Carbon capture and sequestration opportunities at existing biorefineries

Daniel L. Sanchez

Assistant CE Specialist
University of California-Berkeley

Ames Lab / BETO workshop

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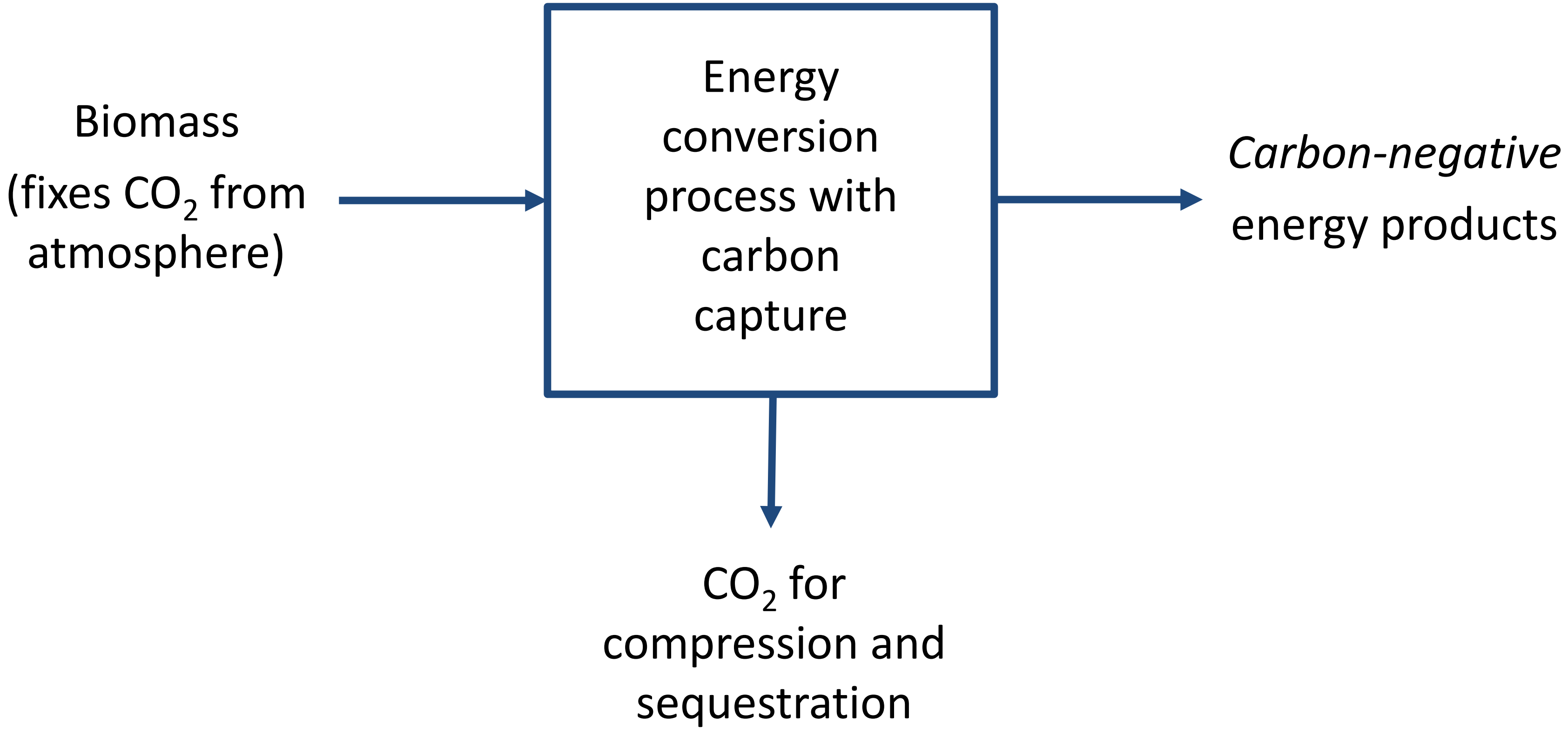
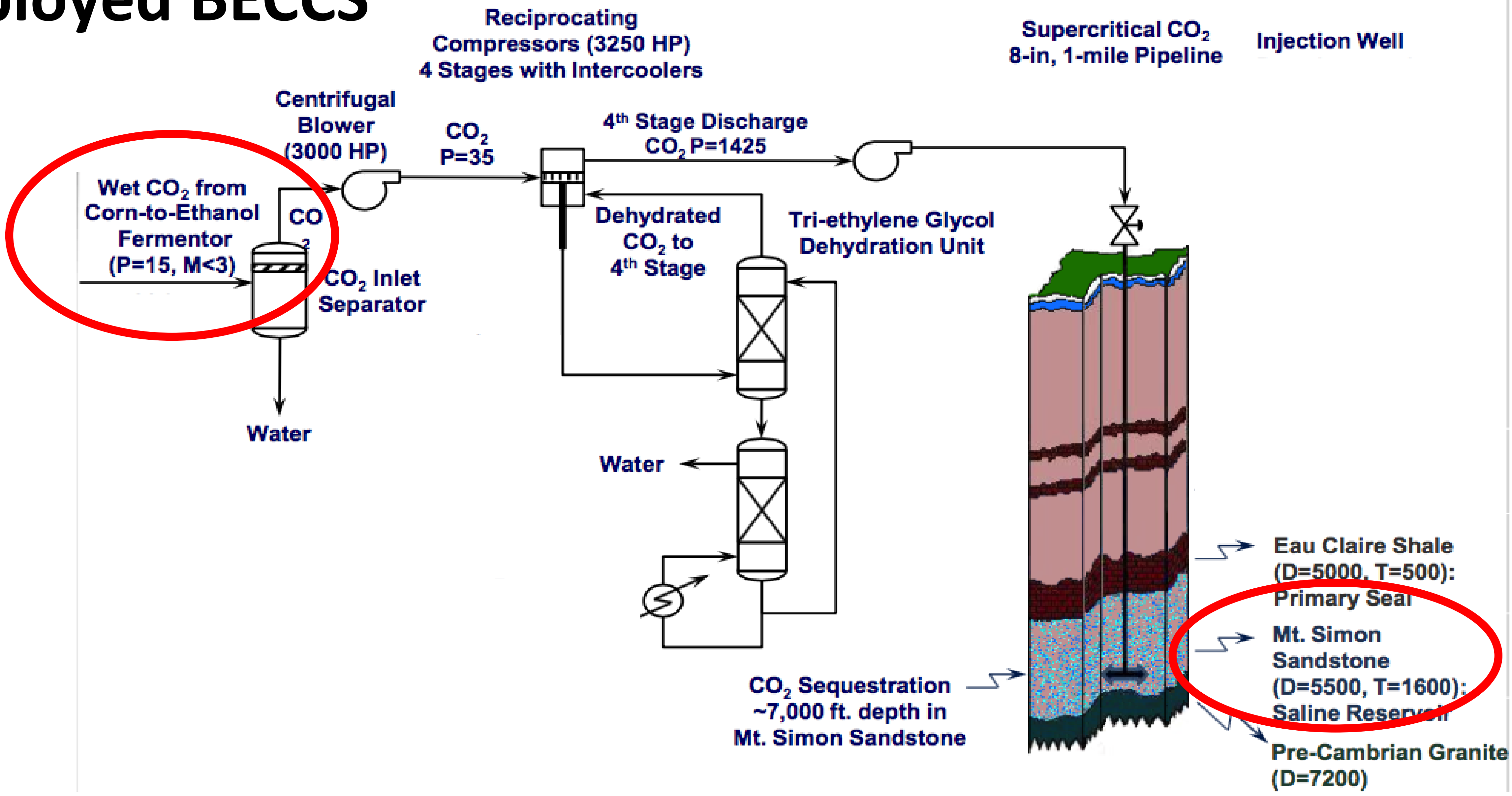
Bioenergy with Carbon Capture and Sequestration (BECCS)



