An Overview of the CO_2 Pipeline Infrastructure

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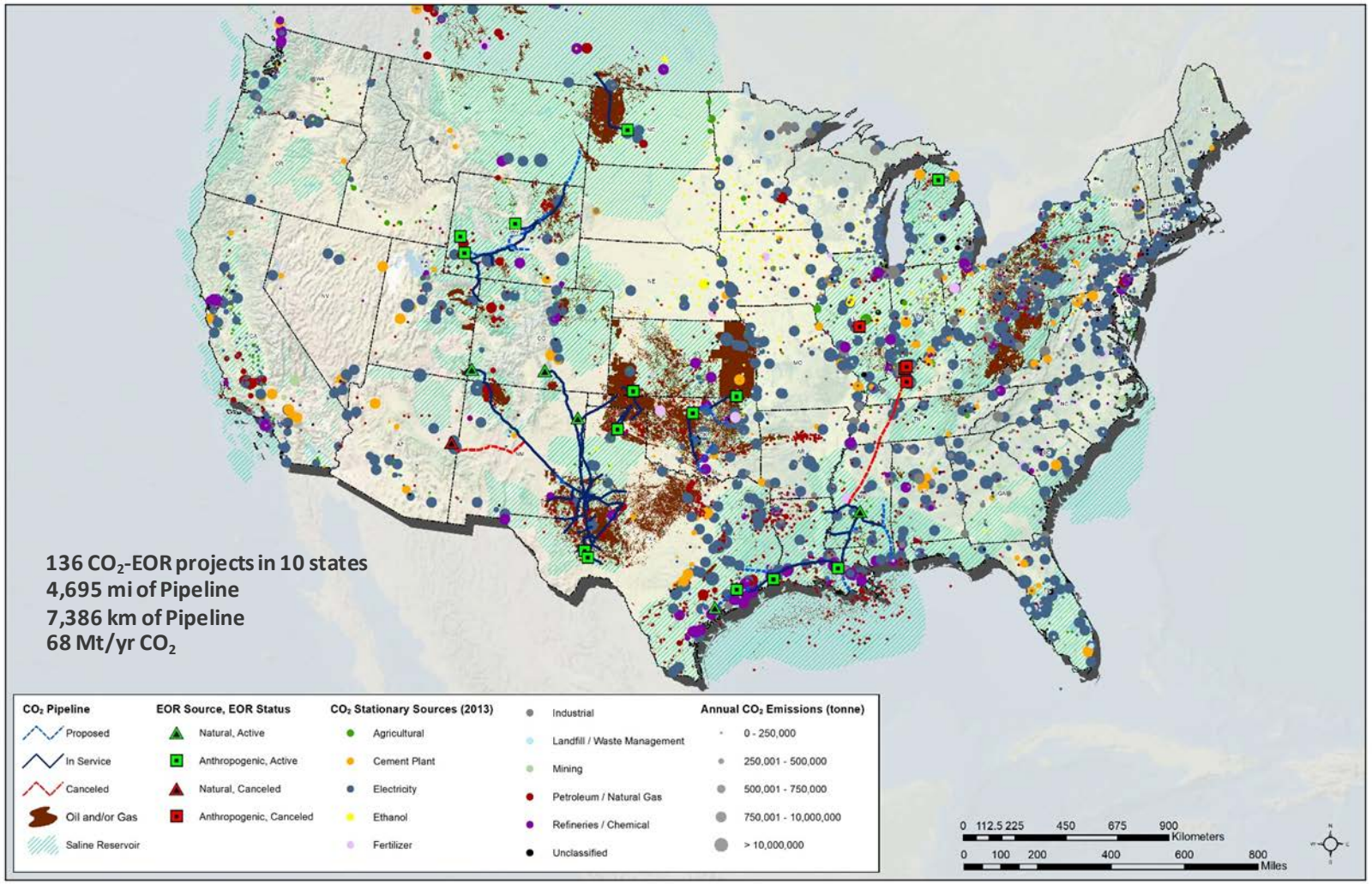
NATIONAL ENERGY TECHNOLOGY LABORATORY

Disclaimer

Representing CCUS – Pipeline Infrastructure Outline

Sources of CO_2 for EOR

CO_2 Source		Reserves (2012)		Production (2015)	
Natural	State	TCF	Mt	MMscf/d	Mt/yr
McElmo Dome	CO	7.2	530	1,230	24
Doe Canyon	CO	0.09	40	170	3.3
Sheep Mountain	CO			30	0.6
Bravo Dome	NM	8	424	260	5.0
Jackson Dome	MS	11	594	1,300	25.0
Sub-Total				73%	57.9
Natural Gas Plant					
Century Plant	TX	3.5		450	8.7
Val Verde	TX			75	1.5
Lost Cabin	WY			50	1.0
Shute Creek	WY	100	5300	360	7.0
South Chester	MI			11	0.2
Sub-Total				23%	18.4
				Capture Rate (2015)	
Industrial	State	Type		MMscf/d	Mt/yr
Coffeyville	KS	Fertilizer		40	0.80
Enid	OK	Fertilizer		35	0.07
Arkalon	KS	Ethanol		15	0.29
Agrium	TX	Fertilizer		26	0.50
Bonanza Energy	KS	Ethanol		8	0.15
Air Products	TX	Hydrogen		52	1.00
PCS Nitrogen	LA	Fertilizer		20	0.39
Sub-Total				4%	3.20
Total					79.50



