# $CO_2$ Transport Methods




***Battelle***
Neeraj Gupta and
Joel R. Sminchak

Maryland Energy Administration Carbon Sequestration Workshop
November 19-20, 2019
Maritime Institute, Linthicum, Maryland

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP



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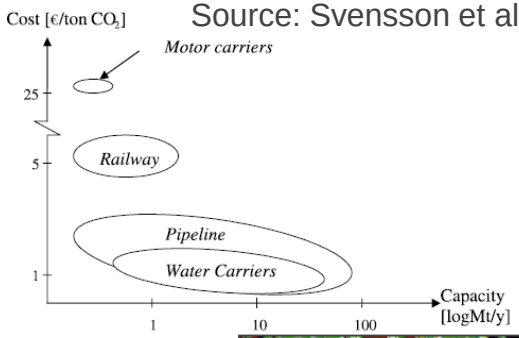
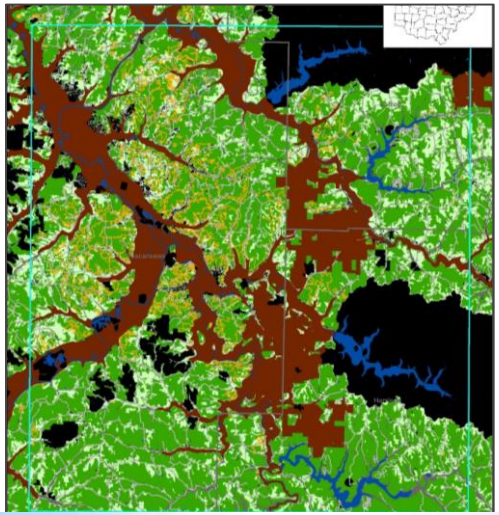
# Outline

1. $CO_2$ Transport Overview
2. Transport Options/Selection
   - Trucking/rail
   - Water carriers
   - Pipelines
3. Pipeline design, routing, and risk assessment
4. Pipeline Routing Example
5. Current $CO_2$ Transport Example

Source: Svensson et al. (2004)



Source: Statoil



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# $CO_2$ Transport Overview

- **Select Transport Option**
  - Trucking or Rail
  - Barges (offshore)
  - Pipeline
- **Determine transport design/operational requirements**
  - Pipeline design and transport aspects
  - $CO_2$ stream characterization
- **Ensure Safe Operations**
- **Conduct Proper Outreach Activities**
  - Ensure stakeholder buy-in
  - Address environmental concerns and social issues
- **Examples of routing – IMSCS-Hub**
- **Examples of existing $CO_2$ transport operations**

Source: Scientific American

# Select Transport Option

**The transport option for a selected project is determined based on the capacity of emissions required for the project and the distance required for transport.**

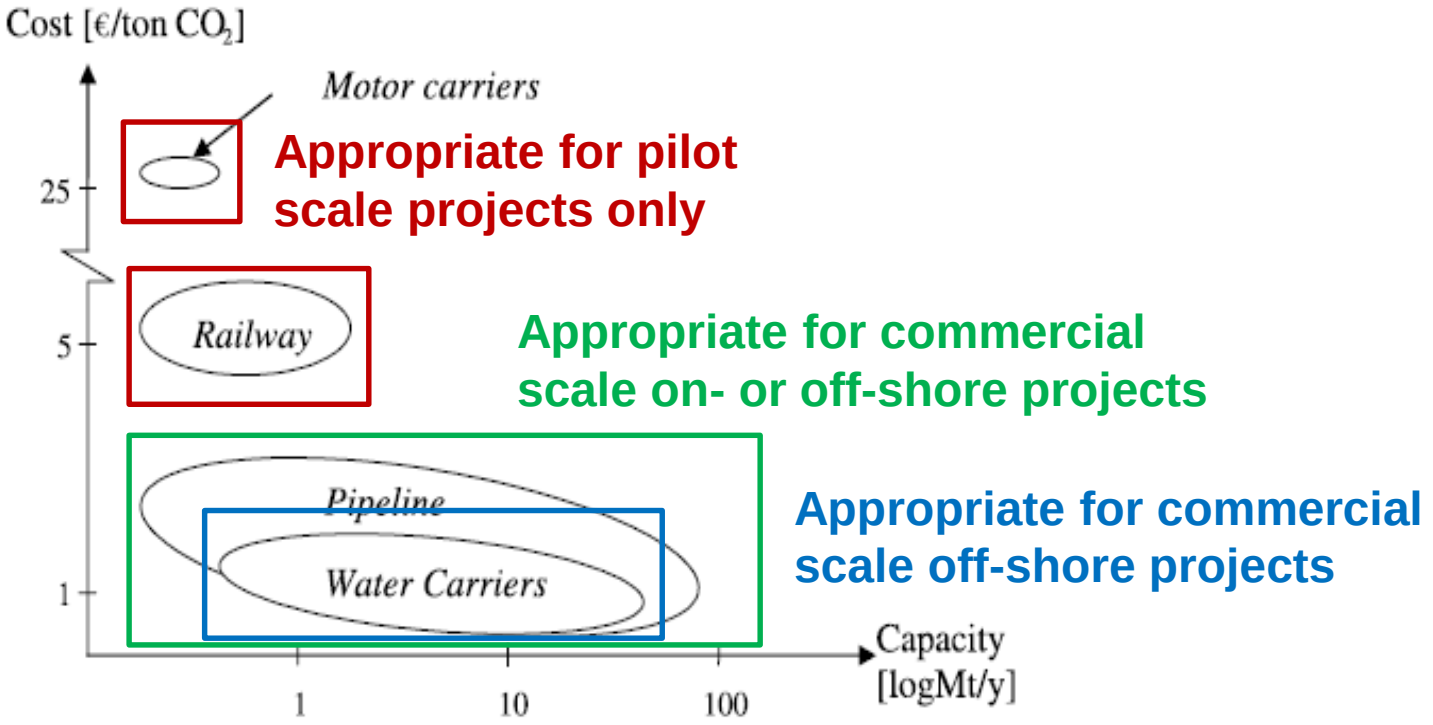


Fig. 2. Cost and capacity for transportation alternatives at 250 km.