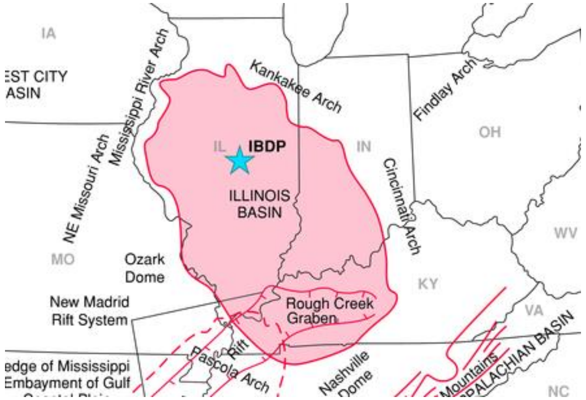
Deployed BECCS



Courtesy of Scott McDonald, ADM

Current deployment: 1 $MtCO_2$/yr

.01% of median
2100 deployment



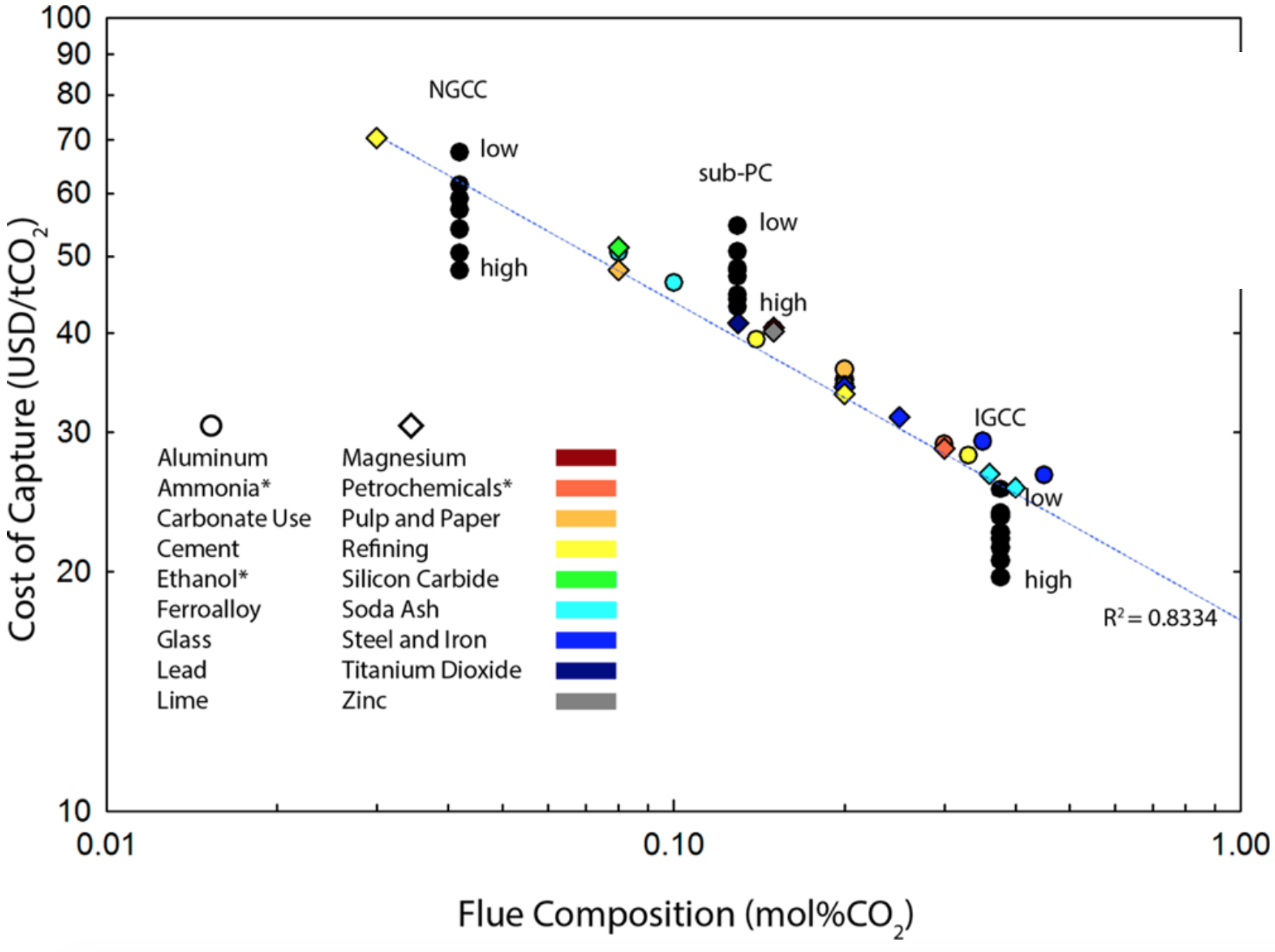
Near-term opportunities for CO_2 capture and sequestration from existing biorefineries in the United States