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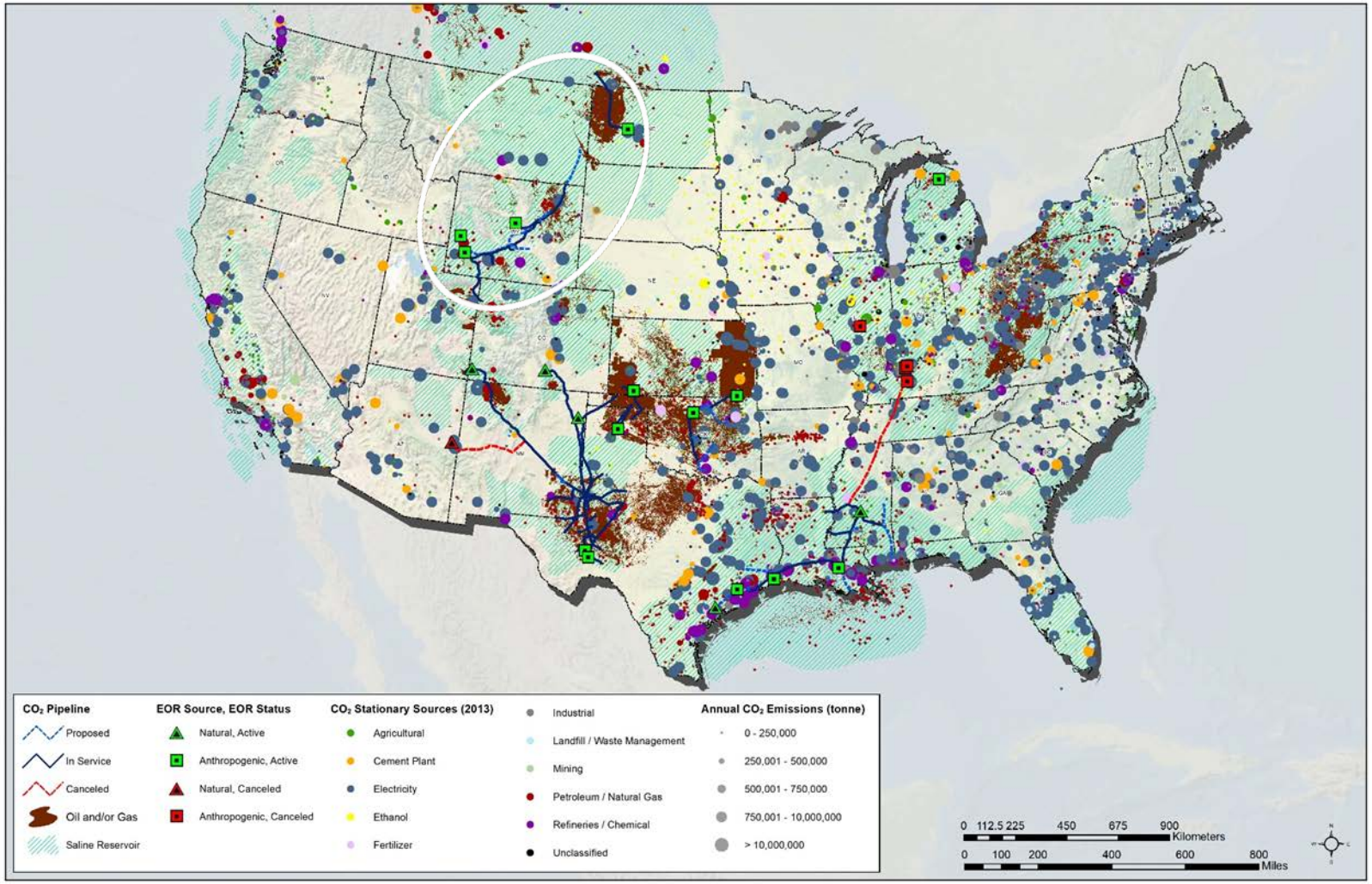
Northern Rockies/Plains

- **Pipeline**
  - 1,010 mi (1,624 km)
  - 7 Operators
  - Greencore pipeline – 2012
    - 232 mi, 20 in, 38.5 ktCO2/d capacity
- **15 EOR Projects**
  - 5 Operators

CO_2 Source

- **Gas Processing Plants**
  - Shute Creek
  - Lost Cabin
  - Riley Ridge
- **Denbury – new projects**
  - Riley Ridge-Natrona Pipeline
    - 243 mi, est $400 MM
  - Cedar Creek Anticline
    - 110 mi pipeline, reservoirs
    - Est $400 MM project costs



Kuuskraa, V., and Wallace, M., 2014. CO_2-EOR set for growth as new CO_2 supplies emerge. Oil & Gas Journal, April 7, 2014.
NETL, 2014, A Review of the CO_2 Pipeline Infrastructure in the U.S. DOE/NETL-2014/1681

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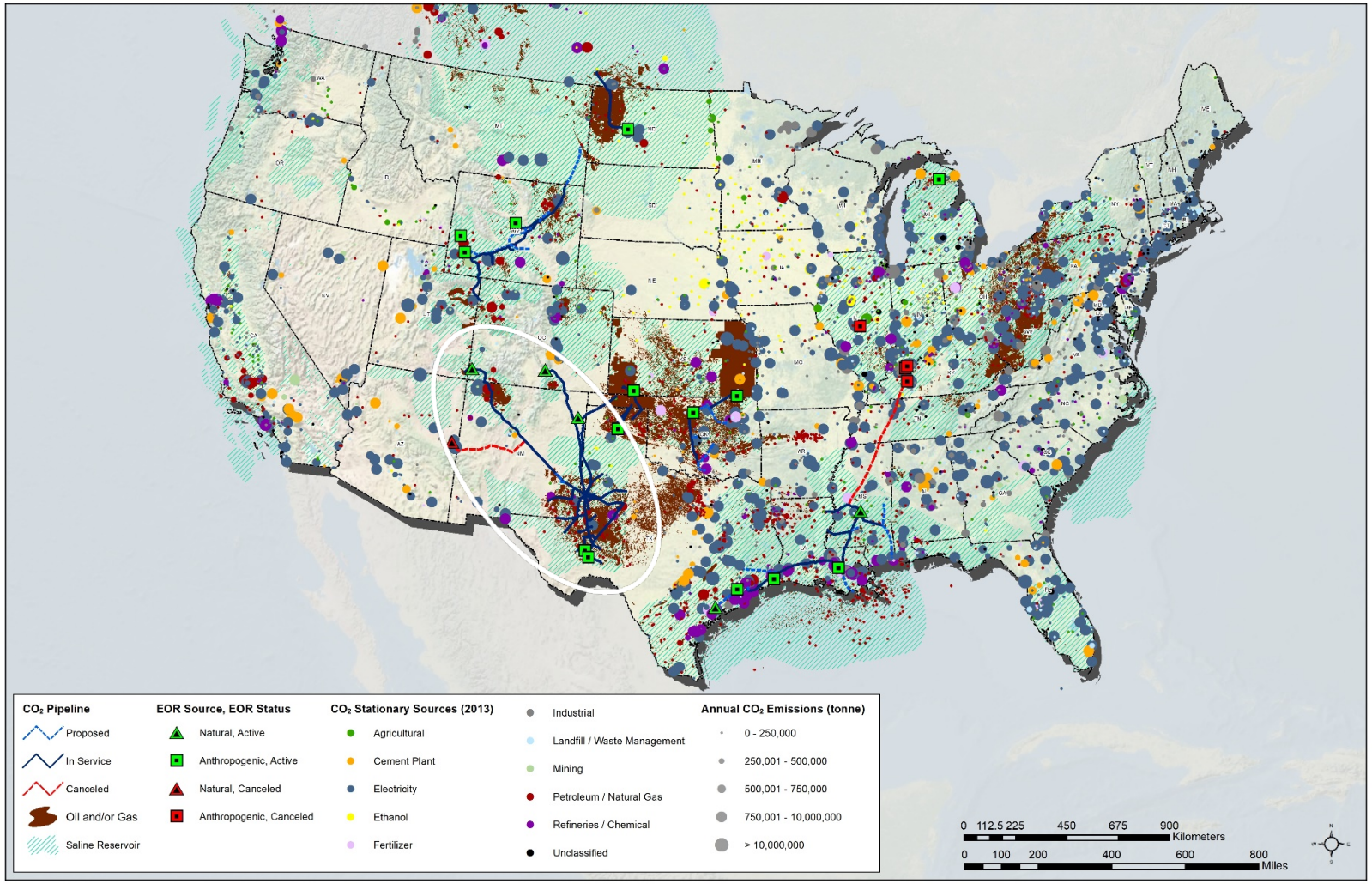
Permian Basin

