CCS PROJECTS FOR THE CEMENT INDUSTRY FROM CONCEPT TO PERMIT

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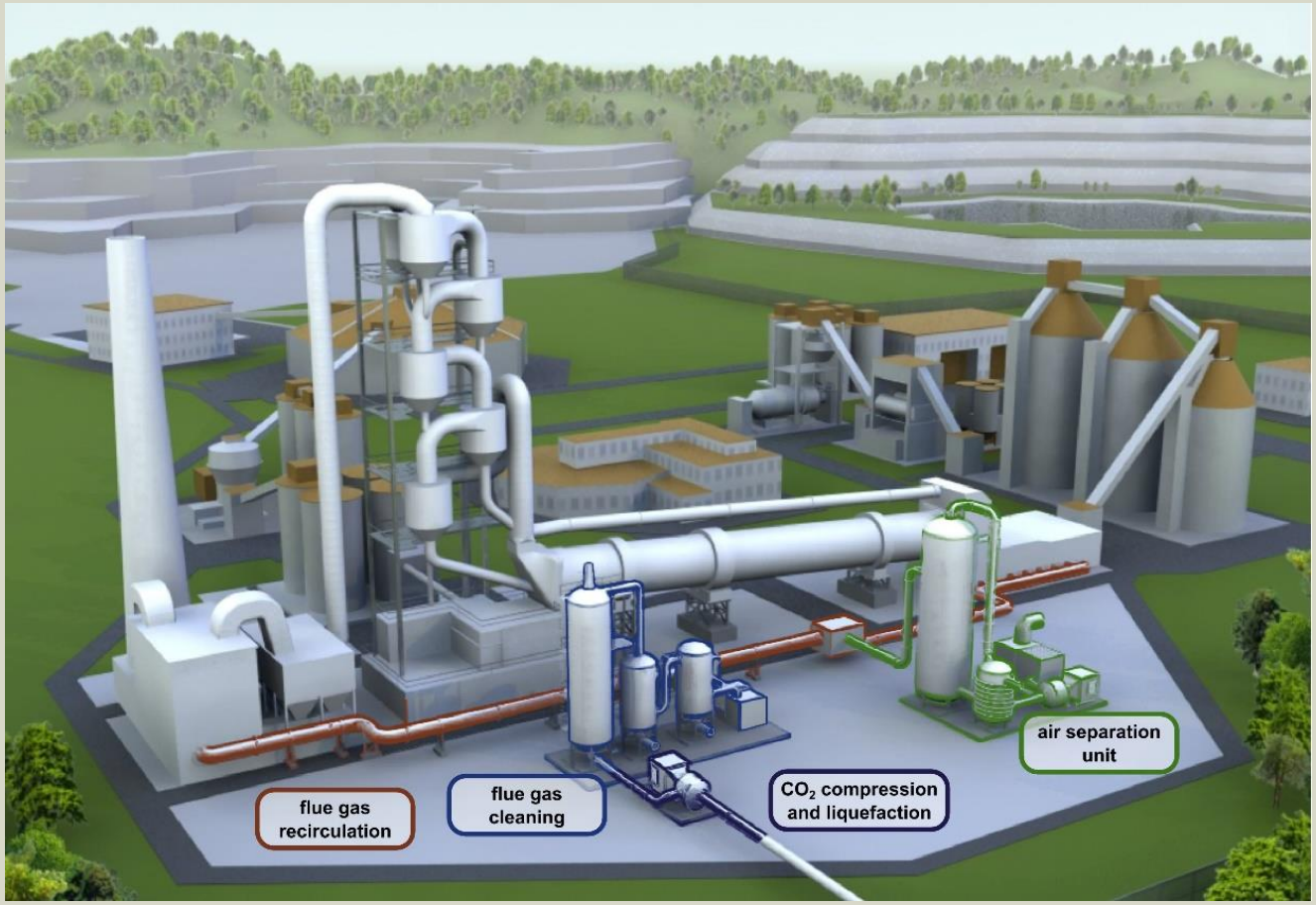
OUTLINE

- CCS CURRENT STATE OF AFFAIRS IN NORTH AMERICA & EUROPE
- STEPS IN A CCS PROJECT/PROJECT DEVELOPMENT
  - Timing Of Data Needs And Degree Of Detail
- INPUTS AT EACH STAGE
  - What Info Is Needed?
- SENSITIVITY TO INPUTS
  - What Is The Impact of Realistic Uncertainty?
  - Getting To Go/No-go



Source: European Cement Research Academy

ECONOMIC FACTORS & INCENTIVES

- **USA**
  - 45Q Tax Credit:
    - $50/Ton In 2021, $85/Ton In 2022, Based On Project Scale And Storage Type
    - Congress Proposals For Further Increases
- **CANADA**
  - Carbon Tax:
    - $50/Ton In 2022, $170/Ton In 2030
  - New Investment Tax Credit (2022)
- **EUROPE**
  - EU ETS: Cap And Trade Market
    - €80/Tonne Average So Far In 2022