Source: Svensson et al. (2004)

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# $CO_2$ Transport for Pilot Testing CCS

Example of short-term injection testing using liquid $CO_2$ tanks at a Power Plant in Appalachian Basin


Setting up for the $CO_2$ Injection Test (September 2008)

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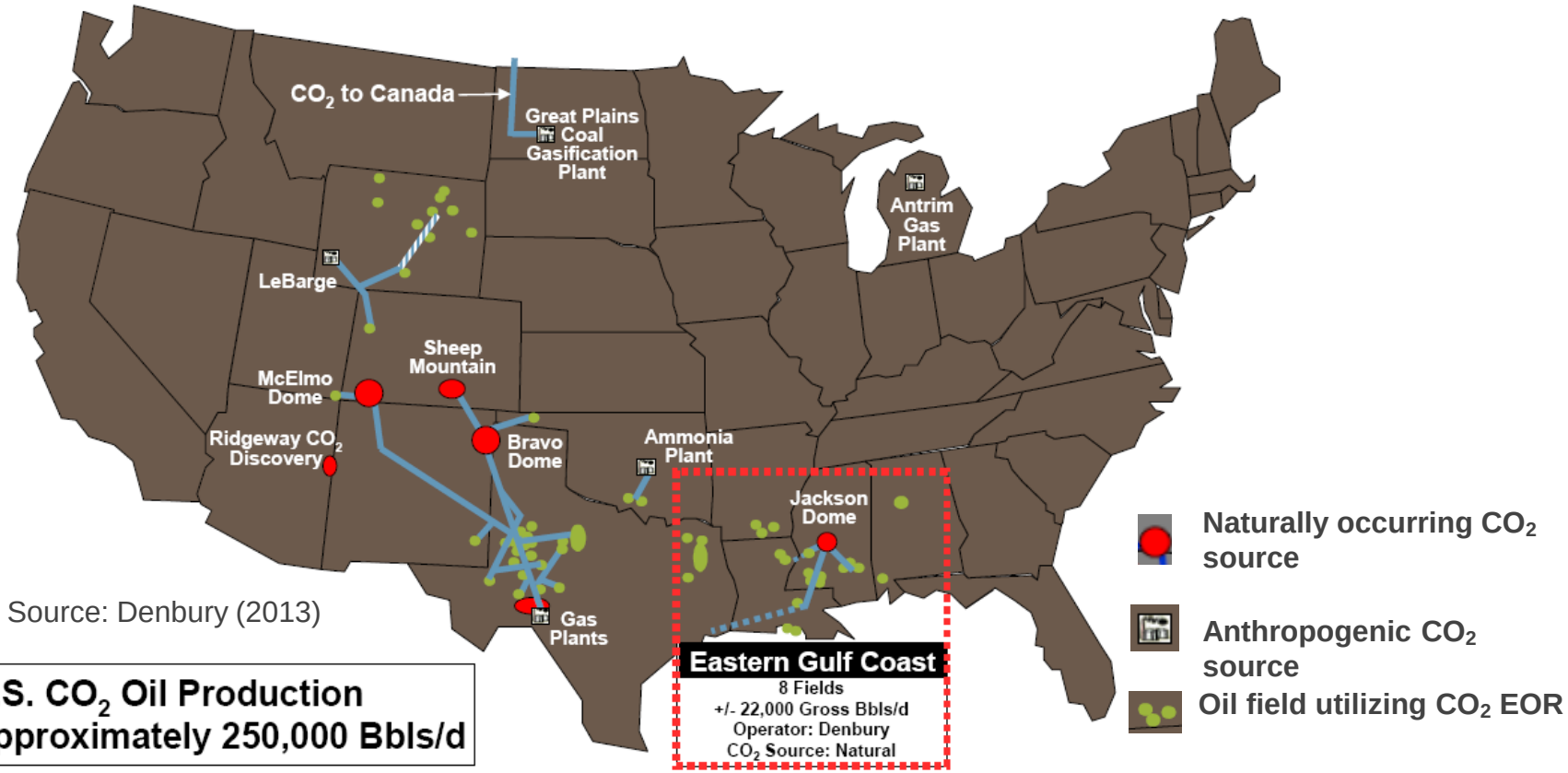
# USA $CO_2$ Pipeline Overview

The largest concentration of pipelines are in the Southwest USA, primarily connecting natural $CO_2$ sources (red circles) to EOR activities in the Permian Basin in West Texas




Source: Denbury (2013)

**U.S. $CO_2$ Oil Production Approximately 250,000 Bbls/d**

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# Large-scale $CO_2$ Transport in the USA Occurs Through Pipelines

- Pipelines are an efficient method to transport $CO_2$ from the source to injection wells
- There are about 3,600 miles (5,800 km) of $CO_2$ pipeline in operation in the USA
- Increasing activity outside USA
- Operational conditions more variable compared to natural gas pipelines
  - Higher operating pressures:
    - $CO_2$ = 1000-3000 psi (~70 to 200 bars)
    - Natural gas $CH_4$ 600-1500 psi (~41 to 100 bars)
  - Different corrosion and fracture issues
- Regulated in USA as liquid pipelines by DoT

Source: PBS

# Design Aspects of $CO_2$ Pipeline Transportation

- **$CO_2$ transported as a supercritical fluid**
  - Pressure 1000-3000 psi (~70 to 200 bars)
  - Pipe diameter from 4 to 30 inches
- **Major Design Issues:**
  - The density varies significantly with temperature and pressure.
  - Water vapor must be minimized to avoid corrosion
  - Leaks can influence integrity since steel generally becomes brittle at cold temperatures
  - Special pumps, valves and meters needed since $CO_2$ is an excellent solvent.