Permian Basin

- **Pipeline – 12 operators**
  - 2,470 mi (3,892 km)
  - Denver and McCamey Hubs
- **75 EOR Projects – 19 operators**

CO_2 Source

- **Natural**
  - McElmo Dome - expansion
  - Doe Canyon - expansion
  - Sheep Mountain – near depletion
  - Bravo Dome
  - St Johns - canceled
- **Gas Processing Plants**
  - Century
  - Val Verde (4 plants)
- **Anthropogenic**
  - Summit Energy - canceled



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NETL, 2014, A Review of the CO_2 Pipeline Infrastructure in the U.S. DOE/NETL-2014/1681

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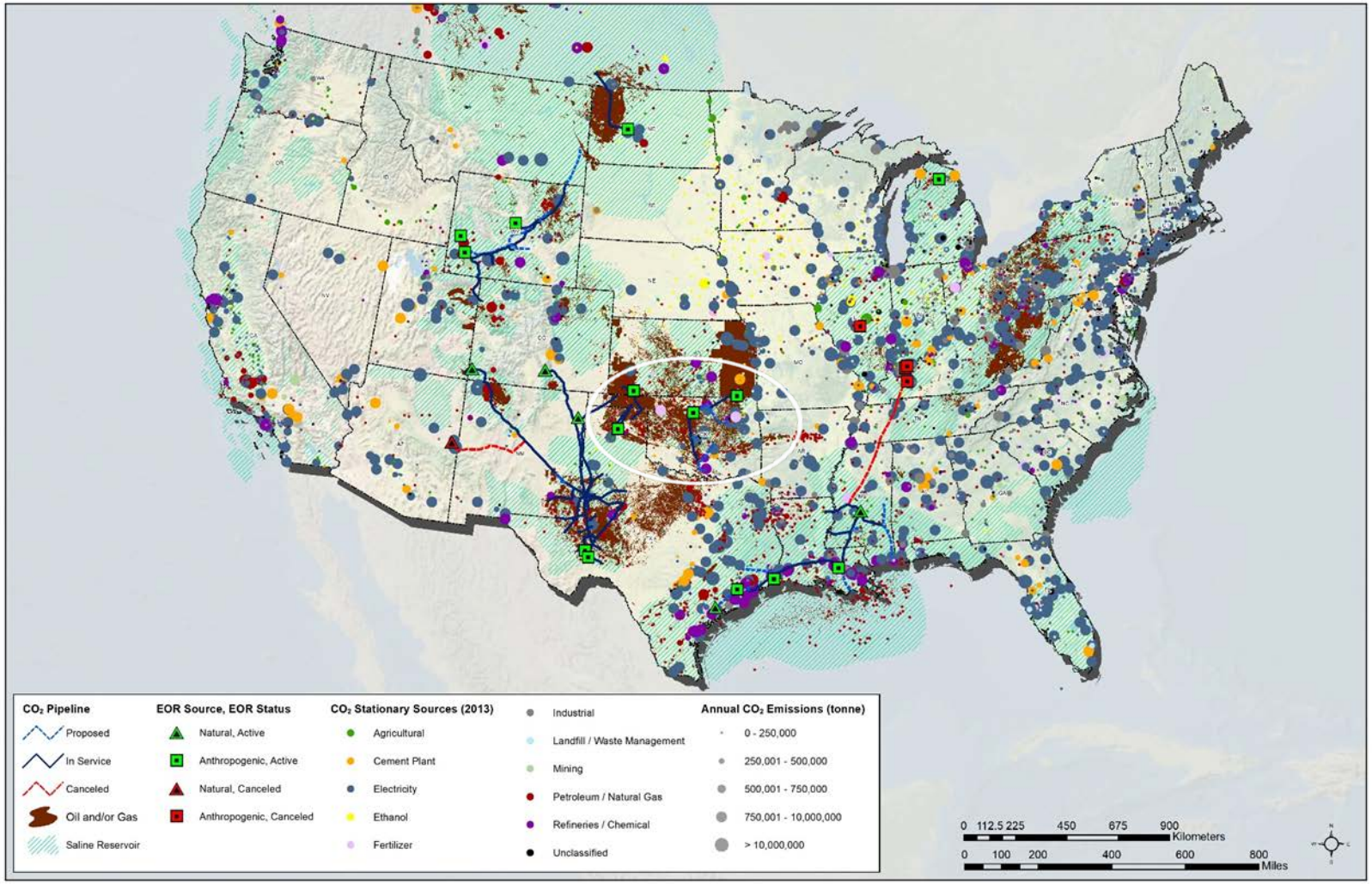
Mid-Continent