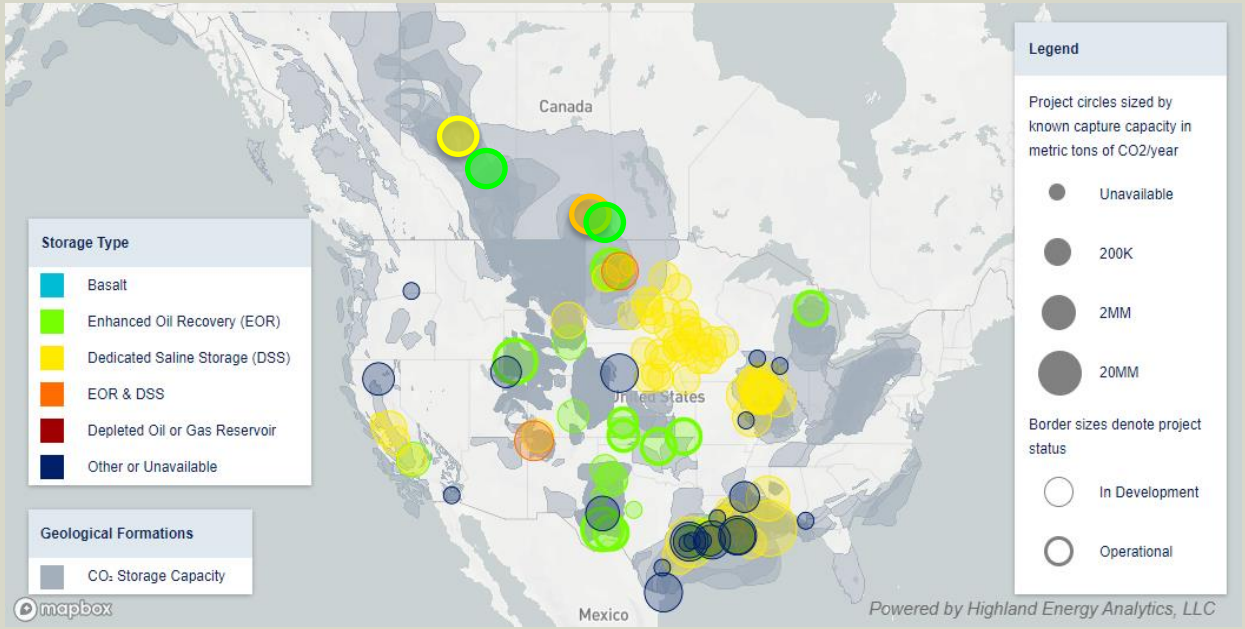
CCS BY STORAGE TYPE

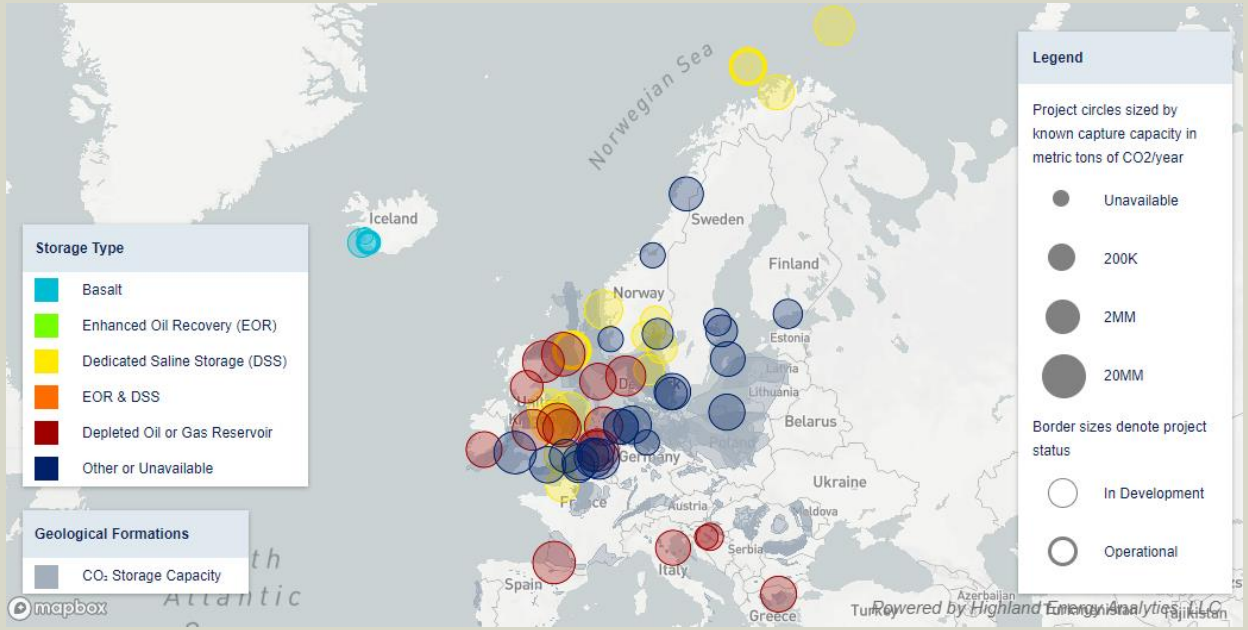
NORTH AMERICA

- Saline Storage And CO2-EOR: 200k To 20MM Tons/Year @ Up To $50/Ton
- Recent Surge In Saline Storage Applications: $85/Ton

EUROPE

- Depleted Oil & Gas Reservoirs





https://www.catf.us

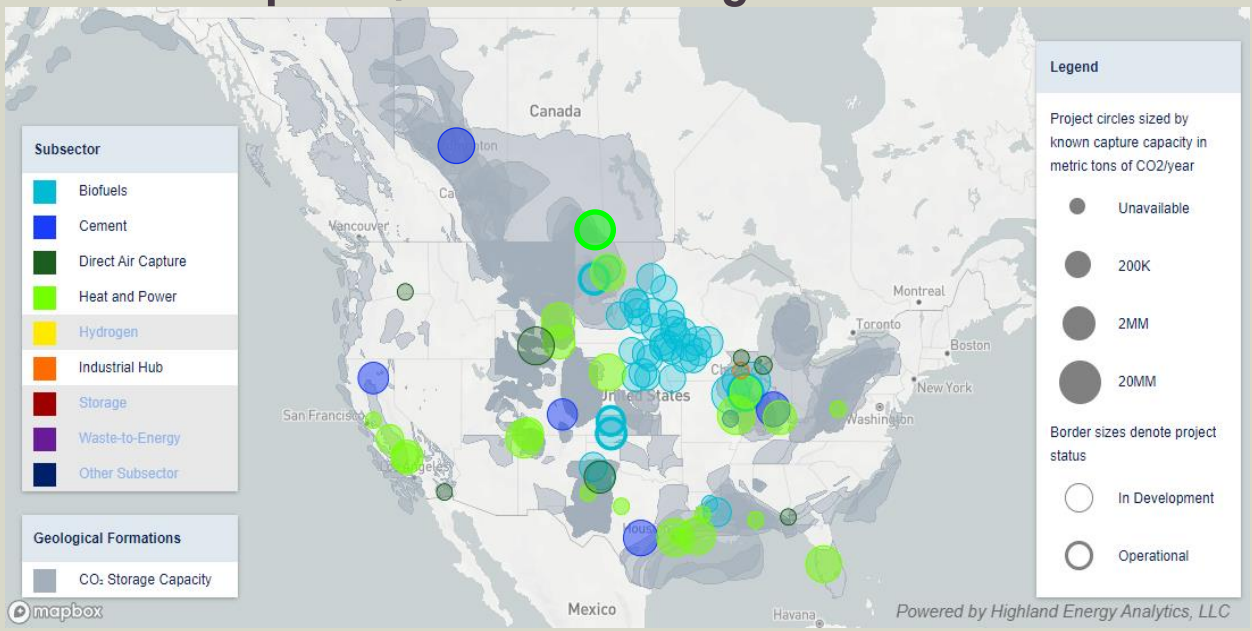
CCS BY INDUSTRY – EXCLUDING OIL & GAS

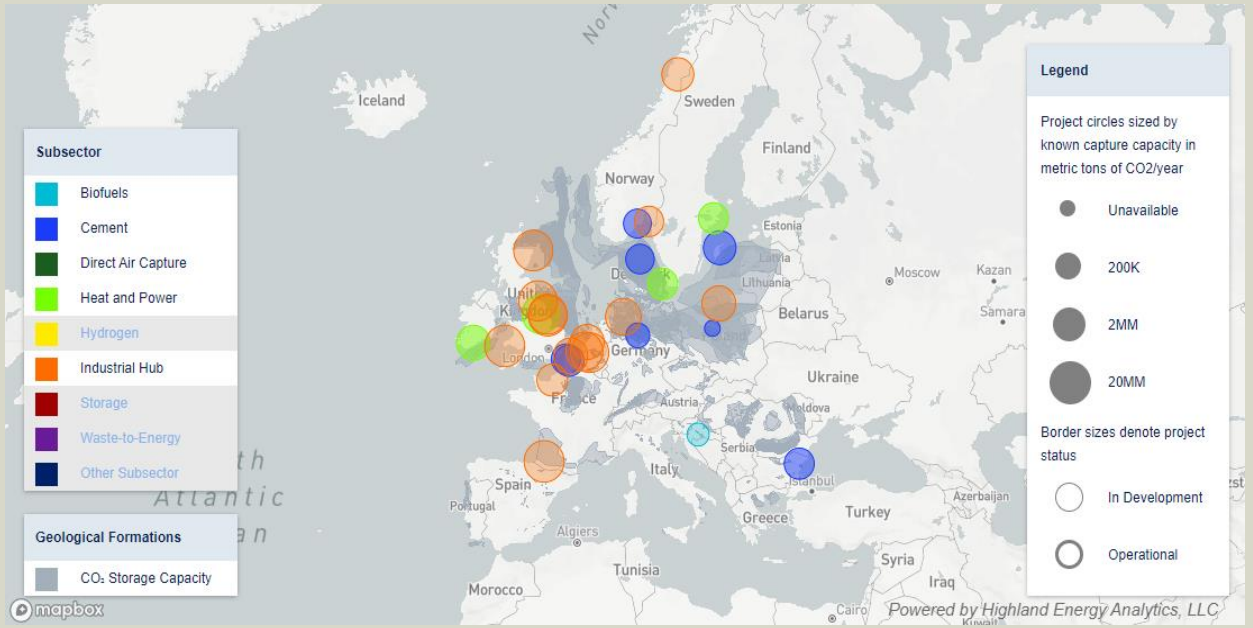
NORTH AMERICA

- Multiple Industries Participating, Progressing Towards Injection Permit
- Cement, Biofuels, Power Plants: Onsite Capture, Onsite Storage