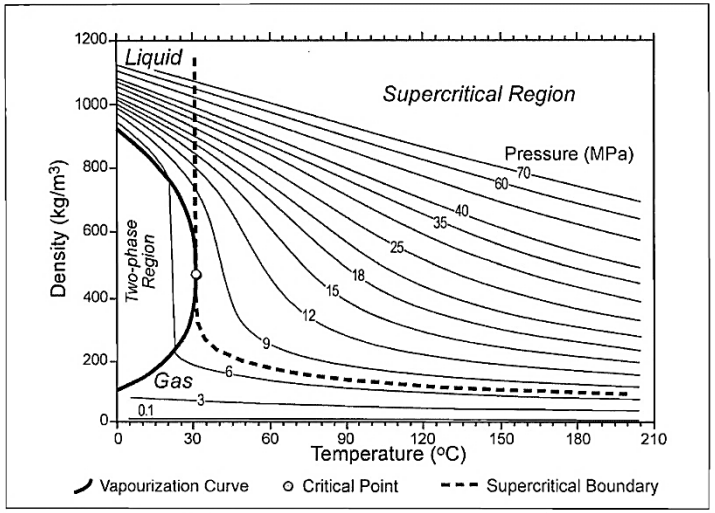


Figure AI.2 Variation of $CO_2$ density as a function of temperature and pressure (Bachu, 2003).

Source: Bachu (2003)

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# $CO_2$ Quality Considerations for Pipeline Transport

- Most world experience in $CO_2$ pipelines with nearly pure supercritical product
- $CO_2$ pipeline specifications = low water, low oxygen, low sulfur, low $H_2S$ to prevent corrosion

| Parameter | Kinder Morgan Specifications |
|---|---|
| Pressure | Pressure NOT less than 1300 psig |
| Product | At least ninety-five mole percent (95%) of carbon dioxide. |
| Water | No free water, and not more than thirty (30) pounds of water per MMcf in the vapor phase. |
| Hydrogen Sulfide | Not more than twenty (20) parts per million, by weight, of hydrogen sulfide. |
| Total Sulfur | Not more than thirty-five (35) parts per million, by weight, of total sulfur. |
| Temperature | Not exceed a temperature of one hundred twenty degrees Fahrenheit. (120 °F). |
| Nitrogen | Not more than four mole percent (4%) of nitrogen. |
| Hydrocarbons | Not more than five mole % (5%) of hydrocarbons and dew point of product (with respect to such hydrocarbons) shall not exceed minus twenty degrees Fahrenheit (-20°F). |
| Oxygen | Not more than ten (10) parts per million, by weight, of oxygen. |
| Other | Not contain more than 0.3 (three tenths) gallons of glycol per MMcf and at no time shall such glycol be present in a liquid state at the pressure and temperature conditions of the pipeline. |

**Kinder Morgan Pipeline $CO_2$ Quality Specifications**

# $CO_2$ Pipeline Transport Regulations

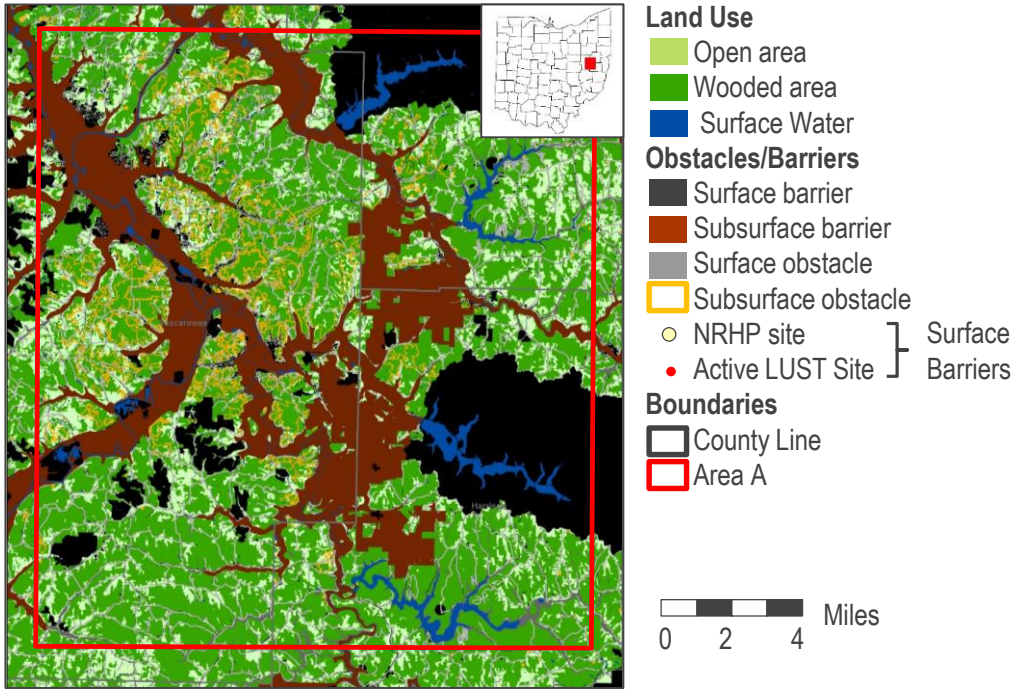
- Mix of inter-state and intra-state regulations for pipeline siting, construction, operations, and safety.

| Category | Location | Regulatory Agency |
|---|---|---|
| **Pipeline Operations and Safety** | Interstate | PHMSA (Pipeline & Hazardous Materials Safety Administration) |
| **Pipeline Siting** | Interstate | FERC (Federal Energy Regulatory Commission) |
| **Pipeline Siting** | Intrastate | MD Board of Public Works, MD Public Services Commission |
| **Pipeline Operations and Safety** | Intrastate | MD Public Service Commission, MD Dept. of the Environment Air and Radiation Management Administration |
| **Compressor Stations Construction & Operation** | Intrastate | MD Dept. of the Environment Air and Radiation Management Administration |
| **Pipeline Construction & Siting** | Interstate or Intrastate | Army Corps of Engineers Nationwide 12 Permit |
| **Pipeline Construction & Siting** | Local | Local Watershed Conservancy District/County Engineers |

# Public Outreach and Stakeholder Acceptance

Communicating project activities to all stakeholders is important for project success and public acceptance.

