Examining Possible CCS Deployment Pathways: Onshore and Offshore (FWP-1022464)

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Disclaimer

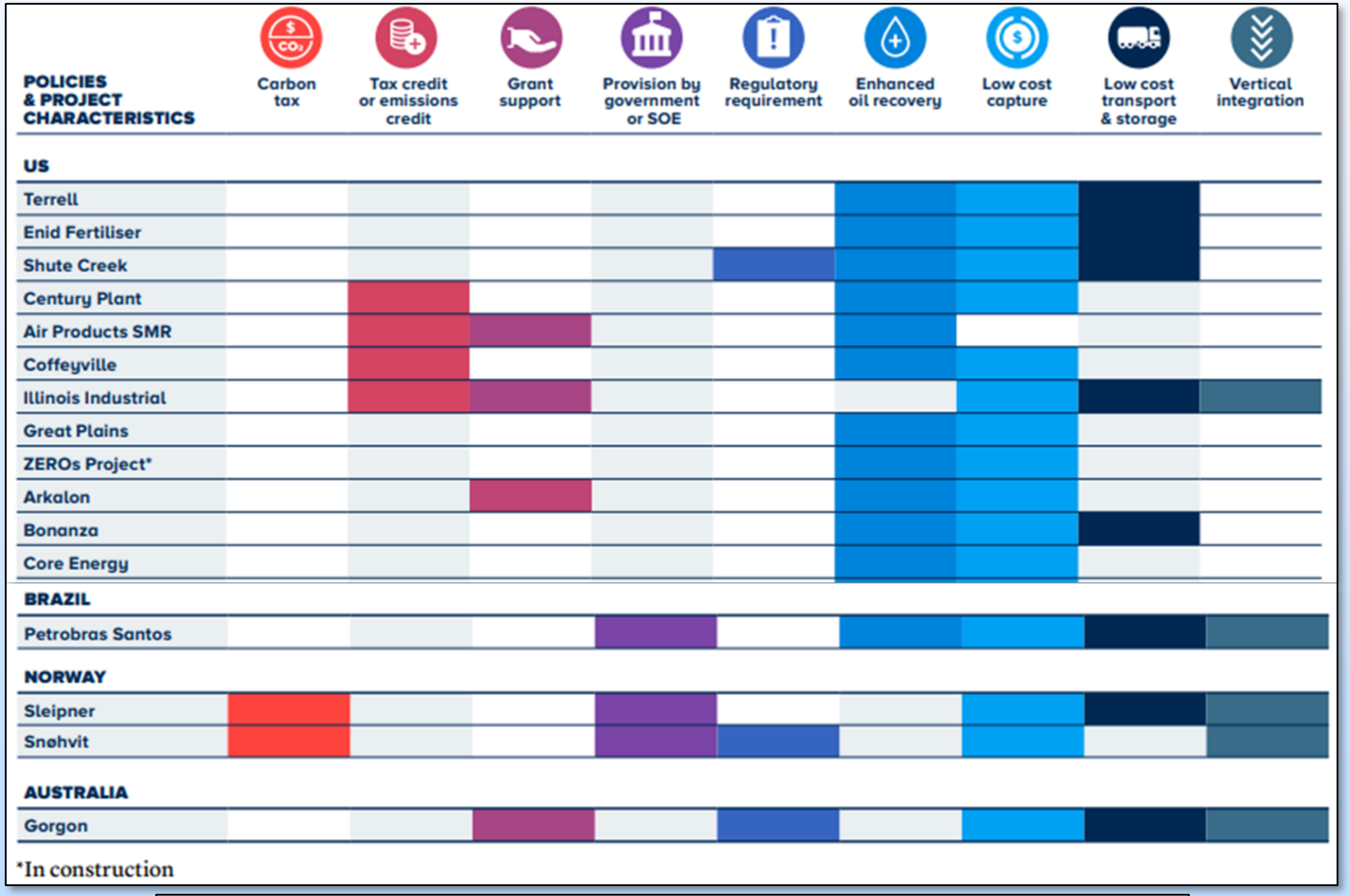
CCS Deployment Challenges and Paths Forward

What factors serve as barriers inhibiting CCS deployment?

- **Cost and financial incentives** are required to mitigate economic barriers and enable widespread CCS deployment; particularly given disaggregated business models across CCSS value chains
- **Multi-faceted analysis of economics, infrastructure, and geology** is required to comprehend and stimulate active and broad market for CCS
- Absence of documented safety and environmental **regulations** in offshore federal waters for storage is limiting offshore CCS attractiveness
- **Balance supply chain incentives** are required to support operators and incentivize stakeholders

What factors serve as enablers that promote CCS deployment?

- **Higher purity CO_2 sources** (NG processing, hydrogen production, and many ethanol production) provide for lower cost of capture and first-mover candidates
- Proximity to **high quality geologic storage sites** where data is available, enabling site evaluation at lower cost, cheaper transport, and more effective and affordable storage operations
- **Economically favorable financial incentives** for capturing and storage CO_2
- Ability to enable **effective integration of diverse source types** with CO_2 transport and storage options across CCS value chain



Enabling attributes of CCS Projects. Source: Global Status of CCS 2020

Presentation Focus and Agenda

NETL's SSAE portfolio of carbon storage analyses aims to generate relevant models, tools, data, and studies that address challenges to CCS deployment and inform industry, regulatory, academic, and public stakeholders on CO_2 storage performance, associated cost drivers, and potential CCS business case viability and/or limitations.

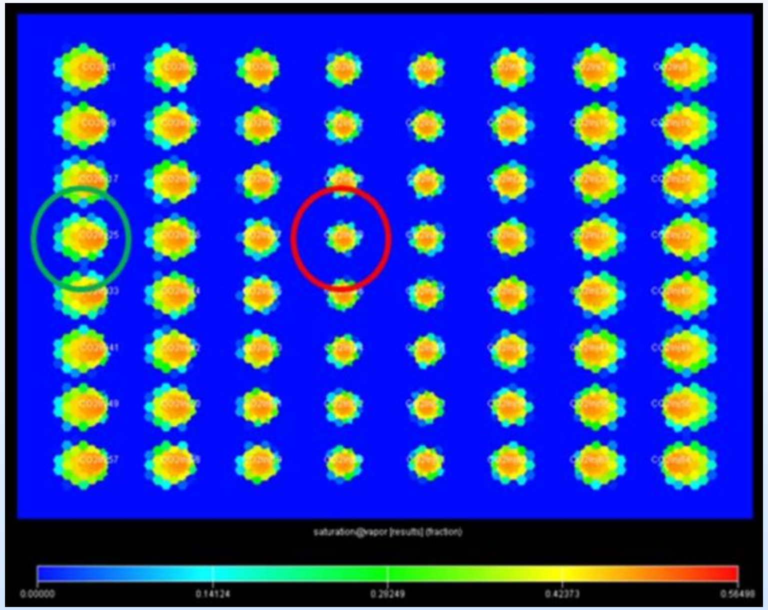
Analysis Discussed	Objectives
Basin-scale CO_2 storage modeling	Analysis of CO_2 plume and pressure evolution behavior to inform basin management strategies and operational decision making
	Assessment of storage complex spacing to prevent pressure interference among projects
Onshore CO_2 EOR	Nation-wide volumetric estimation of CO_2 storage capacity and incremental oil recovery via CO_2 EOR
	Identification of impactful geologic, economic, and design parameters that most affect the performance of CO_2 EOR
Offshore storage pilot project	Identification of technical, economic, and geologic requirements for offshore CO_2 pilot in Gulf of Mexico (GoM)
	Identification of regulatory gaps and economic challenges in offshore CCS environment to utilize single-lease owned storage site away from population
Financial aspects (45Q tax credit)	Identification of financial gaps onshore and offshore, and potential configuration of operation of CCS operator and investor partnership
	Assessment of optimal tax credit monetization opportunities to help bridge financial gaps

Basin-Scale Modeling - Overview

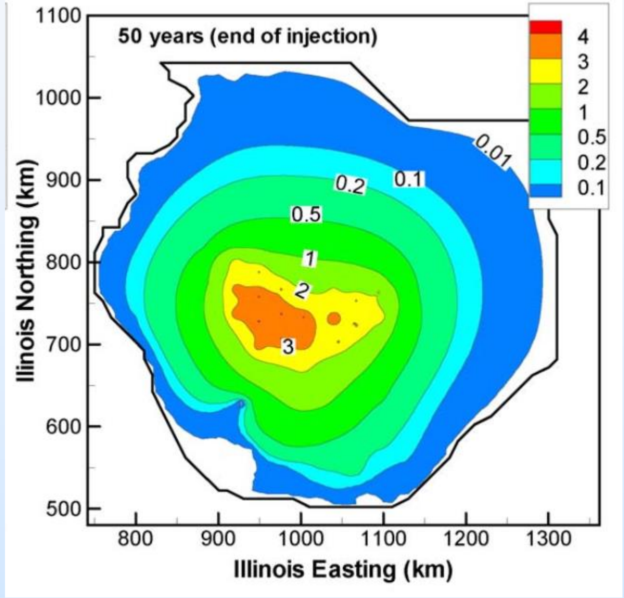
Objectives:

1. Model and analyze multiple CO_2 projects at sedimentary basin scale
2. Model occurrence of multiple reservoirs within sedimentary basin
3. Analyze interaction of these CO_2 storage operations with respect to areal extent of CO_2 plume and associated pressure front that defines AoR per Class VI regulations

CO_2 saturation[1]



Pressure extent[2]



Methodology:

- Using TOUGH3-ECO2M simulator
- Starting analysis from project scale, rather than basin scale
- Building reservoir model using publicly available data on reservoir and fluid properties

Parameter (Our Model)	Unit	Value
Permeability	md	20
Porosity	%	10
Target/Saline Formation Thickness	ft	656
Perforation Interval	-	Entire target thickness

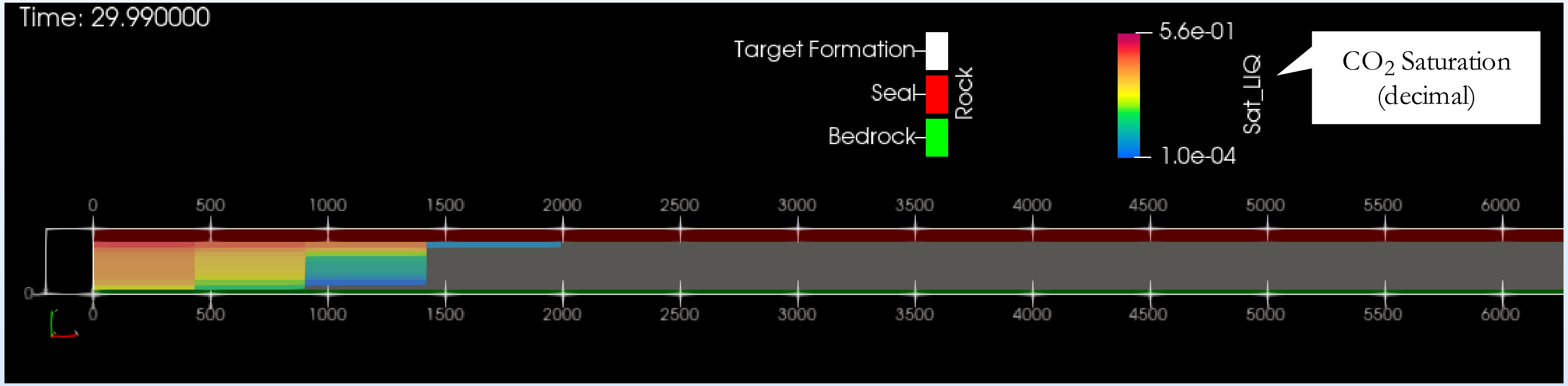
[1]*Teletzke, G., Palmer, J., Drueppel, E., Sullivan, M. B., Hood, K., Dasari, G., & Shipman, G. (2018, October). Evaluation of Practicable Subsurface CO_2 Storage Capacity and Potential CO_2 Transportation Networks, Onshore North America. In 14th Greenhouse Gas Control Technologies Conference Melbourne (pp. 21-26).*
[2]*Birkholzer, J. T., & Zhou, Q. (2009). Basin-scale hydrogeologic impacts of CO_2 storage: Capacity and regulatory implications. International Journal of Greenhouse Gas Control, 3(6), 745-756.*

Modeling Results: CO_2 Plume with 1 Injector

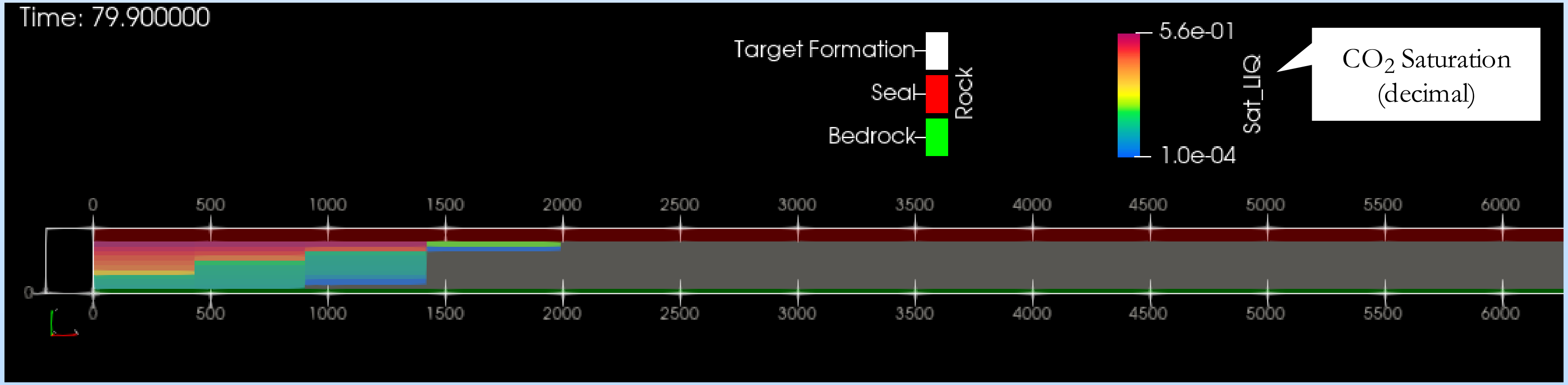
- Radius of CO_2 plume
  - Approximately 2 km at end of 30-yr injection
  - Approximately 2 km at end of 50-yr PISC
- Radius of CO_2 plume does not significantly change during PISC
  - CO_2 vertical distribution takes place during PISC, which increases overall CO_2 saturation in top portion of target formation
- Well spacing to prevent CO_2 plume interference should be larger than 4 km (for baseline case)

Side View

End of 30-yr injection



End of 50-yr PISC

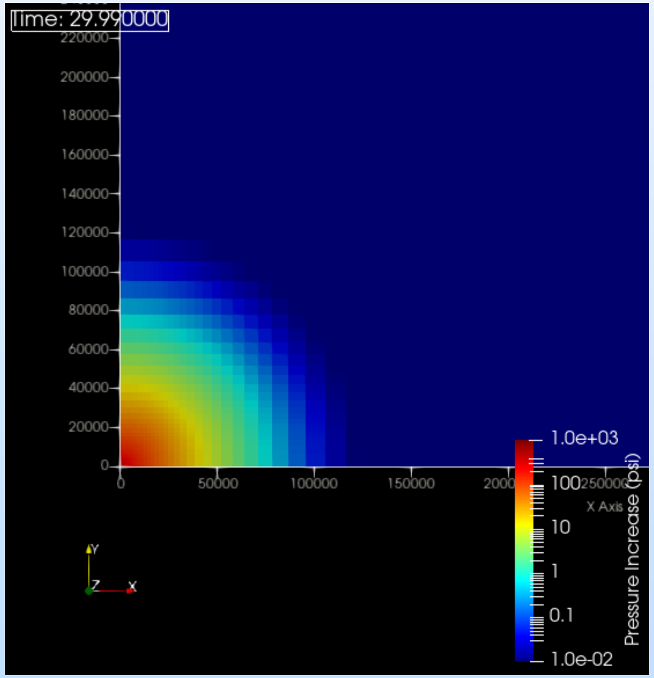


Modeling Results: Pressure Plume with 1 Injector

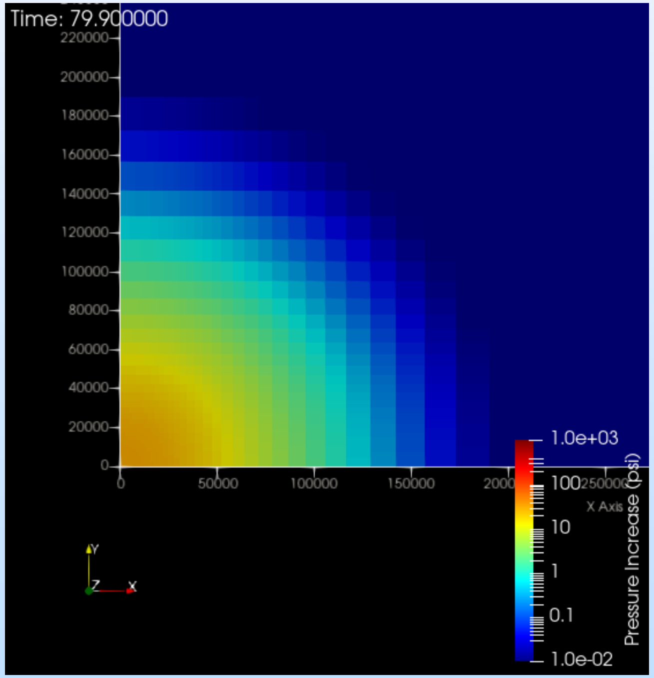
Well spacing to avoid pressure interference is much larger (>10 km) than the well spacing required to avoid CO_2 plume interference (2-3 km)

