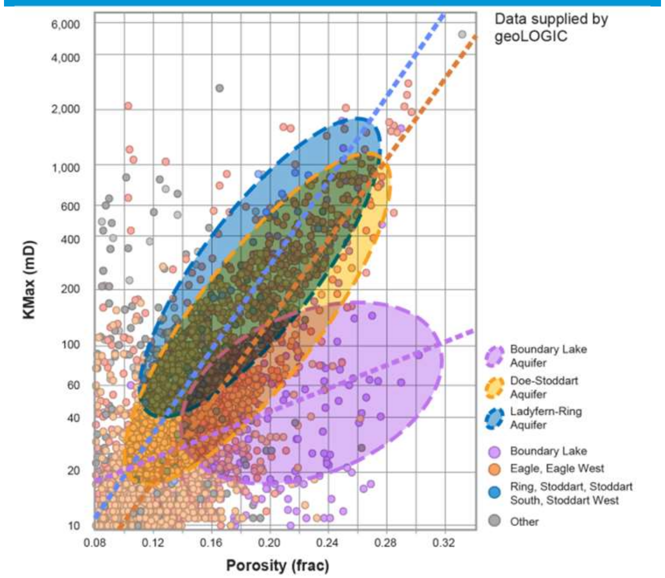
Belloy Example: Maps and Plots

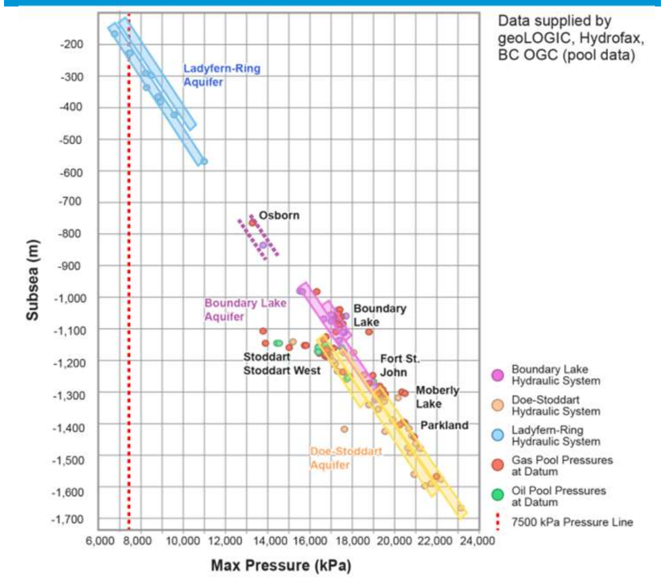
Belloy Subsea Structure



Belloy Porosity-Permeability Plot



Belloy Pressure vs Elevation Plot



Belloy Example: Storage Potential Tables

- Effective storage potential calculations are different for depleted pools and saline aquifers
- Study provides separate summary tables and databases

Depleted Belloy Pools

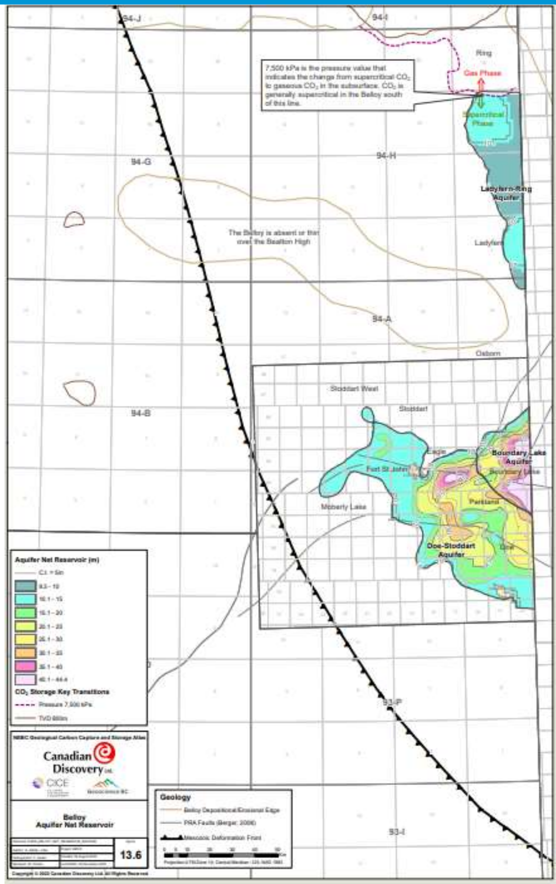
Pool Name	Pool Type	Well Count	Initial Pressure (kPa)	Temperature (°C)	Average Porosity (%)	CO_2 Phase	Theoretical Storage Potential (Mt)	Effective Storage Potential (Mt)
Stoddart Belloy A	Gas	45	16,720	69	16.0	Supercritical	31.7	27.6
Fort St John Southeast Belloy A	Gas	10	19,512	69	9.0	Supercritical	7.8	6.8
Boundary Lake Belloy K	Gas	2	17,394	67	19.4	Supercritical	4.6	4.0

Belloy Aquifer Properties and Storage Potential

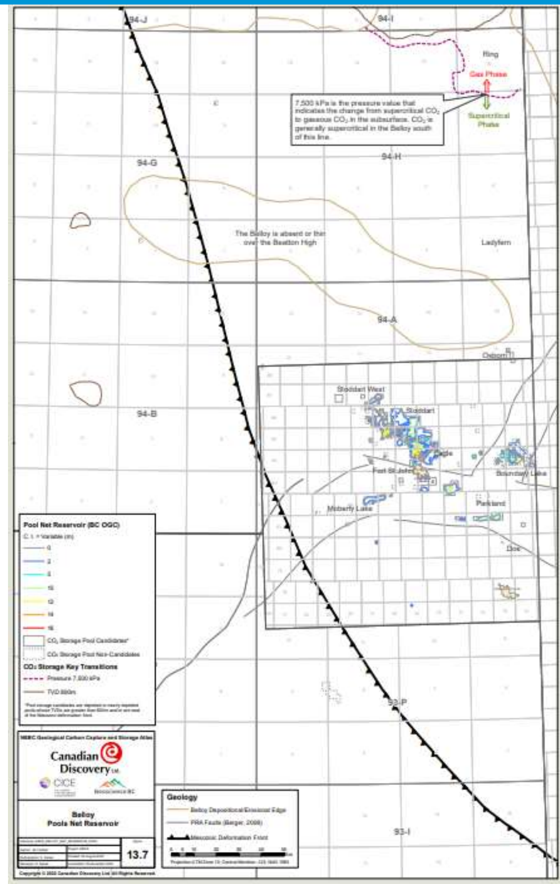
Aquifer Name	Type	Thickness Range (m)	Pressure Range (MPa)	Temperature Range (°C)	Porosity Range (%)	CO_2 Phase	P10 Effective Storage Potential at 0.5% (Mt)	P50 Effective Storage Potential at 2% (Mt)	P90 Effective Storage Potential at 5.4% (Mt)
Boundary Lake Hydraulic System	Aquifer	10-44	15.6-20.1	62-78	11-24%	Supercritical	12.2	48.7	131.4
Ladyfern-Ring Hydraulic System	Aquifer	10-15	7.4-10.8	53-62	16-20%	Supercritical	2.5	10.1	27.4
Doe-Stoddart Hydraulic System	Aquifer	10-45	15.5-29.7	58-104	10-22%	Supercritical	24.9	99.6	268.8