- **Pipeline**
  - 414 mi (712 km)
  - 2 Operators
- **15 EOR Projects**
  - 3 Operators

CO_2 Source

- **Anthropogenic**
  - Coffeyville Fertilizer Plant
  - Enid Fertilizer Plant
  - Agrium Fertilizer Plant
  - Arkalon Ethanol Plant
  - Bonanza Ethanol Plant



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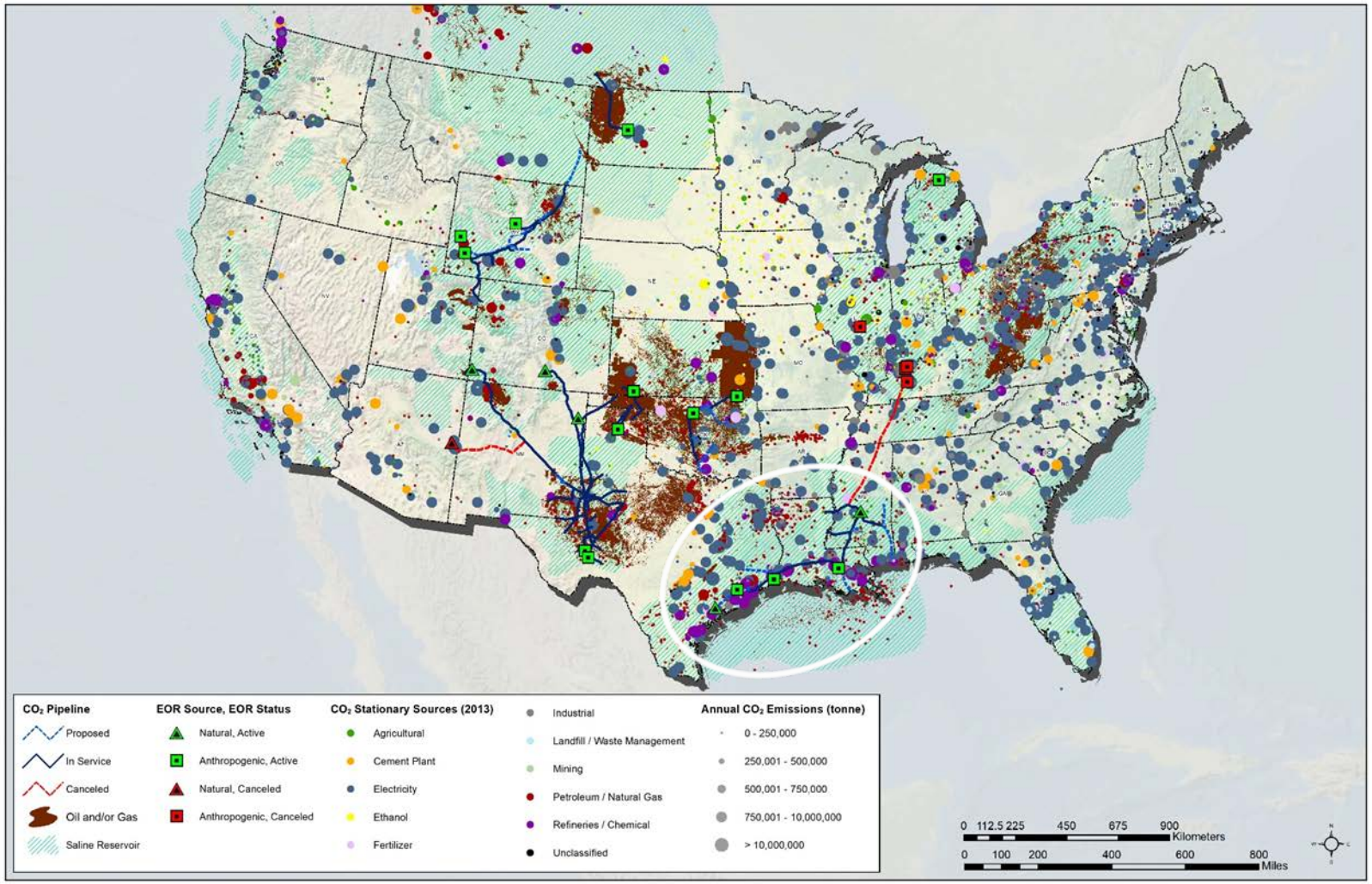
Gulf Coast

- **Pipeline**
  - 781 mi (1,258 km)
  - 2 Operators
  - Green – 2010
    - 323 mi, 24 in, 42.3 ktCO2/d
  - West Ranch - 2016
    - 81 mi, 12 in, 4.4 ktCO2/d (Capture rate)
- **21 EOR Projects**
  - 1 Operators

CO_2 Source

- **Natural**
  - Jackson Dome
- **Anthropogenic**
  - Air Products
  - PCS Nitrogen
  - Petra Nova – new operations