The UC Berkeley **Carbon Removal Laboratory**

Based on Sanchez et al. *PNAS* (2018)

Motivation

- Point source purity is the primary factor that influences the cost of CO_2 captured
- Estimated breakeven capture cost: **~$30/tCO$_2$** for ethanol fermentation
- Capture typically comprises the largest cost in CCS

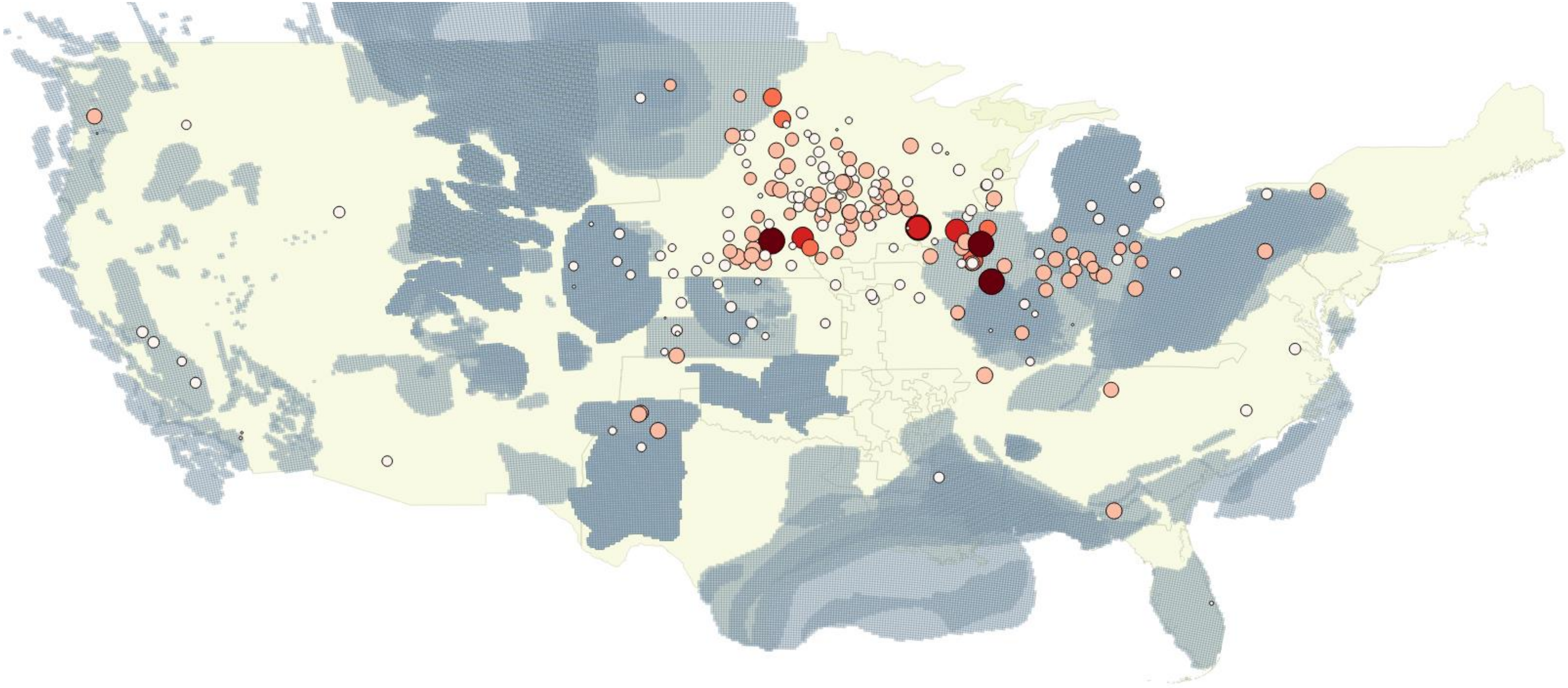


Psarras et al. *ES&T* (2017)

Motivation (2)

- Existing infrastructure and deployments
- Markets: beverage carbonation, dry ice, chemicals, pH reduction
- U.S. merchant CO_2 market: ~10 million tons
- Current sequestration: ~1 $MtCO_2$/yr
  - Estimated cost: $35/ton

Motivation (3)



Scale (MtCO_2/yr)