Belloy Example: CO_2 Effective Storage Potential Maps

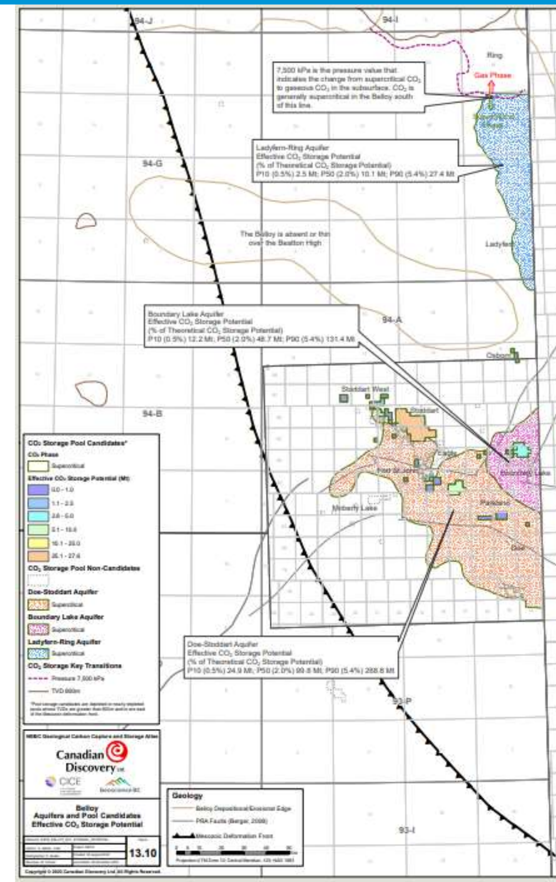
Belloy Aquifer Net Reservoir



Storage Potential of Belloy Depleted Pools



Storage Potential of Belloy Aquifers and Depleted Pools



Summary of Findings

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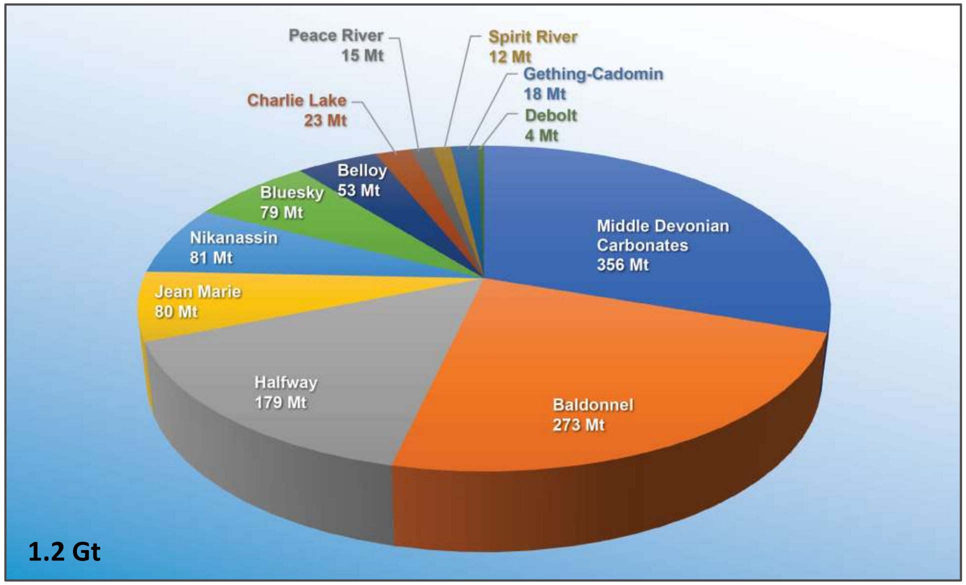
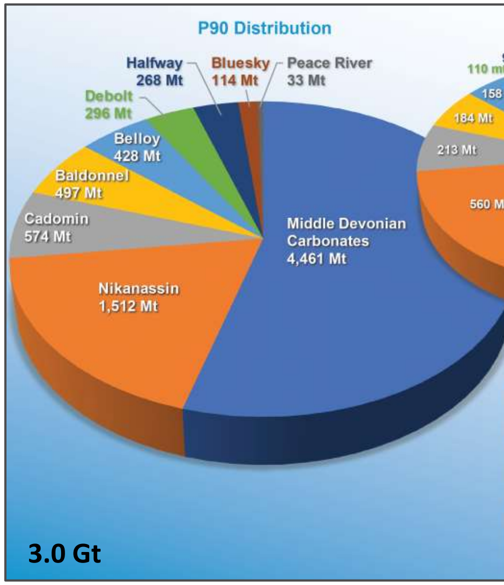
Estimated Storage Potential in NE BC

- Identified ~ **4.2 Gt** of CO_2 storage potential (P50) in formations in the study area
  - » 1.2 Gt in depleted gas pools
  - » 3.0 Gt in deep saline aquifers
  - » Enough storage potential for more than 66 years of stationary source emissions in BC

Estimated Effective Storage Potential in Depleted Gas Pools



Estimated Effective Storage Potential in Deep Saline Aquifers



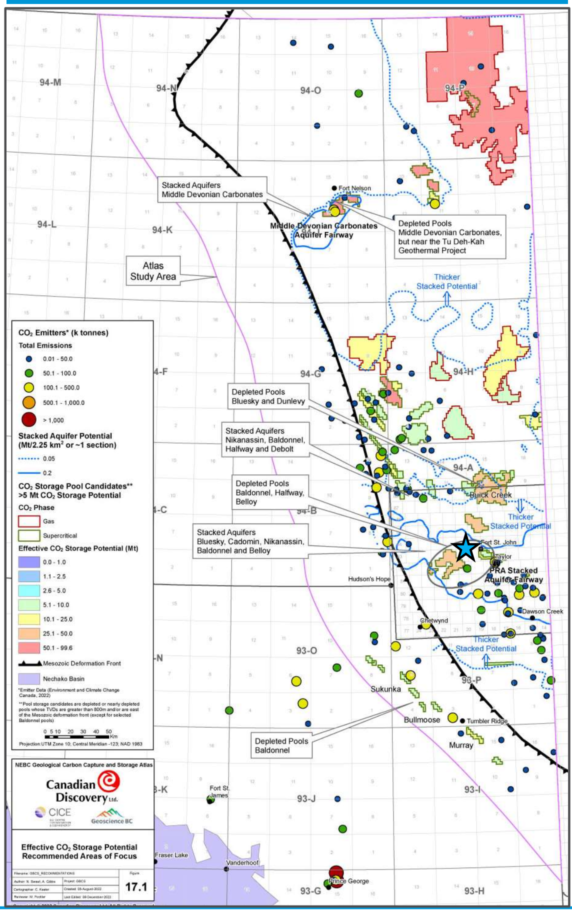
Storage Potential (Mt)