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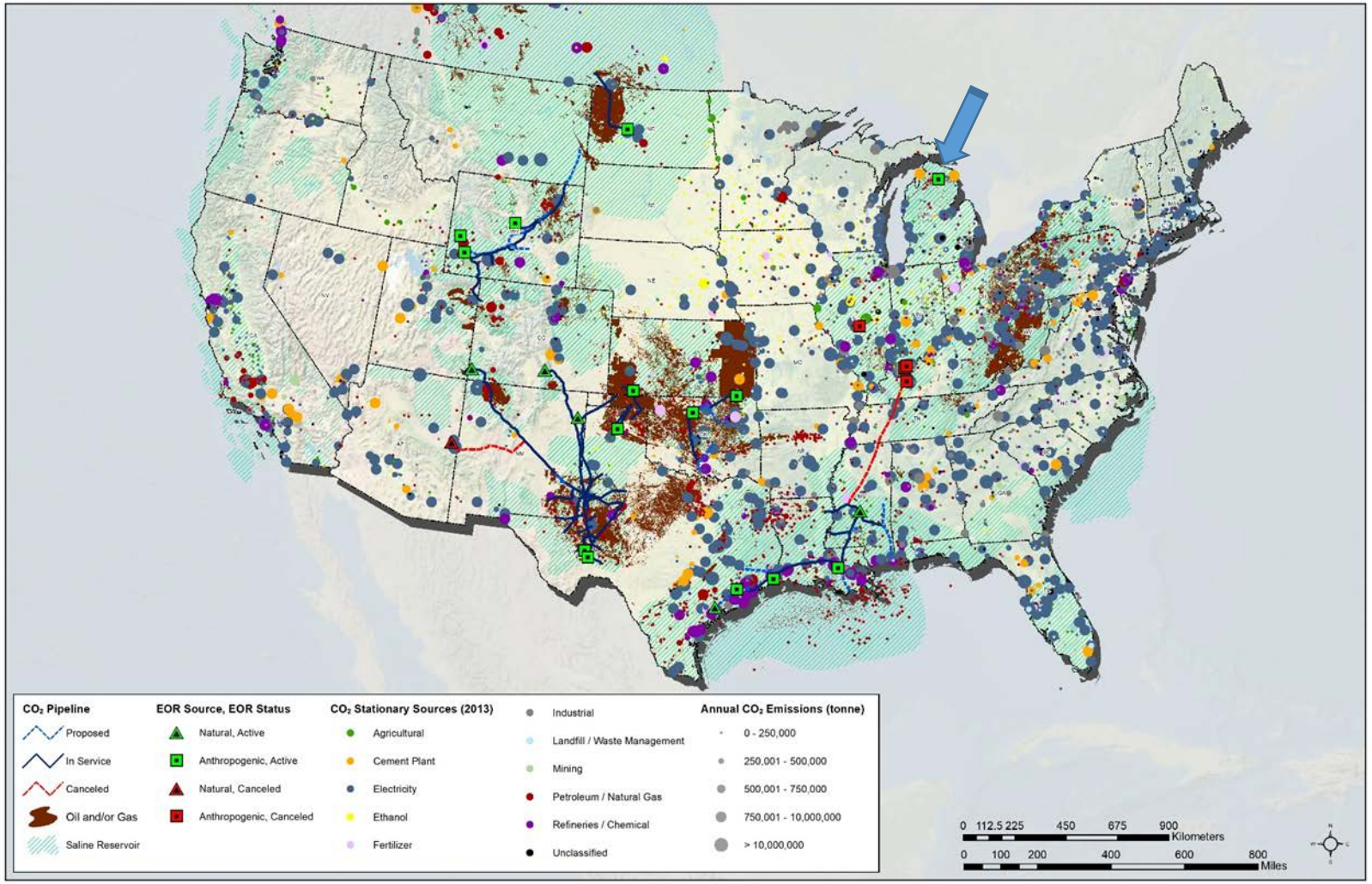
Michigan Basin

- **Pipeline**
  - 11 mi (18 km)
  - 1 Operator
- **9 EOR Projects**
  - 1 Operator

CO_2 Source

- **Gas Processing Plant**
  - South Chester



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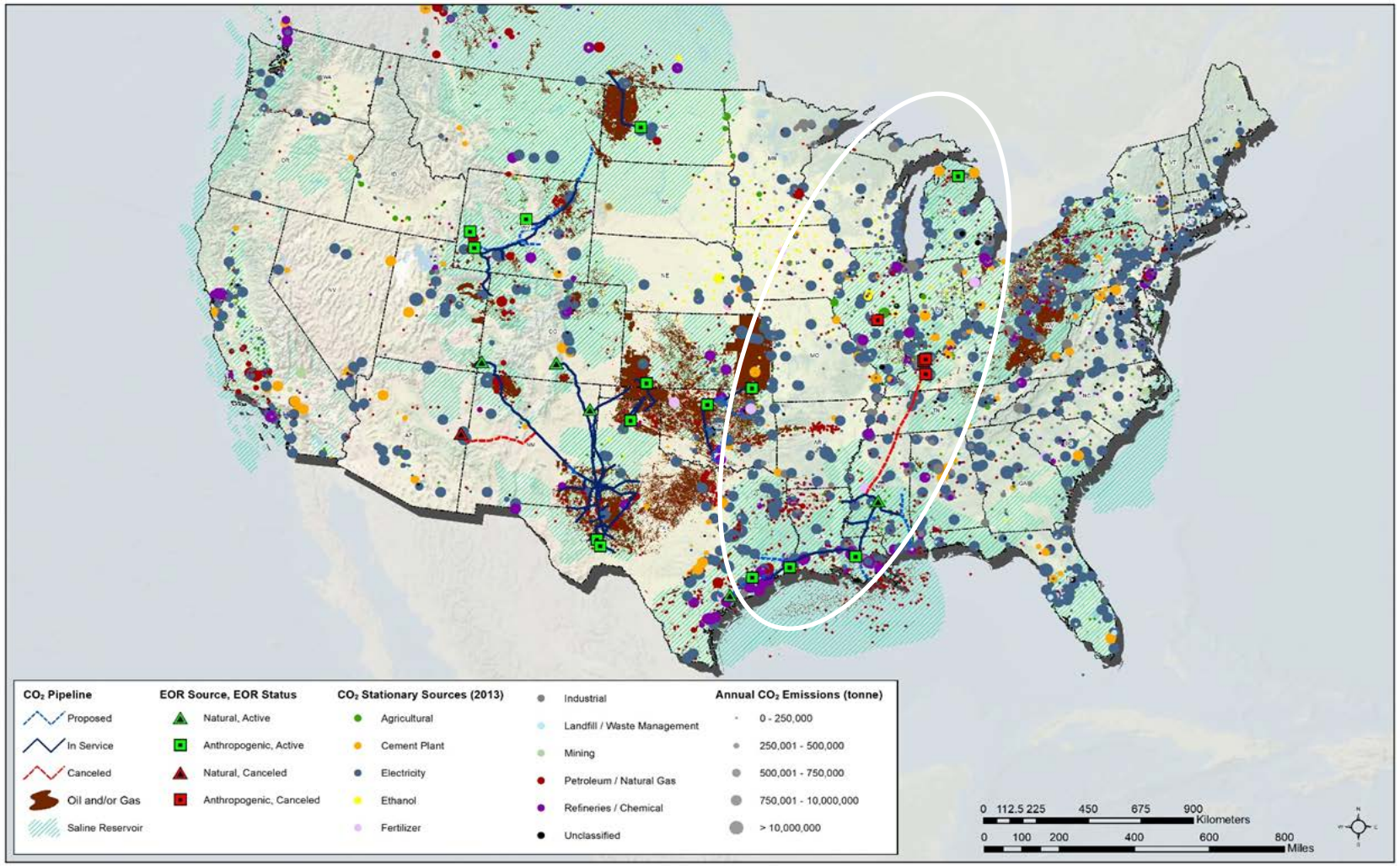
East Pipeline Corridor