EUROPE

- Dominantly Industrial Hubs, Also Cement, None Yet Operational





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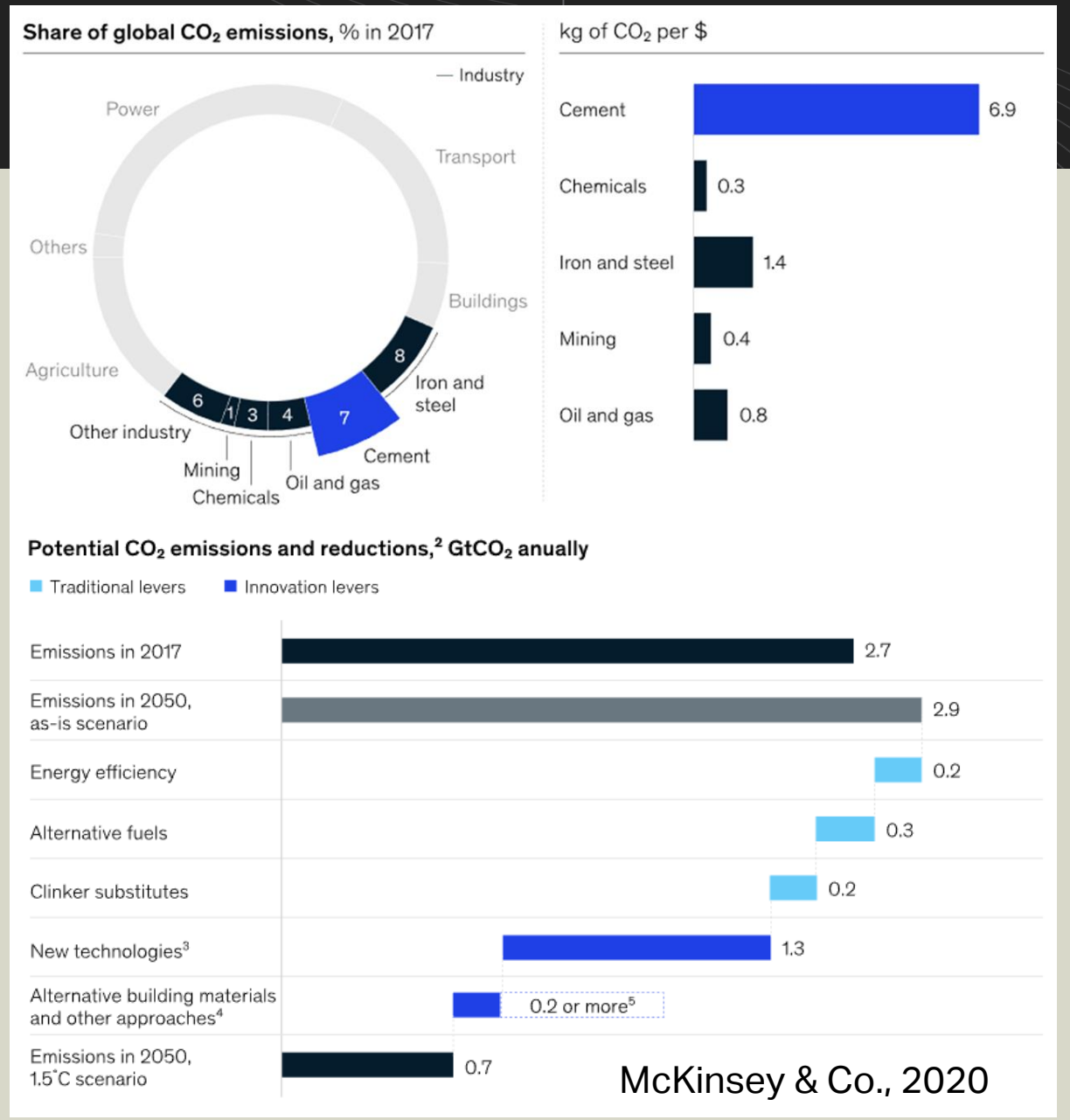
CEMENT CO2 EMISSIONS

- **CO2 EMISSIONS SOURCES**
  - Kiln Fuel & Calcination Dominate (GCCA)
- **CEMENT INDUSTRY EMISSIONS ARE SIGNIFICANT**
  - 7% Of Global Emissions (Mckinsey)
  - 0.59 Ton CO2/Ton Cement (IEA)
  - >4 Billion Tons Global Cement Production (USGS)
  - ~2.7 Billion Tons CO2 Annually
- **REDUCTION OPTIONS**
  - Minor Impacts:
    - Efficiency, Alternative Fuels, Clinker Substitutes
  - Major Impacts:
    - Ccs



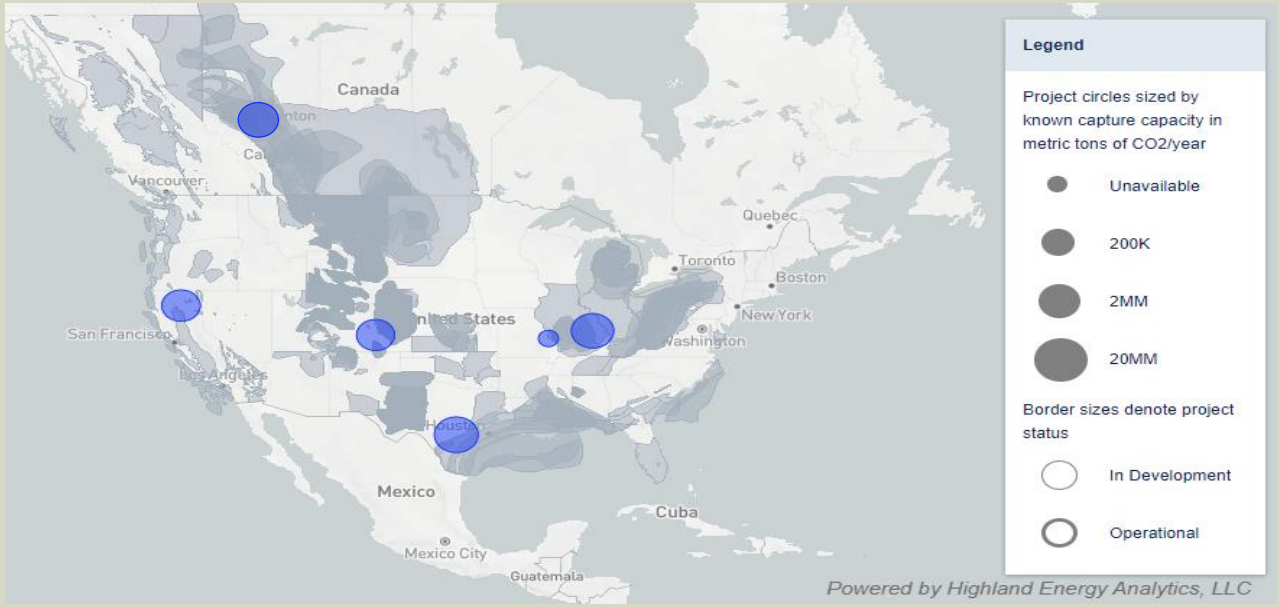
CO2 CAPTURE FOR A CEMENT PLANT

CEMENT PLANT CCS PROJECTS

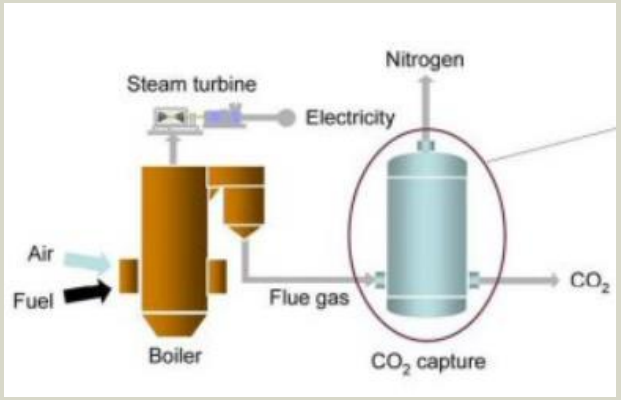
- Combination Direct Air Capture (DAC) And Flue Gas Separation
- DAC Add-on
  - Air Capture
  - CO2 Separation Using Amine Solvents, Membranes, Sorbents
- Flue Gas Separation
  - Post-combustion Flue Gas Treatment
  - Similar Technology Options As DAC