	P10	P50	P90
Mid Devonian Carbonates	413	1,652	4,461
Nikanassin	140	560	1,512
Cadomin	53	213	574
Baldonnel	46	184	497
Belloy	40	158	428
Debolt	27	110	296
Halfway	25	99	268
Bluesky	11	42	114
Peace River	3	12	33
Total	758	3,030	8,182

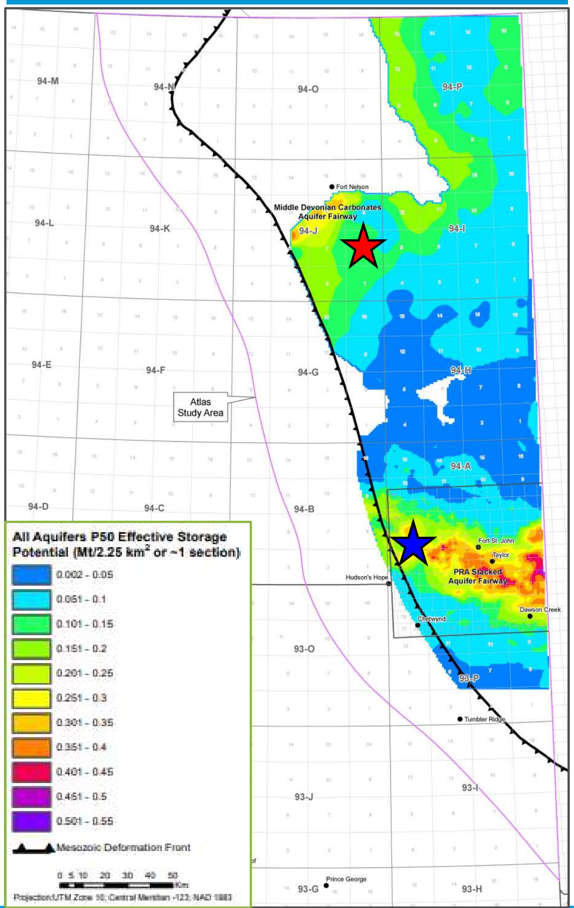
Storage Potential: Summary Maps

- 12 formations (or groups of formations) identified as having storage potential
- Fairway of stacked aquifers with significant storage potential have been identified in the Fort St. John to Dawson Creek area (PRA Stacked Aquifer Fairway) ★
- Substantial aquifer fairway to the south of Fort Nelson (Middle Devonian Carbonates Aquifer Fairway) ★
- Several depleted pools each with greater than 25 Mt of storage potential occur in the Fort St. John area ★

