WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

A LONGER GUIDE TO CARBON CAPTURE AND STORAGE

UNIVERSITY OF
WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

THE CHALLENGE FROM THE P.M.

At an international climate summit convened by U.S. President Joe Biden, Prime Minister Justin Trudeau said Canada will reduce emissions by 40 - 45 % below 2005 levels by 2030

Apr 22, 2021

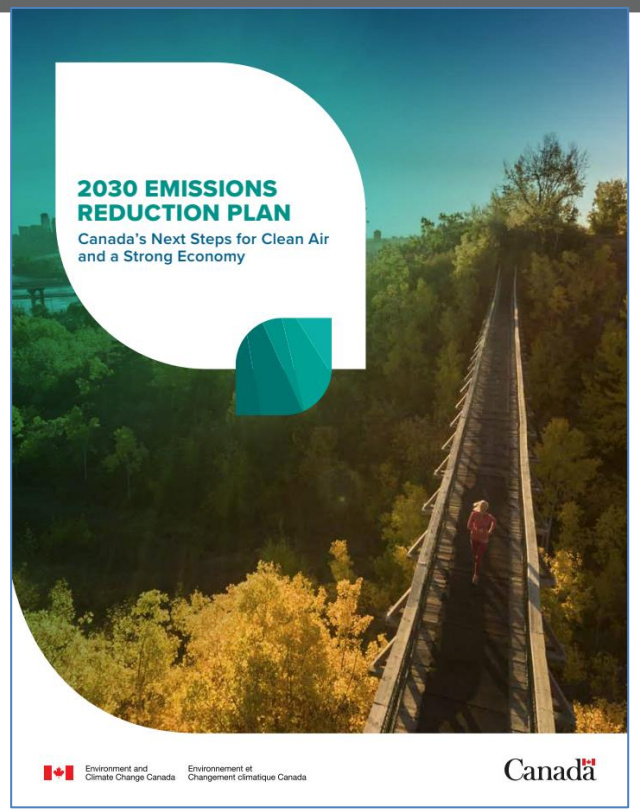
NRCan given $319 million over 7 years in 2021 budget to implement this pledge out of an $8 bn Net Zero Accelerator account

WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

EMISSIONS REDUCTION PLAN FOR 2030

WATERLOO



"This first Emissions Reduction Plan charts a credible path to emissions that are 40 percent lower than 2005 levels by 2030"

"This is the first Emissions Reduction Plan issued under the *Canadian Net-Zero Emissions Accountability Act*. Progress under the plan will be reviewed in progress reports produced in 2023, 2025, and 2027."

From 2030 EMISSIONS REDUCTION PLAN: CANADA'S NEXT STEPS FOR CLEAN AIR AND A STRONG ECONOMY, Environment & Climate Change Canada, Ottawa, 2022

WHERE WE ARE IN MID-2024?

- Canada pledged to be net-zero in carbon dioxide (CO_2) emissions by 2050 in the 2015 Paris Agreement
- Provincial governments regulate CCS within their boundaries
- Only Alberta, B.C. and Saskatchewan meet Federal regulatory standards in mid-2024 that enable industries in these western provinces to receive Investment Tax Credits
- No province in eastern Canada meets these standards yet
- So, no company in eastern Canada can receive the 50% Federal ITCs for capture of its CO_2 emissions

WHY CAPTURE CO_2 EMISSIONS?

Without capturing CO_2 emissions, temperatures will climb further, and the hazards and costs of climate change will be much worse.

Already home insurance premiums rose 64% in Ontario and 140% in Alberta between 2011 and 2021 according to www.Rates.ca.

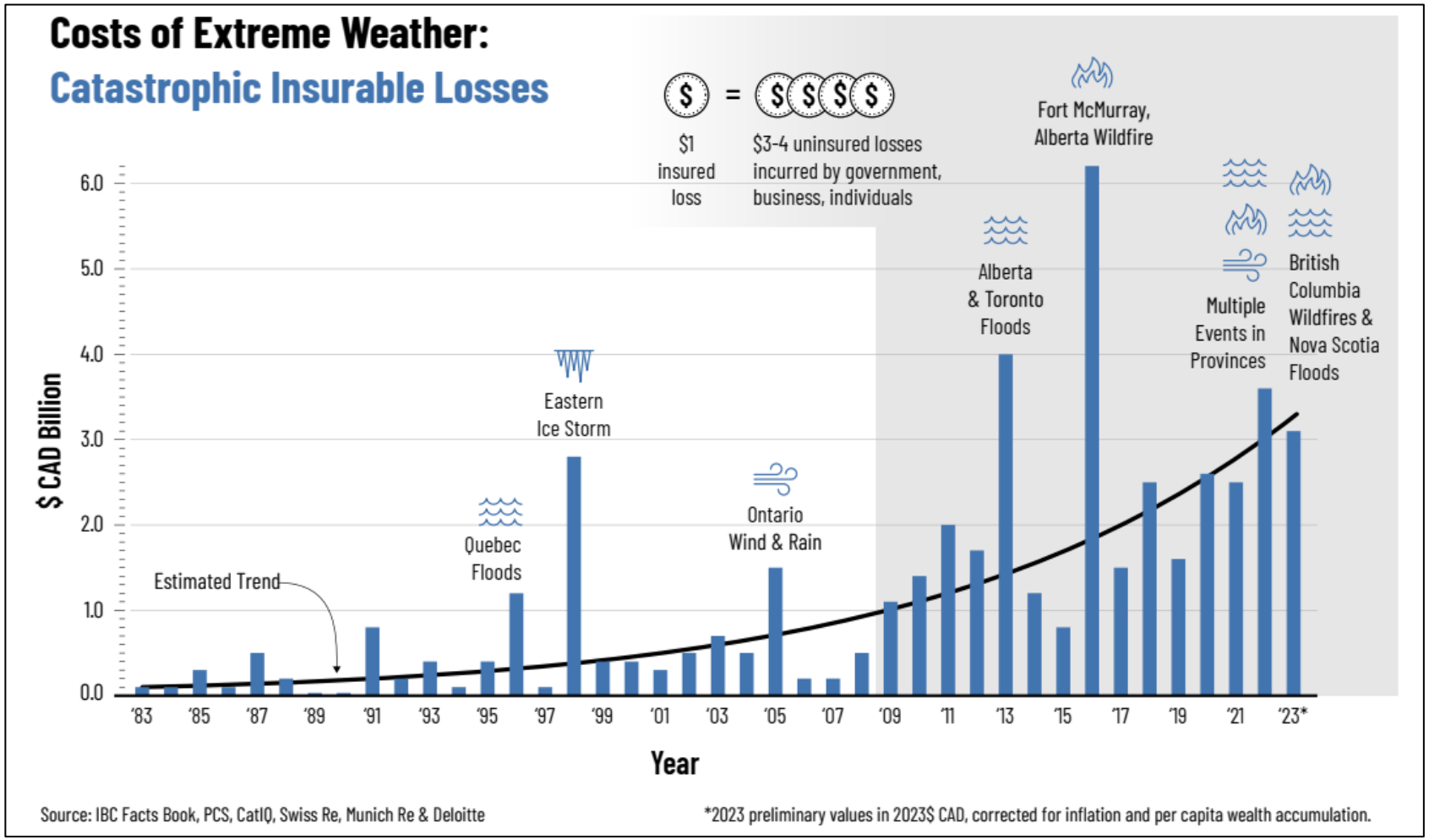
Courtesy Intact Centre on Climate Adaptation

THE HAZARDS AND COSTS OF A WARMER CLIMATE

- forest firestorms from British Columbia to Labrador,
- drought on the Prairies,
- infestations by invasive species carrying disease,
- ice loss from the Arctic Ocean,
- hurricanes in the Atlantic Provinces,
- shoreline erosion in PEI and the Arctic with sea-level rise, and
- tornadoes, flooding and heat waves across Canada.