Identifying sensitive areas, existing operations, land use, and rights-of-way will help site a pipeline project while minimizing issues that could affect stakeholder acceptance. This can be accomplished with publicly available information.




Map of Tuscarawas Co., Ohio shows areas to avoid (barriers), minimize contact (obstacles), and simplified land use. The map considers the following:

- Environmentally sensitive areas (critical habitats, wetlands, etc.),
- Culturally sensitive areas (historical and cultural sites, etc.),
- Existing operations (oil and gas, mining, etc.)
- Active cleanup sites, and
- Simplified land use (open or wooded areas)



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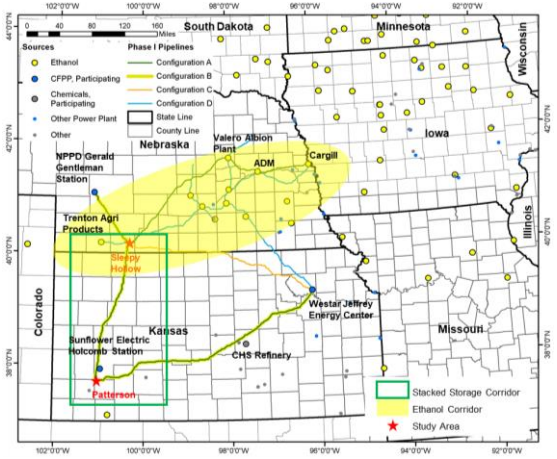
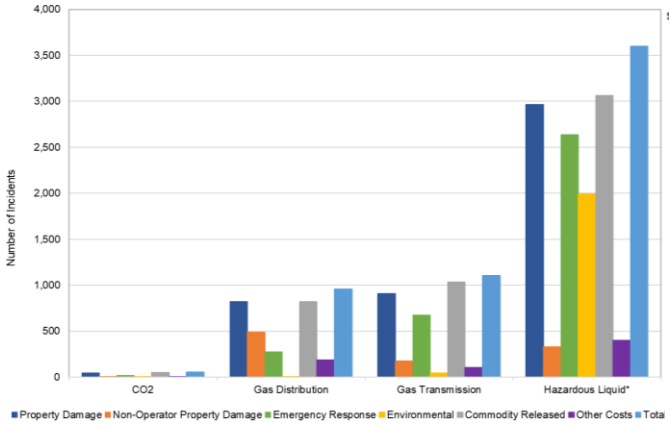
# Pipeline Risk Assessment

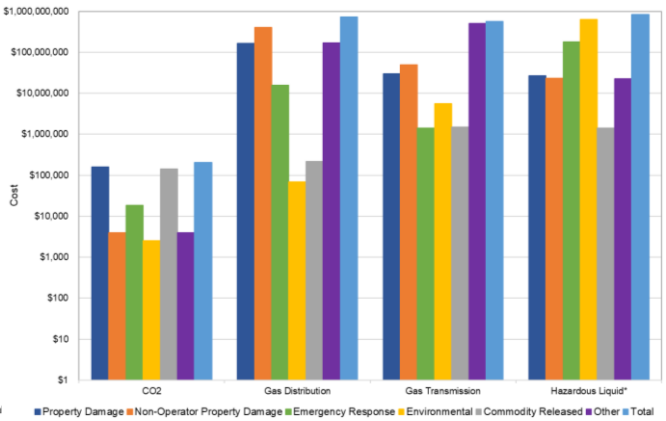
Risk assessment with likelihood and severity calculated based on incident data show that $CO_2$ pipelines have fewer and less severe impacts than other pipelines.




Pipeline routes




**Number of accidents associated with each type of cost for $CO_2$, gas distribution, gas transmission, and non-$CO_2$ hazardous liquids pipelines**




**Maximum costs by cost type for $CO_2$, gas distribution, gas transmission, and non-$CO_2$ hazardous liquids pipelines.**

| Config. | Mileage | $CO_2$ | | Gas Distribution | | Gas Transmission/Gathering | | Non-$CO_2$ Haz. Liquid | |
|---|---|---|---|---|---|---|---|---|---|
| | | Average | Median | Average | Median | Average | Median | Average | Median |
| a | 344 | $428,592 | $114,025 | $576,689 | $66,381 | $6,283,642 | $752,329 | $22,524,529 | $758,212 |
| b | 295 | $367,542 | $97,783 | $494,544 | $56,926 | $5,388,588 | $645,165 | $19,316,094 | $650,211 |
| c | 79 | $98,427 | $26,186 | $132,437 | $15,245 | $1,443,046 | $172,773 | $5,172,784 | $174,124 |
| d | 1546 | $1,926,171 | $512,448 | $2,591,747 | $298,331 | $28,239,854 | $3,381,104 | $101,229,426 | $3,407,545 |