Recommended Areas of Focus

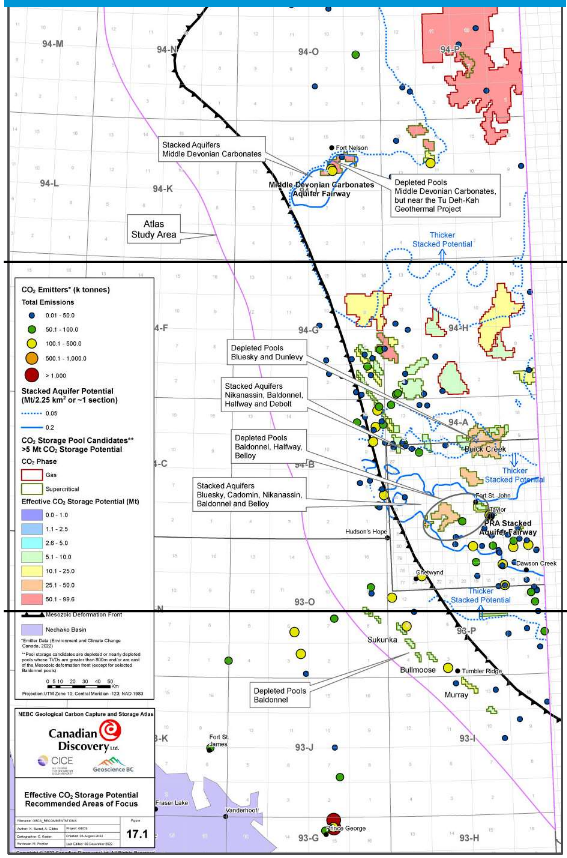


NEBC Study Area Stacked Aquifers P50

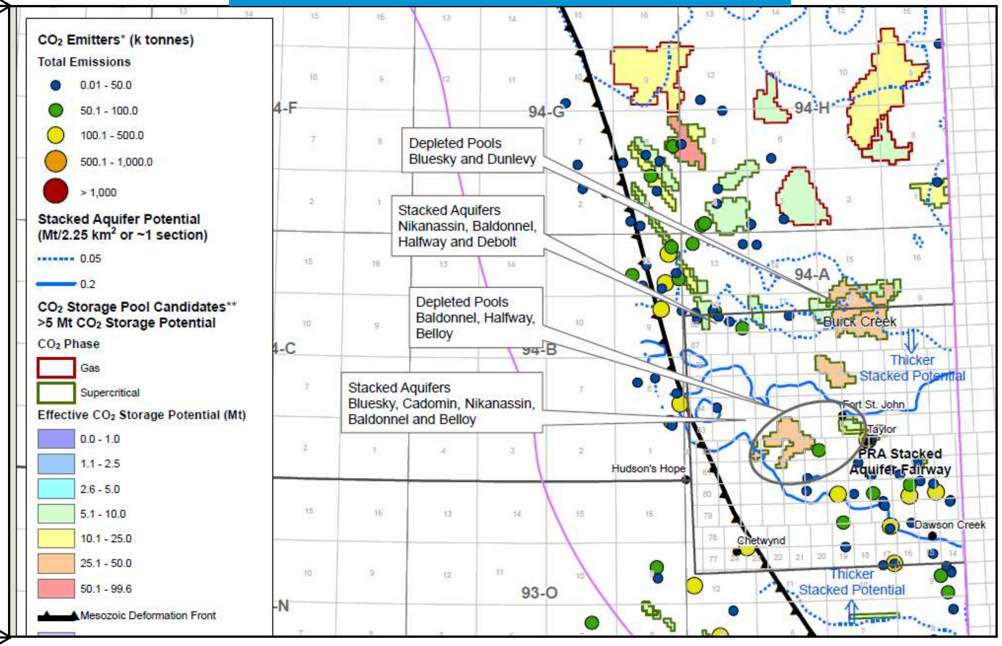


PRA Recommended Areas of Focus

Recommended Areas of Focus



Peace River Arch Area of Focus

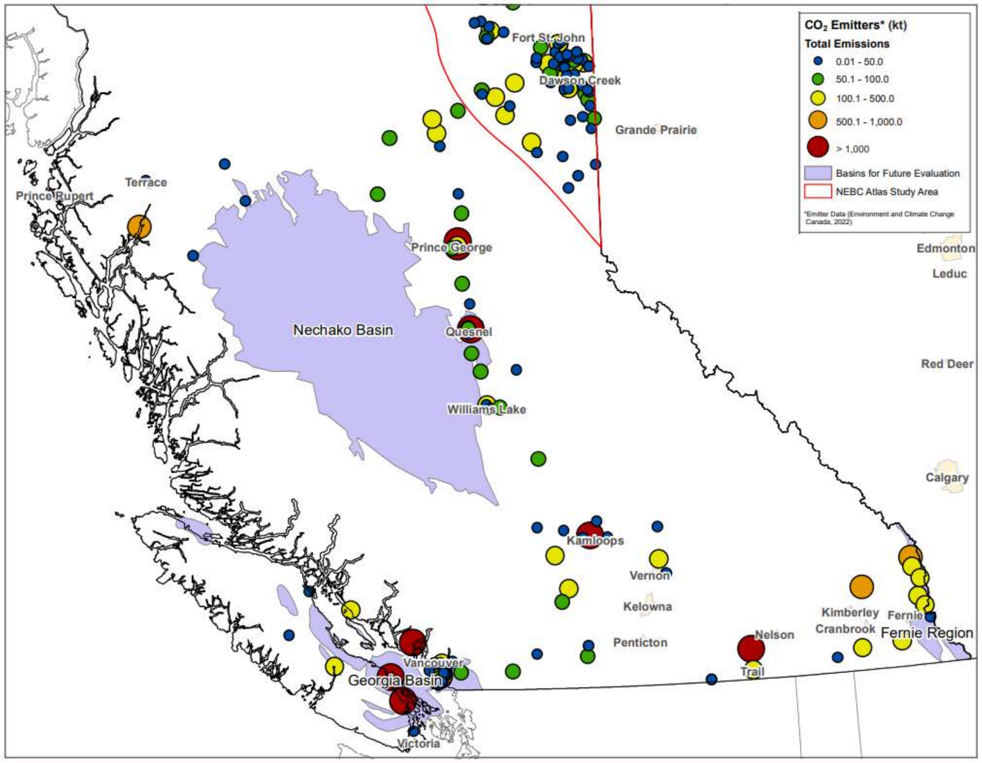


Recommendations

- Further analyses of identified knowledge gaps
  - Emissions and infrastructure
  - Containment risks
  - Storage risks
  - Injectivity risks

- Other areas of BC
  - Nechako Basin
  - Fernie Basin
  - Georgia Basin

Basins for Future Evaluation



© Canadian Discovery Ltd. *Figure 17.2*

Acknowledgements

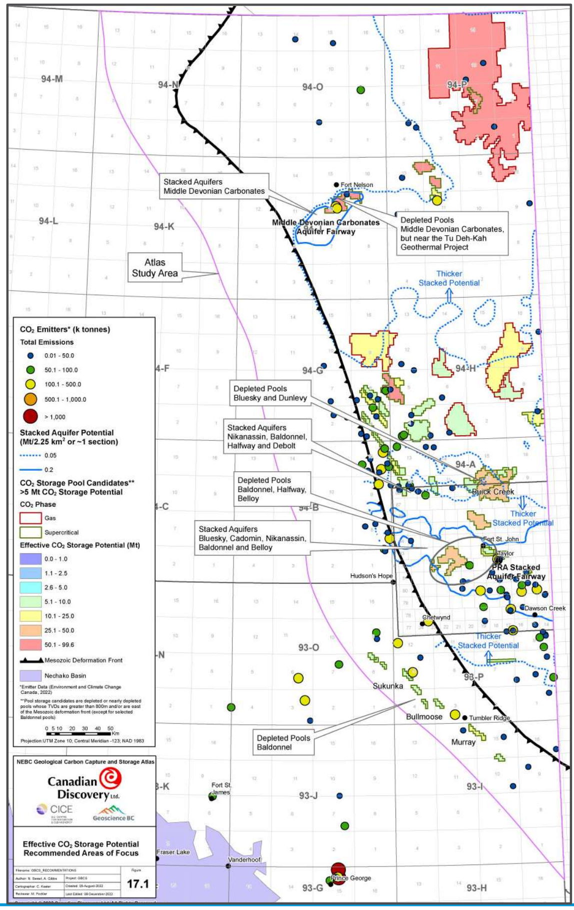
- The project partners acknowledge that this research concerns the territory of the Treaty 8 First Nations of British Columbia. We encourage anyone considering new development or activities in their territories to engage early and engage often with appropriate Indigenous groups. The Province of British Columbia's Consultative Areas Database can be used to identify potentially impacted First Nations and their respective contacts. (https://www2.gov.bc.ca/gov/content/data/geographic-data-services/landuse/contacts-for-first-nation-consultation-areas)

- We thank the project partners:
  - Geoscience BC
  - BC Centre for Innovation & Clean Energy (CICE)
  - Ministry of Energy, Mines and Low Carbon Innovation's (EMLI) Hydrogen Office

- CICE and Geoscience BC are grateful to the Province of British Columbia for funding this project

- Where to access the atlas:
- https://www.geosciencebc.com/projects/2022-001/

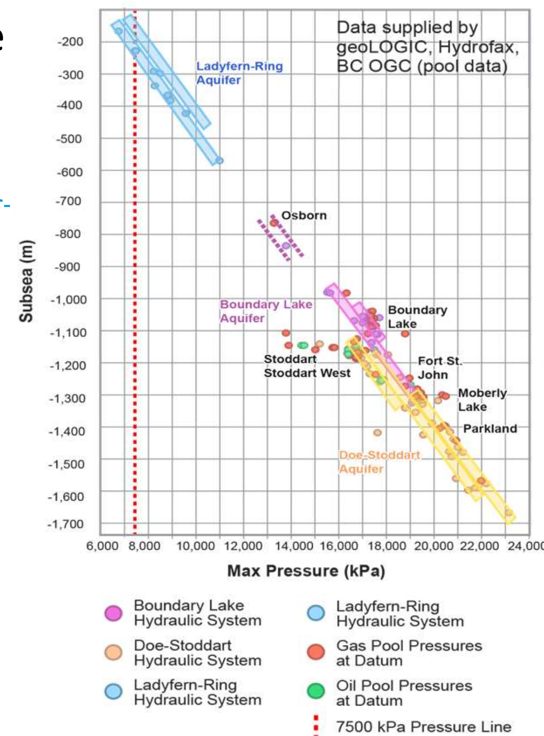
Effective CO_2 Storage Potential Recommended Areas of Focus

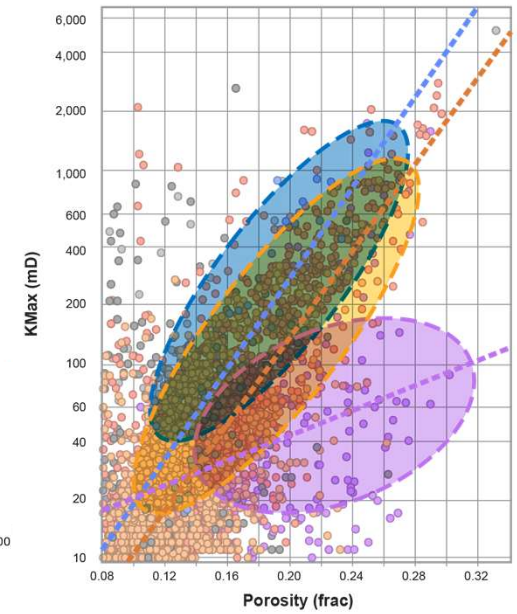


Upcoming Technical Talks

- Canadian Discovery Ltd will be presenting more technically detailed talks
  - » CDL Webinar March 21
    - https://cdl.canadiandiscovery.com/corporate/cdl-ccus-webinar-series
  - » SPE Conference March 15-16
    - https://www.spe-events.org/canadianenergytechnology
  - » GeoConvention May 15-17
    - https://geoconvention.com
  - » Acid Gas Symposium May 23-25
    - http://agis.spheretechconnect.com