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

FLOODS AND WILDFIRES ARE OUR GREATEST HAZARDS



Courtesy Intact Centre on Climate Adaption at uWaterloo, IBC and CatIQ

WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

HOW DOES CARBON CAPTURE WORK?

Carbon Capture and (geological) Storage – or CCS – is a suite of technologies for removing CO_2 from industrial emissions, transporting them via pipeline to a storage hub and finally injecting them into deep rock reservoirs.

This is Shell Canada's capture plant at Scotsford, Alberta. The CO_2 emissions from adjacent hydrogen generation are sent to this plant. Here the CO_2 is first captured and then transported 65 km north for geological storage.

Capture plants like this cost ~$1+ Billion per million tonnes CO_2.

Photo courtesy Shell Canada

CO_2 TRANSPORTATION OPTIONS

Advantage		*Disadvantage*
The transportation volume is large and the transportation cost is low.		The one-time investment of pipeline facilities is large.
Not affected by weather and traffic. No special railway facilities need to be built.		The requirements for gas source and destination are high, and they need to be close to the railway.
Not limited by source and destination. There is no need to invest in the construction of transportation facilities.		Transportation costs are high. Vulnerable to weather and traffic conditions. Fuel and labor costs are high.
Good economy. Transportation technology is mature.		The temperature and pressure control requirements of the transport equipment are high.

From Lu et al., 2020, J. Cleaner Production.

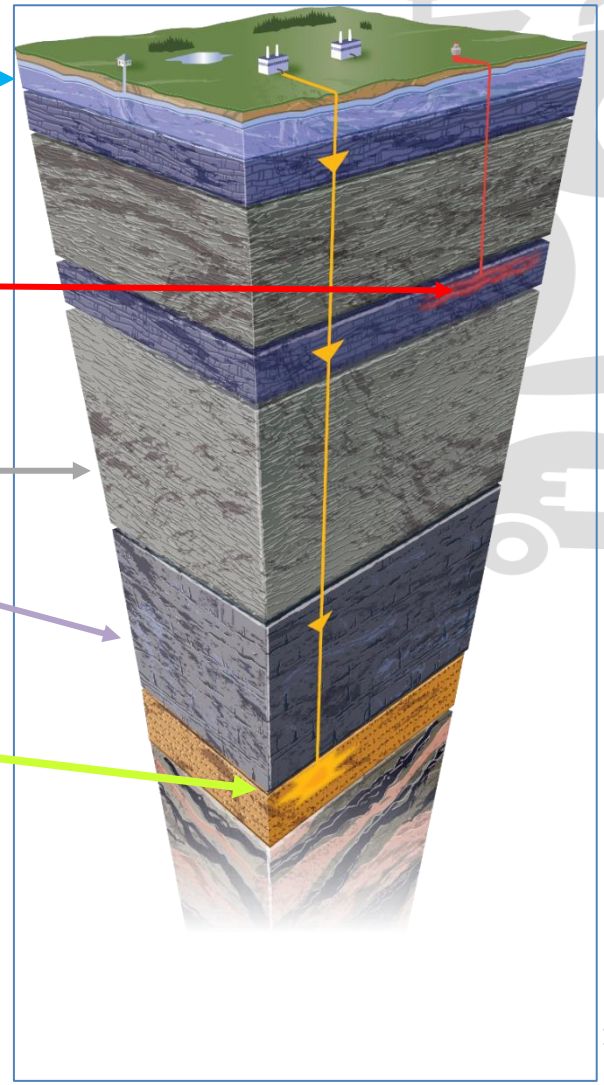
GEOLOGICAL CO_2 STORAGE

Shallow fresh-water aquifers must be protected from deep CO_2 storage

Oil and gas reservoirs are also shallow

The impermeable caprock prevents upward leakage of the buoyant CO_2

CO_2 injection and storage will occur about 1 km deep into a saline aquifer



Risks and Potential Hazards

The hazards of CCS appear manageable if the CSA standard is followed by the developer

They include:

- Leakage from **legacy oil & gas wells** if not plugged
- **Induced seismicity** may be felt (minor earth trembling)
- Leakage through **unknown faults** in the storage reservoir