- **Michigan**
- **Gulf Coast**
- **Denbury pipeline - canceled**
  - Connect Jackson Dome and sources in Illinois, Indiana and Kentucky
    - Taylorville Energy Center IGCC – Illinois
    - Cash Creek IGCC - Kentucky
    - Kentucky NewGas SNG – Kentucky
    - Indiana Gasification IGCC – Indiana
  - 500 to 700 mi pipeline
    - Est $1 billion cost
- **Two other proposed pipelines in Mississippi**
  - Connect gasification plant on Gulf Coast with Free State Pipeline
  - Connect Kemper County IGCC with Heidelberg Field in Mississippi



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East and West Pipeline Corridors

Eastern Corridor

- Access to significant population of Power Plants
- Significant Industrial Sources
- EOR potential
- Existing CO_2 pipeline network
- Access to significant CO_2 storage potential

Western Corridor

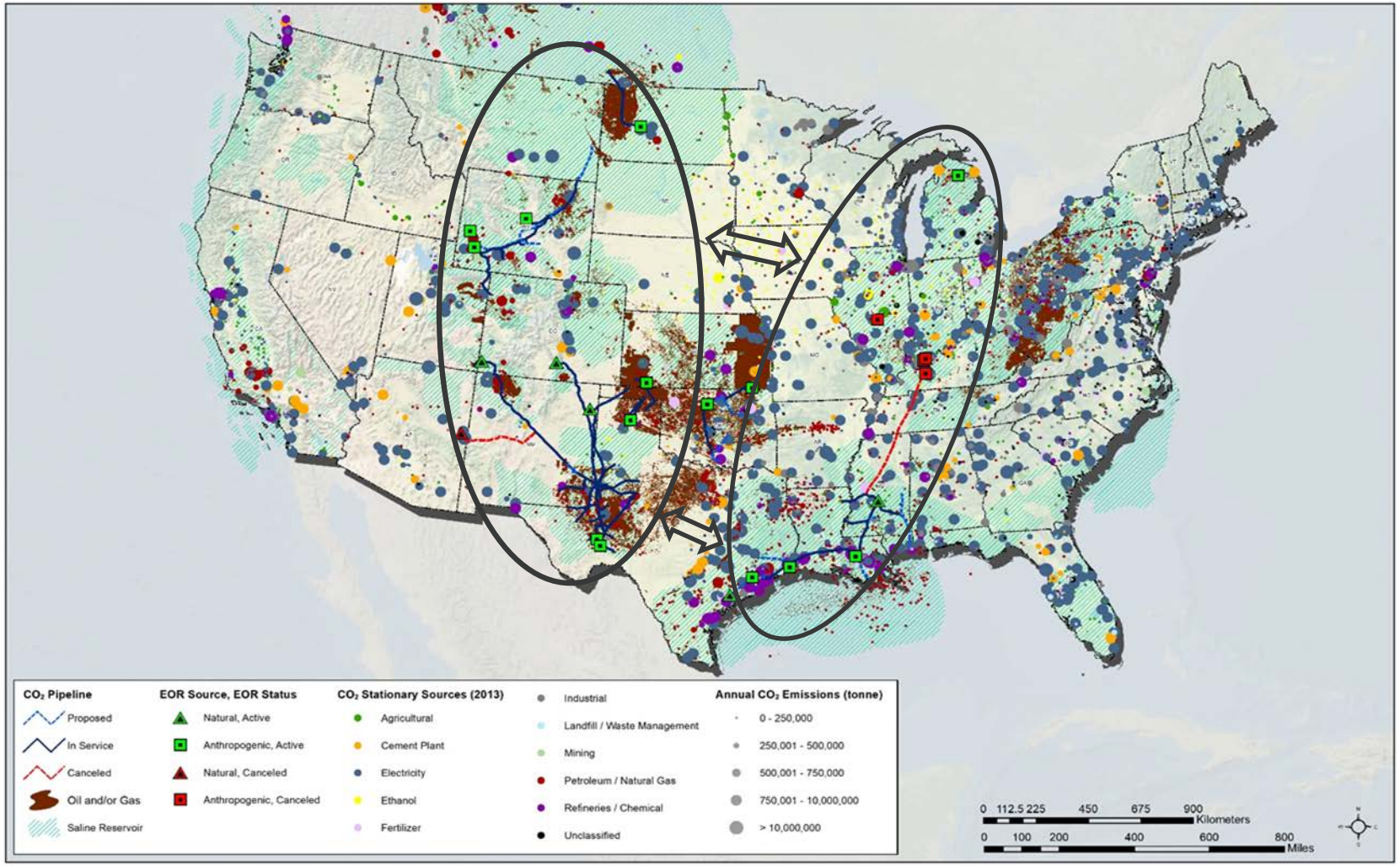
- Extensive natural sources of CO_2
- Significant EOR/ROZ potential
- Extensive CO_2 pipeline network
- Good CO_2 storage potential

Iowa Connector

- Tie in ethanol sources
- Connect northern plains resources to eastern markets

Texas Connector

- Gulf Cost CO_2 sources to Permian Basin
- Permian Basin has supply shortage and significant ROZ potential



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Pipeline Capital Costs; Sale of CO_2

CO_2 Pipeline Capital Costs for Various Pipelines

Pipeline Project	Year	Cost $/in dia-mi	Inflation Adj 2009$
Dakota Gasification	2000	37,300	46,500
Hall-Gurney (Kansas)	2001	22,000	26,650
Regression Analysis of FERC Data	2003	33,800	39,400
Coffeyville Resources	2007, 2009	52,100, 83,300	54,000, 83,000
Oil & Gas Journal - Avg of NG Pipelines	2008	65,100	64,900
Green Pipeline	2009	93,750	

A Policy, Legal, and Regulatory Evaluation of the Feasibility of a National Pipeline Infrastructure for the Transport and Storage of Carbon Dioxide, IOGCC, December 2010.