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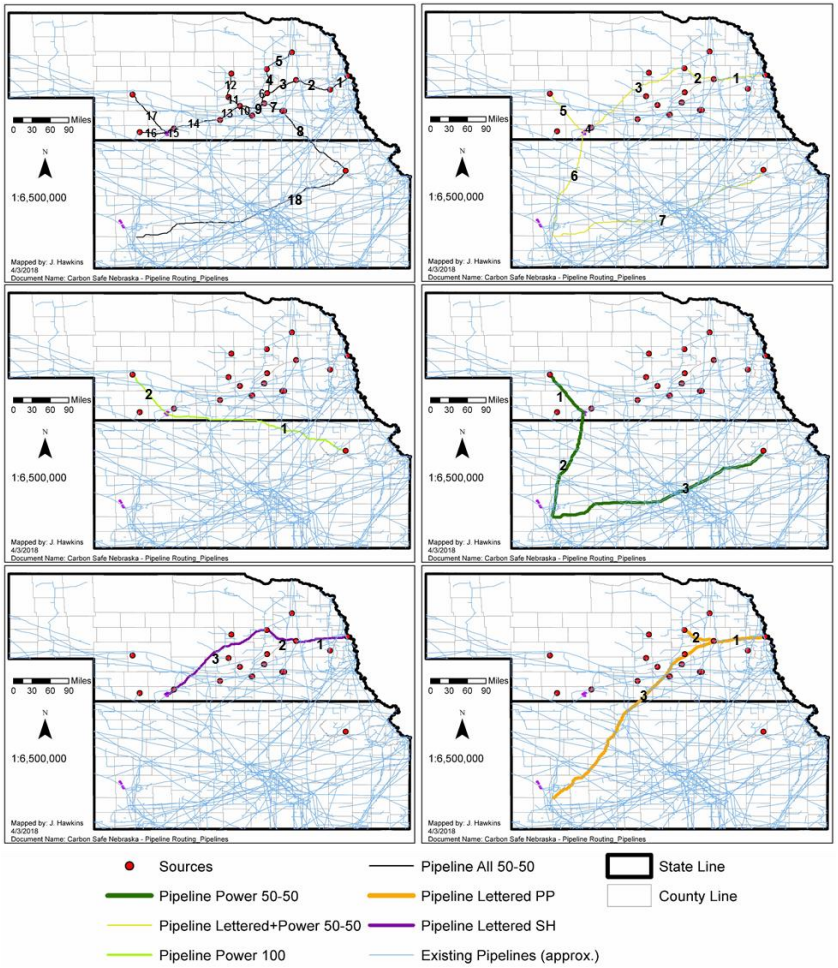
# Pipeline Routing – IMSCS-Hub Example

- Ethanol plants in the region use natural gas as a fuel for processing corn.
  - Natural gas pipelines run to every ethanol plant in Nebraska and Kansas.
  - These pipelines occur within 3 miles of each potential site in Nebraska and Kansas.
- Routes generated the weighted-cost surface involves laying a grid overtop of the geographic area and determining the cost to traverse from one cell to a neighboring cell.
- Included Kansas and Nebraska existing pipeline rights of way
- Sources were hardwired into the system




*Examples of pipeline routes generated using SimCCS.*



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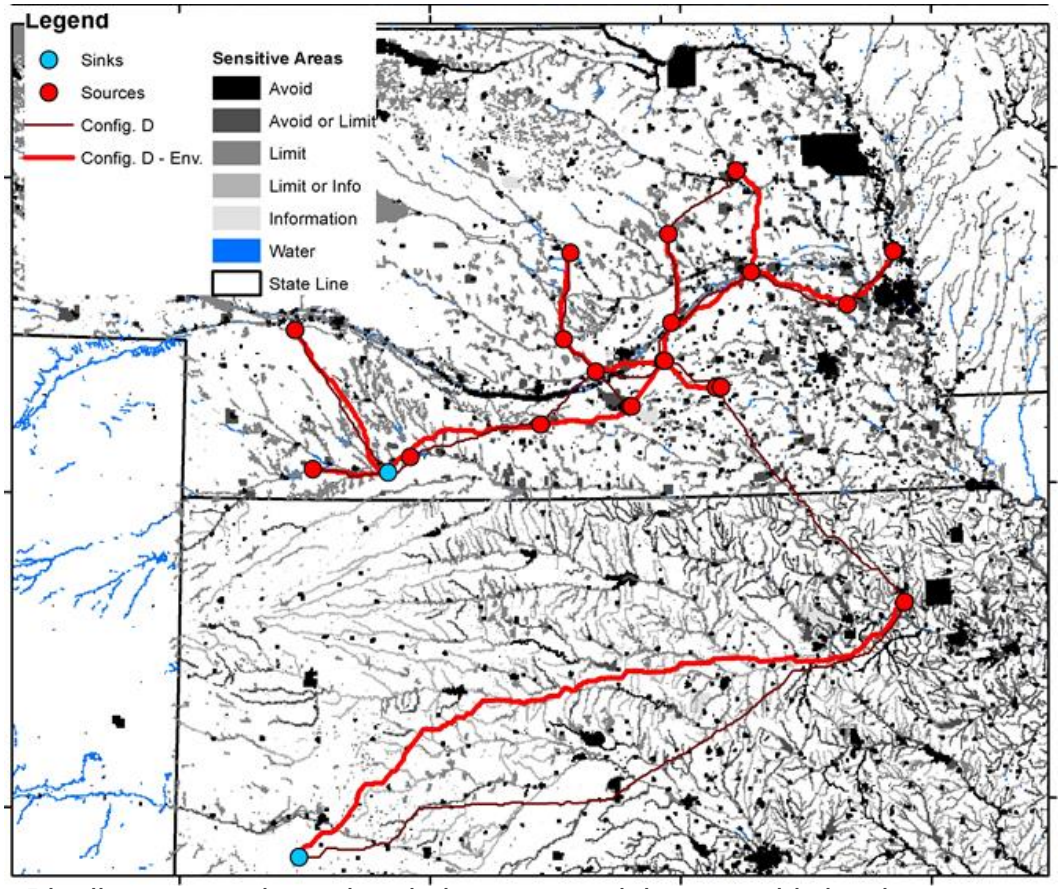
# Geographic barriers – IMSCS-Hub Example