These hazards are minimized by competent site characterization

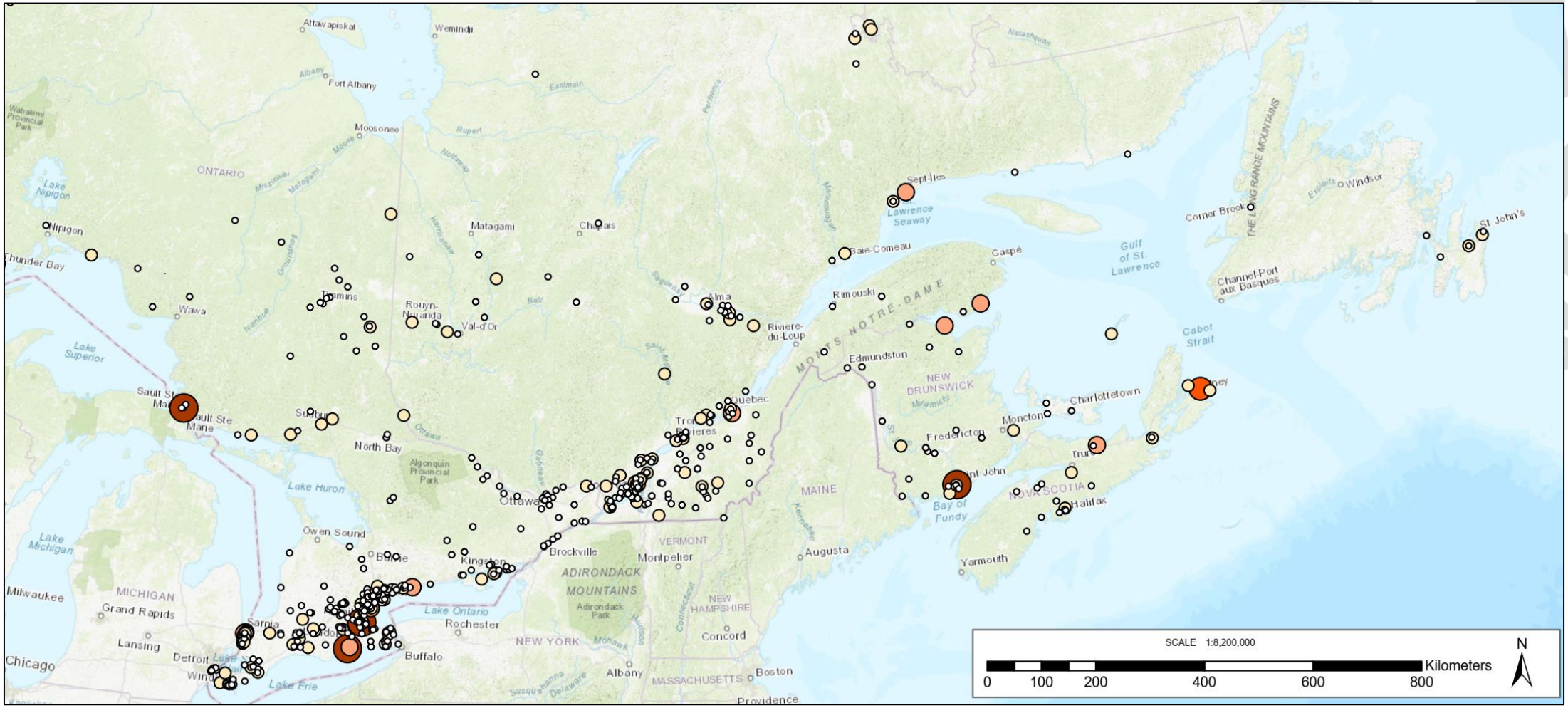
MMV

Measurement, Monitoring and Verification = MMV

- Measurement of gases in soil and wells + groundwater and surface-water quality surrounding a CCS injection site
- This Area of Review may be 10-20 km in radius
- Monitoring begins before any CO_2 is injected and continues until after injection ends and the project is closed
- Verification of the data is by independent experts

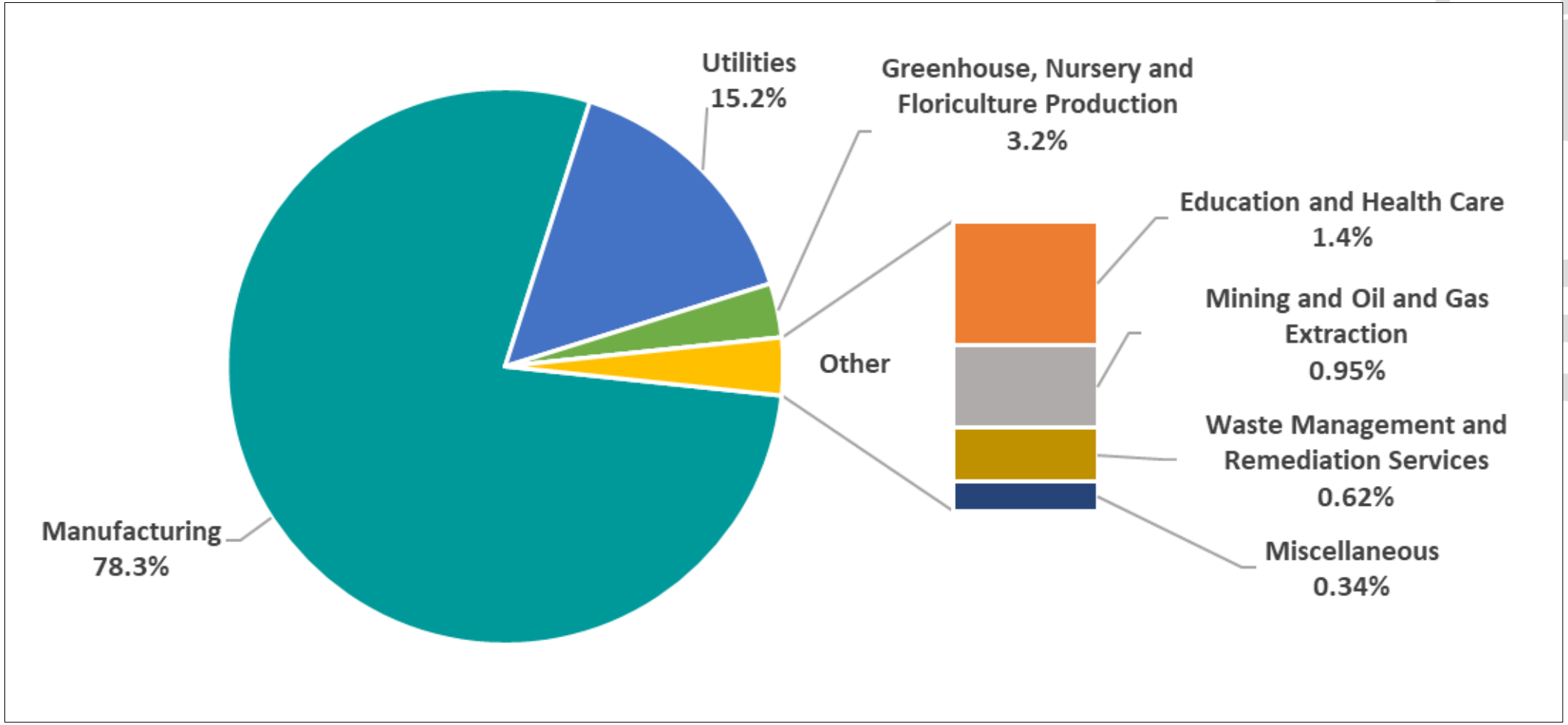
WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