$$M_{CO2eff} = A_t \cdot h_g \cdot \phi_{est} \cdot \rho_{CO2}\, E_{saline}$$





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Appendix Slides

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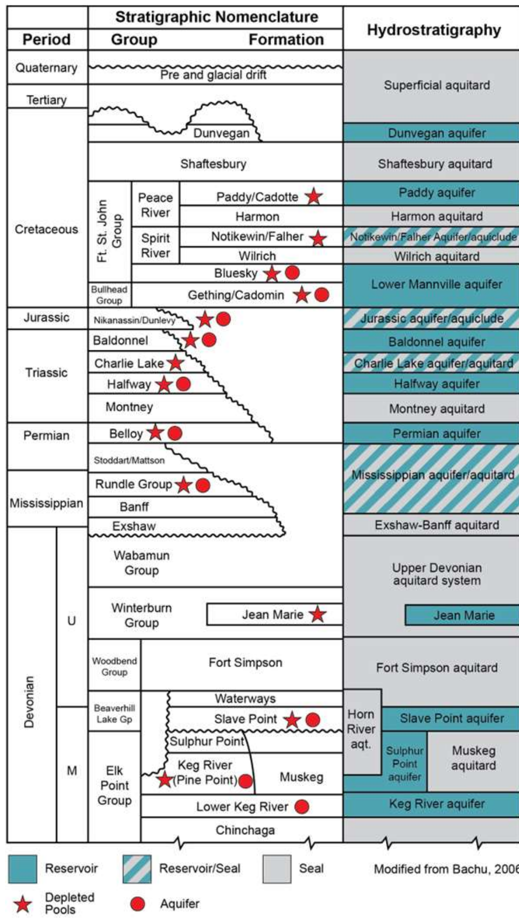
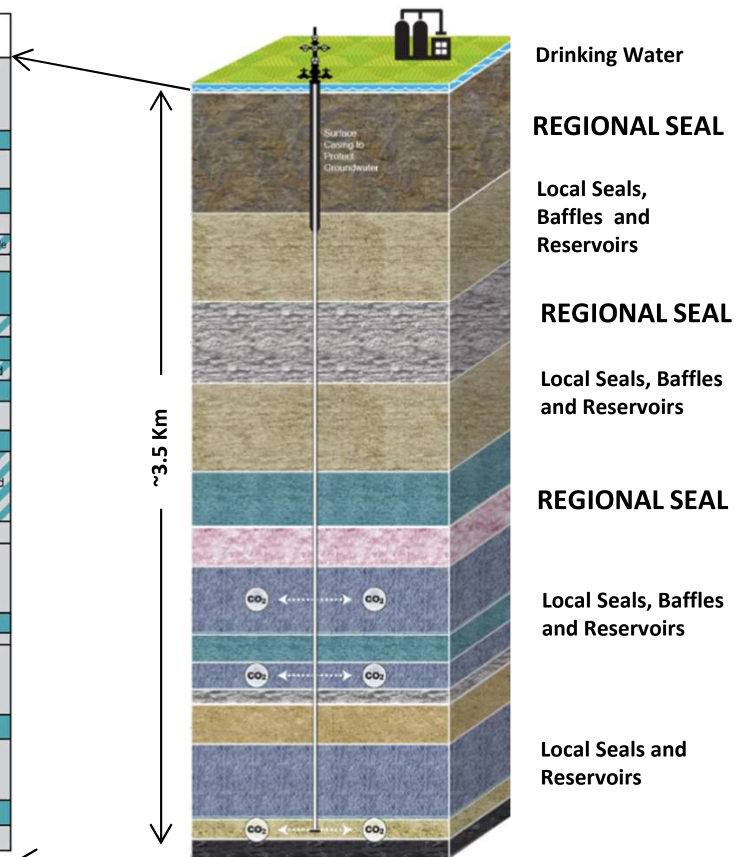
NE BC Geological Carbon Capture And Storage Atlas: Workflow

- Focused on depleted/nearly depleted pools and saline aquifers in 12 rock units (formations)
- High-level look at geology, reservoir quality and conditions, and hydrodynamic continuity determined:
  - Whether a formation might be suitable for carbon storage
    - Sufficient reservoir
    - Seals
  - Whether sufficient information was readily available to create quantitative storage estimates
    - Existing mapping
    - Additional mapping to fill in data gaps





Generalized Geological Column

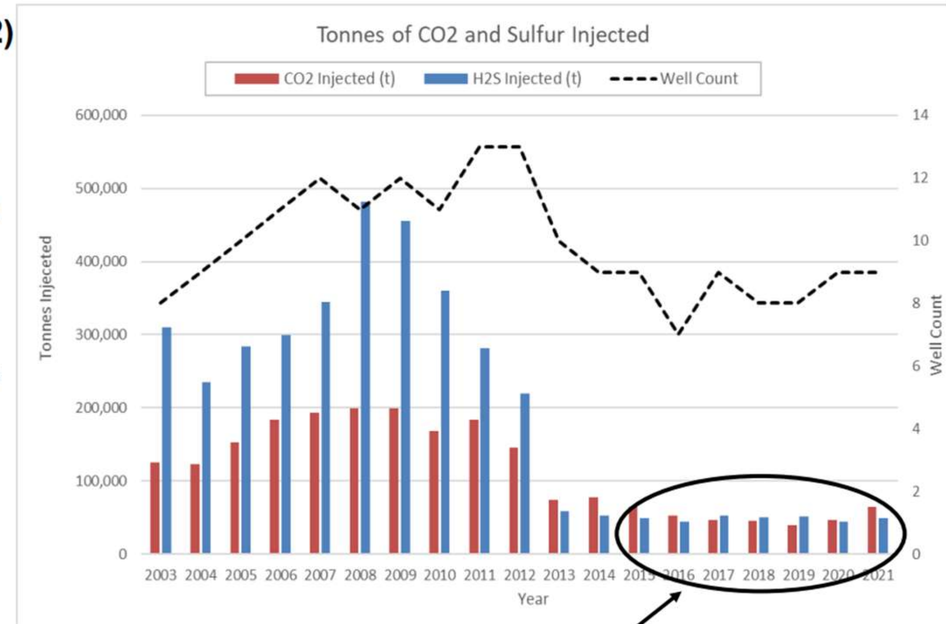
Atlas Provides Case Studies of Existing Canadian Storage Sites

- Examples of existing carbon storage projects in Canada
  - Shell Quest NW of Edmonton
  - Aquistore in Saskatchewan
- Since 1996 2.6 Mt of CO_2 have already been safely stored in 13 acid gas (H_2S and CO_2) disposal wells in NE BC
  - Extensive regulatory oversight experience with long-term integrity of wells and containment in formations

Acid Gas (H2S & CO2) Disposal Wells

Total of **2.63 megatonnes of CO2 have been sequestered**, as of December 2021.