Aerial View

Pressure Difference (End of 30-yr Injection)



Pressure Difference (End of 50-yr PISC)

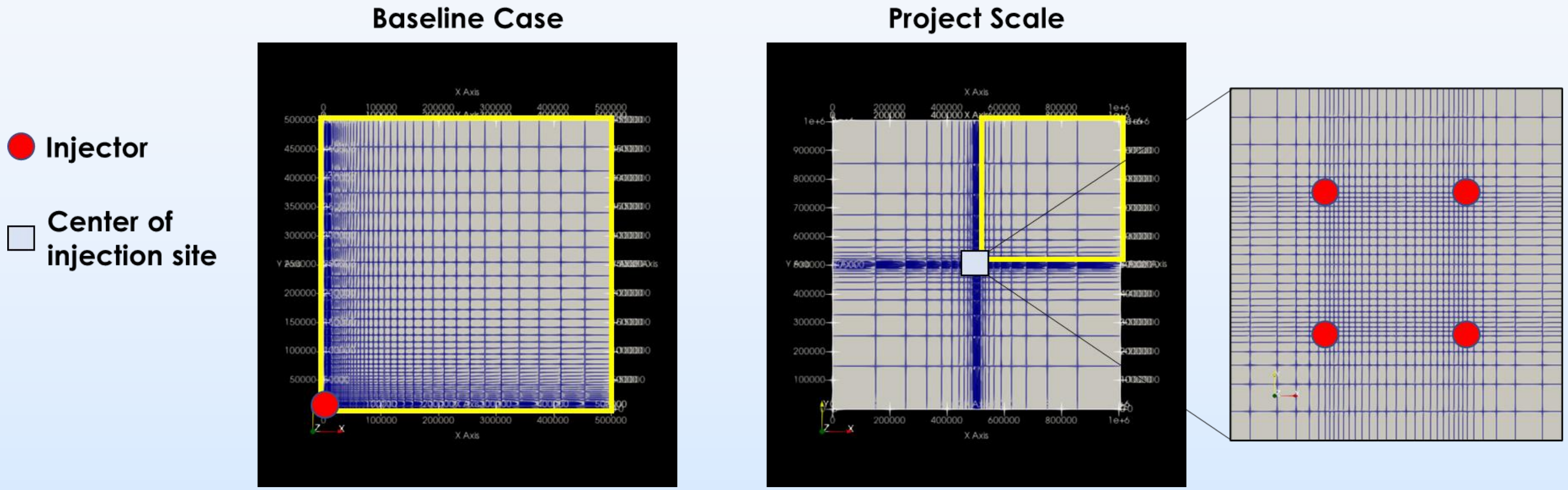


Pressure propagates beyond CO_2 plume

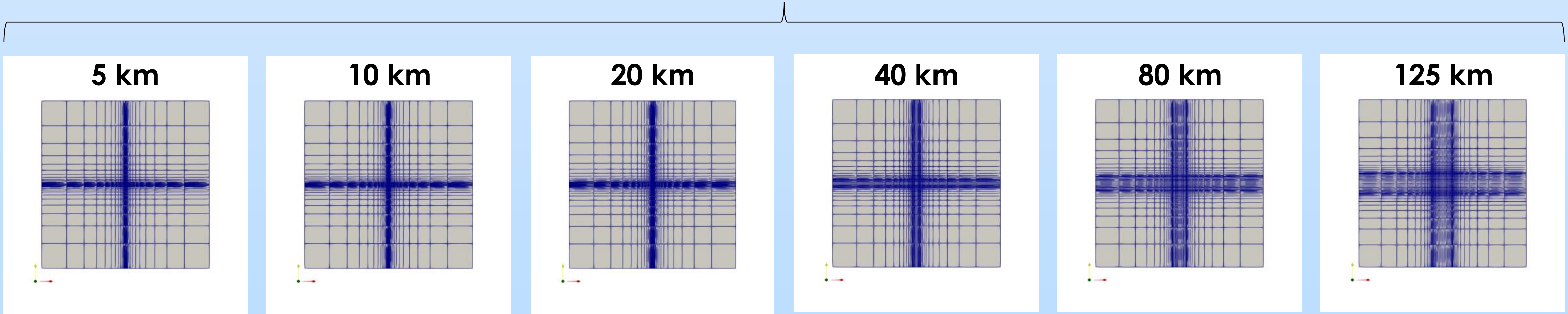
Pressure Difference (compared to ambient pressure) (psi)	Maximum Radius of Pressure Difference (km)	
	End of 30-year Injection	End of 50-yr PISC
0.1	95	154
1	71	113
10	45	62
100	14	None (max of 40 psi at 1 km)

Next Steps: Sensitivity on Geologic Parameters and Well Spacing

- Sensitivity on geologic parameters:
  - Boundary condition at the top of seal
  - Boundary condition at the lateral (potential neighboring basin)
  - Boundary condition at the top and lateral end combined
  - Seal permeability
  - Target formation permeability
  - Target formation compressibility
  - Seal compressibility
  - Target formation porosity
  - Target formation thickness



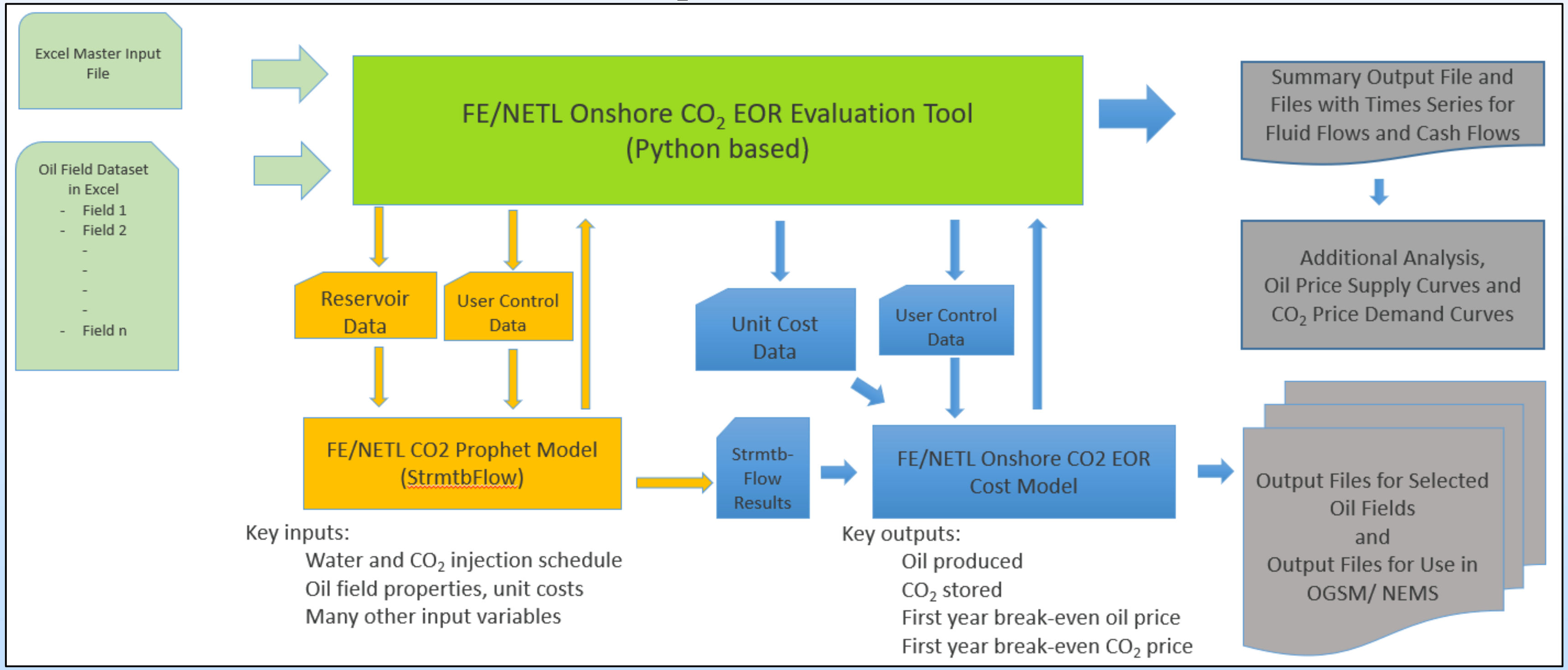
Sensitivity on Well Spacing



Onshore CO_2 EOR - Overview

- CO_2 EOR is established, safe, and economically-viable approach for U.S. decarbonization
- NETL has assessed CO_2 EOR "size of the prize" in contiguous United States for miscible water alternating gas CO_2 EOR
- Objectives:
    - Assess onshore U.S. CO_2 EOR resource capacity (CO_2 storage and incremental oil production)
    - Perform trend analyses on results and sensitivity analysis on CO_2 EOR Evaluation System used (**schematic on the right)**

