Cost Analysis Associated with Capture, Transport, Utilization, and Storage of CO_2

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- **Introduction**
- Current Models
  - FE/NETL CO_2 Saline Storage Cost Model (CO_2 Storage Cost Model)
  - FE/NETL CO_2 Transport Cost Model (CO_2 Transport Cost Model)
- Carbon Capture, Utilization, and Storage (CCUS) Modeling
- Life Cycle Analysis
- Models Under Development
- Ongoing Initiatives (Analogs, Economics, Geology)
- Conclusions

Carbon Capture Utilization & Storage

- Current Active Models
  - FE/NETL CO_2 Saline Storage Cost Model
  - FE/NETL CO_2 Transport Cost Model
- Model Development
  - FE/NETL Offshore CO_2 Saline Storage Cost Model
  - FE/NETL CO_2 Prophet
  - FE/NETL CO_2-EOR Cost Model
    - Will be adapted for offshore application
- Life Cycle Analysis Models
  - CO_2-EOR Life Cycle (CELiC) Model
- Ongoing Work

  - Analysis with or without use of models

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- **Current Models**
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  - **CO_2 Transport Cost Model**
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Current Models

- **CO_2 Storage Cost Model**
  - Designed to meet Class VI regulations, estimate cost of compliance
  - Geologic database representative of geologic section in numerous basins
  - Can model storage costs for a single reservoir or multiple reservoirs
  - Model assumes successful operations

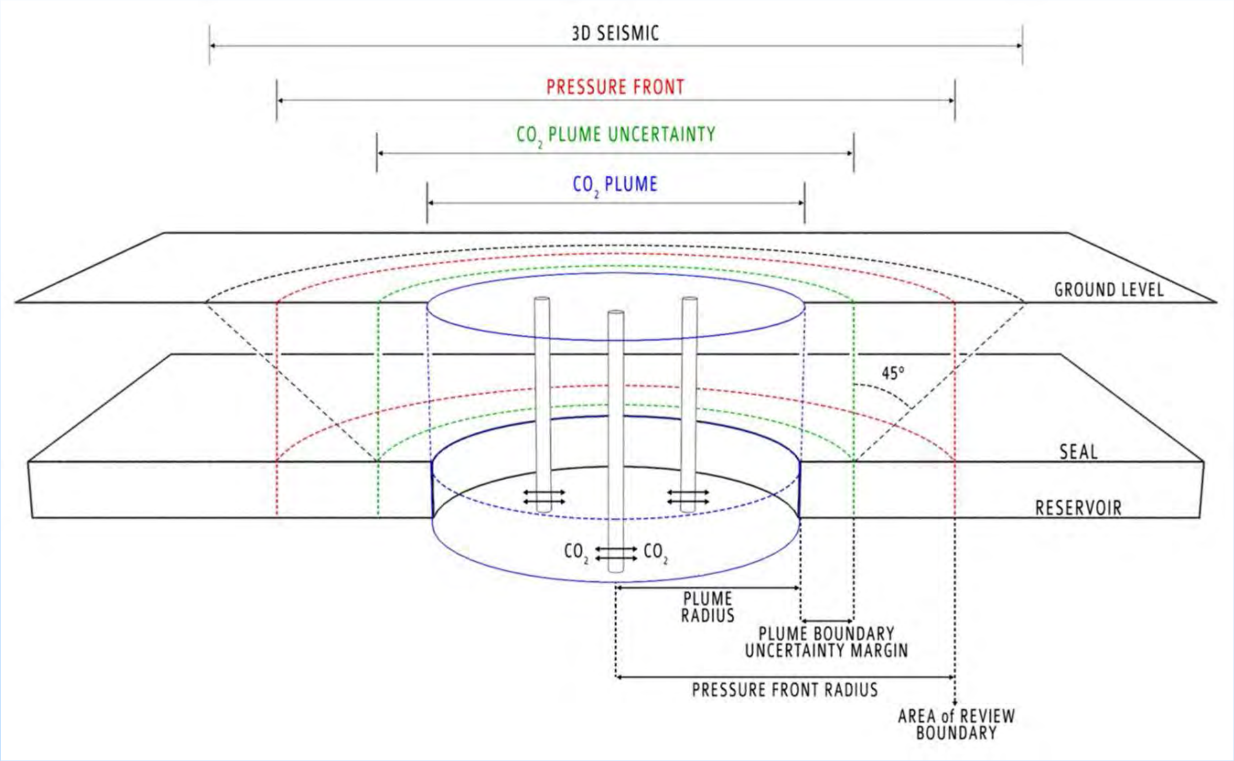
- **CO_2 Transport Cost Model**
  - Point-to-point transport cost modeling

CO_2 Storage Cost Model

Site Screening	Site Selection & Characterization	Permitting & Construction	Operations	PISC & Site Closure	Long-Term Stewardship
	UIC Class VI Regulations				Developing state regulations
			Class VI Permit		
0.5 to 1 year	3+ years	2+ years	30 to 50 years	10 to 50+ years	Rest of civilization
Gather existing data; develop several prospects	Select a site; acquire new data (drill wells, shoot seismic); prepare permitting plans	Permit awarded to drill/test injection wells; final approval to begin injection; install MVA network	Inject CO_2; remediate existing wells as needed; new monitoring wells as needed; conduct MVA	Monitor site per plan; maintain financial responsibility; establish non-endangerment; close and restore site	Another entity (e.g., a state) takes over
Assemble acreage block (surface access/pore space)		Secure financial responsibility upon permit application; as required, maintain financial responsibility through operations and PISC			
	25% success rate assumed		Pay $/tonne fees*		
Negative cash flow			Positive cash flow	Negative cash flow	Covered by fee paid during ops

*Per tonne cost associated with several cost items: long-term stewardship (state sets rate), insurance to cover emergency & remedial response (financial responsibility), a per/tonne "royalty" to pore space owner