SEPARATED CO2

- Compression To Supercritical State
- "Liquid" Above 1500 Psi (1000 Mpa)



DAC



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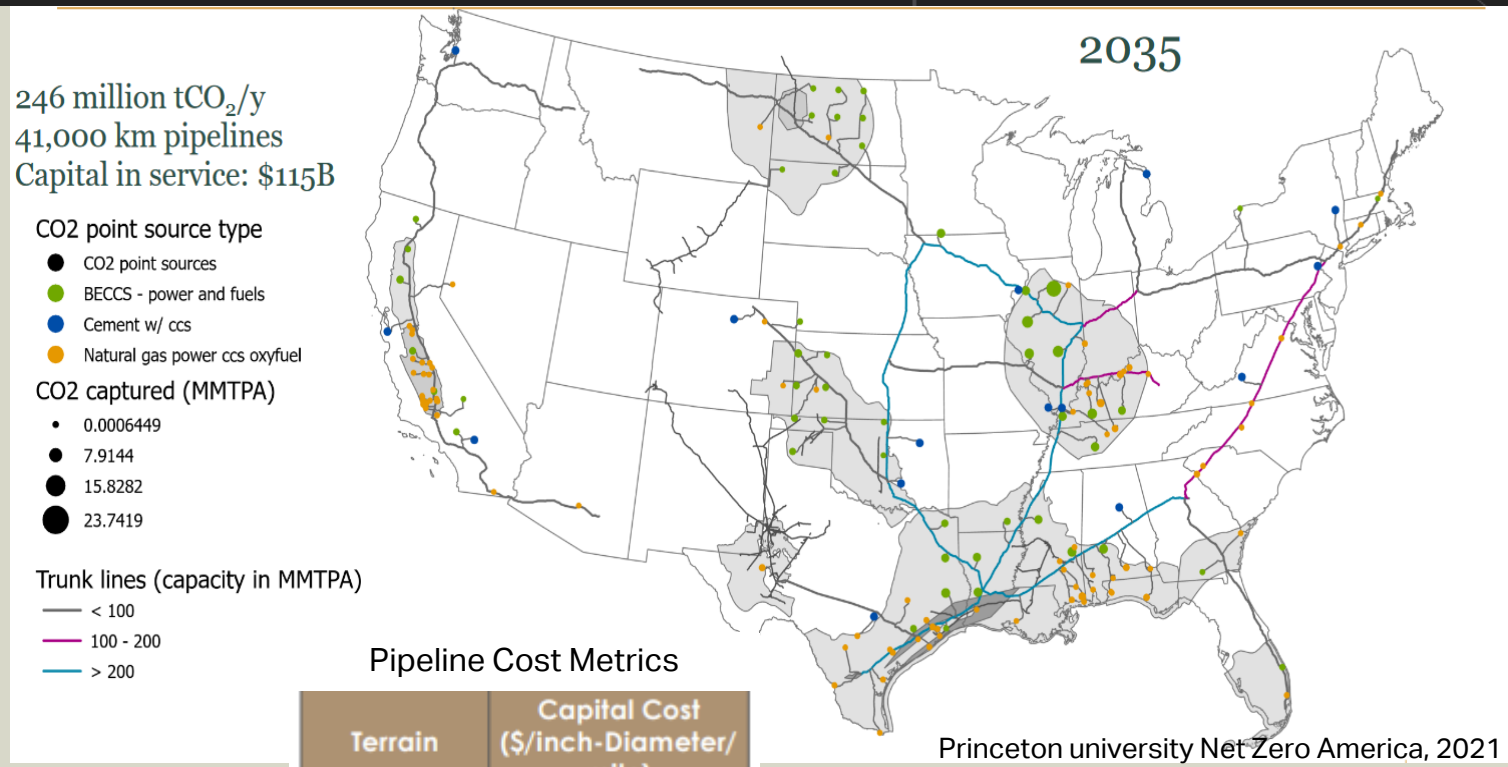
WHAT TO DO WITH YOUR CO2 AFTER CAPTURE

- **SUBSURFACE SEQUESTRATION ON-SITE**
  - Availability, Capacity, Risks?
  - Start permitting process for CO2 sequestration
- **OFF-SITE SEQUESTRATION OR USE (PIPELINE)**
  - Costs/risks of pipeline vs onsite injection
    - Limited CO2 Pipeline Infrastructure
    - Expensive To Build
    - Not Everyone Likes Pipelines
  - Existing EOR pipeline nearby?
- **UTILIZATION (MINERALIZATION)**
  - Carbon-cured Concrete



Princeton university Net Zero America, 2021

Pipeline Cost Metrics

Terrain	Capital Cost ($/inch-Diameter/mile)
Flat, Dry	$50,000
Mountainous	$85,000
Marsh, Wetland	$100,000
River	$300,000
High Population	$100,000
Offshore 150'-200' depth)	$700,000

CO2 PROJECT PERMIT PROCESS

CANADA

- No Universal Well-defined Process Yet
- Provincial Differences, AER Draft Directive 065
- Generally Consistent With ISO 27914 And EPA UIC Program

USA

- States Without Primacy:
  - EPA UIC Class VI Well-defined Set Of Rules
  - 2 Permits, 14 Pending In The Queue
- States With Primacy: ND (2018), WY (2020), Several In Process:
  - Work With State Regulator, Multiple Applications In Process