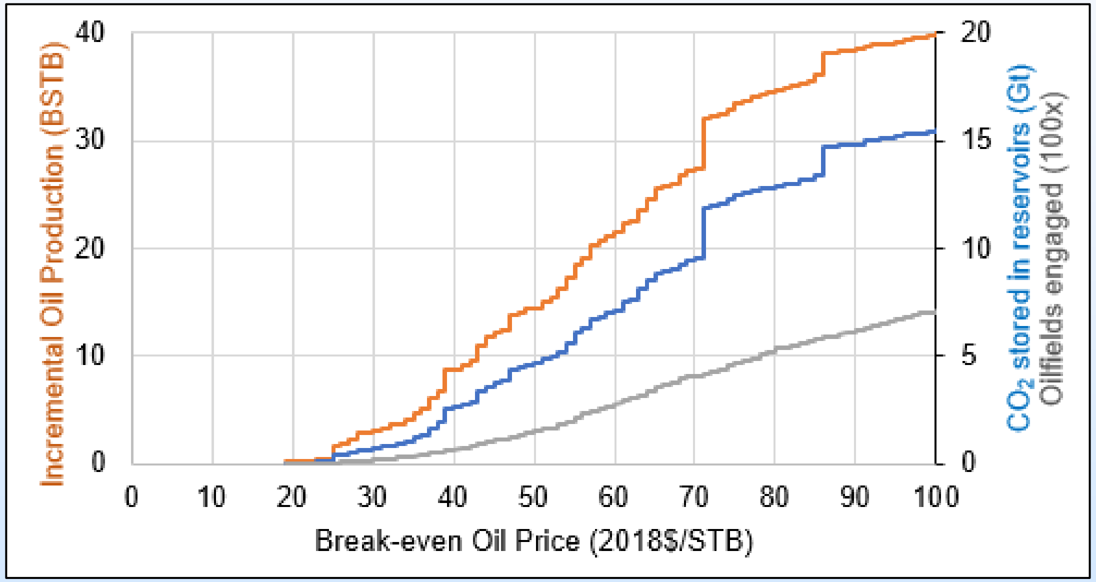
FE/NETL Onshore CO_2 EOR Evaluation System Flowchart



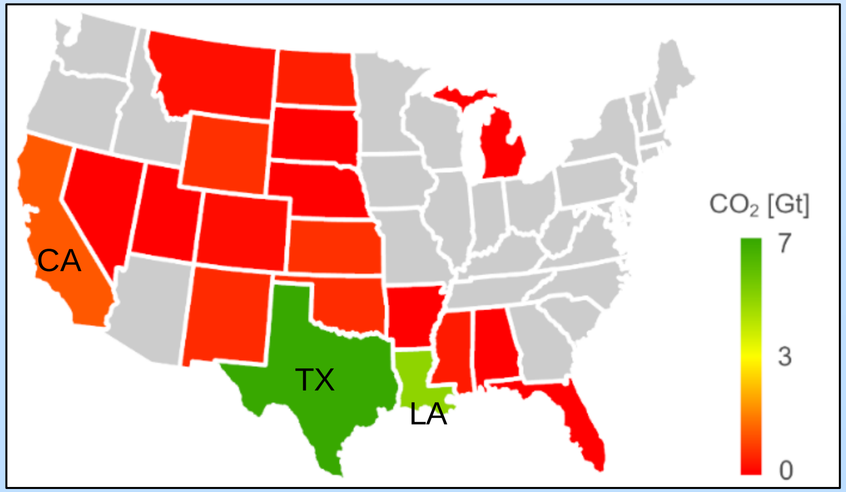
Onshore CO_2 EOR Results

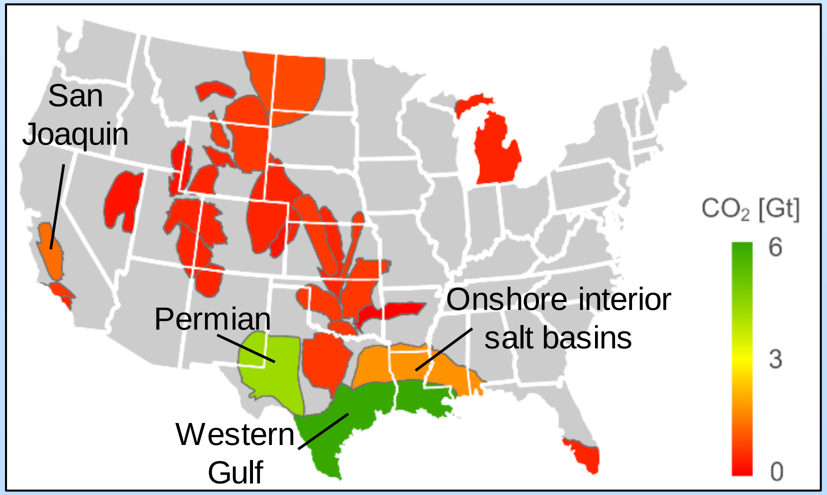
- Technically feasible CO_2 EOR in contiguous United States (at oil prices < $1,000/STB when CO_2 cost is = $30/t) could store over 19 Gt of CO_2 and could produce over 49 BSTB of incremental oil
- Takeaways:
  - 81% of CO_2 EOR resource capacity is economically feasible (at oil prices <$100/STB), concentrated in 34% of the technically feasible oilfields
  - Approximately 16 Gt of CO_2 storage and 40 BSTB of incremental oil production is economic
- CO_2 EOR estimates using CO_2 EOR Evaluation System are most sensitive to uncertainties in reservoir size; conformance; new well drilling and associated CAPEX

Cost Supply Curve for Economic CO_2 EOR



Economic CO_2 Storage Capacity by State and Basin from CO_2 EOR





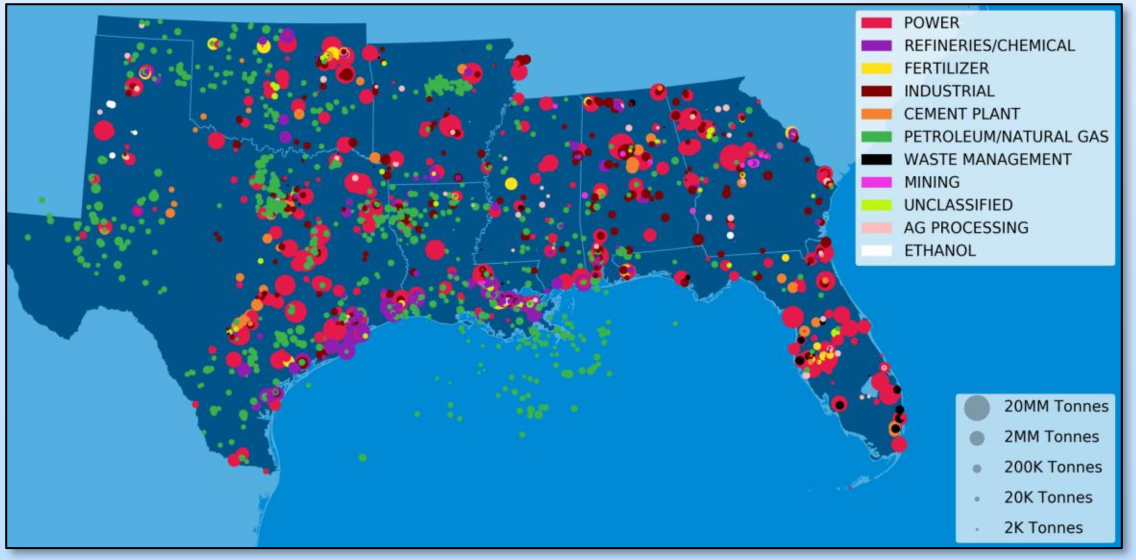
Over 75% of economic CO_2 EOR resource capacity is concentrated in 4 basins over 3 states (*labeled in figure to left*)

Offshore CO_2 Storage - Overview

In United States, an enormous opportunity exists for capturing CO_2 from sources onshore and deploying CO_2 storage offshore in the Gulf of Mexico (GOM)

Advantages to Offshore Storage in GOM[3,4]

- ✓ Supplement to onshore storage options
- ✓ Sites located away from populated areas
- ✓ Reduced risk to USDWs
- ✓ O&G infrastructure in place to potentially reuse
- ✓ Proximity to industrialized zones on coastline
- ✓ Single entity (state or federal) pore space owner



Challenges to Offshore Storage in GOM[3,4]