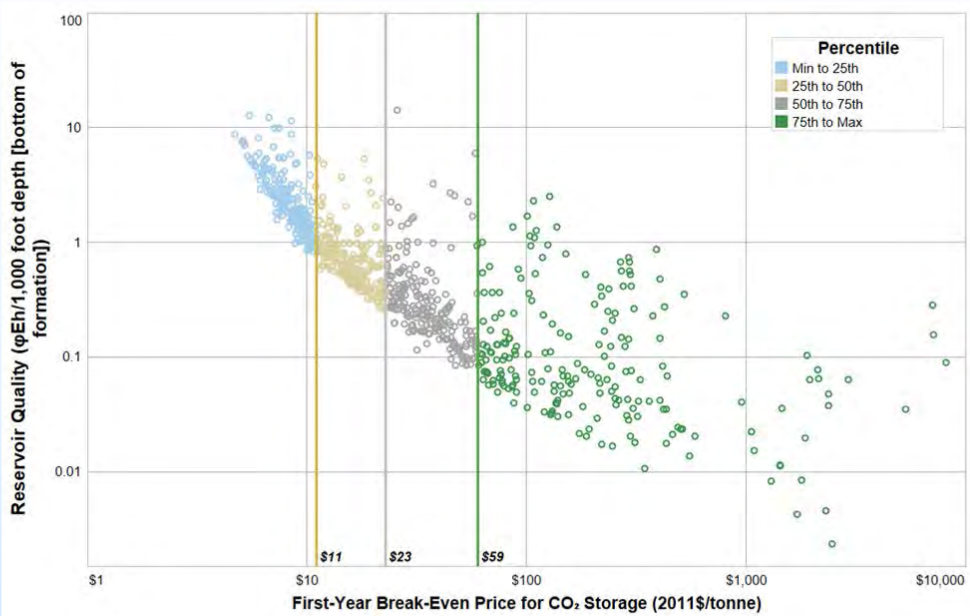
CO_2 Storage Cost Model

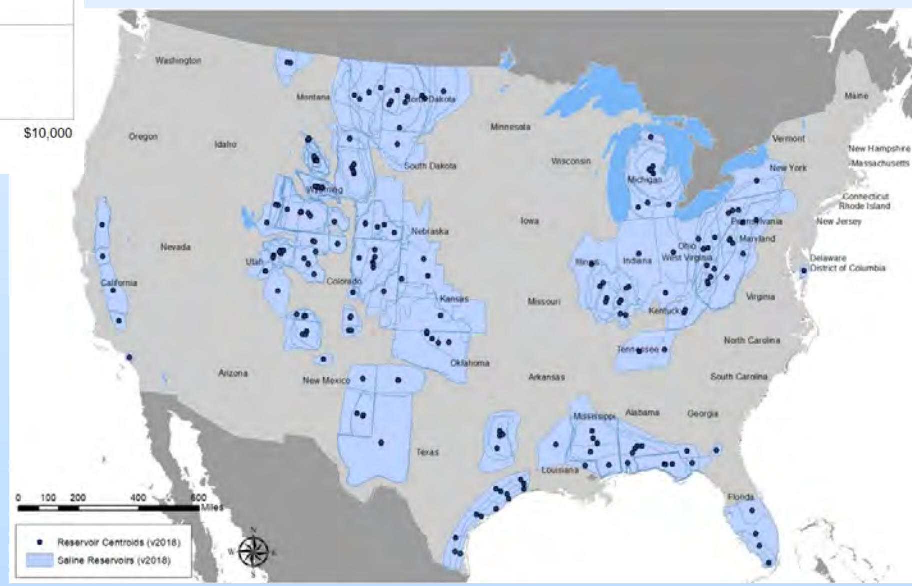


Cost Drivers:

- **Reservoir quality**
- **Areal extent of plume**
  - Area of review
  - Drives monitoring costs
    - » Monitoring wells
    - » Seismic
  - Corrective action
  - Financial responsibility
- **Injection**
  - Annual mass of CO_2 injected
  - Number of injection wells
  - Class VI permit

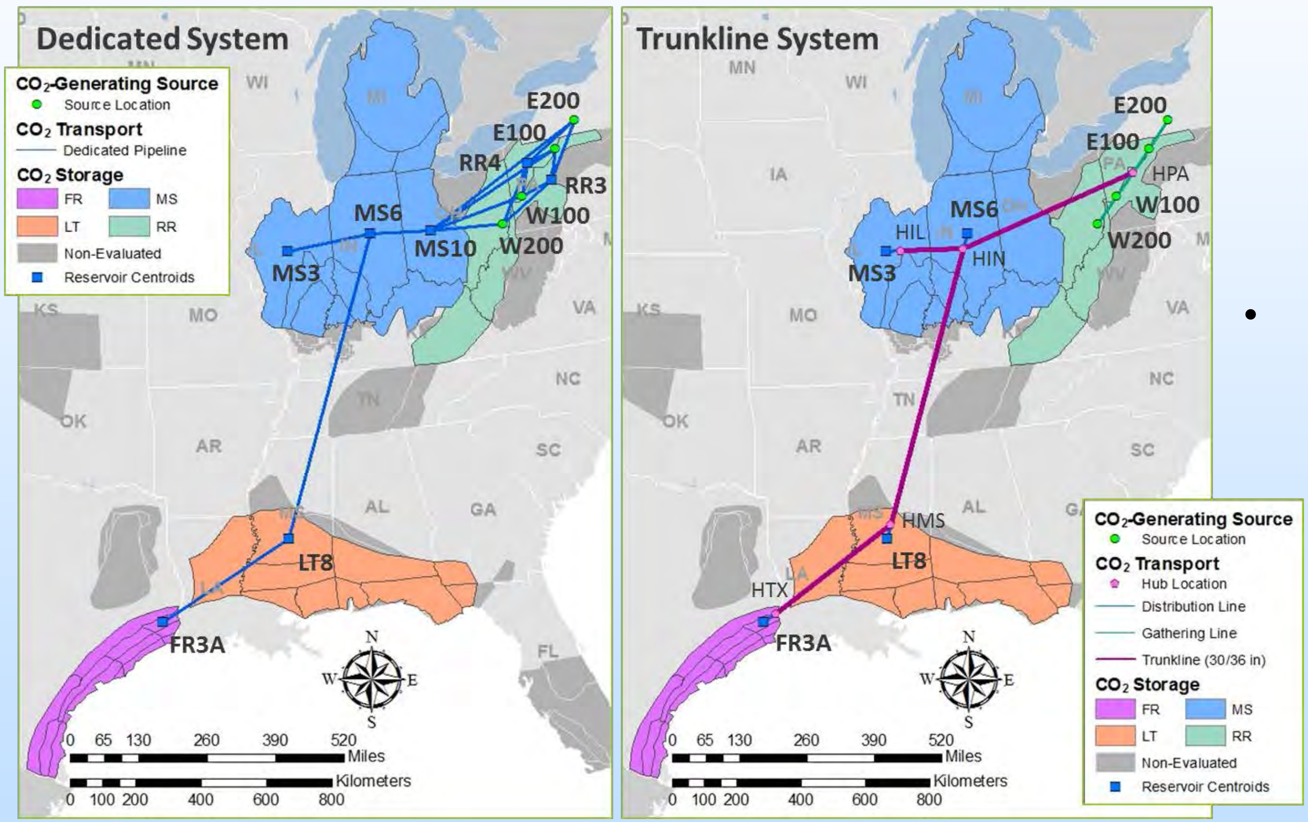
CO_2 Storage Cost Model





- Storage resource potential exists across continental United States
- Geo-database: 87 formations in 36 basins across 27 states
- Quality of these potential reservoirs is variable

CO_2 Transport Cost Model



Grant, T., Guinan, A., Shih, C., Lin, S., Vikara, D., Morgan, D., and Remson, D., "Comparative analysis of transport and storage options from a CO_2 source perspective," *International Journal of Greenhouse Gas Control*, vol. 72, pp. 175-191, 2018.