Dedicated geological storage (worldwide, 2016): 3.7

Enhanced oil recovery (anthropogenic, worldwide, 2016): 28

Total ethanol (fermentation) resource (US): 45

Total ethanol resource (worldwide, 2015): 73

Total enhanced oil recovery (worldwide): ~80

Problem statement

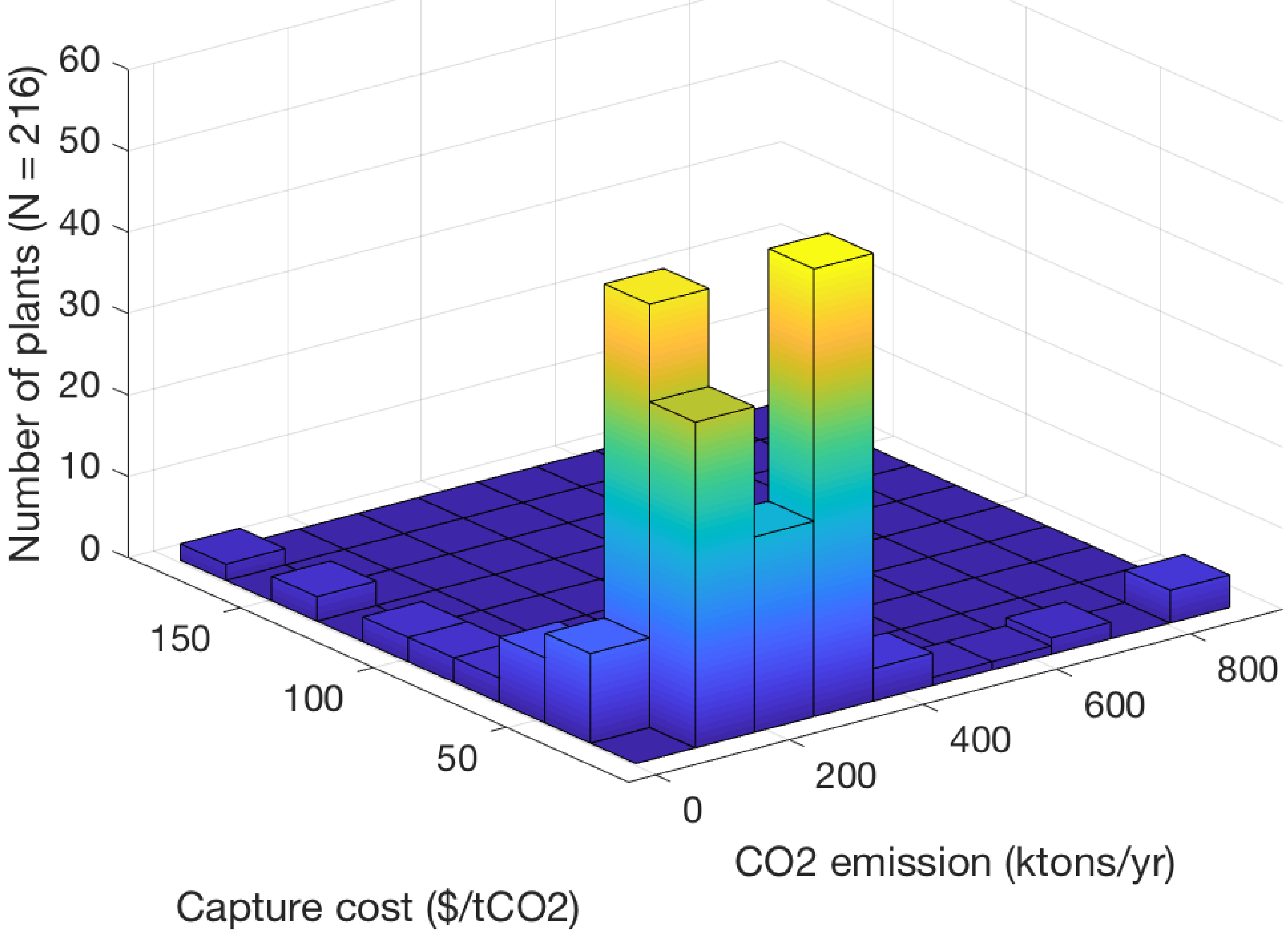
We study the abatement potential and costs of near-term biogenic CO_2 capture and sequestration from biorefineries in the United States using process engineering, spatial optimization, and lifecycle assessment