Additionally, 8.6 megatons of SO2 diverted from atmospheric release, if had been flared.



Largest individual well sequestered 0.55 Mt CO2.

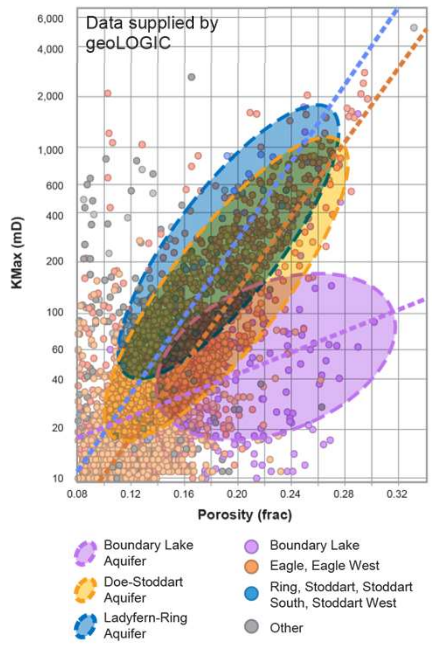
Total ~50% CO2, individual wells range 30 – 90% CO2

BC Reserves and Production Report 2021

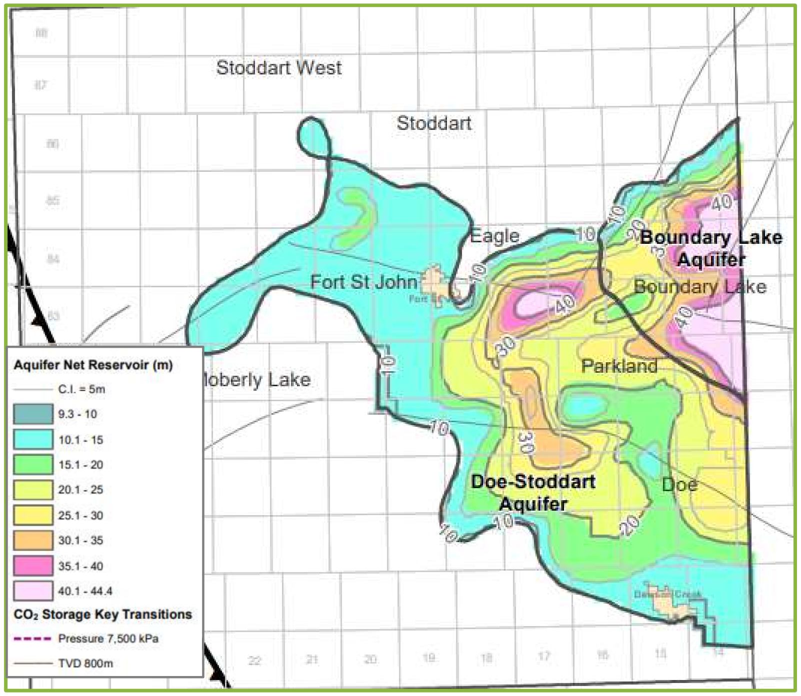
Workflow For Saline Aquifers (Geological)

- Pore volume estimation requires net reservoir thickness maps and porosity estimates
- Net reservoir thickness contours sourced from several existing studies
- CDL merged datasets and provided geological support to fill in any gaps between previously existing datasets in Atlas study area
- Filtered core data were used to provide a quick, high-level estimate of average porosity and porosity-permeability trends
- Aquifers divided into areas based on common properties (ex. Boundary Lake area more carbonate-rich in Belloy)

Porosity –Permeability Correlations



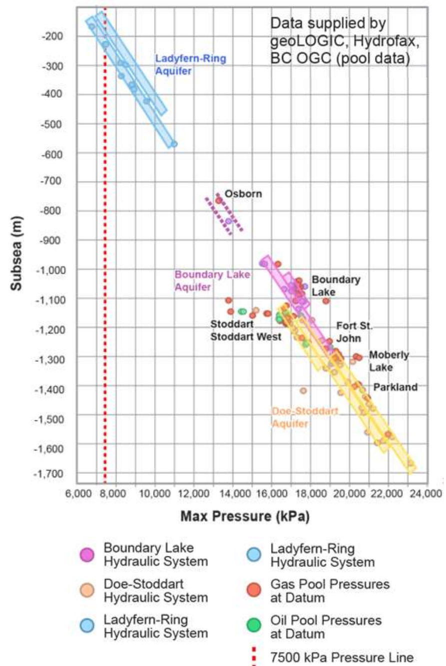
Belloy Aquifer Net Reservoir Thickness



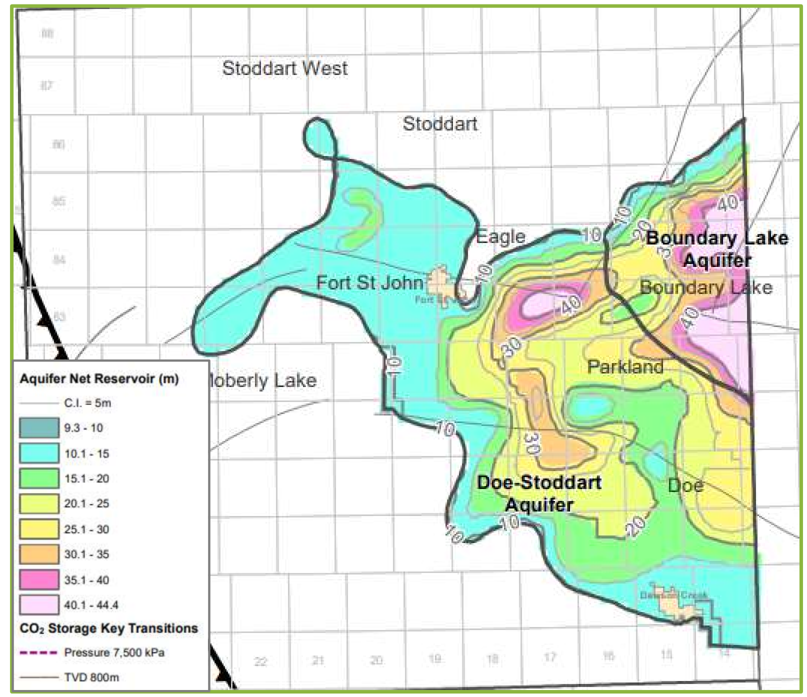
WORKFLOW FOR SALINE AQUIFERS (HYDRODYNAMIC)

- Hydro-Fax drillstem test (DST) data and Pressure-Depth ratio mapping from previous studies used to estimate absolute pressure
- Temperature gradient determined from geothermal gradient mapping
- Absolute pressure and temperature needed to determine the CO_2 density (ρCO_2) at reservoir conditions from equations of state
- DST data and the initial pressure and datum depth of depleted pools used to create a pressure vs elevation (P/E) graph
- Provide information on extent and flow of aquifer