- **Two pipeline networks: dedicated pipeline system and trunkline pipeline system**
  - Straight line segments routed through modeled storage sites
  - Trunkline hubs 30 mi (48 km) from storage sites
- **CO_2 Transport Cost Model was used to estimate all pipeline transportation costs**
  - Cost based on mass of CO_2 transported, transport distance, and elevation at each end of the pipeline
  - Pipeline diameter and number of booster pumps were determined by the model
  - Five trunkline capacities with pipe diameters of 12 in to 36 in were modeled

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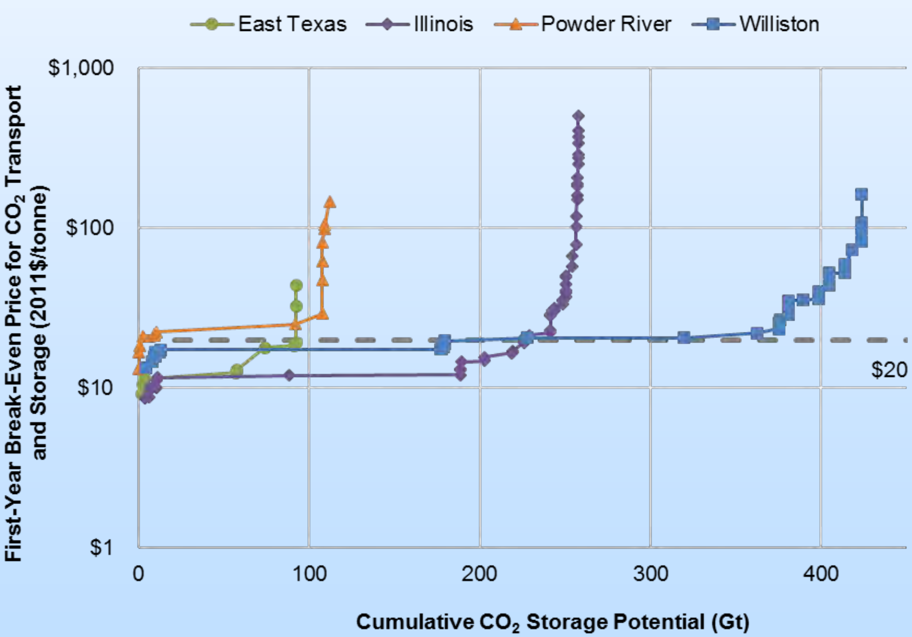
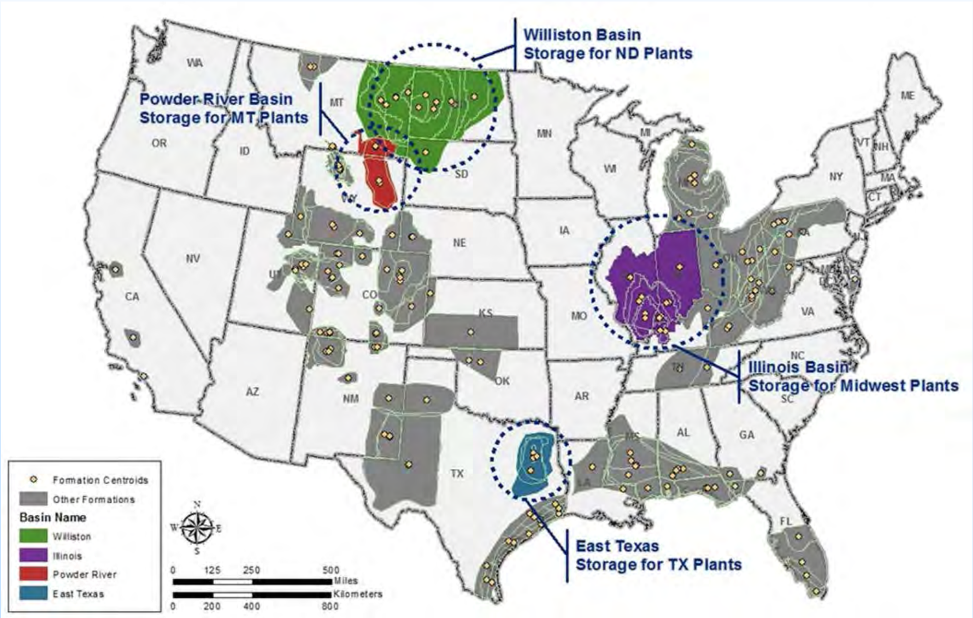
CCUS Modeling

Four Basin Study

- Provide storage and transport costs for CCUS modeling
- Source using local coal