LOCATION OF PRINCIPAL EMITTERS IN EASTERN CANADA



WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

CO_2 emissions in SW Ontario by industrial sector

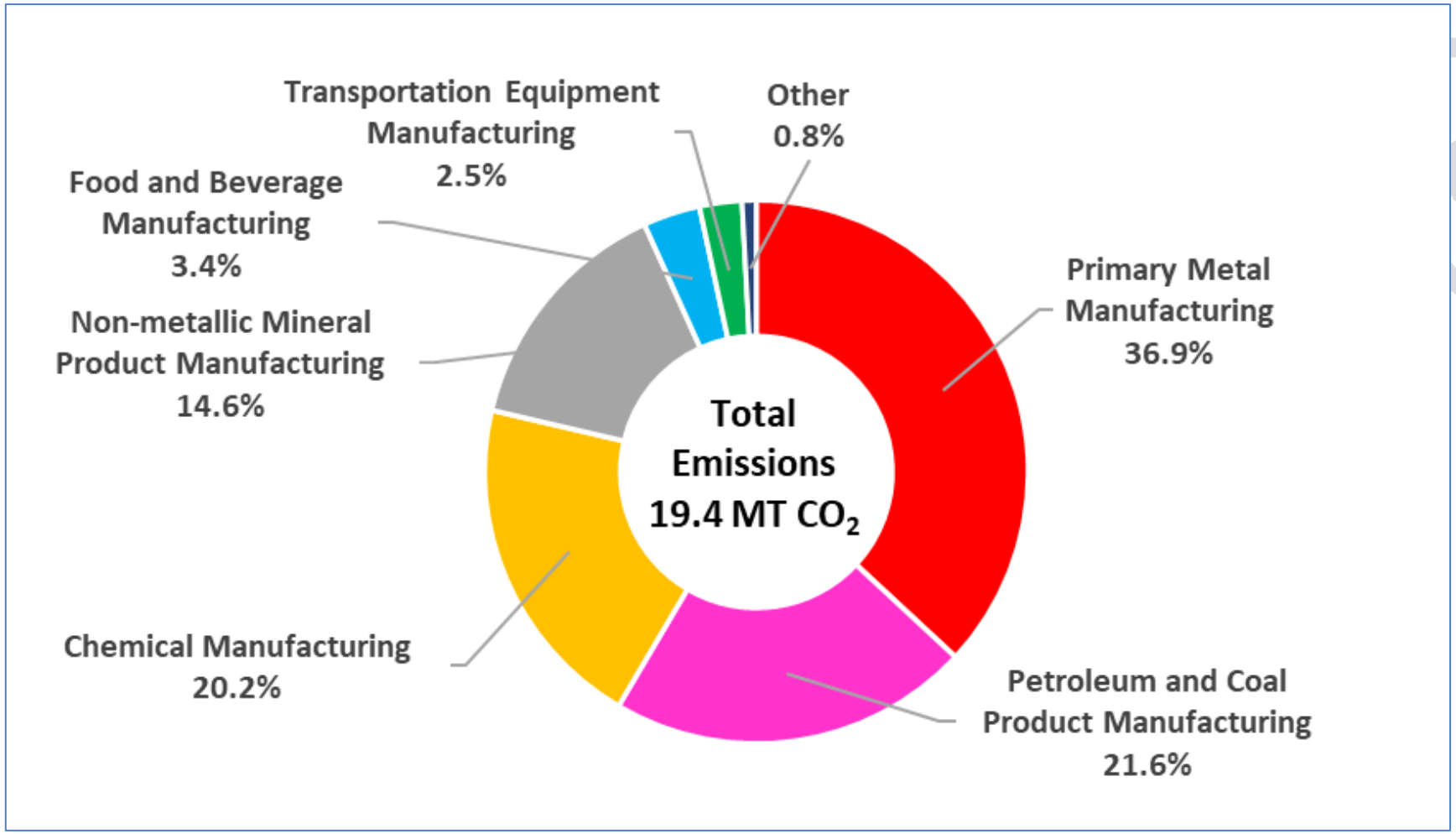


Total 24.8 Mt in 2020

WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

CO_2 emissions in SW Ontario by manufacturing sub-sector



Total 19.4 MT in 2020

WATERLOO

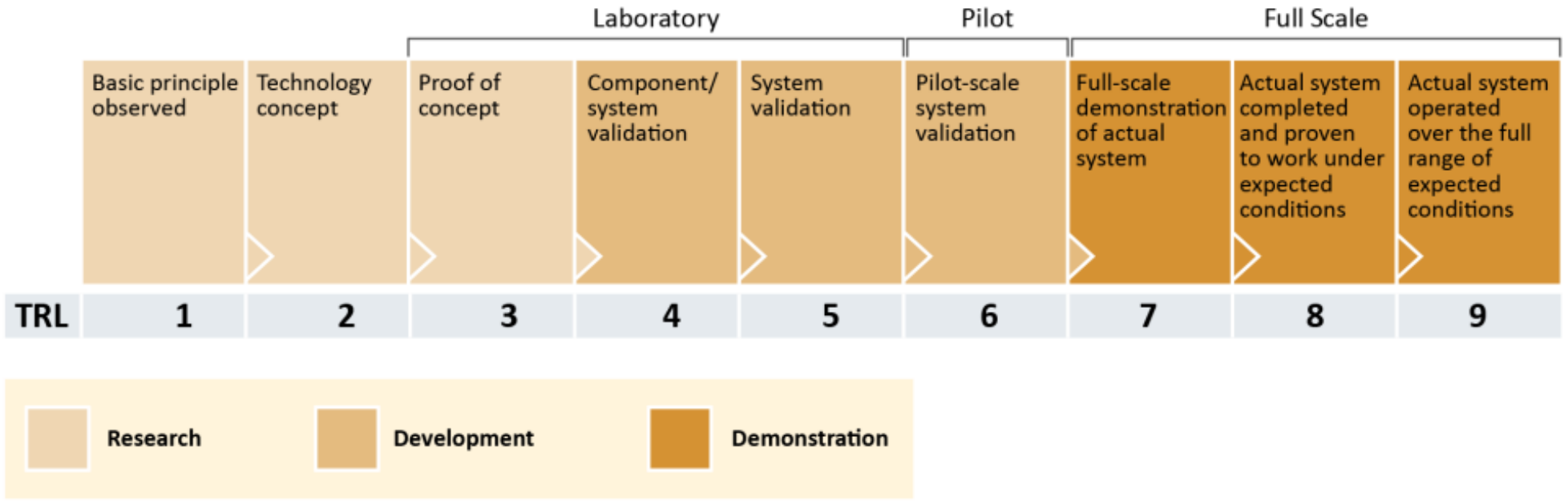
WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

WATERLOO

To accomplish a 40% CO_2 emissons reduction, we must consider:

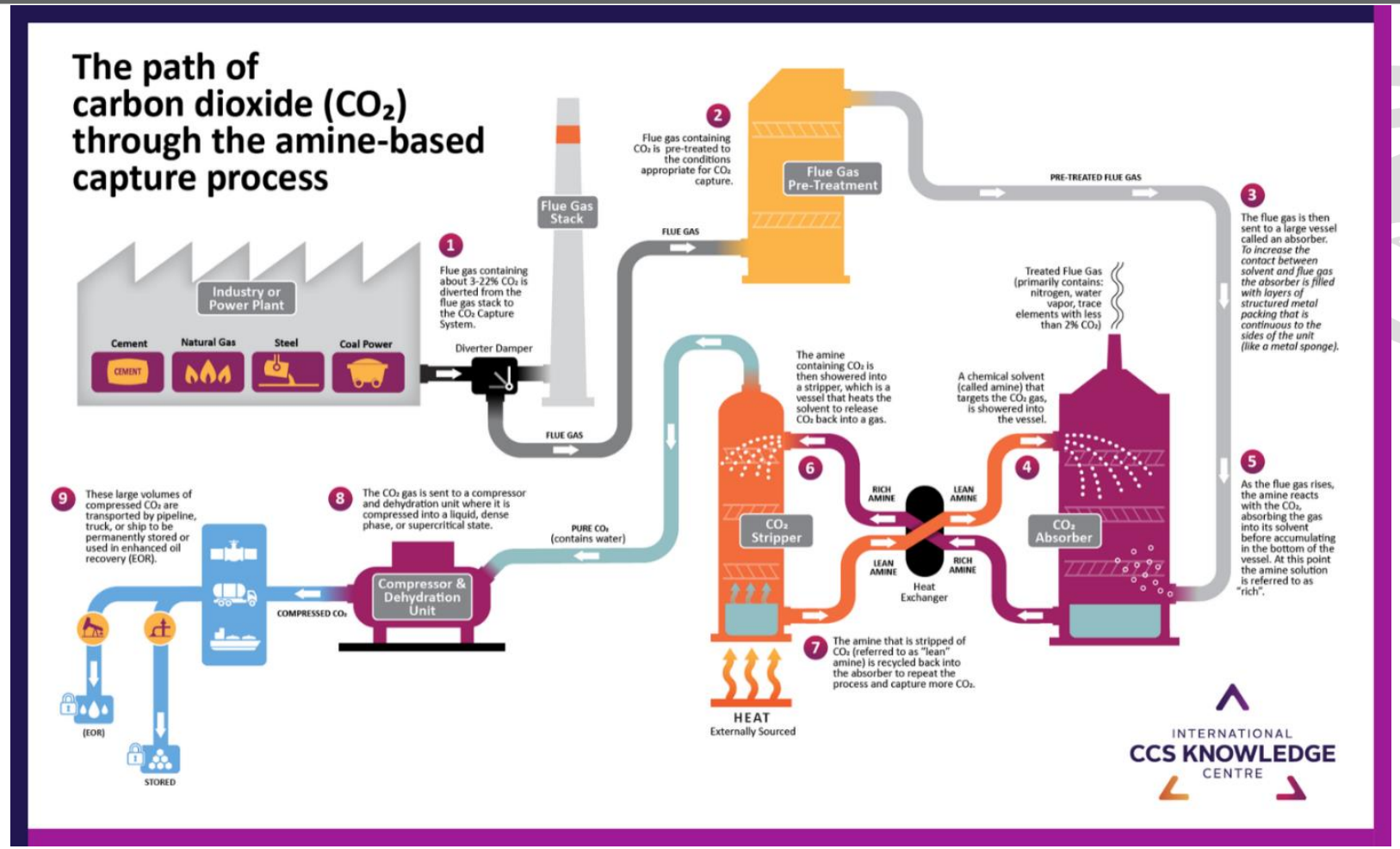
1. Technology readiness and financial incentives for CCS
2. Location of emitters and storage sites
3. Time required to plan and construct CCS

Schematic of Technology Readiness Levels



Source: GAO summary of information from Department of Energy, Global CCS Institute, and National Academies of Sciences, Engineering, and Medicine. | GAO-22-105274

TECHNOLOGY READINESS AND FINANCIAL INCENTIVES FOR CCS



AMINE ABSORPTION CARBON CAPTURE: **TRL 9**

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

AMINE ABSORPTION CARBON CAPTURE at Quest, Alberta

CO_2 Capture Capacity: 1 Million Tonnes/yr [MT/yr] since 2016

CO_2 Source: Steam Methane Reformer for H_2 Manufacturing and Bitumen Upgrading

80% CO_2 capture efficiency, limited by upgrader

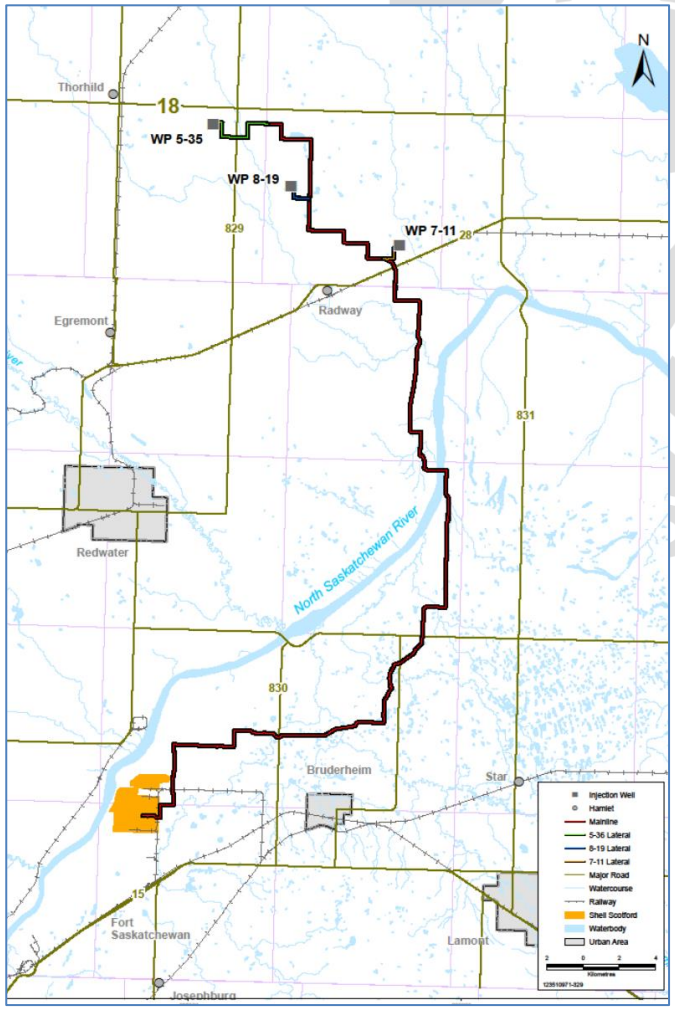
CO_2 transported as dense phase 65 km to wellfield

WATERLOO

Quest wellfield

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

65 km Pipeline: $P_{operating}$ = 9-10 MPa, Z 245.1 Carbon Steel
3 Injectors are 5-7 km apart
Sequestration lease: 3670 km^2
Injectivity: >150 T/hr



WATERLOO

Quest Geology

Reservoir:

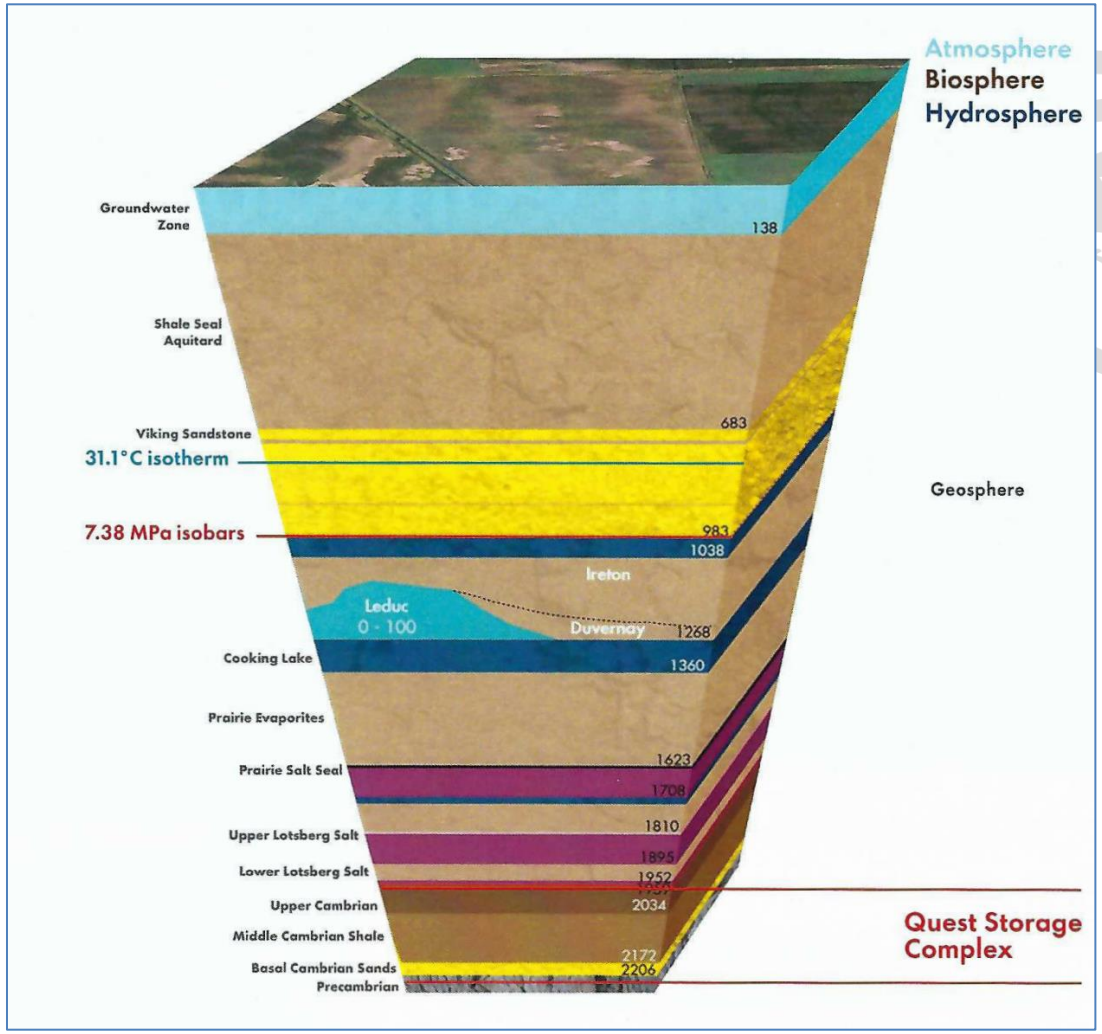
- Basal Cambrian Sands
- 2206 m bgs
- θ = 17%
- 1000 mD

Caprock:

- Lotsberg Salt

Monitoring Wells

in the Cooking Lake Fm (1360 m)



WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

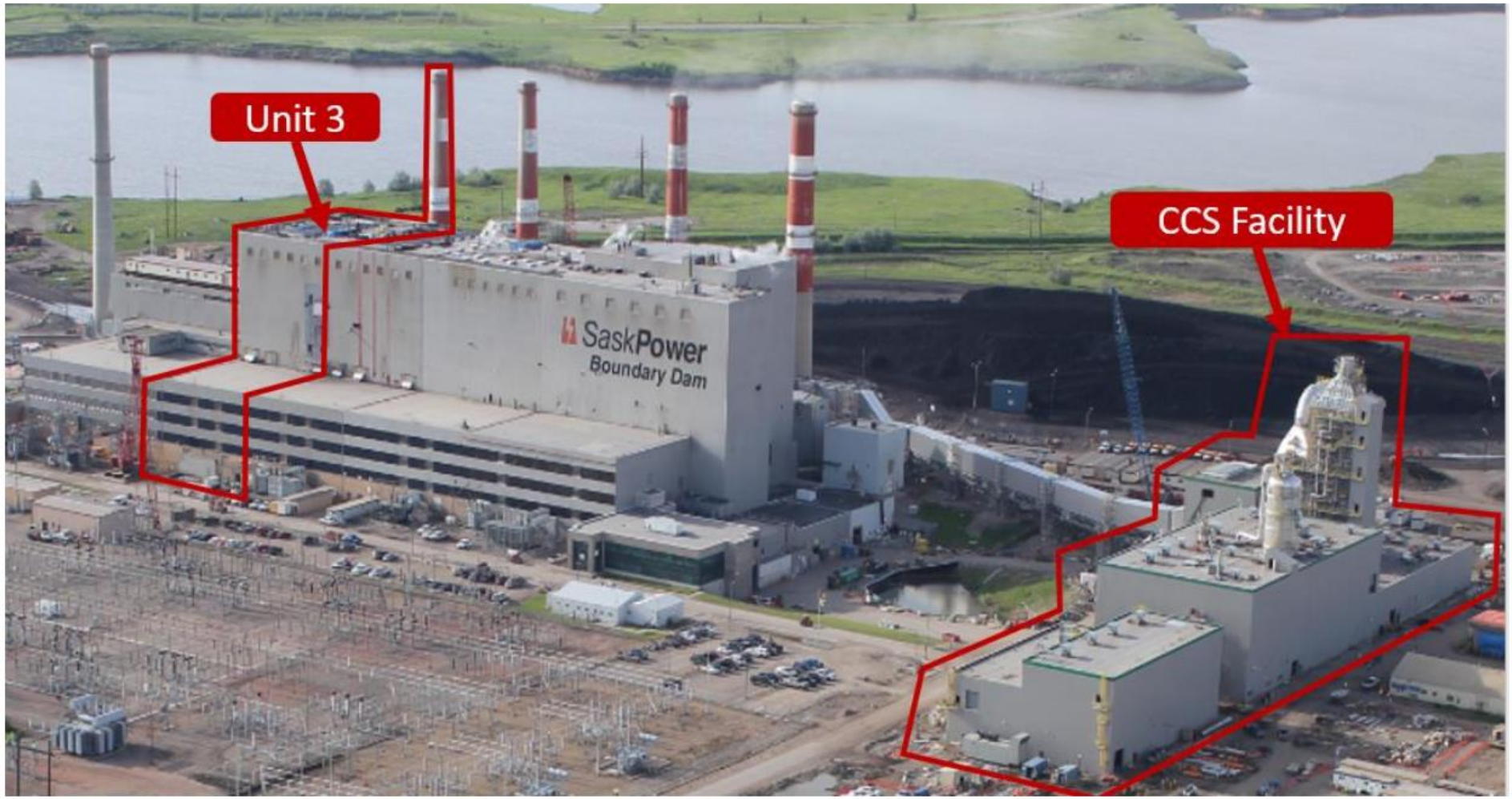
AMINE ABSORPTION CARBON CAPTURE at Boundary Dam 3 Unit, Saskatchewan

CO_2 Capture Capacity in Unit 3: ~ 0.6 Million Tonnes/yr [MT/yr] since 2014

CO_2 and SO_2 Source: Coal-powered electricity generation, amine-absorption units for both CO_2 and SO_2