Delivered Price of CO_2

From Natural Source	$1.25/mcf	$22/ton	
New Contracts	$1.25 to 1.50/mcf	$22 to $26/ton	$60 to $70/BO
Recent Contracts		$30/ton	$70/BO
High Purity Sources	$1.30 to $1.70/mcf	$23 to $30/ton	
Low Purity Sources	$2.85 to $4.00/mcf	$50 to $75/ton	
Great Plains Synfuels	$1.10/mcf	$19/ton	

A Policy, Legal, and Regulatory Evaluation of the Feasibility of a National Pipeline Infrastructure for the Transport and Stoage of Carbon Dioxide, IOGCC, December 2010.

- **Recent Pipeline Projects:**
  - Green – La & Tx Gulf Coast; 24 in, 314 mi, trade journal cost report - $660 million ($87,580/in-mi)
  - Greencore – Wy; 20 in, 232 mi, trade journal cost report - $285 million ($61,422/in-mi)
  - Petra Nova – Tx Gulf Coast; 12 in, 81 mi, cost not known.

- **Price of CO_2:**
  - Generally 1% to 2% of the price of oil as cost per mcf of CO_2

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CO_2 Pipeline Standards

- **Pipeline Standards**
  - CO_2 transported as a dense phase liquid
    - —Supercritical at 1,070 psi and 88ºF
    - —55ºF to 110ºF and 1,250 psi to 2,200 psi range for transport
  - Usually use thicker wall pipe than for natural gas
  - Pipeline standards table:
    - —Prevent corrosion
    - —Impact on MMP in reservoir
  - CO_2 delivered to pipeline meeting pipeline standards

CO_2 Stream Compositions form Various Processes

Component	Kinder Morgan CO_2 Pipeline Specs	Ethanol Plant	Great Plains Synfuels Plant	Gas Processing Plant	Coffeyville Resources Ammonia-UAN Fertilizer Plant	Food-Grade CO_2 Specs
CO_2	≥ 95% vol	> 98% vol	≥ 96.8% vol	≥ 96% vol	99.32% vol	≥ 99.9% vol
Water	≤ 30 lb/MMcf	Dry	< 25 lb/MMcf	≤ 12 lb/MMcf	0.68% vol	≤ 20 ppmw
H_2S	≤ 20 ppmw		< 2% vol	≤ 10 ppmw		≤ 0.1 ppmw
Total Sulfur	≤ 35 ppmw	40 ppmv	< 3% vol	≤ 1 ppmw		≤ 0.1 ppmw
N_2	≤ 4 % vol	0.9% vol	0 ppm			None
Hydrocarbons	≤ 5 % vol	2300 ppmv	1.3 % vol	≤ 4 % vol		CH4 ≤ 50 ppmw; others ≤ 20 ppmw
O_2	≤ 10 ppmw	0.3 % vol	0 ppm	≤ 10 ppmw		≤ 30 ppmw
Other	Glycol ≤ 30 gal/MMcf		Glycol 0.8% vol			Glycol ≤ 330 ppmw
Temperature	≤ 120ºF	120ºF	100ºF	≤ 100ºF	100ºF	

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Environment, Health and Safety

- **Pipeline and Hazardous Materials Safety Administration (PHMSA)**
  - Federal safety standards adopted by States
- **Pipeline Safety**
  - Between 1986 – 2008
  - 12 accidents across 3,500 mi CO_2 pipeline network
    - —Due to damage, corrosion, leaks/blowouts
  - No injuries or fatalities reported
  - It helps that CO_2 is non-explosive

IOGCC, 2010, A Policy, Legal, and Regulatory Evaluation of the Feasibility of a National Pipeline Infrastructure for the Transport and Storage of Carbon Dioxide, December 2010.

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CO_2 Pipeline Business Models

- **Gov't/Public Option**
- Local, State or Federal entity to finance or build pipeline/facility
- Charter a corporation to do so
- 3 States have chartered a corporation or authority:
  - Alaska, North Dakota, Wyoming
- **Duke Energy: options on CO_2 pipeline**
- Owning, recover as part of rate base
- Leasing capacity, pipeline owned by 3rd party
- Joined ownership with 3rd party
- Sell CO2 to pipeline owner/company
- Pay pipeline company to deliver to end point
- Share emission allowances with pipeline company in return for them taking CO_2. (Own or ship?)

Private Sector Options

	Dedicated	Open Access
***Intra*state**	Mostly single operator Sometimes multiple owners Mostly without eminent domain State & local siting approval Fed approval IF cross Fed lands Deliver own CO_2 (private) Deliver 3rd party CO_2 (contract carrier): Limited access Negotiated rates, not subject to economic regulations	Provide transport to multiple users Owner may also sell CO_2 to end user May use eminent domain but: Subject to economic regulations Required 3rd party access Common Carrier status Many pipelines built without eminent domain
***Inter*state**	Built without use of eminent domain State & local siting approval Limited access Negotiated rates No Fed approval involved	Requires some Fed (BLM) lands: FLPMA MLA If state public utility commission involved: Common Carrier status imposed Regulation of rates

IOGCC, 2010, A Policy, Legal, and Regulatory Evaluation of the Feasibility of a National Pipeline Infrastructure for the Transport and Storage of Carbon Dioxide, December 2010.

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Federal Incentives:

- Master Limited Partnerships (MLP)
  - Commonly used for oil and gas pipelines; for depleting natural resources.
  - Energy Improvement and Extension Act of 2008 extends MLPs to industrial sources of CO_2
  - Proposed Master Limited Partnerships Parity Act of 2015-2016 would include CCUS projects
- Private Activity Bonds (PAB)
  - Power plants lose PAB eligibility in 1986
  - Petra Nova uses PABs because it is located in a storm exclusion zone
- Carbon Dioxide Investment and Sequestration Tax Credit
  - A proposed refundable tax credit providing up to $2 billion for CCS property,
- Section 45Q Tax Credit
  - Modified to increase credits for saline and EOR storage but not applicable to pipeline.