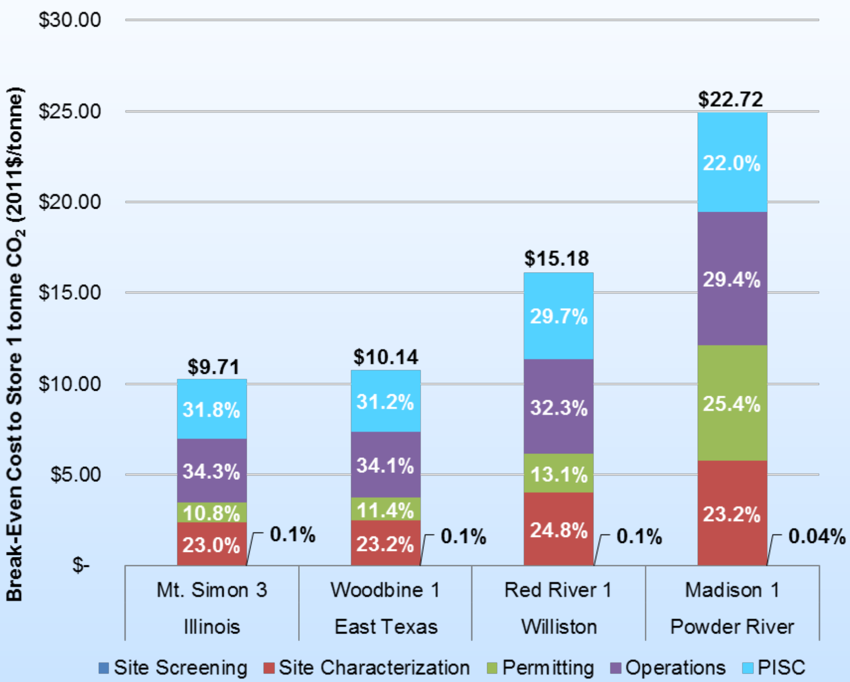




NETL., "Quality Guidelines for Energy System Studies: Carbon Dioxide Transport and Storage Costs in NETL Studies," U.S. Department of Energy, DOE/NETL-2017/1819, *Found at:* https://www.netl.doe.gov/research/energy-analysis/search-publications/vuedetails?id=1027

CCUS Modeling

Four Basin Study

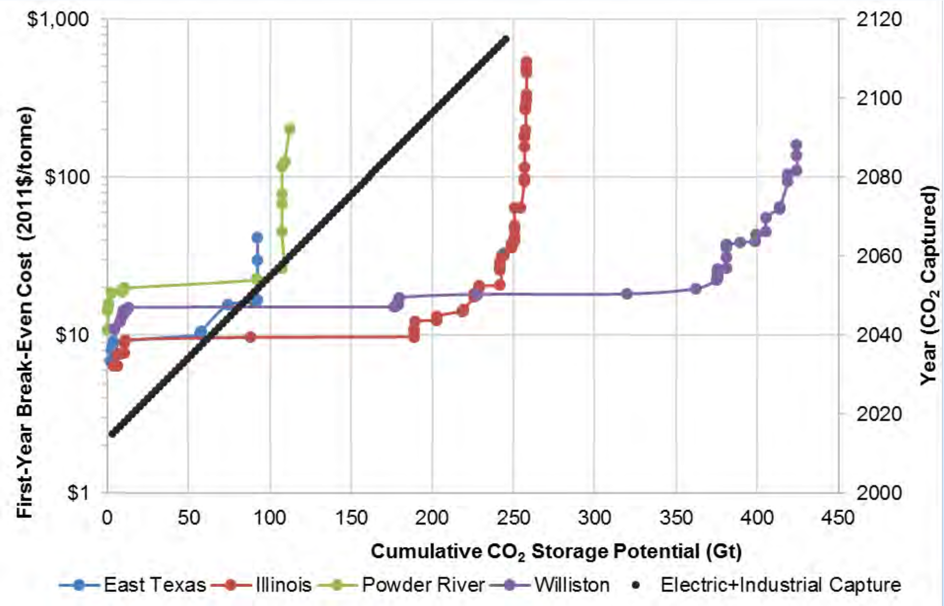


	Mt. Simon 3 Illinois	Woodbine 1 East Texas	Red River 1 Williston	Madison 1 Powder River
Thickness (ft)	1,000	700	530	833
Permeability (mD)	125	500	39	5
Porosity (%)	12	20	14	10
Storage coefficient	5.6	5.4	7.3	6.4
Number of active injection wells	3	3	3	9
Injection well depth (ft)	5,320	6,250	9,580	11,883
Monitoring wells (dual completed)	15	15	18	19
Monitoring wells (above seal)	11	11	14	15
Total monitoring wells	26	26	32	34
Maximum 3-D seismic area (mi^2)	70	73	113	131

- Increased percentage of cost during permitting for Red River and Madison due to increase in drilling and completion costs for a deeper reservoir
- Madison reservoir is deepest of the four modeled here, plus it requires more than double the injection wells

CCUS Modeling

Four Basin Study



Plant Location	Basin	Transport (2011$/tonne)	Base Case Storage (2011$/tonne)	Total T&S (2011$/tonne)	T&S Value for System Studies (2011$/tonne)
Midwest	Illinois	2.28	9.71	11.99	12
Texas	East Texas		10.14	12.42	12
North Dakota	Williston		15.18	17.46	17
Montana	Powder River		22.72	25.00	25

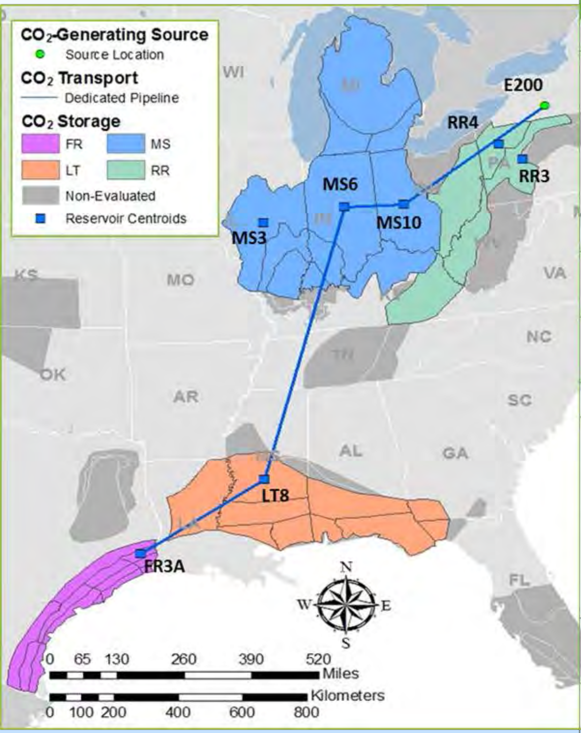
- Cumulative storage potential cost supply curve for each basin
- CO_2 capture curve for electric and industrial sources suggests sufficient potential storage

- Pipeline configuration
  - 3.2 Mt/yr CO_2
  - 100 km (62 mi) distance
  - 2,200 psig inlet, 1,200 psig outlet