- Air Quality
- Surface Water
- Aquifers
- Wetlands
- Vegetation/Land Cover
- Land Ownership
- Protected Lands
- Historic Places
- Wildlife
- Mines
- Contaminated Sites
- Socioeconomic Resources




*Pipeline routes shown in relation to potential geographic barriers, one that considers environmental issues (bright red) and he other that does not (dark red).*



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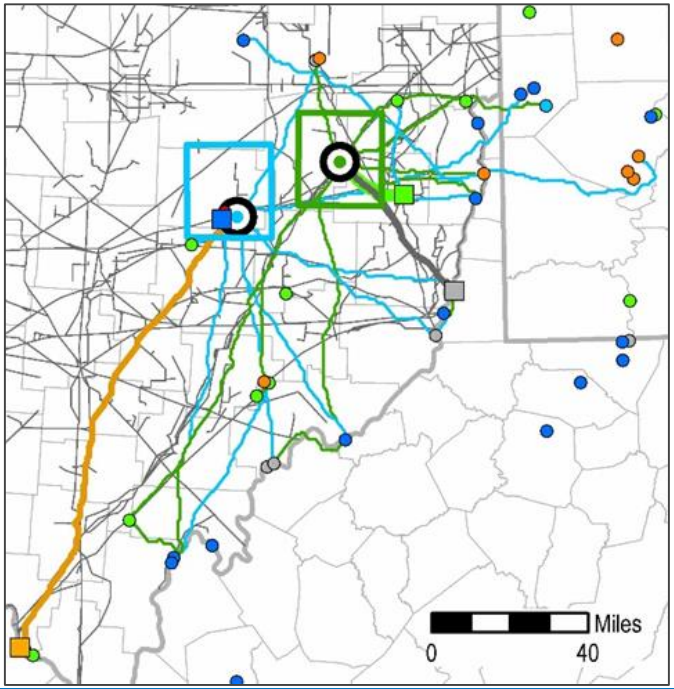
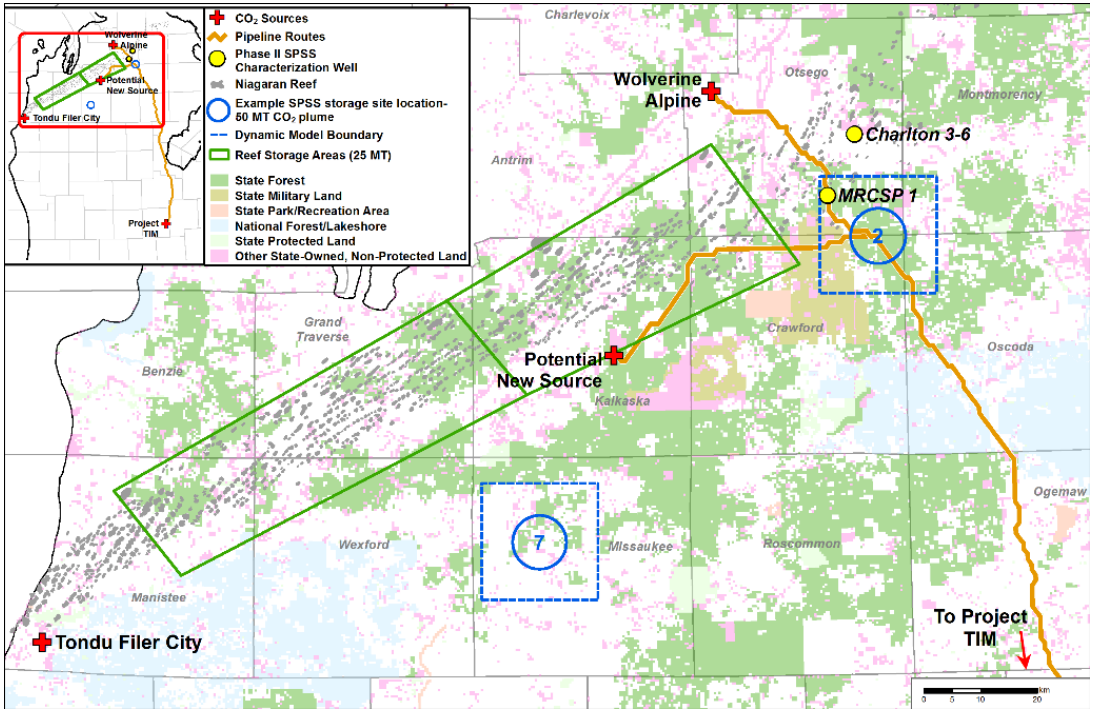
# Pipeline Infrastructure Screening

- Examples Maps
  - Southern Ohio
  - Northern Michigan





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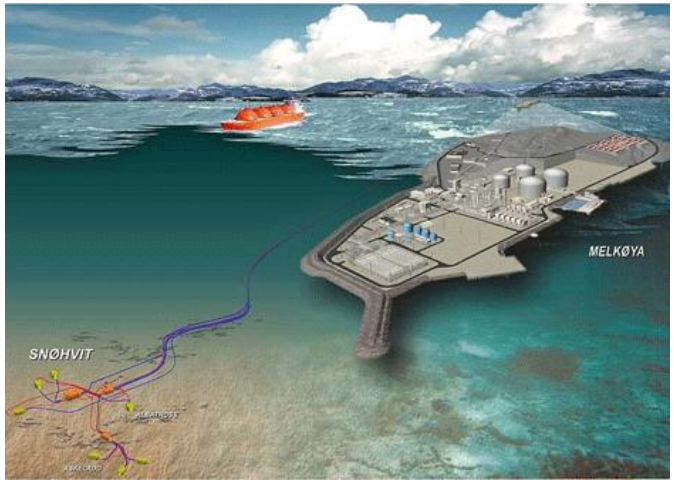
# Statoil - Snohvit Undersea Pipeline