Pressure vs Elevation Plot



Belloy Aquifer Net Reservoir Thickness

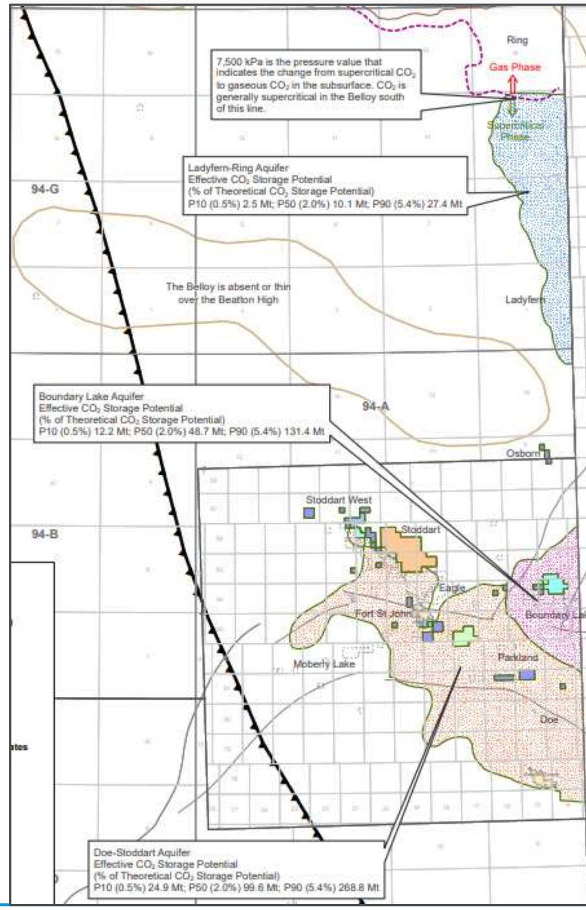


Saline Aquifers: Storage Potential

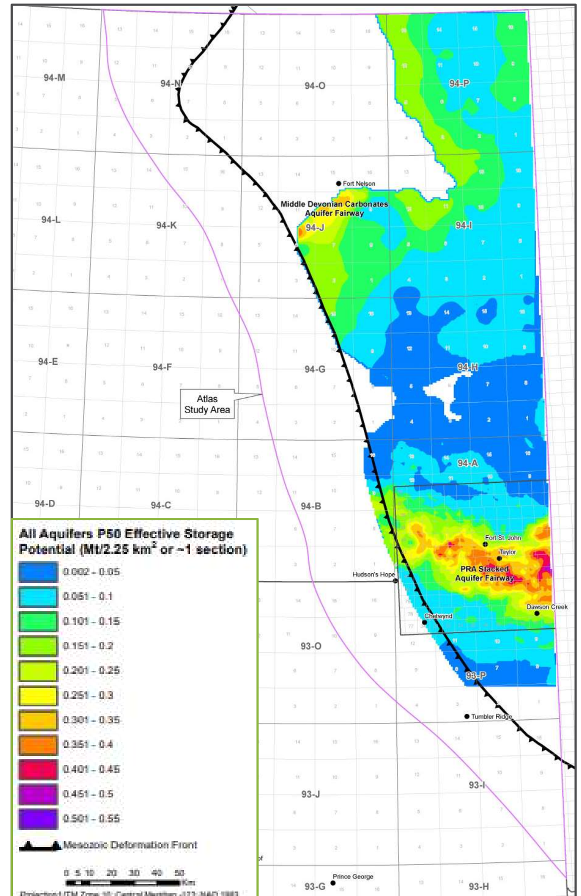
- Net reservoir, average porosity, and reservoir temperature and pressure extracted grid within study area
- CO_2 density determined for each grid cell and theoretical storage potential calculated
- Cells combined to determine Total Theoretical Storage Potential in Mt
- E_{saline} values similar to previous U.S. DOE-NETL CCS Atlas publications (2010, 2012, 2015) used to calculate Effective CO_2 Storage Potential
- Grids stacked to determine Storage Potential in stacked aquifer targets

$$M_{CO2eff} = A_t \cdot h_g \cdot \phi_{est} \cdot \rho_{CO2}\, E_{saline}$$

Belloy Storage Potential – Aquifer and Pool Candidates



NEBC Study Area Stacked Aquifers P50 CO_2 Effective Storage Potential

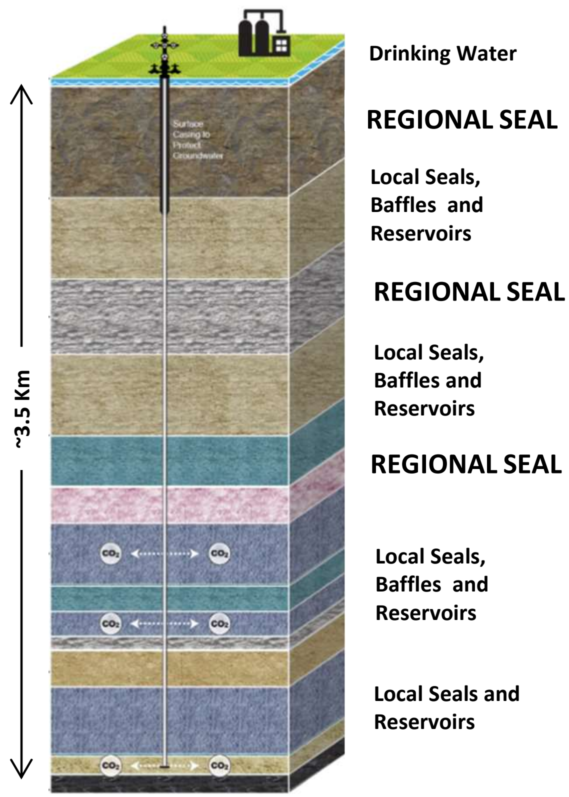


How is Containment Ensured?

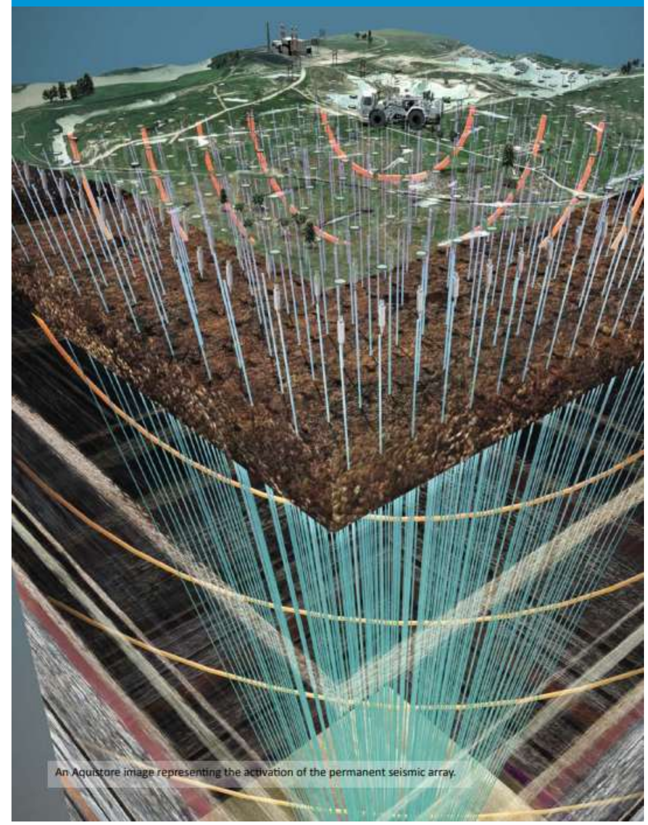
- Identifying Reservoirs and Seals
- Protecting Groundwater
  - Proper Monitoring, Measurement and Verification Plan
  - Mitigating risk of legacy wellbores