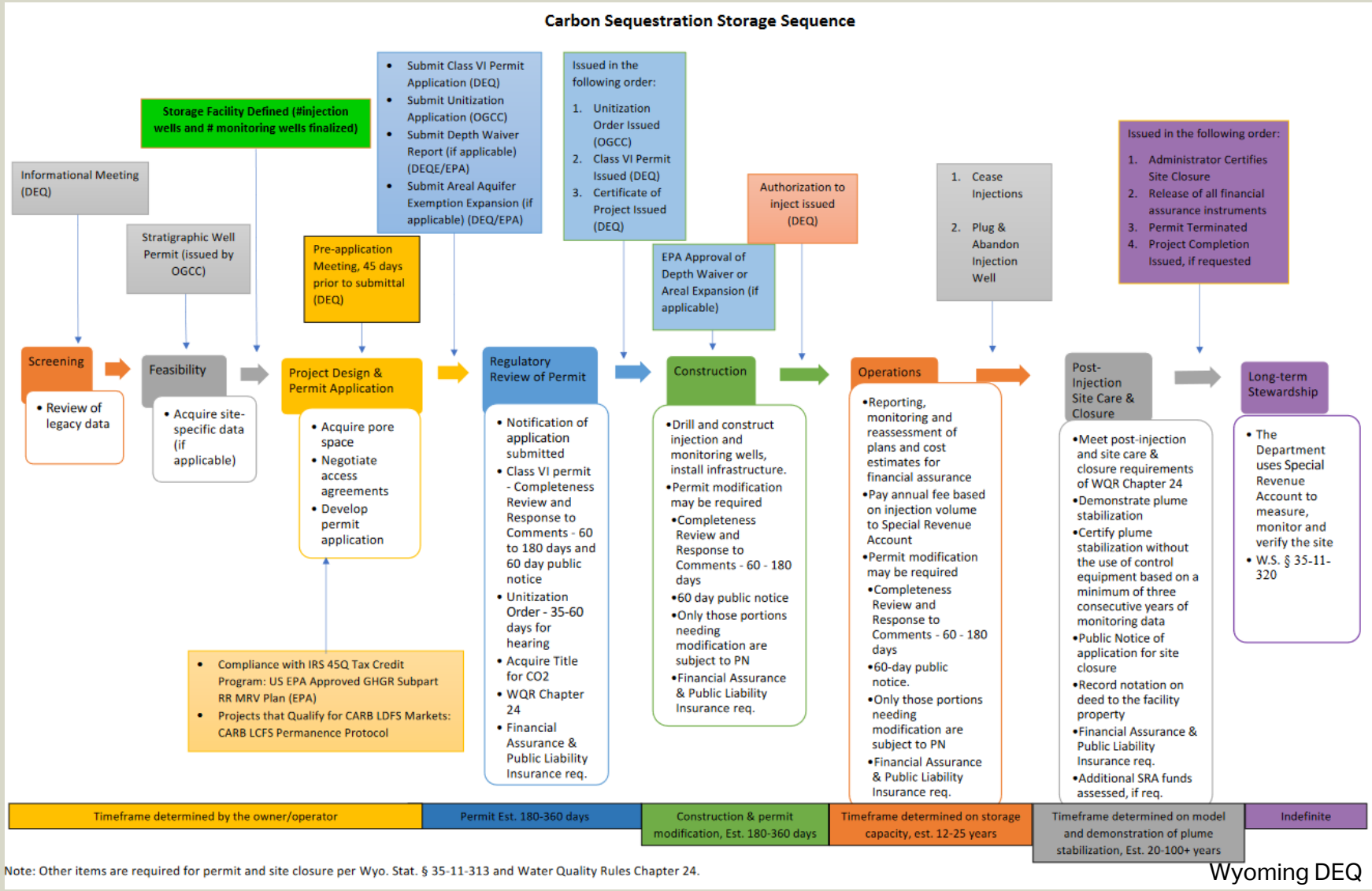
~1M metric tons of CO2 per year

EUROPE

- National Differences, Adhere To ISO 27914

PROJECT PROCESS WYOMING DEQ EXAMPLE

1. **PRE-SCREENING**
   - Available Data, Simple Modeling
   - Go/No-go Risks And Site Selection
2. **FEASIBILITY**
   - Detailed Modeling, Data Gaps, Acquisition Plan
   - Containment Risk Assessment, Area-of-Review (AOR), Measurement Monitoring and Verification (MMV) Plan
   - Regulatory Application
3. **FEED**
   - Injection & Monitor Wells, Data Collection
4. **CONSTRUCTION, OPERATION, VOLUME VERIFICATION FOR TAX CREDITS, LONG TERM MONITORING**



Wyoming DEQ

1. PRE-SCREENING: QUESTIONS TO ANSWER

1. SUITABLE INJECTION ZONE?

- Rock Formation That Is:
  - Deep Enough, Porous Enough, Thick Enough, Saline

2. SUITABLE SEAL?

- Seal Must Be:
  - Impermeable, Laterally Extensive, Mechanically Competent
  - Primary And Secondary Seals Are Optimal

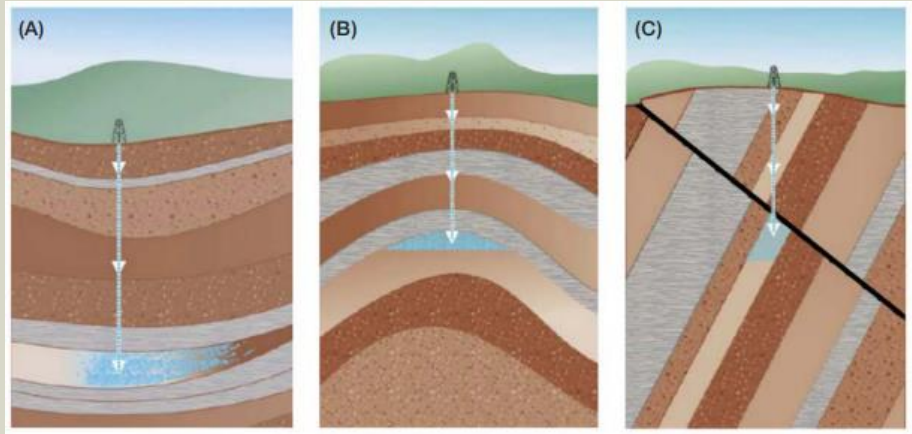
3. PORE SPACE AVAILABLE?

- Can Subsurface Rights Be Obtained?
- Is Surface Access Reasonable?

4. PROS AND CONS OF EACH OPTION

- Simple Models To Simulate CO2 Injection
- Often Several Options, Rank Options For Site Selection

$$V_{CO2} = area * thickness * porosity * SCO_2$$



US DOE NETL

WILLISTON BASIN PRE-SCREENING EXAMPLE

- **WINNIPEG AND DEADWOOD SANDS**
  - Porous And Permeable
    - 6 To 10%,10 To 100 Md
  - Laterally Extensive
  - >200,000 ppm Salinity
- **WINNIPEG (ICEBOX) SHALE**
  - Tight, Primary Seal, Regionally Extensive