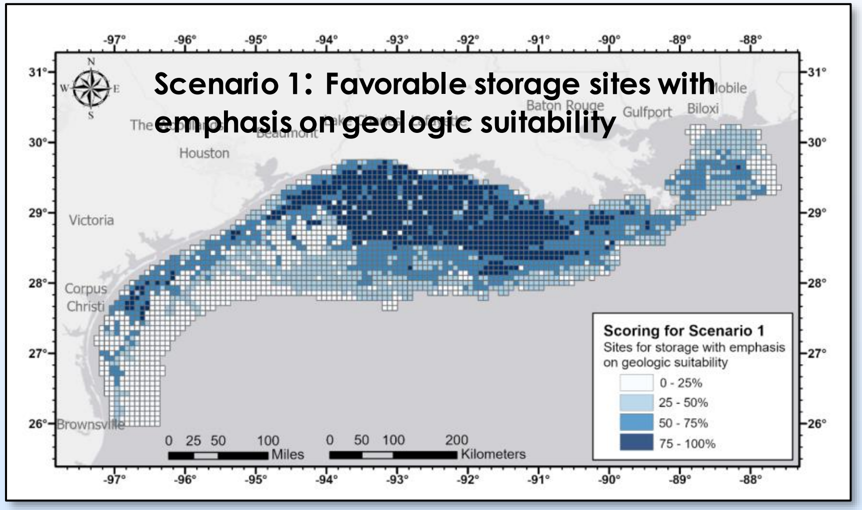
- ➢ High costs relative to onshore
- ➢ Lack of accurate / current cost data for O&G equipment
- ➢ Compatibility of O&G infrastructure with
- ➢ Source-to-sink matching challenges:
  - Disparity in the types and location of onshore CO_2 sources
  - Source-specific proximity to potential sites with diverse geologic conditions offshore
  - Multitude of O&G infrastructure in place that could potentially be repurposed for CCS
  - Potential preference for onshore storage

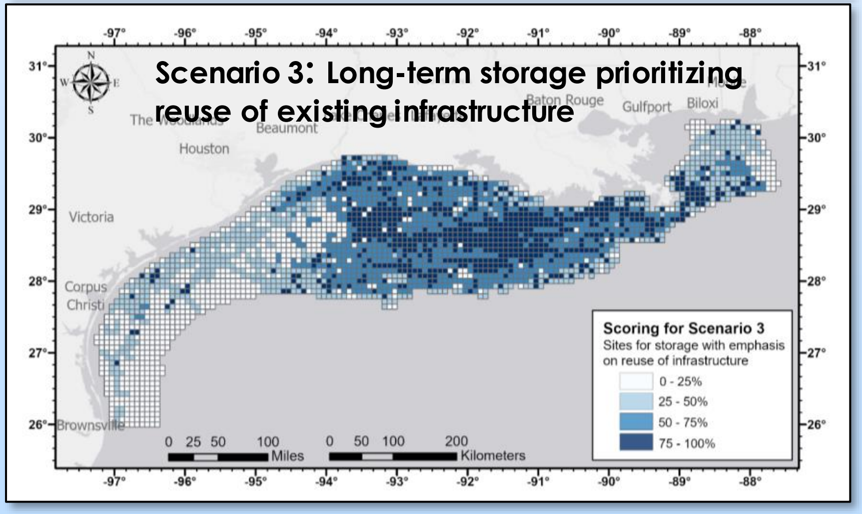
[3] *Vidas, H., Hugman, B., Chikkatur, A., and Venkatesh, B. 2012. Analysis of the Costs and Benefits of CO_2 Sequestration on the U.S. Outer Continental Shelf.. ICF International. Fairfax, Virginia*
[4] *Schrag, D. 2009. Storage of Carbon Dioxide in Offshore Sediments. Science. Vol. 325., Issue 5948, pp. 1658-1659.*

Multi-Criteria Study for CCS Site Screening

- 14 criteria from publicly available geographic information system (GIS) layers utilized and aggregated over 2,559 spatially balanced points across the study area using NETL's Cumulative Spatial Impact Layers™ (CSIL) GIS tool
- Criteria were weighted by qualitative expert opinion relative to their perceived importance to given scenarios. – the output of combined criteria values and weights enables regional CO_2 storage suitability differentiation

Scenario	Description	Location of High-Ranking Regions
1	Long-term **storage** with emphasis on geologic suitability	Off the Louisiana coast and extending to mid-continental shelf
2	**EOR** with emphasis on maximum oil return	More sporadic but some clusters formed off coast of Texas near Corpus Christi
3	Long-term **storage** prioritizing reuse of existing infrastructure	Offshore Louisiana near continental shelf edge (e.g., approximately 100 miles offshore from Lake Charles)
4	**EOR** with emphasis on reuse of existing infrastructure	Along Louisiana coastline, some located near shore but mostly concentrated near continental slope





- Due to highly flexible methodology, new maps can be easily generated by adjusting criteria weights based on new project goals
- Pending submission of manuscript to the *International Journal of Greenhouse Gas Control*

Offshore CO_2 Storage Pilot Project Overview

Working toward developing technical (infrastructure, equipment, and monitoring) and geologic criteria needed for an initial CO_2 storage site in the Gulf of Mexico and evaluate the cost magnitude of pilot project

Criteria	Consideration	Criteria Status (In Development)
1-Project type	Storage formation	Saline storage
2-Pilot objectives	Research objectives	• Evaluate two different project considerations where CO_2 would be captured from onshore sources and piped offshore for long-term storage in geologic formations in GoM • Gain insight on potential cost (capital and operating) and equipment needs when considering offshore CO_2 storage operations in GoM at pilot-scale • Two pilot project considerations could be reasonably similar in terms of water depth and transport mechanism and would reuse existing top-side offshore infrastructure • Two pilot considerations would vary in their locations in GoM, distance from shore, geologic conditions, and federal vs. state jurisdiction • Cost and equipment considerations, influenced mostly by differences in geologic conditions and distance from shore in this case, will be compared between each pilot project type
3-Operations	Risk preference Injection rate Operation duration	Least cost risk should coincide with least environmental risk Demonstration Scale - (at least 0.5 million metric tons per year [Mt/yr]) Medium-term (12-year) to capture full 45Q benefit
4-Geology	Jurisdiction/water depth/proximity to land	Configuration #1: state waters (Texas) Configuration #2: federal waters (not restricted to Texas, but still shallow waters)
5-Infrastructure	Offshore infrastructure approach Offshore CO_2 transportation Offshore injection site Onshore CO_2 source	Reuse existing infrastructure Pipeline Platform Agnostic to onshore CO_2 source(s); study constrained to the coastal offtake hub, pipeline transport, and storage site
6-Monitoring	CO_2 Plume Pressure (in and above-zone) Microseismic Geochemical Well Integrity	*In development – open to feedback*
7-PISC	Duration Monitoring / frequency Decommissioning	*In development – open to feedback*

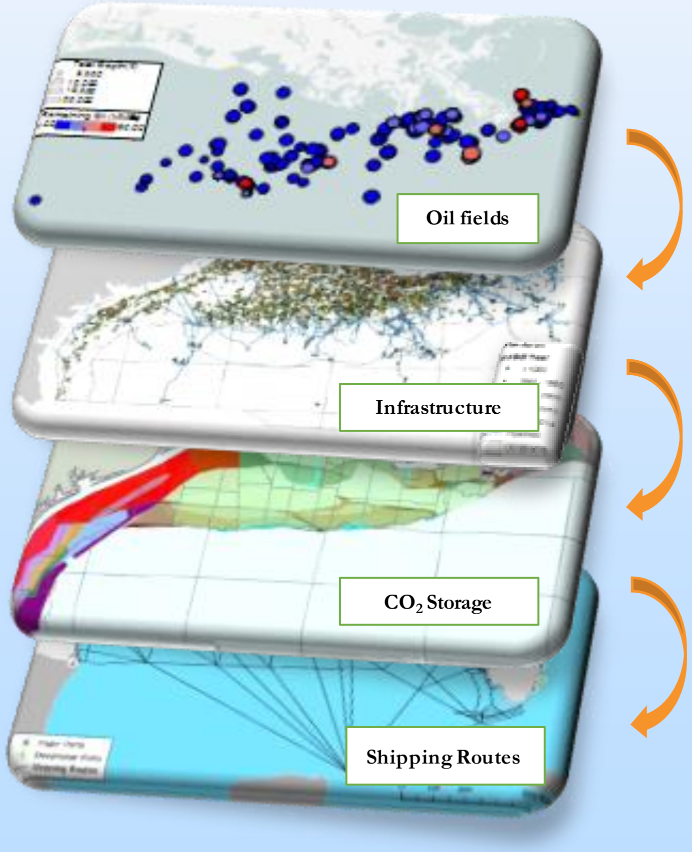
2 scenarios will be developed:

1. Texas state waters
2. Federal waters

Leveraging Existing Multi-Criteria Tool for Pilot Project

CSIL™ and multi-criteria layering framework will be used to screen for high-priority locations for offshore CO_2 saline storage pilot based on pilot project criteria and attributes