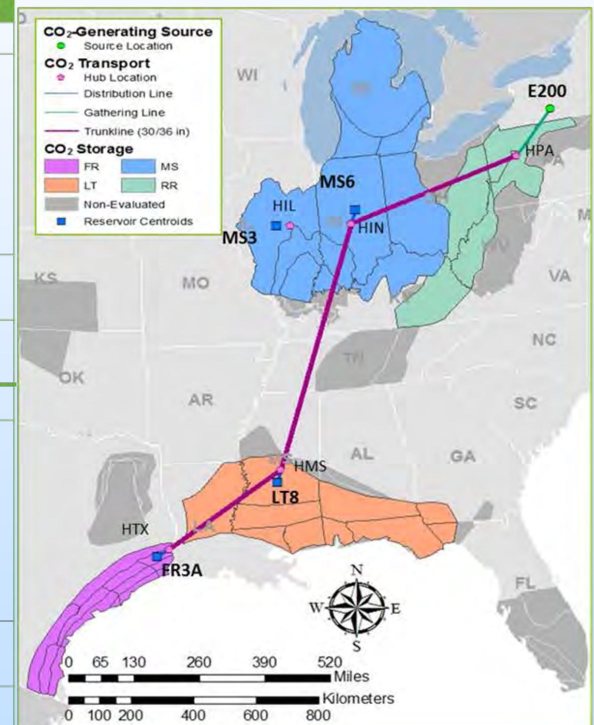
NETL., "Quality Guidelines for Energy System Studies: Carbon Dioxide Transport and Storage Costs in NETL Studies," U.S. Department of Energy, DOE/NETL-2017/1819, *Found at:* https://www.netl.doe.gov/research/energy-analysis/search-publications/vuedetails?id=1027

CCUS Modeling

Dedicated Pipeline System vs. Trunkline Pipeline System



Dedicated Pipeline System			Cost $/tonne	Trunkline Pipeline System			Cost $/tonne
Capture (0.65 Mt/yr)			18.00	Capture (0.65 Mt/yr)			18.00
Transport Route	Diameter (in)	Distance (mi)		Transport Route	Diameter (in)	Distance (mi)	
E200 – FR3A	8	1,358	155.52	E200 – HPA	8	121	14.43
				HPA – HIN	30	360	5.55
				HIN – HMS	36	549	8.30
				HMS – HTX	36	281	4.24
				HTX – FR3A	8	30	3.73
Total		1,358	155.52	Total		1,341	36.25
Storage	FR3A			Storage	FR3A		
Dome			19.30				19.30
Regional Dip			20.82				20.82
CCUS				CCUS			
Dome			192.82	Dome			73.55
Regional Dip			194.34	Regional Dip			75.07
Capture (3.58 Mt/yr)			57.82	Capture (3.58 Mt/yr)			57.82
Transport Route	Diameter (in)	Distance (mi)		Transport Route	Diameter (in)	Distance (mi)	
E200 – FR3A	12	1,358	41.89	E200 – HPA	12	121	4.35
				HPA – HIN	30	360	5.55
				HIN – HMS	36	549	8.30
				HMS – HTX	36	281	4.24
				HTX – FR3A	12	30	0.86
Total		1,358	41.89	Total		1,341	23.30
Storage	FR3A			Storage	FR3A		
Dome			5.73				5.73
Regional Dip			7.58				7.58
CCUS				**CCUS**			
Dome			**105.44**	**Dome**			**86.85**
Regional Dip			**107.29**	**Regional Dip**			**88.70**



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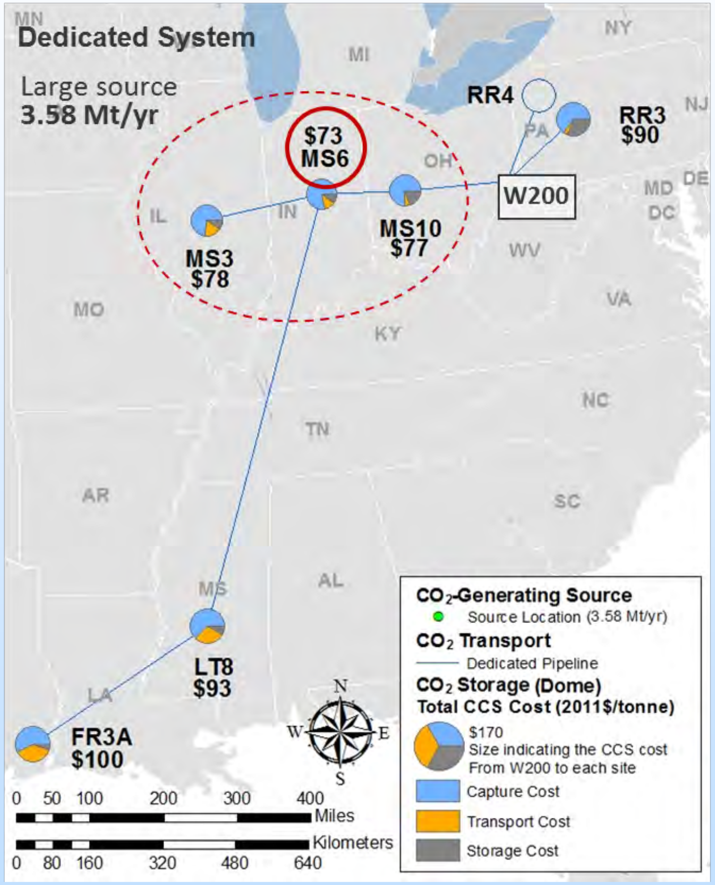
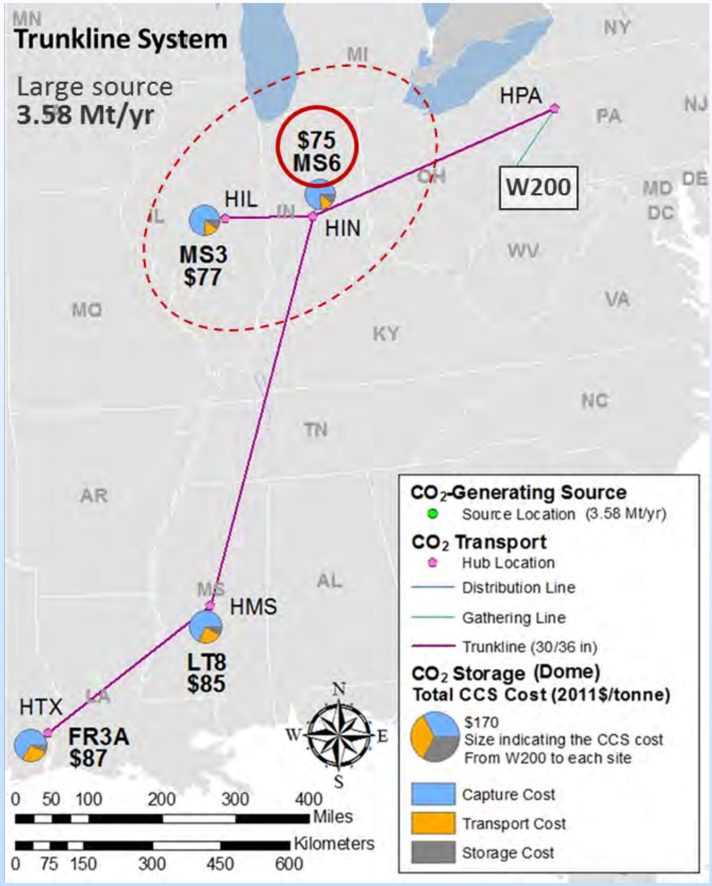
CCUS Modeling