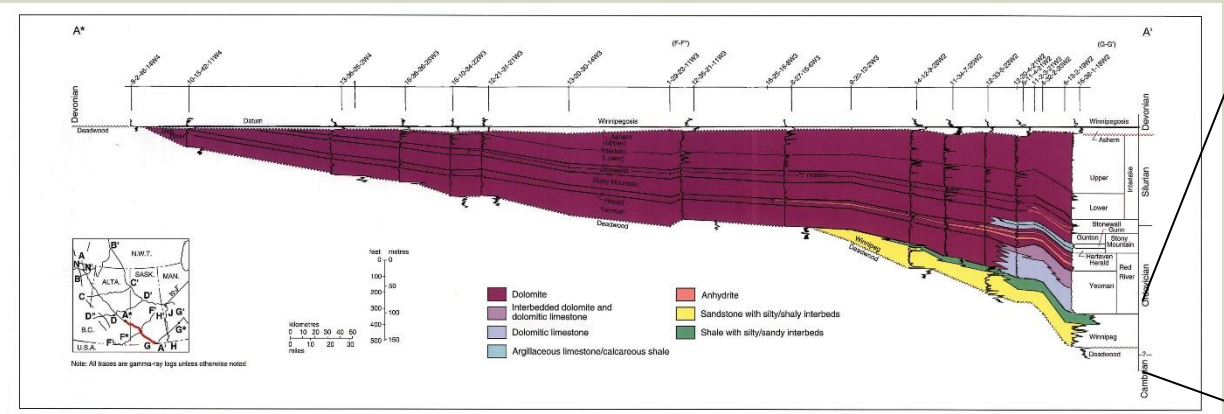
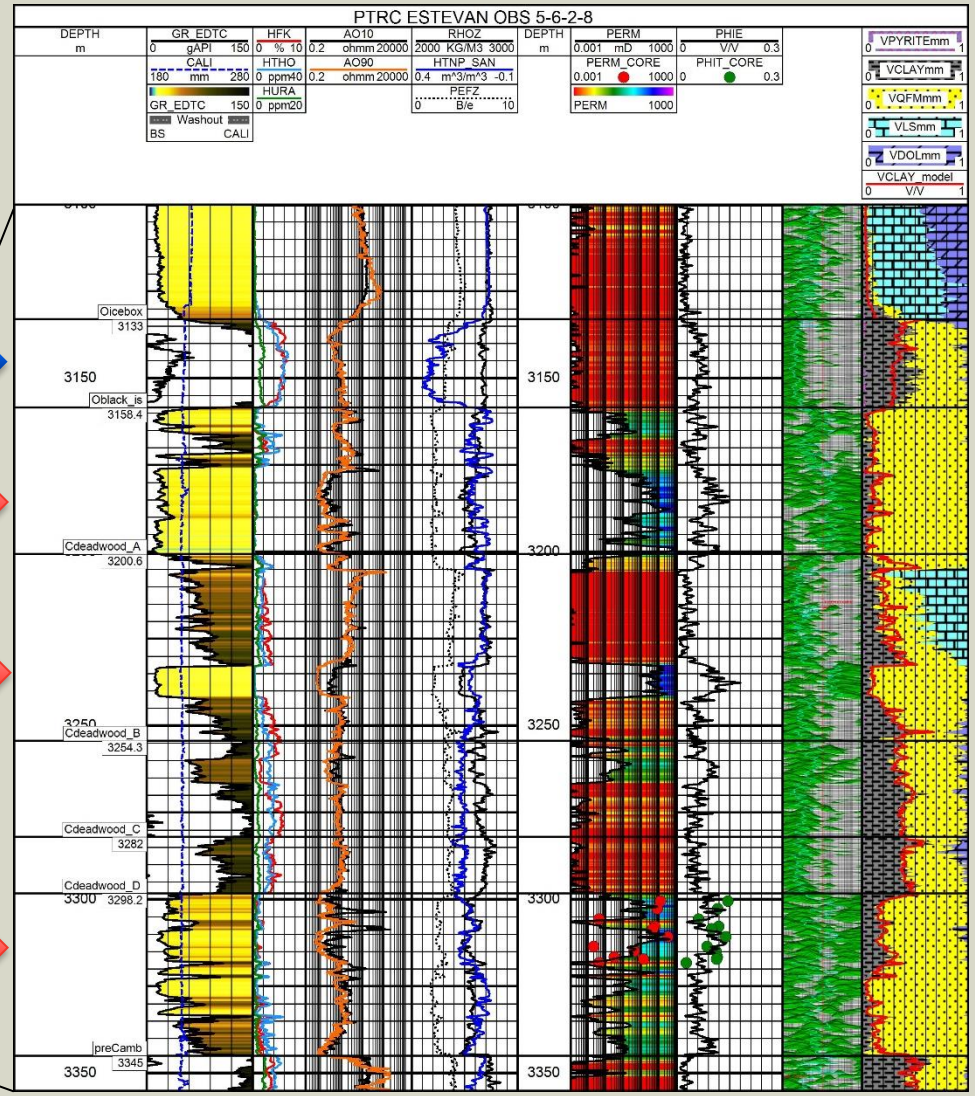


Figure 9.15 Regional cross section A*-A', segment of A-A' from central Alberta to southeastern Saskatchewan; datum,top of Ashern Formation. Crosses F*-F', G-G*.

WCSB Atlas



2. FEASIBILITY LEVEL STEPS TO FOLLOW

1. SITE CHARACTERIZATION OF SUBSURFACE

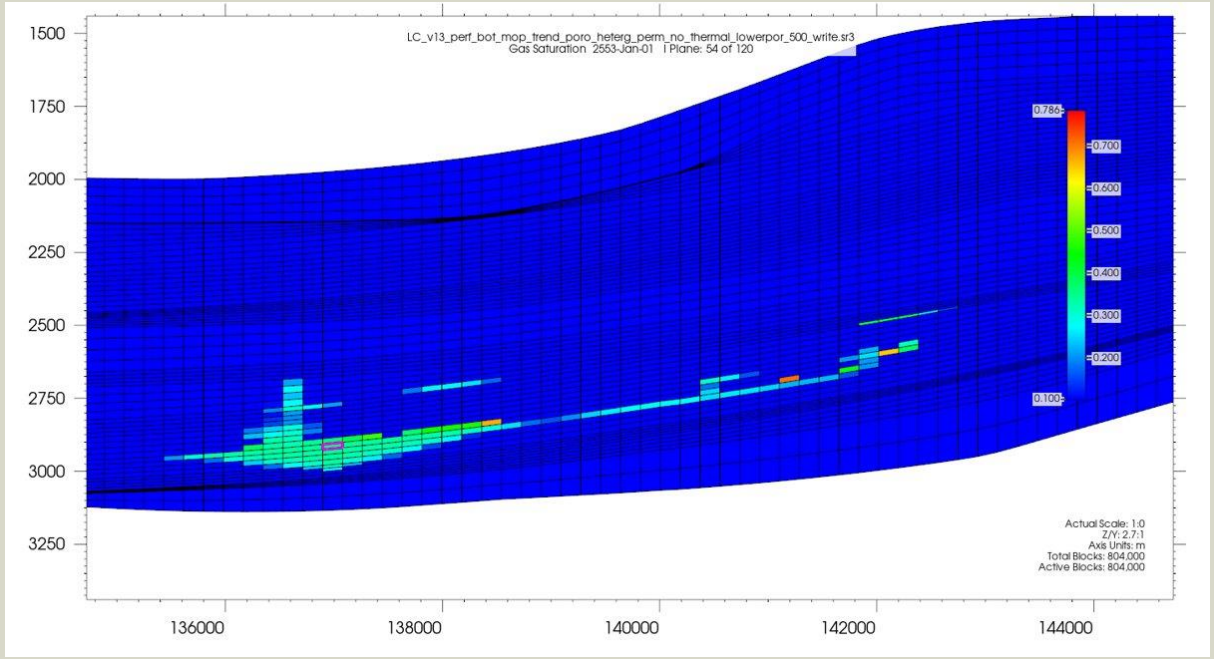
- Detailed Model Of Subsurface
  - Rocks And Their Properties
  - Use Existing Data? Acquire New Data?

2. SIMULATE INJECTION

- Injection Pressure, Plume Size & Trapping Mechanisms
- Sensitivity Analysis For Uncertainties
- Containment Risk Assessment, AOR, MMV Plan
- Technically & Economically Feasible?