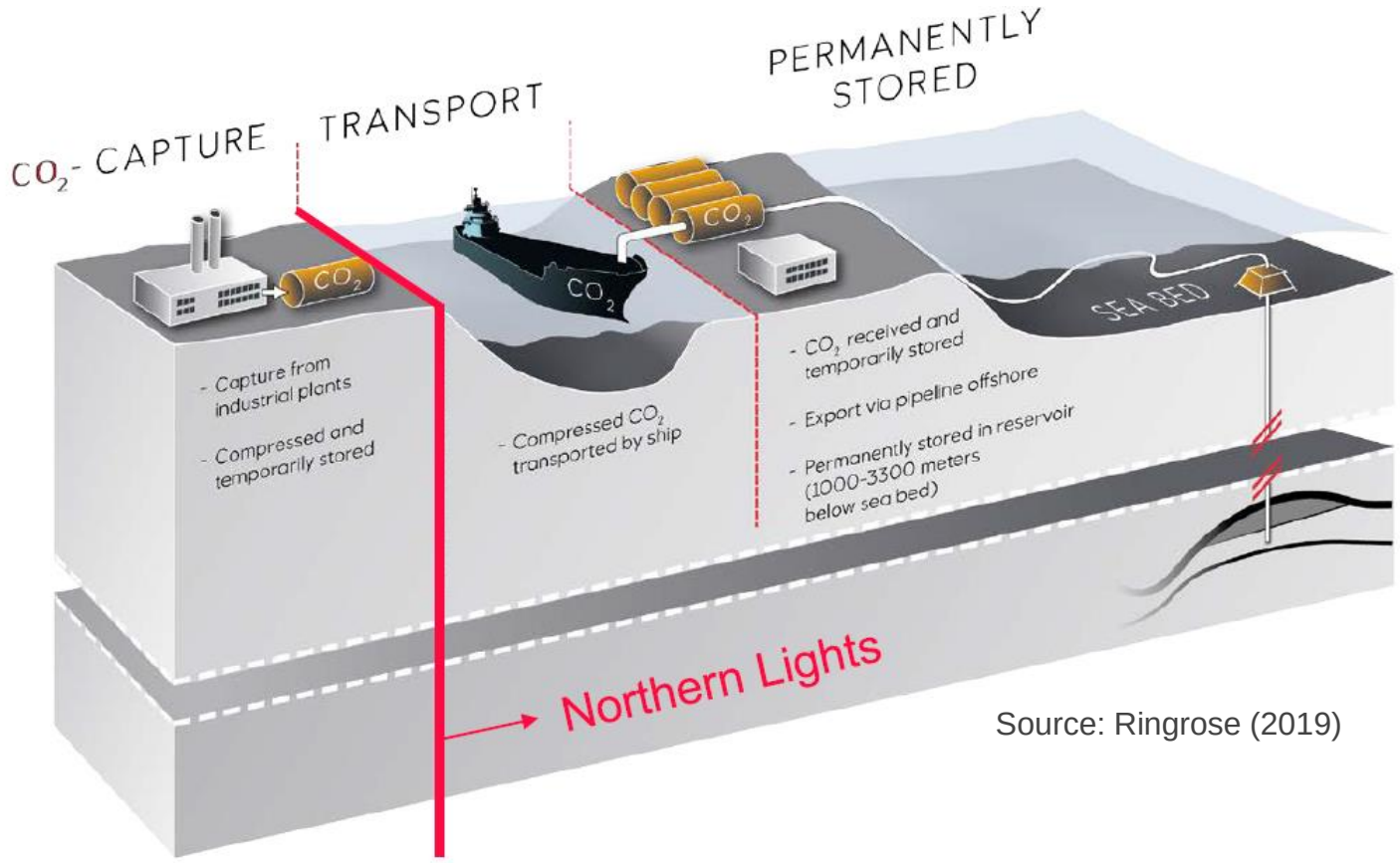
- Natural Gas processing from Barents Sea production
- $CO_2$ separation using amine process
- 145 km undersea $CO_2$ pipeline
- 700,000 tons/year, since 2008




Source: Statoil

# Shipping for Off-Shore Projects

Example of a proposed offshore project in Scandinavia where $CO_2$ is transported by ship and pipeline.




Source: Ringrose (2019)