Dome Structure





- **MS6 low cost CCS for both pipeline systems**
- **Dedicated pipeline lowers cost to Mt. Simon over trunkline – by $1-$2**
  - Dedicated 254 mi (408 km)
  - Trunkline 512 mi (824 km)
- **Source at W200 has storage options**
  - Multiple reservoirs at small cost difference

Year: 2011$ | Capture: 3.58 | Source Location: W200 | Structure: Dome | Systems: Dedicated, Trunkline

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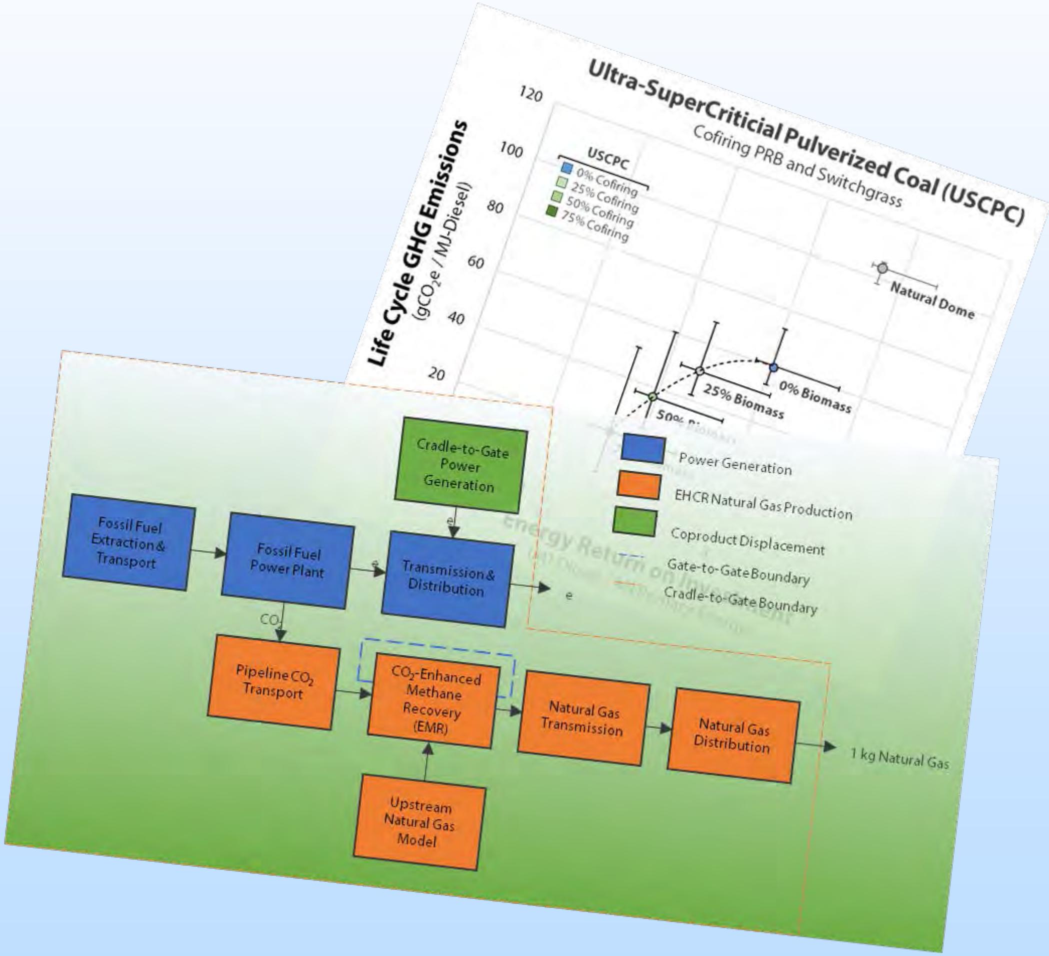
Storage Activity Life Cycle Analysis

July 2017 to July 2018 Accomplishments

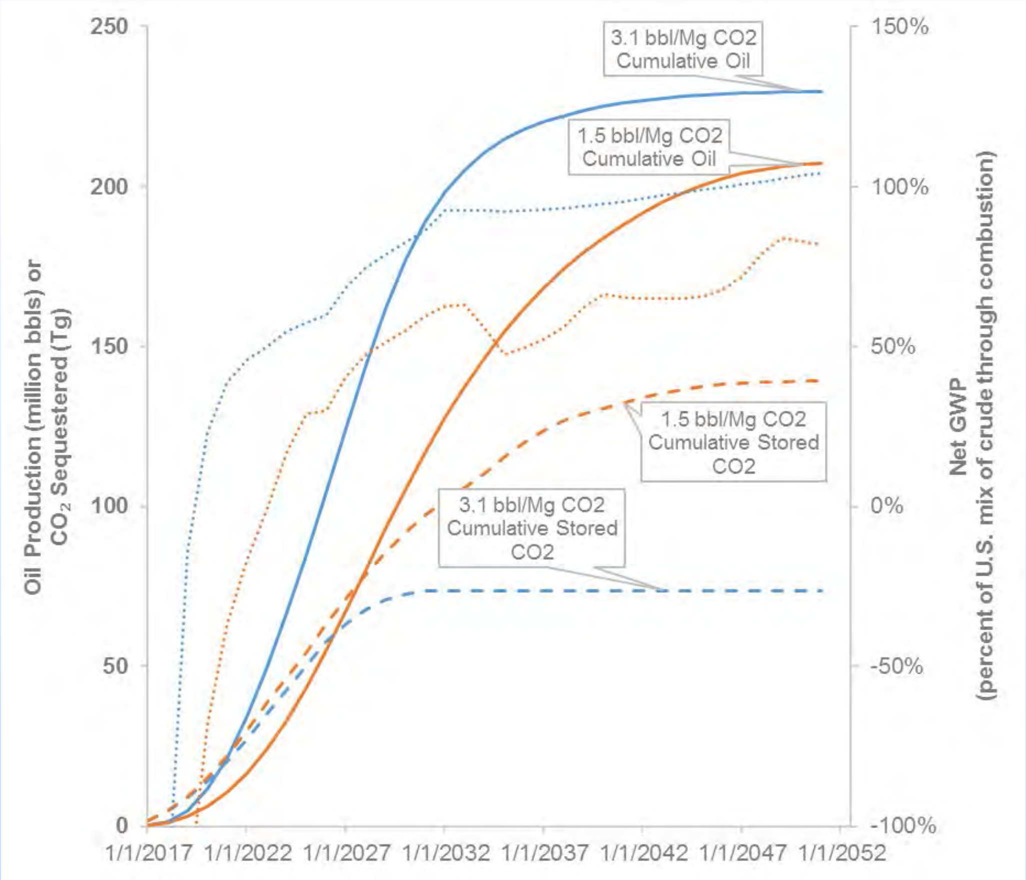
- Outreach – Presentations at LCA conference on *Net Energy Analysis of CO_2-Enhanced Oil Recovery (EOR)* and *CO_2-Enhanced Methane Recovery* (October 2017)
- A public version of the CO_2-EOR Life Cycle (CELiC) Model will be finalized (September 2018)
- Expanded life cycle inventories for two models: saline aquifer storage and CO_2-EOR