3. DISCUSSION WITH REGULATOR

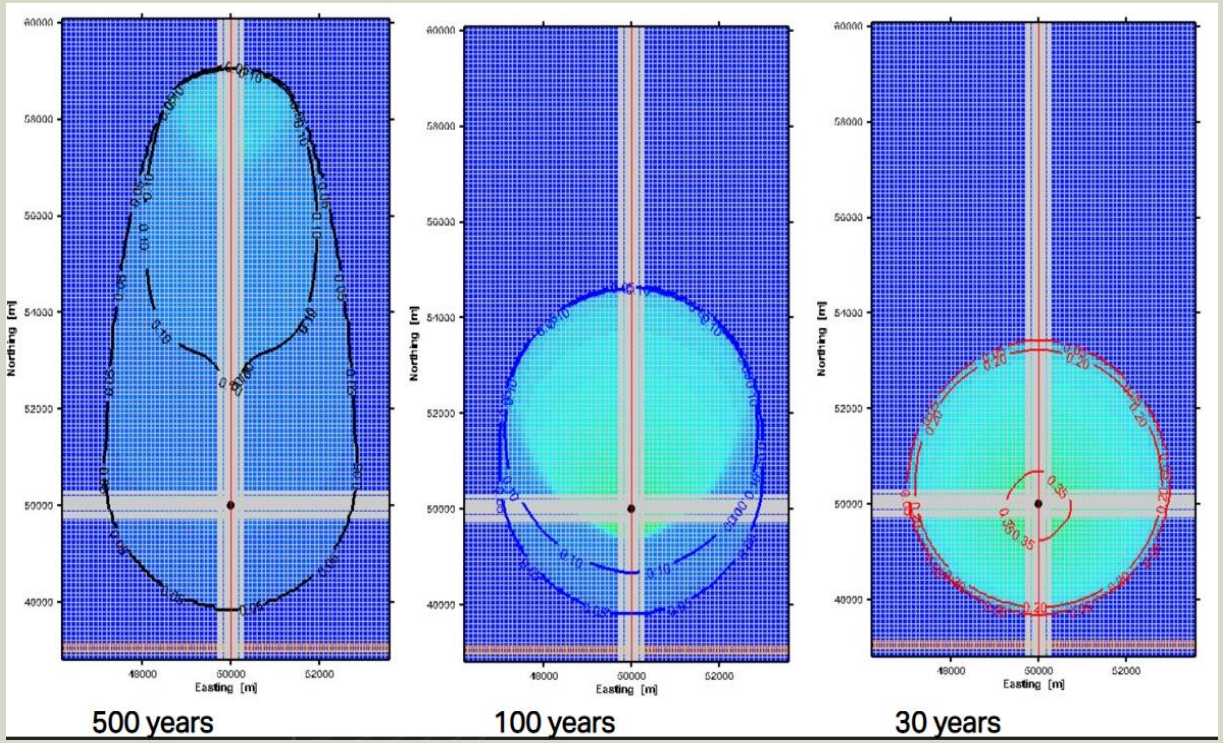
- Outline Plans, Clarify Their Concerns
- Identify Data Gaps, Timing Of Data Acquisition



Cross Sectional View of CO2 Plume Distribution and Movement

FEASIBILITY EXAMPLE & SENSITIVITY

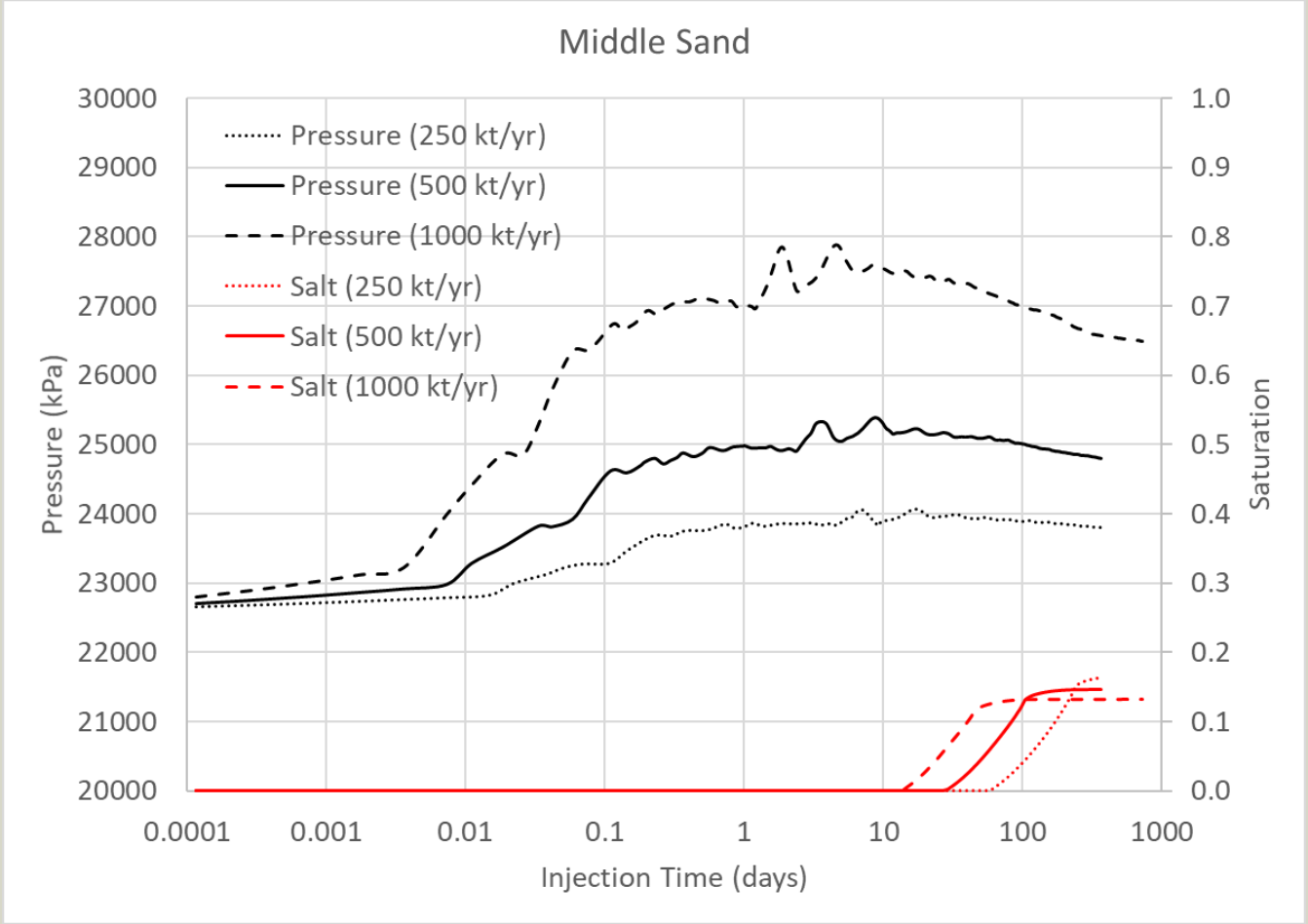
- **DEEP SALINE STORAGE**
  - Example Williston Basin Type Project, Well Characterized
  - Onsite CO2 Capture, Onsite Storage
- **SENSITIVITY**
  - Injectivity, Maximum Wellhead Injection Pressure (MWHIP), CO2 Plume Size
  - Guidance For Key Data Gaps
  - Is The Project Technically Possible?
  - Plume Migration with Dip
- **OBJECTIVE:**
  - File CO2 Injection Permit Application
  - Or, Move On To Another Option