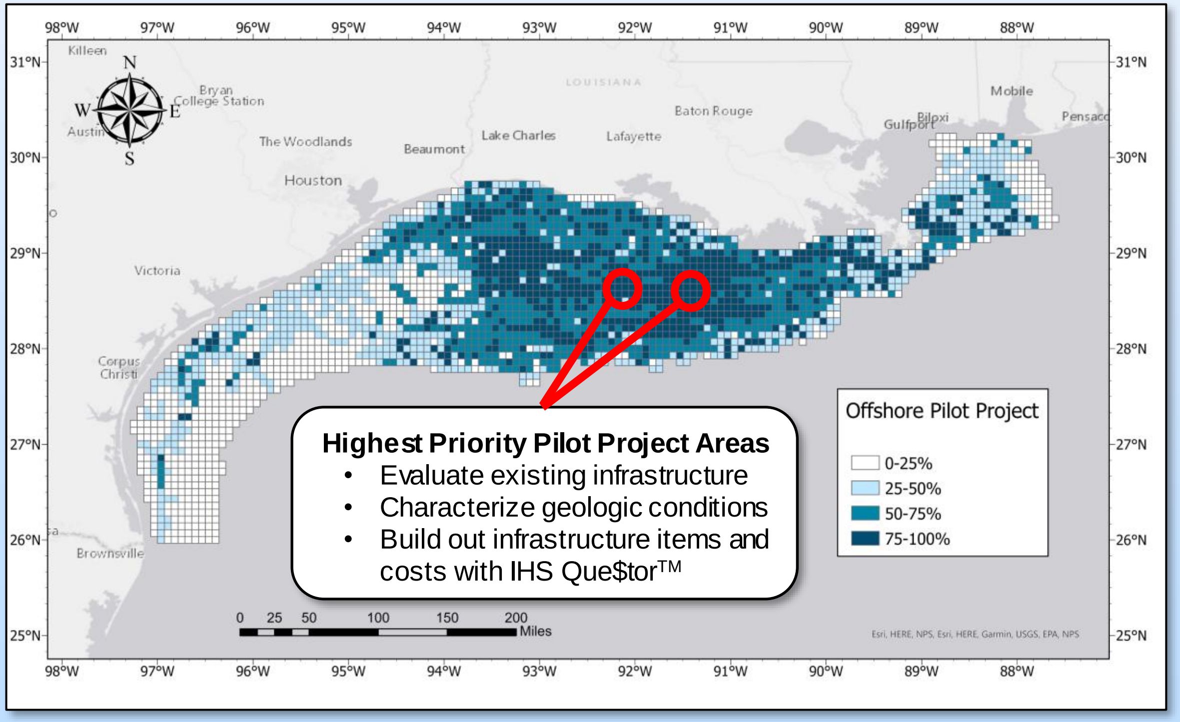
Multi-criteria layering framework



Set of new weights for pilot project criteria

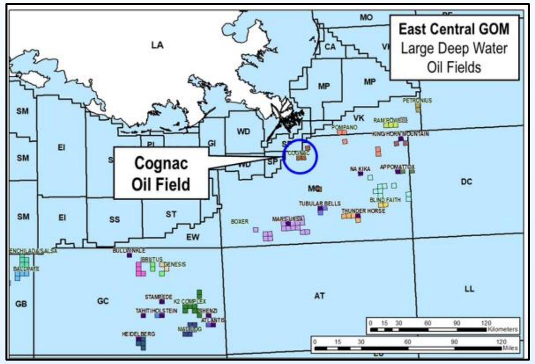
Scenario "5"

Offshore pilot project



Next Steps: Equipment and Cost Estimates Using Que$tor™

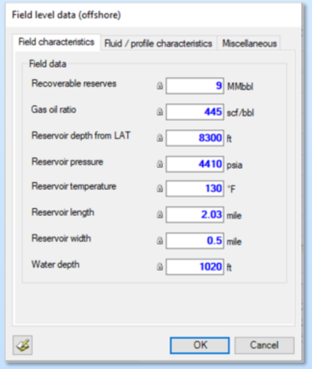
- Oil and gas lifecycle (planning through decommissioning) capital and operating cost estimation software developed by IHS
- Provides a foundation to conduct analyses of offshore CO_2 saline storage or associated storage with CO_2-EOR operations
- **Goal:** Use Que$tor™ to benchmark infrastructure components and costs for offshore CO_2 storage pilot project



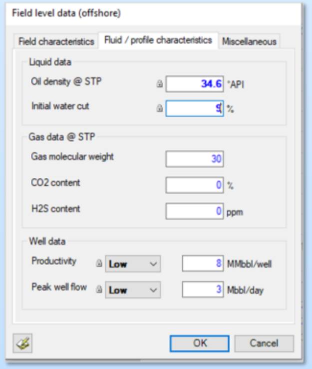
Use Case: Replication of Cognac Offshore Oil Field Case Study - Link

- Que$tor inputs are specific to O&G development
- Equipment and costs will require amending to account for CO_2-specific infrastructure, monitoring, and operational considerations

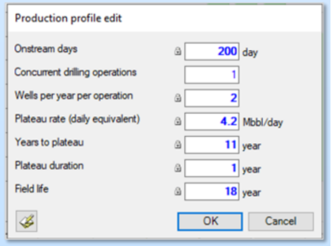
Field Characteristics

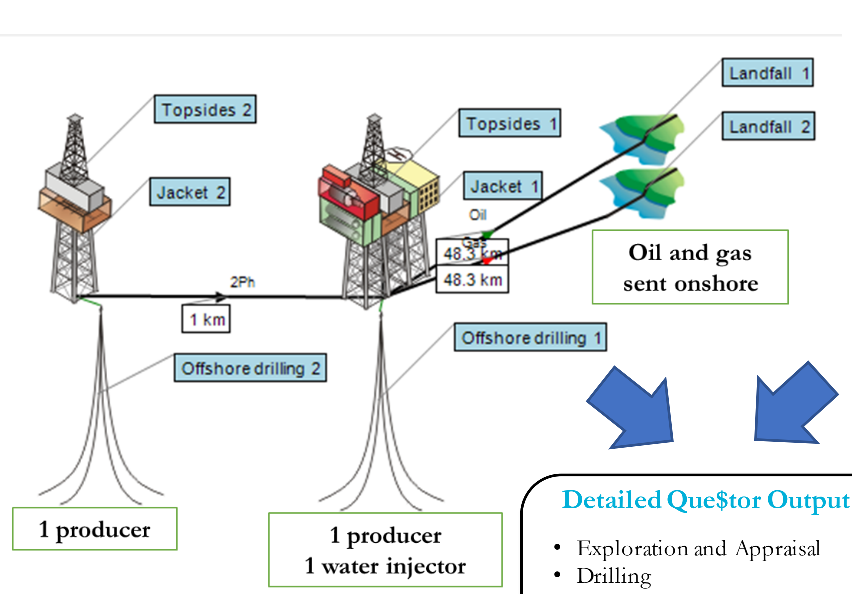


Fluid Characteristics



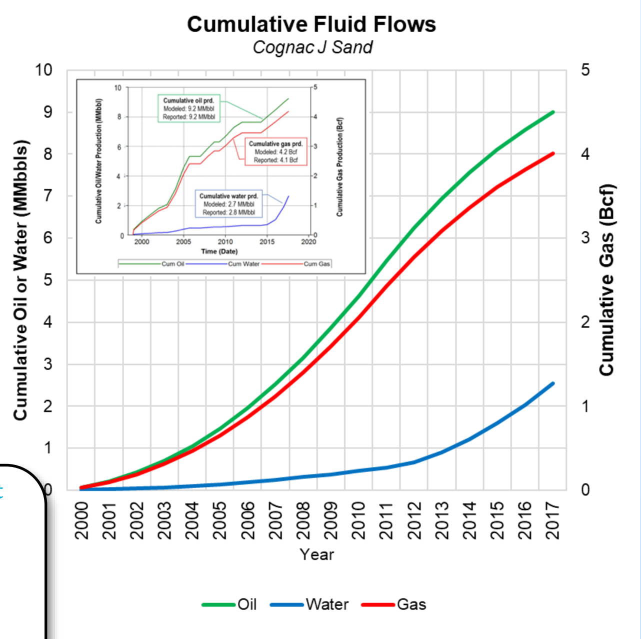
Production Profile





Detailed Que$tor Output

- Exploration and Appraisal
- Drilling
- Facilities
- Fixed / Variable O&M
- Decommissioning
- CO_2 emissions