Storage Activity Life Cycle Analysis (cont'd)

Upcoming Work

- Abstract accepted for LCA XVIII – Ft. Collins, CO – the life cycle interactions of saline aquifer characteristics and location
- Variability of environmental impacts of anthropogenic CO_2-EOR due to variability in EOR reservoirs and changing U.S. electricity generation mix
- Environmental impacts of transition from anthropogenic CO_2-EOR to saline aquifer storage (Class II to Class VI)



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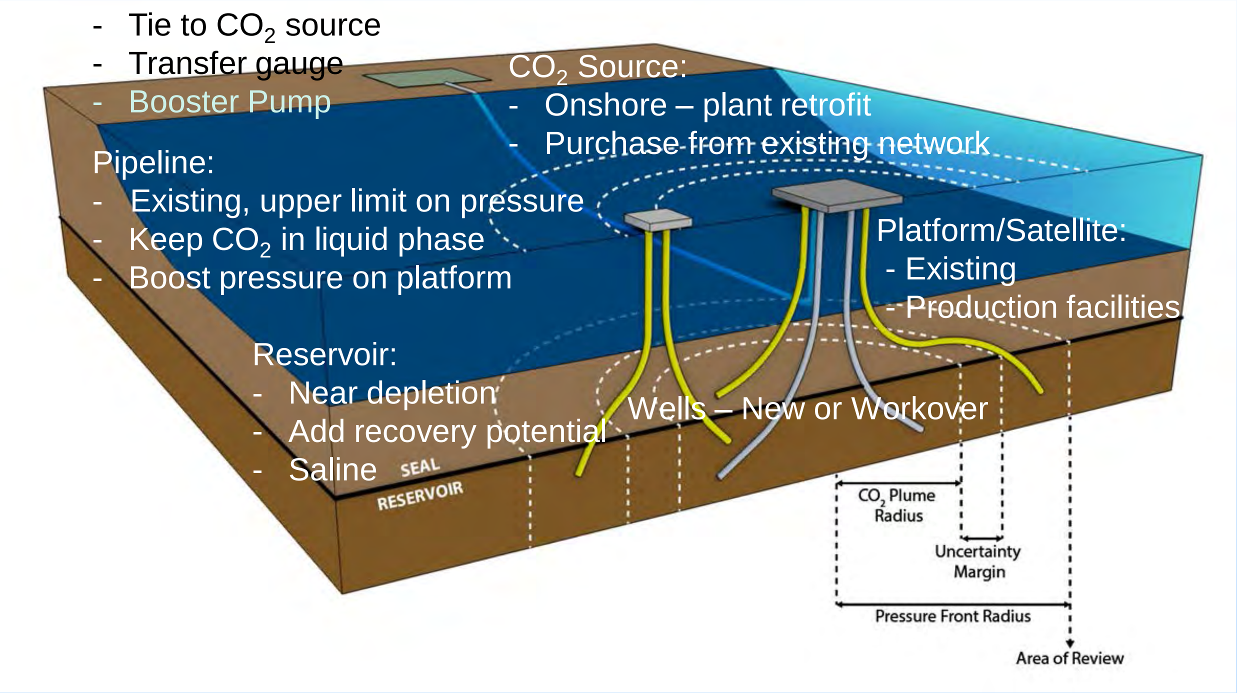
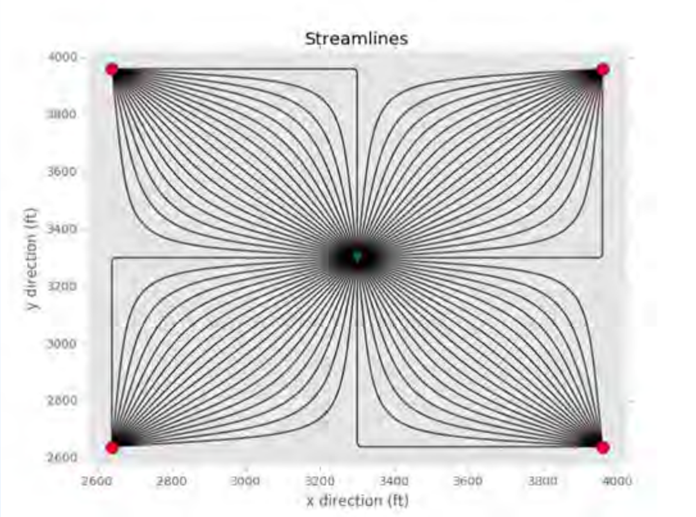
FE/NETL Offshore CO_2 Saline Storage Cost Model