Plume Migration Post Injection

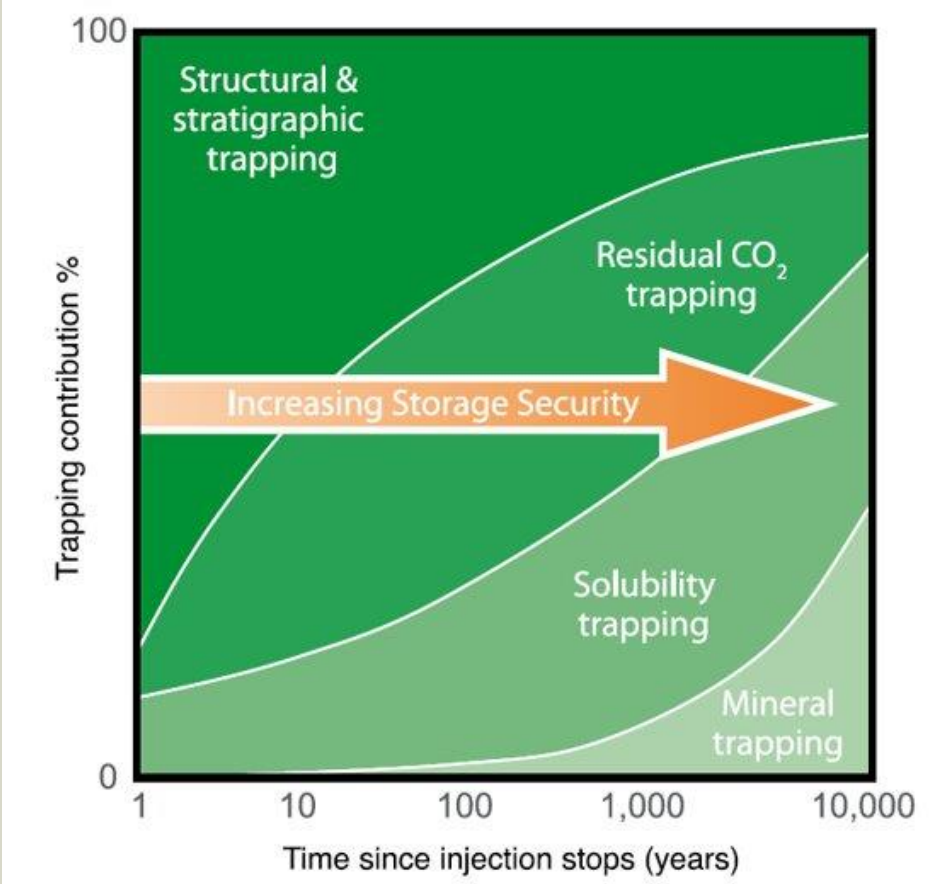
EXAMPLE RATE SENSITIVITY: 1 YEAR OPERATIONS

- 250K, 500K, 1000K TONS/YR
- SALT SCALE DIFFERENCES
  - More Scale Early With Higher Rates
  - More Total Scale With Lower Rates
- PRESSURE DIFFERENCES
  - Higher Pressure With Higher Rate
  - Controlled By Transmissivity
  - Fluid Mobility Also Plays A Role



RISK FACTORS

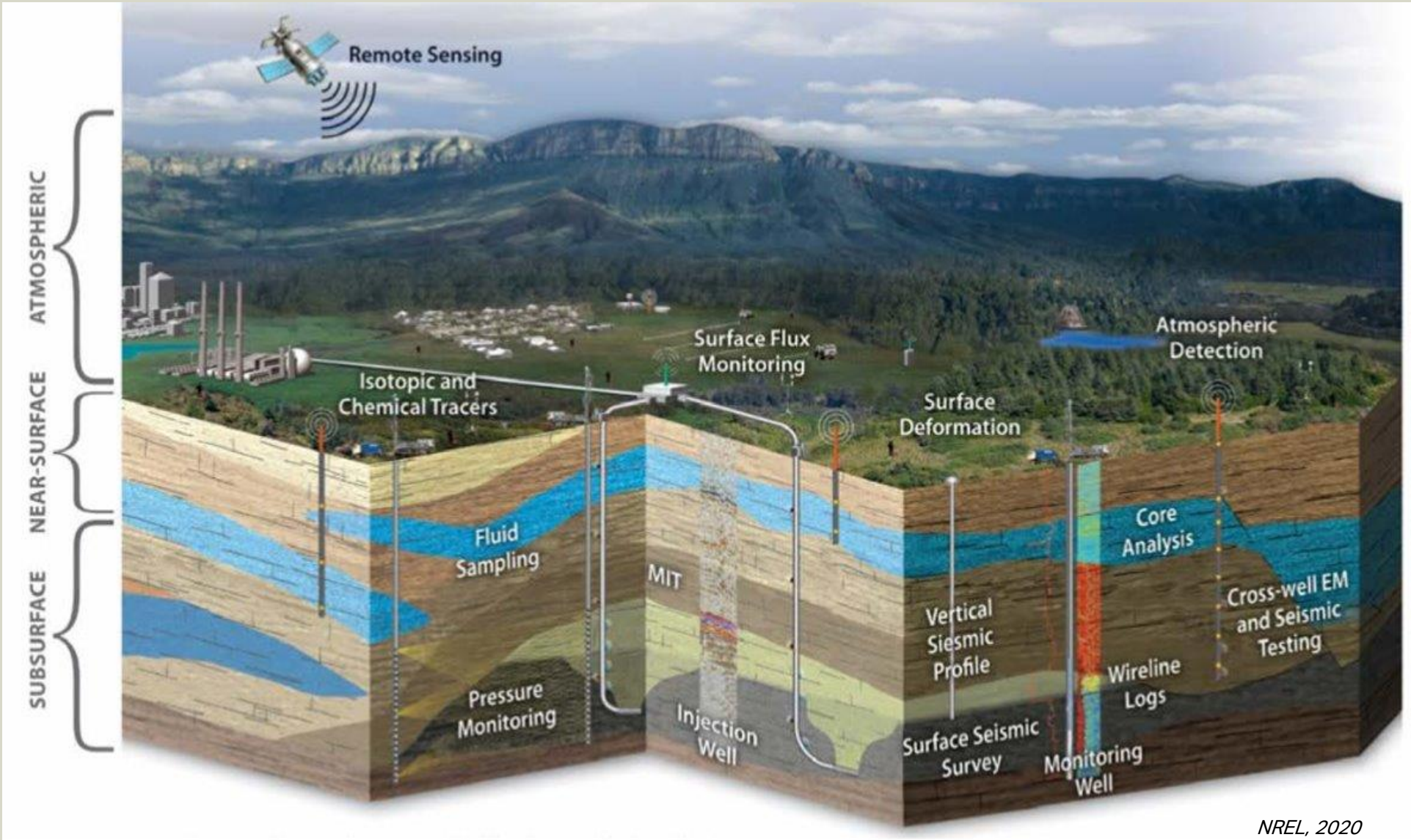
- **TECHNICAL/OPERATIONAL**
  - Do We Know What We Don't Know?
    - Models Adequately Constrained
    - Knowledge Of Legacy Wells
    - Decreasing Injectivity, Workovers
  - Multiple Seals, Pressure Relief Zones, Faults
  - Corrosion
  - Inherent Security Of Trapping Mechanism
- **REGULATORY**
  - Early Discussions Avoid Surprises
- **SOCIETAL**
  - Wells Are Very Low Visibility, Pipelines Are Not



ICCP Report 2005

CONTAINMENT MONITORING

- **PROJECT-SPECIFIC REQUIREMENTS**
  - Scheduled Measurements & Reporting
  - Permanent Instrumentation Installs
    - Fiber Temperature/Acoustic On Casing
    - Pressure Gauges At Wellhead/Downhole
    - MS Monitoring
  - Collection Of Samples
    - Downhole Fluid, Injectate
  - Testing
    - Wireline Logging, Corrosion Monitoring
    - Mechanical Integrity Test (MIT)
    - Injection Falloff Test
  - Early Detection Of Problems, Allows For Model Calibration



NREL, 2020

SUMMARY

- **FEASIBILITY**
  - Not A Lengthy Process To Reach Go/No-go: Several Months To A Year
  - Identify Injection Zones, Realistic Injection Rates And Pressures
  - Decision To Move Forward Or Not
- **MOVING TO PERMIT APPLICATION**
  - Degree Of Iteration Is Site-specific
  - Geomechanics, More Detailed Modeling May Be Required
  - Get In The Regulator Queue With A Well Laid-out Plan
  - Refine From There
- **CO2 TAX CREDITS HAVE CREATED A SIGNIFICANT ECONOMIC OPPORTUNITY FOR THE CEMENT INDUSTRY AND OTHER CO2 POINT SOURCE INDUSTRIES**

RESPEC

QUESTIONS?