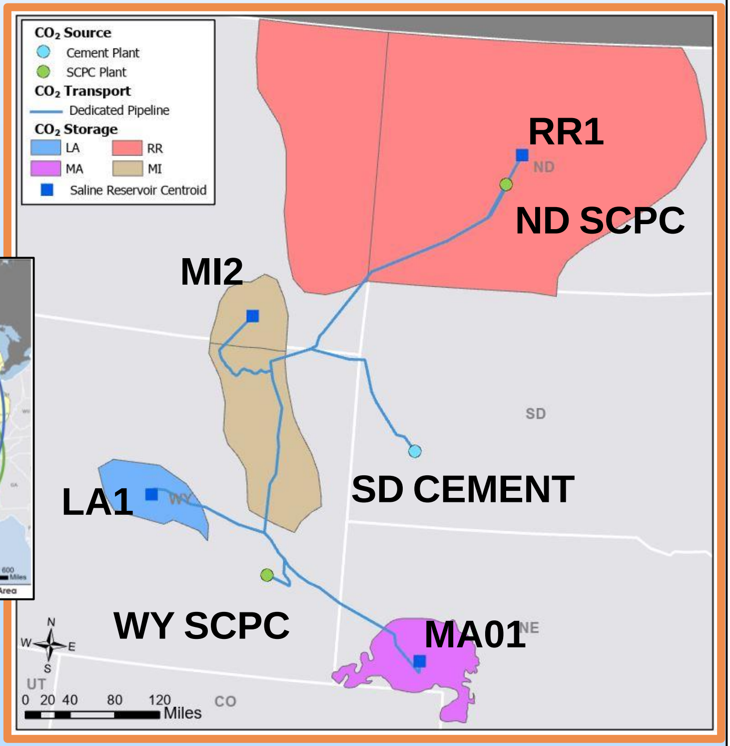
Financial Aspects of CCS - Overview

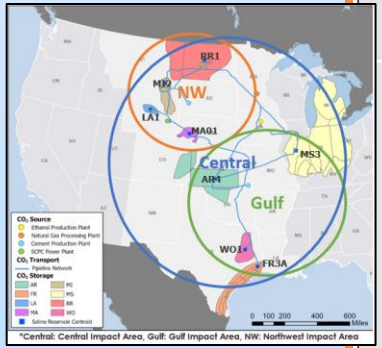
- **Section 45Q tax credits (45Q) are available to qualified carbon capture projects to incentivize CCS deployment**
- **NETL is working to develop capability to quantify impact of 45Q on carbon management costs**
  - Assessing impact of 45Q on **economic CCS project** costs (45Q Impact Assessments)
  - Developing model that **honors IRS and U.S. Treasury guidance** on 45Q and tax equity partnerships (45Q TEP Modeling)
- **Integrating costs across CCS network, leveraging NETL's resources and models for**
  - **Capture:** Cost and Performance Baselines for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity; Cost of Capturing CO_2 from Industrial Sources report
  - **Transport:** FE/NETL CO_2 Transport Cost Model (CO2_T_COM)
  - **Storage:** FE/NETL Onshore CO_2 Saline Storage Cost Model (CO2_S_COM)
- **Develop capability to model complexities of tax equity partnerships**
  - FE/NETL 45Q Tax Credit Monetization Model **(in development)**

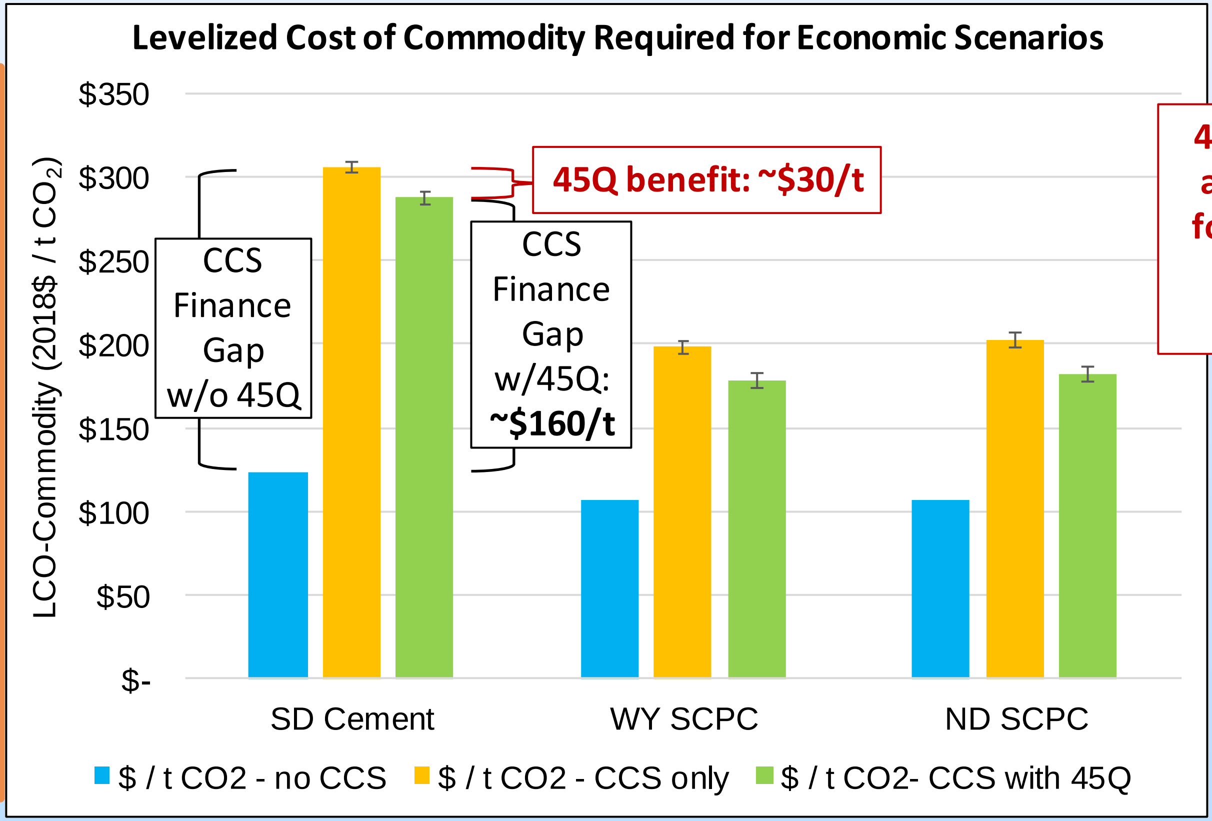
45Q Impact Assessments

- NW Central U.S. 45Q Impact case study (***unpublished***) and CCS Finance Gap and SCC Tax study (***Energies***, 2021)[5]
- Accounted for basic tax equity partnership assumptions but did not account for monetization of non-45Q tax benefits (like asset depreciation and negative income)
- Results: \$50/tCO_2 45Q lowers CO_2 management costs by ~\$29-\$34/tCO_2 (2026\$) but does not itself close finance gap (even with carbon emission penalties)
- Finance gap in these studies made up by increased price of produced commodity (i.e., electricity or cement)
- Detailed tax equity partnership modeling is warranted

NW Central U.S. 45Q Impact Case Study







45Q benefit accounting for non-45Q benefits: ~\$42/t

[5]A. Steele, T. Warner, D. Vikara, A. Guinan, and P. Balash, "Comparative analysis of carbon capture and storage finance gaps and the social cost of carbon," Energies, vol. 14(11), 2987, 2021.

45Q Tax Equity Partnership (TEP) Modeling

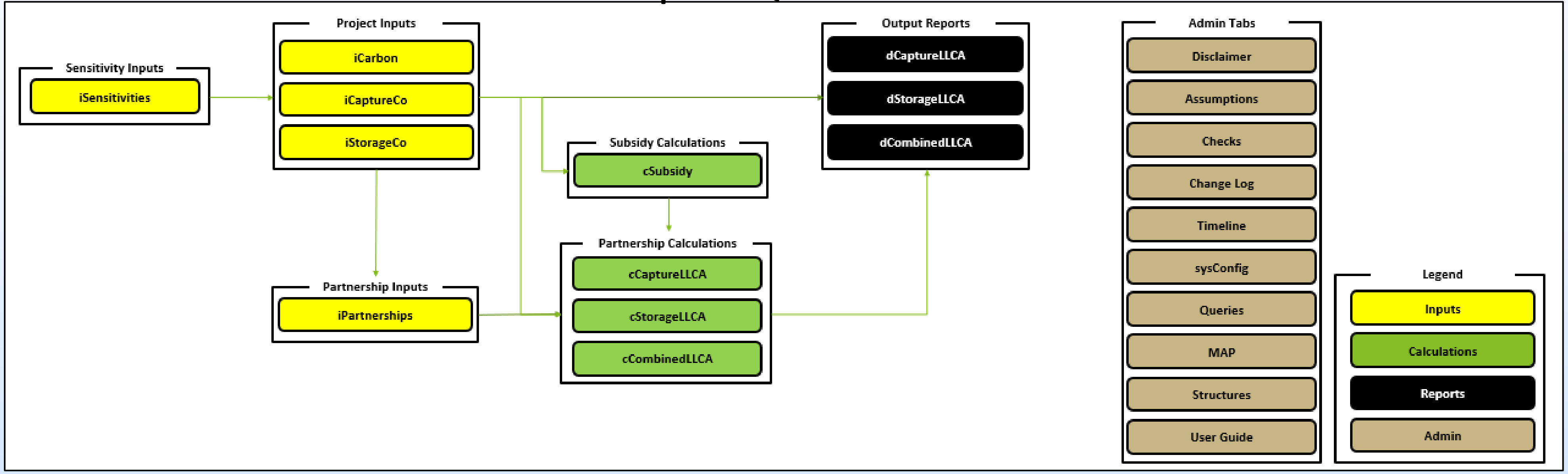
- Previous NETL 45Q impact assessments used broad TEP assumptions and did not account for non-45Q tax benefit monetization available through TEPs