NETL and Great Plains Institute, 2017, Siting and Regulating Carbon Capture, Utilization, and Storage Infrastructure. Workshop Report. U.S. DOE. Found at: https://www.energy.gov/sites/prod/files/2017/01/f34/Workshop%20Report--Siting%20and%20Regulating%20Carbon%20Capture%2C%20Utilization%20and%20Storage%20Infrastructure.pdf

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State Incentives:

- Property Tax Exemption
- Reduced Income Tax
- Severance Tax Reduction
- Sales Tax Reduction on CCUS Equipment
- Rate Recovery

NETL and Great Plains Institute, 2017, Siting and Regulating Carbon Capture, Utilization, and Storage Infrastructure. Workshop Report. U.S. DOE. Found at: https://www.energy.gov/sites/prod/files/2017/01/f34/Workshop%20Report--Siting%20and%20Regulating%20Carbon%20Capture%2C%20Utilization%20and%20Storage%20Infrastructure.pdf

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What is the pipeline's connection?

- **Source**
  - Large sources have billion dollar costs presenting financial challenges
    - —Texas Clean Energy Project: a $2.4 billion project canceled 2016 when DOE withdrew funds
      - New IGCC located in middle of Permian Basin with good promise but no significant financing beyond Federal awards ($450 M))and investment tax credits ($637 M)
    - —Petra Nova began capture January 2016
      - A $1 billion post-combustion retrofit utilizing captured CO_2 for EOR
      - Able to use Private Activity Bonds; also equity investment; $190 M US DOE CCPI grant
  - Smaller sources: lower costs and higher CO_2 purity
    - —Natural Gas Plants, Ethanol Plants, Fertilizer Plants, Hydrogen Plant
  - Natural Sources

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What is the pipeline's connection?

- **EOR**
  - Present in 10 states: Montana, Wyoming, Colorado, Utah, New Mexico, Texas, Oklahoma, Louisiana, Mississippi and Michigan
  - 75 projects in the Permian Basin since 1972 (Texas and New Mexico)
    - —Between 0 and 7 projects established in any particular year

- **Saline**
  - No commercial projects
  - Decatur, Illinois: ADM and Illinois ICCS

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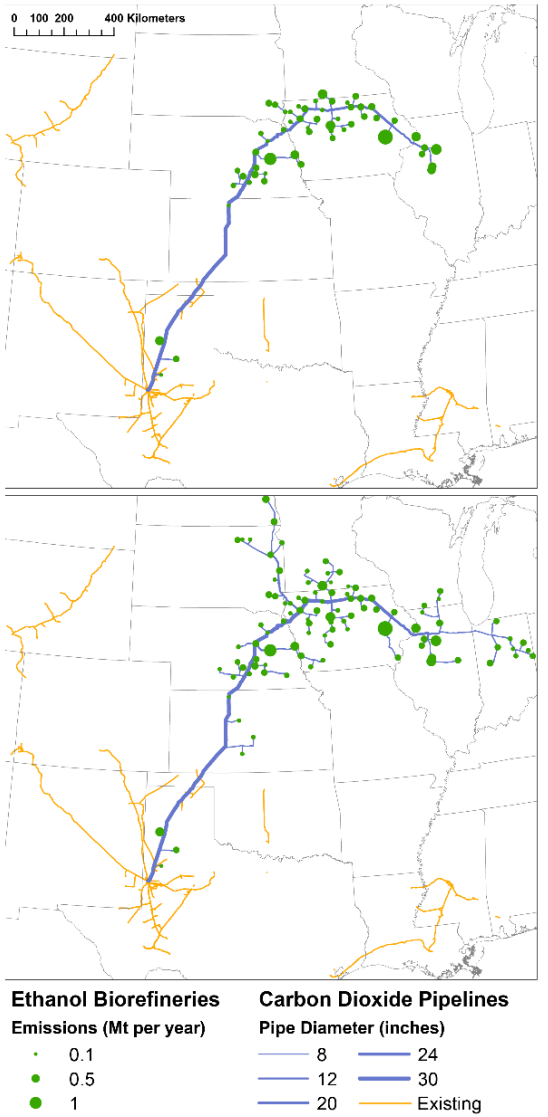
CO_2 Pipeline Modeling Example

- **Commercial-Gov't** (equity and Gov't Loans)
  - 19.0 Mt/yr from 63 Ethanol Plants.
  - Capital Costs
    - $4.3 B pipeline
    - $1.6 B capture

- **Full-Gov't** (Gov't Loans)
  - 28.7 Mt/CO2 from 108 Ethanol Plants (McElmo Dome 24 Mt/yr)
  - Capital Costs
    - $6.7 B pipeline
    - $2.6 B capture
  - 2,000 km (1,242 mi) trunkline
  - 5,000 km (3,100) mi) feeder lines

- **Tie to Permian Basin EOR**
- **Open access interstate pipeline**
- **Claim 45Q credit, CO_2 sold at $23/tonne**



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Plant		3 to 5 year capital expenditure period					BEGIN CCUS	Production operations 30 years						
Transportation				3 year capital expenditure period				Transportation operations 30 years						
Storage Saline	Site Screening	Site Selection & Characterization			Permitting & Construction			Injection operations 30 years				Post-injection site care and closure 50 years		
Storage EOR					Prospet Screening	Field/Facility design & construction		Injection-production operations 30 years						
Year	1	2	3	4	5	6		7	8	35	36	37	38	85	86

- **Coordination of effort needed by each link of the CCUS value chain**
- **For plant: new or retrofit construction**
- **Transportation: right-of-way, permitting, construction**
- **Storage: saline reservoir meeting Class VI requirement; EOR Class II requirements**
- **A lot happening at each end of the pipeline**

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- **Conclusions**
  - Projects at each end of the pipeline need to be successful
  - To connect successful projects, a pipeline needs solid financials and access to incentives
  - Business models are varied and may depend on open access status of pipeline and business relationship to source and/or EOR/saline storage operator
  - Current CO_2 EOR pipeline construction is financed/done by operators
  - One successful large-scale CO_2 capture project incorporates EOR and built their 81 mile pipeline themselves.

Questions