Monitoring at the Surface

Generalized Geologic Column

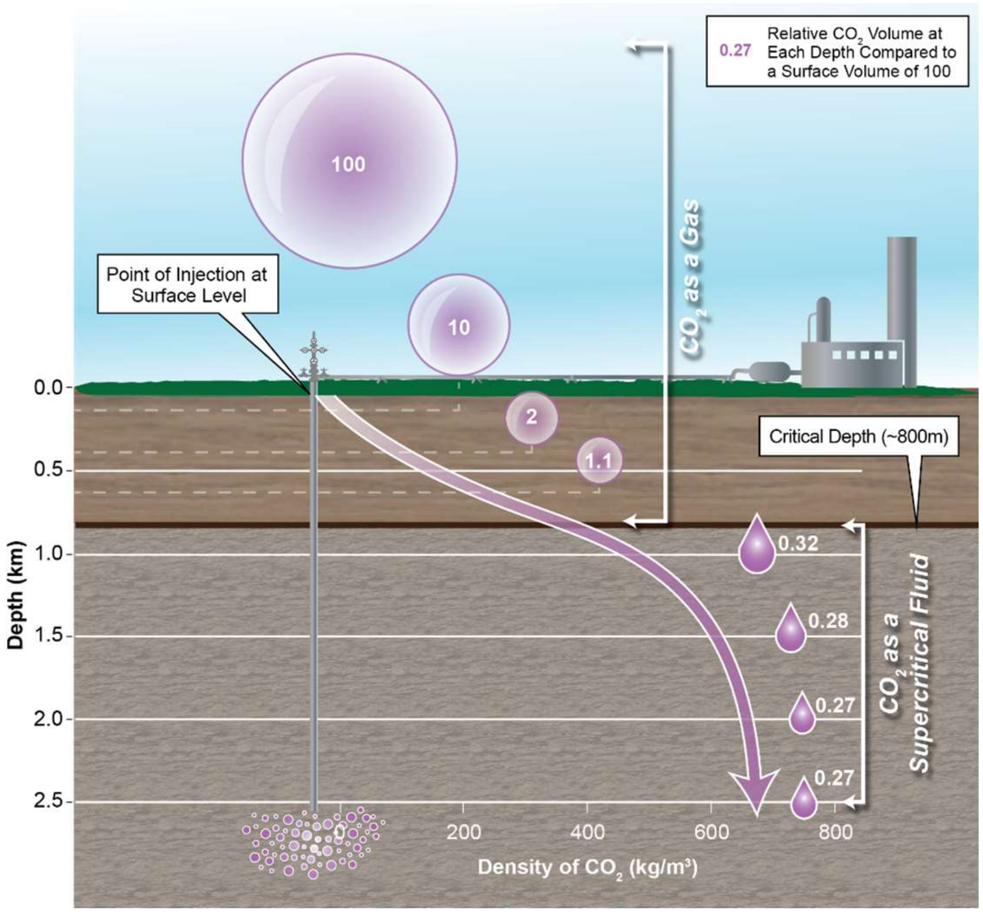


Monitoring in the Subsurface



https://www.globalccsinstitute.com/archive/hub/publications/192038/aquistore-co2-storage-worlds-first-integrated-ccs-project.pdf; PCOR Partnership Atlas, 6th Edition

What Do We Mean by Storing CO_2 as a "Supercritical Fluid"?

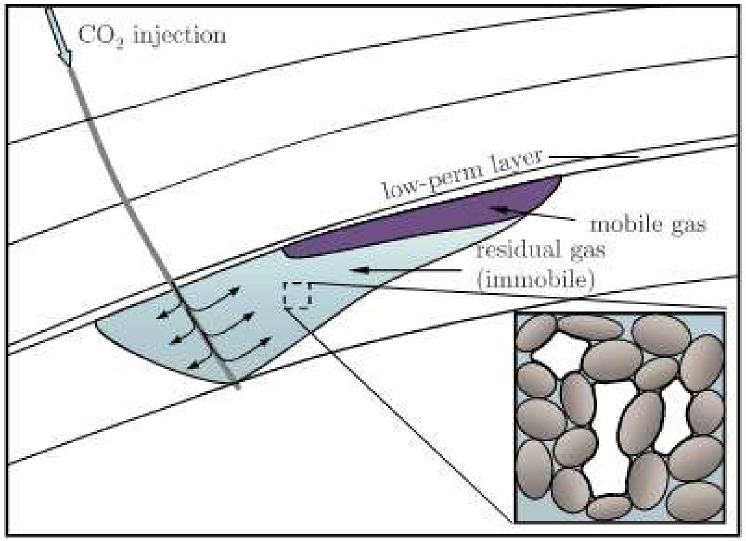


Modified by CDL from NETL (2021) for Donaldson (2021b); PCOR Atlas (2021)

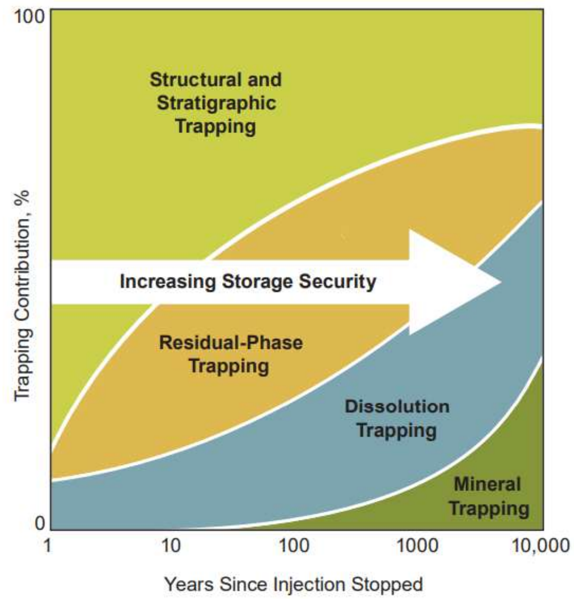
- CO_2 is a supercritical (or dense phase) fluid above 31°C and 7,500 kPa
  - Dense like a liquid, but has low viscosity like a gas
- Storage of supercritical CO_2 is ideal because the required storage volume is 0.3% of the gas phase at surface, greatly increasing the amount that can be stored
- FUN FACT: This liquid-like form of carbon dioxide has a host of other applications, such as decaffeinating coffee!

How Does a CO_2 Plume Travel? How Does it Get Trapped?

CO_2 Plume Movement



CO_2 Trapping



- CO_2 plume is lighter than water and tends to migrate to the top of the aquifer and follow the seal
- CO_2 gets stored in the formation through physical trapping, residual trapping in the pore space, dissolving into formation water, or reacting with minerals in the rock to form new minerals
- CO_2 becomes more securely trapped as time passes

Juanes et al. (2006); PCOR Partnership Atlas, 6th Edition