- This project has developed 45Q Tax Credit Monetization (TCM) model that:
  - Demonstrates how 45Q value is distributed and monetized among CCS participants within TEP
  - Calculates how much subsidy (if any) is needed to make CCS project economic

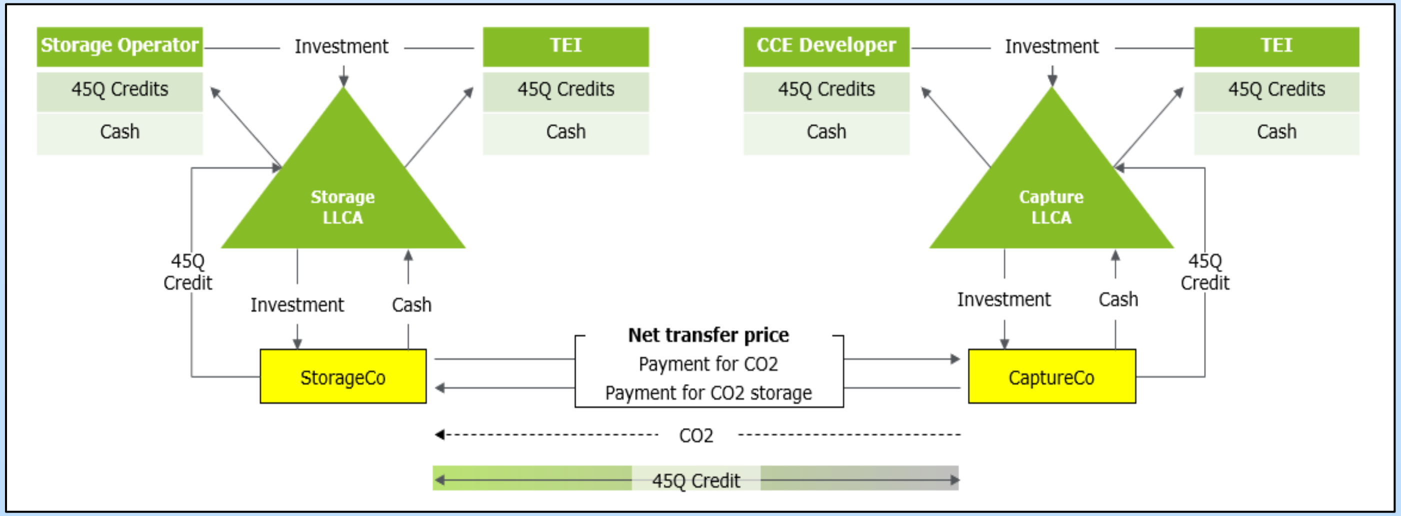
- Current status: finalizing Excel®-based 45Q TCM Model and applying 45Q TCM Model to onshore and offshore CCS project

45Q TCM Model Screenshots

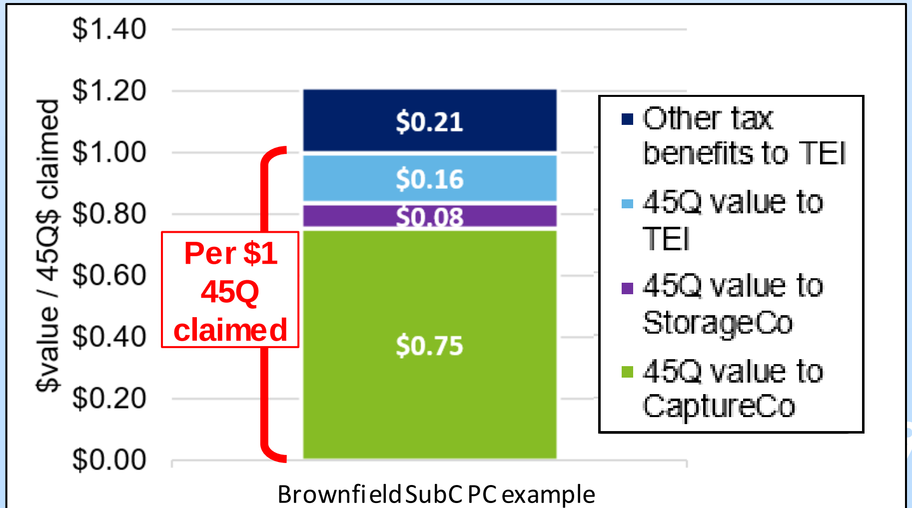
Map of 45Q TCM Model Tabs



Partnership Structure Schematic for Separate Capture and Storage Ownership

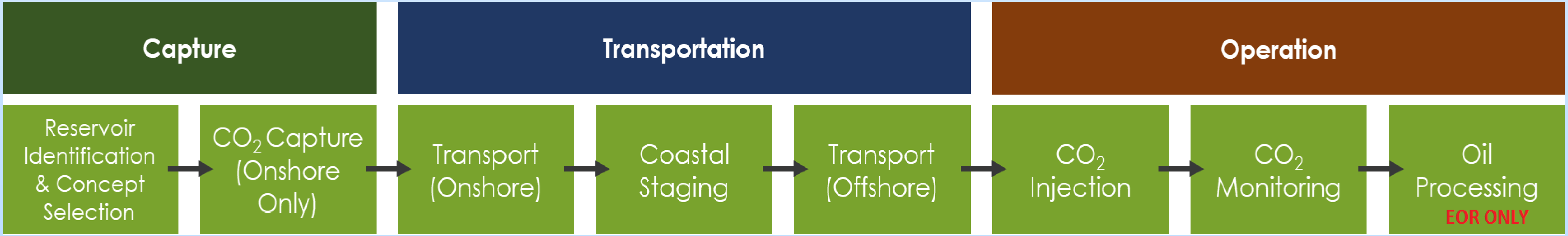


Example Dashboard Output:
45Q Value Distribution Among CCS Participants



45Q TCM Model Application

- Economic assessment of various scenarios on and offshore
  - Aiding in expansion of CCS in GoM
- Utilize 45Q TCM Model for scenarios to:
  - Determine optimal structure for monetization of CO_2 storage/associated storage project 45Q tax credits
- Building on previously developed supply chain model for exploratory analysis of economics of CCS in GoM
  - Reviewing barriers including CO_2 storage regulations (local, state, and federal)



Conclusions

Analytical models, tools, data, and analyses developed by NETL SSAE/collaborators provide extensive portfolio of resources that can apprise stakeholders of both technical and economic aspects associated with implementing commercial-scale CO_2 storage projects

- Basin-scale modeling provides assessment of storage complex spacing to prevent CO_2 plume and pressure interference. Analysis on optimum well spacing provides insights to determination of AoR to inform regulatory stakeholders
- Onshore CO_2 EOR analysis provides nation-wide volumetric estimation of CO_2 storage capacity and incremental oil recovery which can increase market interest for deploying CCS technology
- Offshore pilot project is unique CCS opportunity because it involves single-lease owner and project can be deployed away from population areas. However, policies/regulations in offshore need further documented clarity to support offshore CCS deployment
- 45Q tax credit can help finance CCS projects but analysis suggests that 45Q tax credit alone might not be adequate to solve the financial gap. Therefore, 45Q tax equity partnership modeling aims to assess distribution of monetization among CCS participants and calculate required subsidy amount to make CCS project economic

NETL is aiming to further facilitate deployment of onshore and offshore CCS moving forward by extending existing toolset capability, relevance, and follow-on analyses to coincide with ongoing technology maturation – helping to enable launch of geologic carbon storage industry

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Arun Iyengar	Chung Yan Shih	Anna Wendt	

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Questions?

Resources and Recent Publications

MODELS

- FE/NETL CO_2 Transport Cost Model
- FE/NETL CO_2 Saline Storage Cost Model
- FE/NETL CO_2 Prophet Cost Model
- FE/NETL Onshore CO_2 EOR Cost Model

TOOLS

- NETL-developed Cumulative Spatial Impact Layers™ (CSIL) GIS tool:
    - Literature
    - Dataset
- TOUGH Multiphase Flow Simulator

PRODUCTS (Manuscripts)

A. Steele, T. Warner, D. Vikara, A. Guinan, and P. Balash, "Comparative analysis of carbon capture and storage finance gaps and the social cost of carbon," Energies, vol. 14(11), 2987, 2021.

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