89% CO_2 capture efficiency, extensive learning-by-doing with numerous operational problems

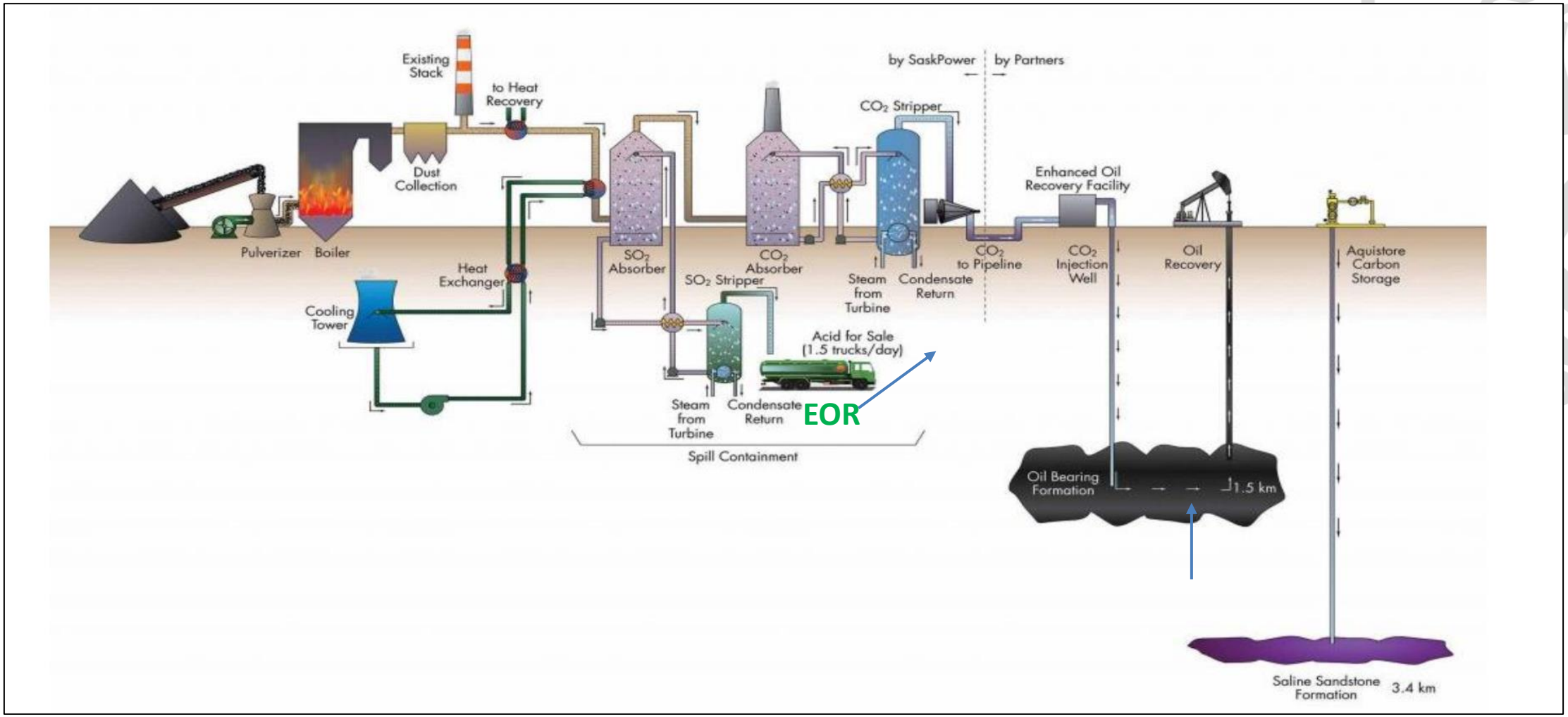
CO_2 transported as dense phase 70 km to wellfield for Enhanced Oil Recovery & 2 km to Aquistore for dedicated C storage



WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

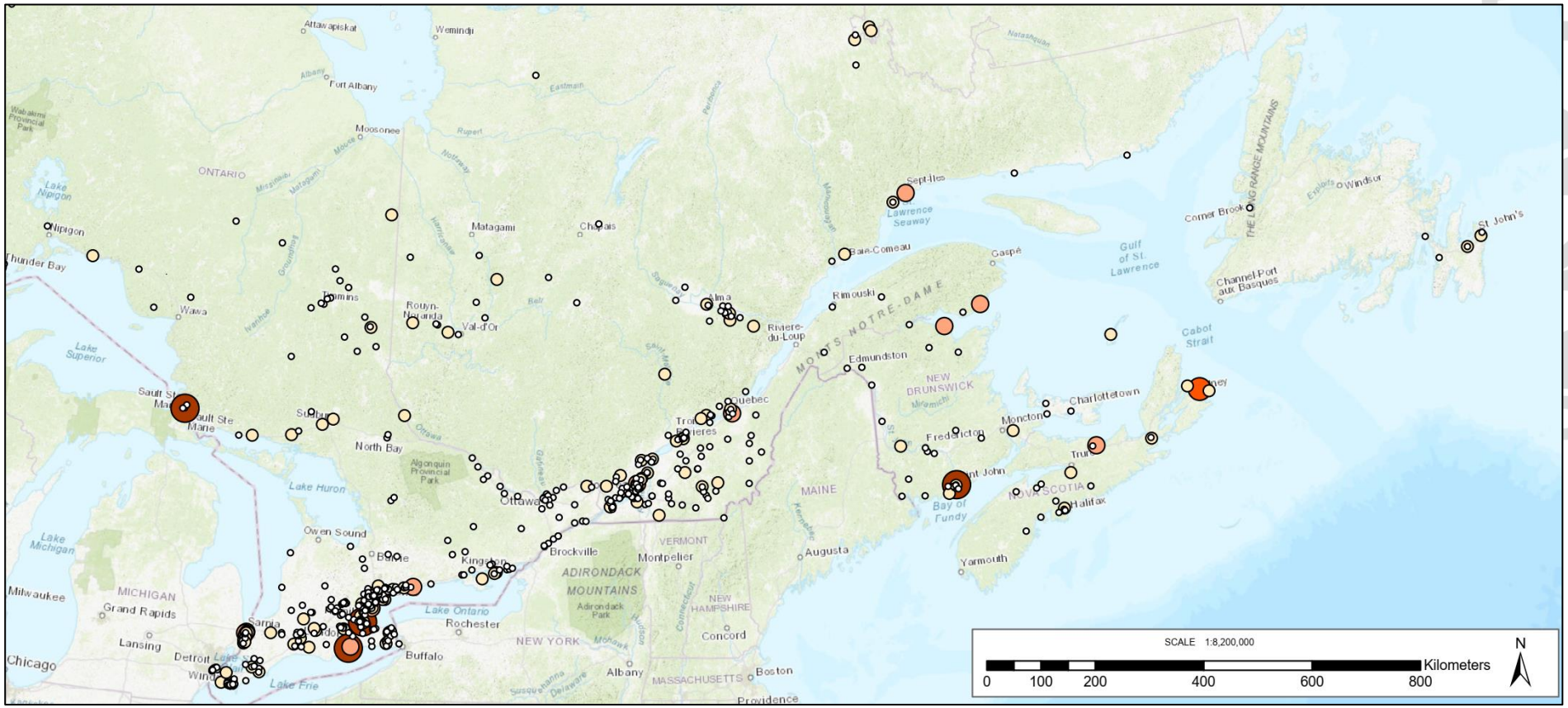
AQUISTORE: dedicated CO_2 storage from Boundary Dam Unit 3



WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

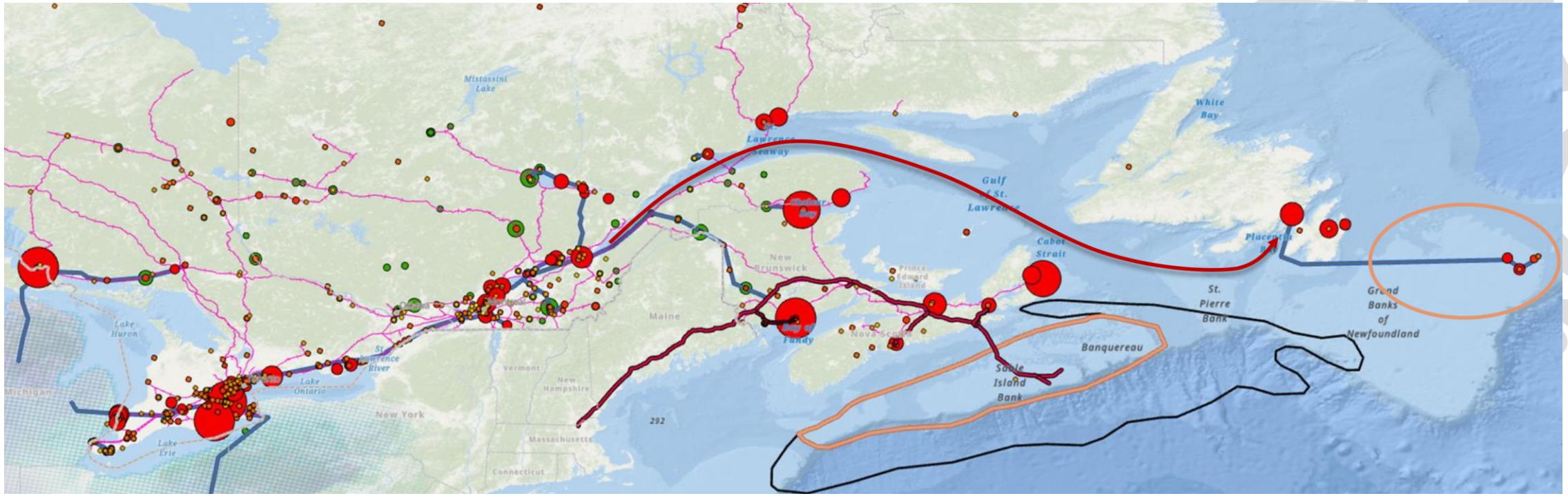
The Challenge for CCS in Eastern Canada



Industrial CO_2 sources are widely distributed but geological storage sites are limited

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

Natural Resources Canada is considering off-shore storage by 2050



How will we transport it to off-shore depleted oil & gas fields?

WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

LOCATION OF EMITTERS AND GEOLOGICAL STORAGE SITES

"Our biggest challenge is to match sequestration sites to CO_2 sources."

WATERLOO

CSA Guidelines for Geological CO_2 Storage Sites

The geological storage reservoir should be:

1. >800 m deep to allow p_{max} → 9 MPa
2. sealed by competent caprock with minimal groundwater inflow from surrounding rock
3. *Preferably,* near major CO_2 emitters & pipelines
4. *Preferably,* penetrated by few oil and/or gas wells requiring plugging
5. *Preferably,* large pore volume available for CO_2 storage so limited Δp
6. *Preferably,* few critically-stressed faults that might slip with fluid injection → *felt earthquakes*!

CSA Z741 STANDARD

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

LOCATION OF GEOLOGICAL STORAGE RESERVOIRS

WATERLOO

Saline Cambrian Aquifers

- *North Shore of Lake Erie*
- *Perhaps south shore of St Lawrence, Quebec*

Offshore Nova Scotia & Newfoundland

- *Pipelines to Montreal and then ship offshore?*

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

CCS INVESTMENT DECISIONS OF $1B+ REQUIRE DETAILED SITE CHARACTERIZATION

- CO_2 storage hubs must be PROVEN by drilling and testing + seismic
- Followed by numerical simulation of CO_2 migration through the storage reservoir
- Cost per borehole: $5M+
- Each storage-well hub will require ~ $50-100M

WATERLOO

WISE
WATERLOO INSTITUTE
FOR SUSTAINABLE ENERGY

TIME REQUIRED TO PLAN AND CONSTRUCT CCS

WATERLOO

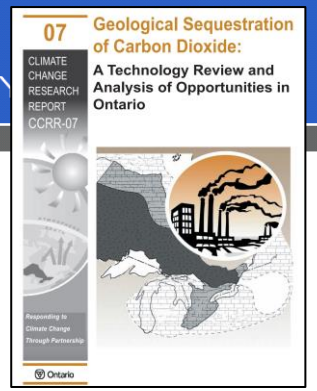
Storage hubs for dedicated geological storage require:

1. 3-8 years to develop and prove injection sites
2. ~ $30M to prove available PV and CO_2 injectivity
3. Large-scale numerical simulation to determine Δp effects – "the pressure plume" – and CO_2 migration
4. Evaluation of reservoir continuity/compartmentalization
5. Hydraulic interference of neighbouring hubs?
6. Δp effects on caprock & basement faults?
7. Sealing of any penetrating legacy wells

In SW Ontario we need to prove ~10 MT annual CO_2 storage by 2025 to allow planning & construction to begin storage before 2030

TIME REQUIRED TO PLAN AND CONSTRUCT CCS

WISE
WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY



ERCB

Shell Canada Limited

Application for the Quest Carbon Capture and Storage Project

Radway Field

July 10, 2012

Province of Ontario

Started: summer 2023

Design a framework to regulate commercial-scale geologic carbon storage projects on Crown and private land.

Refine and adapt framework

Anticipated start: 2025

1996 Sleipner

2004 Shafeen report

2006 2007 *Toronto CCS Workshop*

2012 2015 **Quest & BD3 startup**

2020 **2023** Site characterization?

2026 Cost analysis + FID?

2030 Construction?

WATERLOO

For More Information, Please Contact

Armughan Al-Haq

Manager

Program Development & Partnerships

Waterloo Institute for Sustainable Energy

519 888 4567 ext. 38759

armughan.al-haq@uwaterloo.ca

www.wise.uwaterloo.ca