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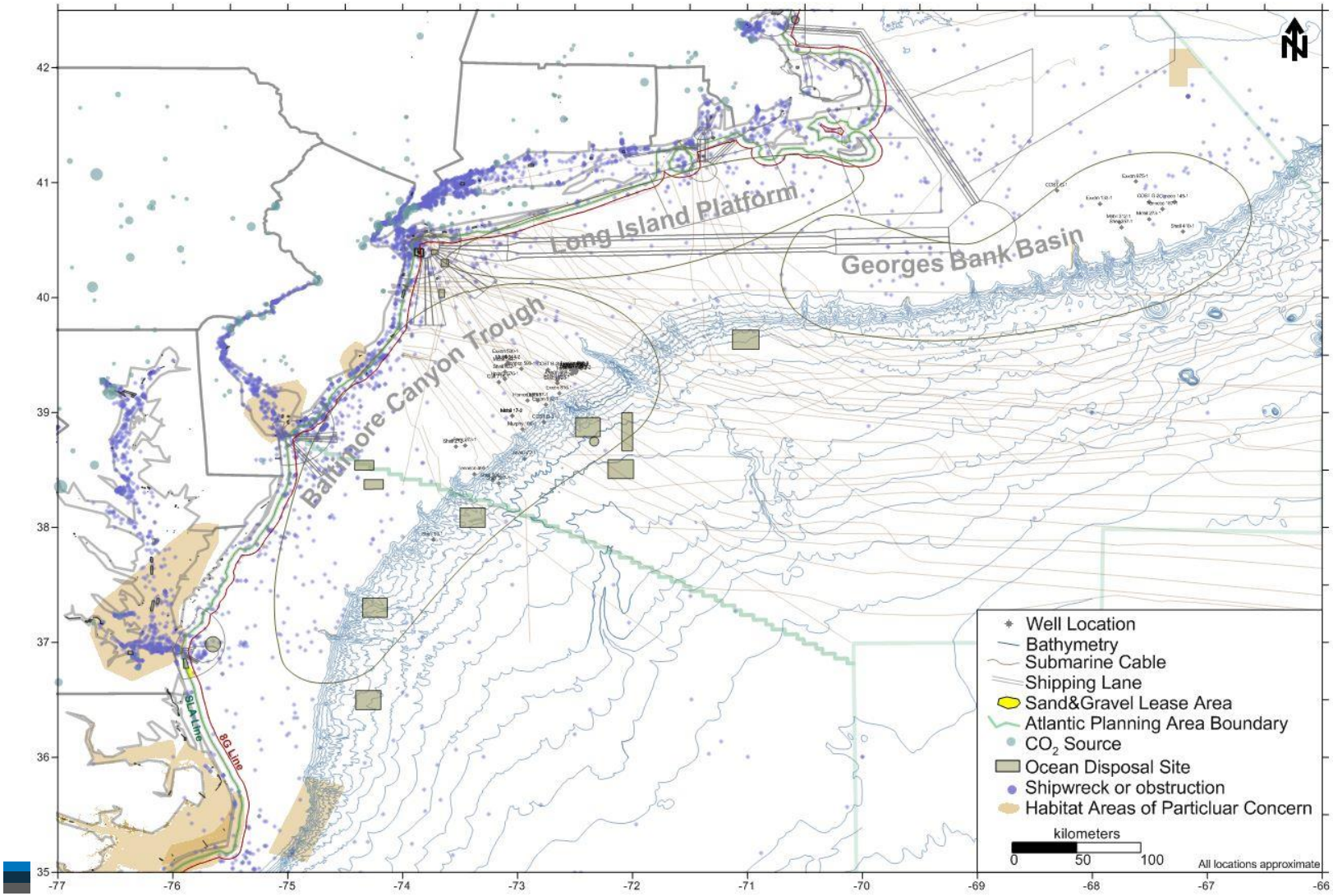
# Pipeline Risk Assessment

- Risk Factors- Mid-Atlantic Offshore Continental Shelf



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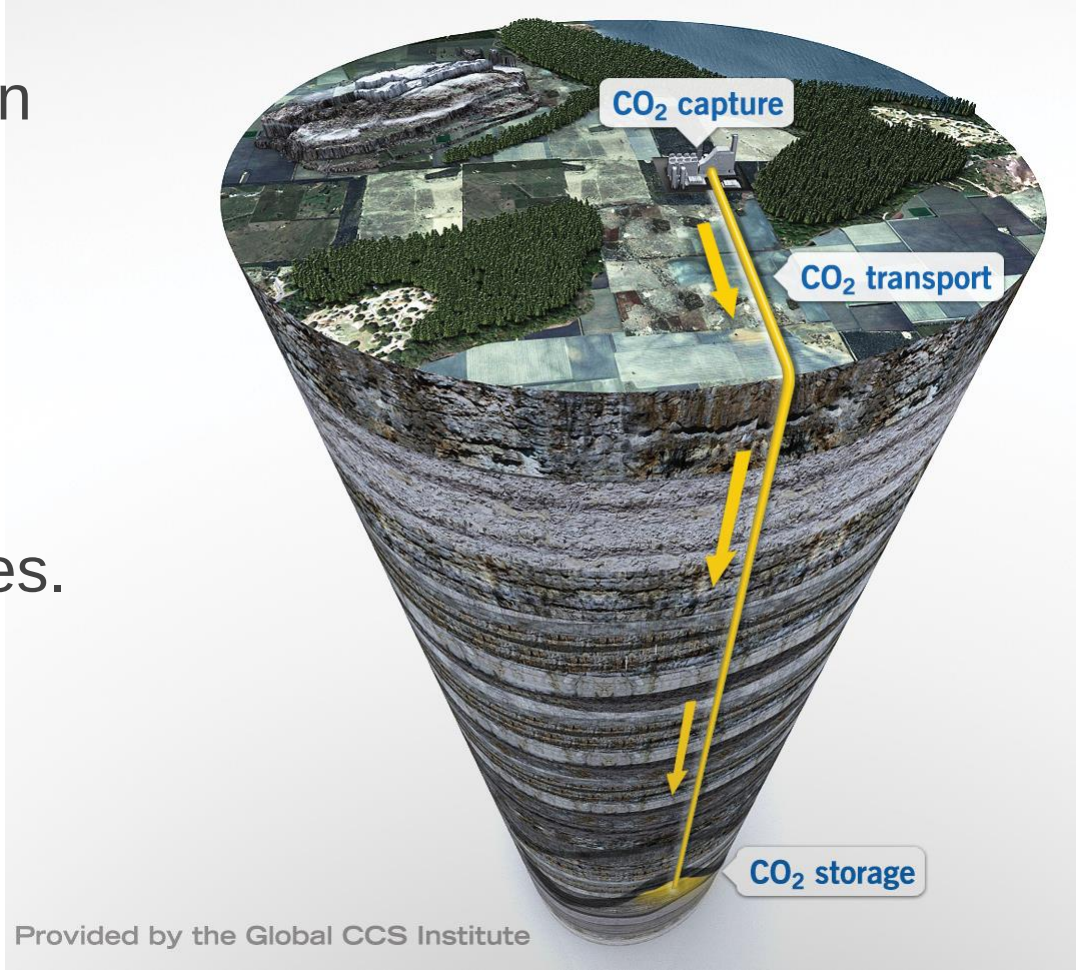
# Moving Forward

- Best transport options in Maryland?
- Key issues facing $CO_2$ transport in Maryland.
- Source-sink matching.
- Feasibility, FEED studies.
- Policy support.



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# Questions?


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