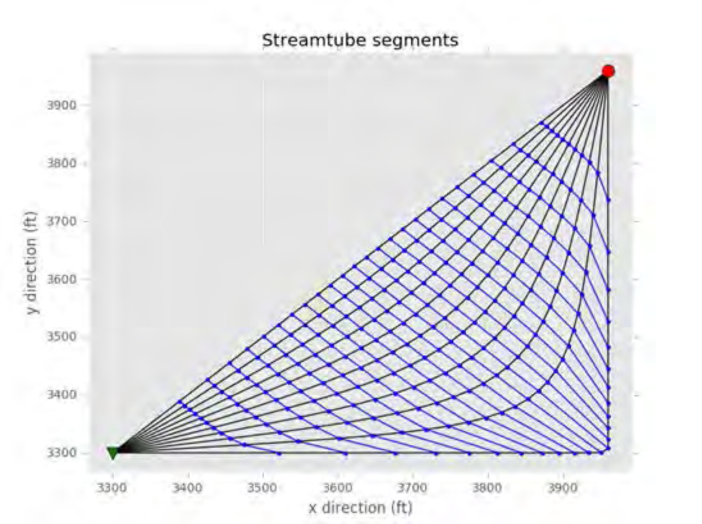
- **Water Depth**
  - More steel
- **Distance from Shore**
  - Longer pipeline
  - Travel distance
- **Plume area**
  - Place onshore challenges under water
- **Injection wells**
  - Directional drilling
- **DOI (BOEM/BSEE)**
  - Regulatory oversight



FE/NETL CO_2 Prophet Model

- Simplified pattern-oriented streamline / stream tube black oil reservoir simulation program originally developed by Texaco E&P for DOE in early 1990s
  - Very fast, can simulate 30 years of CO_2 EOR operations in 5 to 20 seconds per pattern
  - Uses too little CO_2 to produce a barrel of oil (too efficient) and, consequently, stores too little CO_2
- Program recently updated so CO_2 needed to extract oil is more realistic
- Currently completing calibration of key variables using field data from 25 CO_2 EOR sites





FE/NETL CO_2 EOR Model

	Regional evaluation for a specific site	Site selection & characterization	Permitting	Operations	Post-Injection Monitoring	Long-term Stewardship
Geologic Storage (GS) Class VI	Negative Cash Flow			Positive Cash Flow Injection Fee	Negative Cash Flow	Developing State Regulations
	Volume of emissions to sequester & pore space needed. Geologic, geophysical, engineering, financial & social. Identify several prospective sites. Begin assembly of acreage block.	Assemble/acquire new data. Drill new well(s) & acquire seismic. Get necessary permits. Finish assembling acreage block. Prepare required plans for Class VI permit. FEED for site. Establish financial responsibility.	Submit all plans and financial responsibility for permit application. Approval to drill injection wells. State approves site permit. Drill Inj. Wells, incorporate new data in plans (AoR, etc) & present to Director. Injection operations approved. Have 180 days to submit MRV plan per Subpart RR regs.	Finish construction of surface facilities and MVA grid. Begin injection of captured CO2. Follow plans, AoR every 5 yrs., annual reporting. Annual MIT. Drill new monitoring wells/perform corrective action as plume expands. P&A injection wells per plan. Some financial responsibility instruments released.	Present PISC & site closure plan to Director. Apply for reduced time period. Follow PISC & site closure plan. P&A all wells, restore sites. Release of financial responsibility insturments. Establish non-endangerment.	Trust Fund covers costs Another entity accepts long-term stewardship, oversees trust fund, pays site costs, settles all claims.
	0.5 to 1 year	3+ years	2+ years	30 to 50 years	10 to 50+ years	Rest of Civilization

	Prospect Screening	Facility/Field Design	Facility/Field Construction	Operations
Enhanced Oil Recovery (EOR) Class II	Negative Cash Flow			Positive Cash Flow Oil & Gas Sales
	Technical and Economic: - Reservoir & recoverable oil - Facilities & costs	Wells, processing plant, pipelines, pattern development, etc. Permitting, unitization. Contract for CO2.	Drill/workover wells, build plant, install pipelines, connect with CO2 source, etc.	Begin injcetion of CO2. Production of oil, gas, CO2 and water; Gas processing, separation. Recycling of CO2, purchase new CO2, Recycle/dispose of prod water as needed. O&M. Closeout. P&A wells at end.
	1 to 2 years			20 to 50 years

FE/NETL CO2 EOR Cost Model

- Uses Input-Output from CO_2 Prophet
- Field level cash flow analysis
- Brownfield or Greenfield (ROZ) analysis
- Eval up to 10 oil prices & 5 CO_2 cost values at each of the oil cost values
- Break-even cost of oil for a specific cost of CO_2

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Ongoing Work

- Analog Studies
  - Natural Gas Storage
  - Class I Injection
  - CO_2-EOR Leakage
- Co-Model with NRAP
  - NsealR
- ROZ Reservoir Data
  - Permian Basin
    - San Andres
    - Greyburg
  - Other Basins
- Water Withdrawal
  - Multi-basin
  - Update technology
- Economic Analysis
  - FutureGen2, Petra Nova
  - LaBarge/Shutte Creek
  - Anthropogenic Sources
  - Investment preference
- Offshore modeling
  - Assess infrastructure
  - Initial assessment of costs
- Beta-testing EOR models

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Conclusions

- **NETL CCUS modeling is providing insight into the strengths and weaknesses of CCUS**
  - Four Basin study, CCS network analysis
  - LCA analysis
- **Other analysis provides knowledge on other factors that can impact CCUS**
  - Economic analysis of large scale project, CO_2 sources
  - Developing geologic data: for ROZ, for storage cost model (onshore & offshore)
- **Publicly available models are utilized by others to assess their own projects**
  - Expands CCUS analytical capabilities
  - Provides NETL feedback on models

Acknowledgements

- **NETL Research & Innovation Center**
  - Kristin Gerdes – Associate Director Systems Engineering & Analysis (SEA) Division
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- **Mission Execution and Strategic Analysis (Contractors)**
  - KeyLogic Systems, Inc.
  - Leidos
  - Deloitte
  - Advanced Resources International (ARI)

Questions

Resources

- **Link to FE/NETL CO_2 Saline Storage Cost Model**
  - https://www.netl.doe.gov/research/energy-analysis/search-publications/vuedetails?id=2403
- **Link to FE/NETL CO_2 Transport Cost Model**
  - https://www.netl.doe.gov/research/energy-analysis/search-publications/vuedetails?id=630
- **Recent Publications:**
  - Vikara, D., Shih, C., Lin, S., Guinan, A., Grant, T., Morgan, D., and Remson, D., "U.S. DOE's Economic Approaches and Resources for Evaluating the Cost of Implementing Carbon Capture, Utilization, and Storage (CCUS)," *Journal of Sustainable Energy Engineering*, vol. 5, no. 4, pp. 307-340, 2017.
  - Grant, T., Guinan, A., Shih, C., Lin, S., Vikara ,D., Morgan, D., and Remson, D., "Comparative analysis of transport and storage options from a CO_2 source perspective," *International Journal of Greenhouse Gas Control*, vol. 72, pp. 175-191, 2018.