Estimate CO_2 volumes, and capture, compression, transportation, and sequestration costs

Minimize total costs of CCS network via integer programming over range of feasible policy incentives

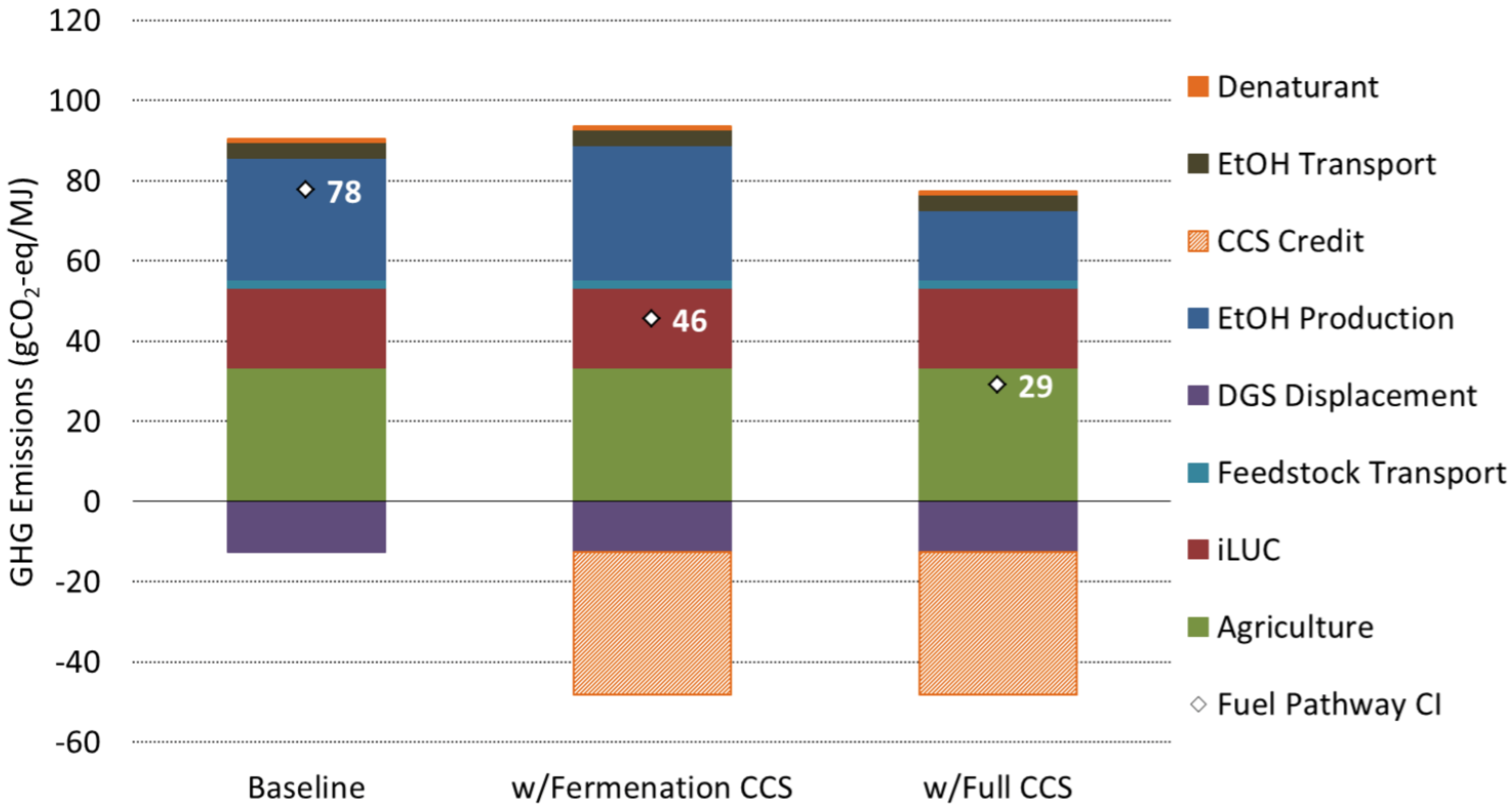
Calculate emissions impacts and abatement costs for CA's Low Carbon Fuel Standard and other policies

Results



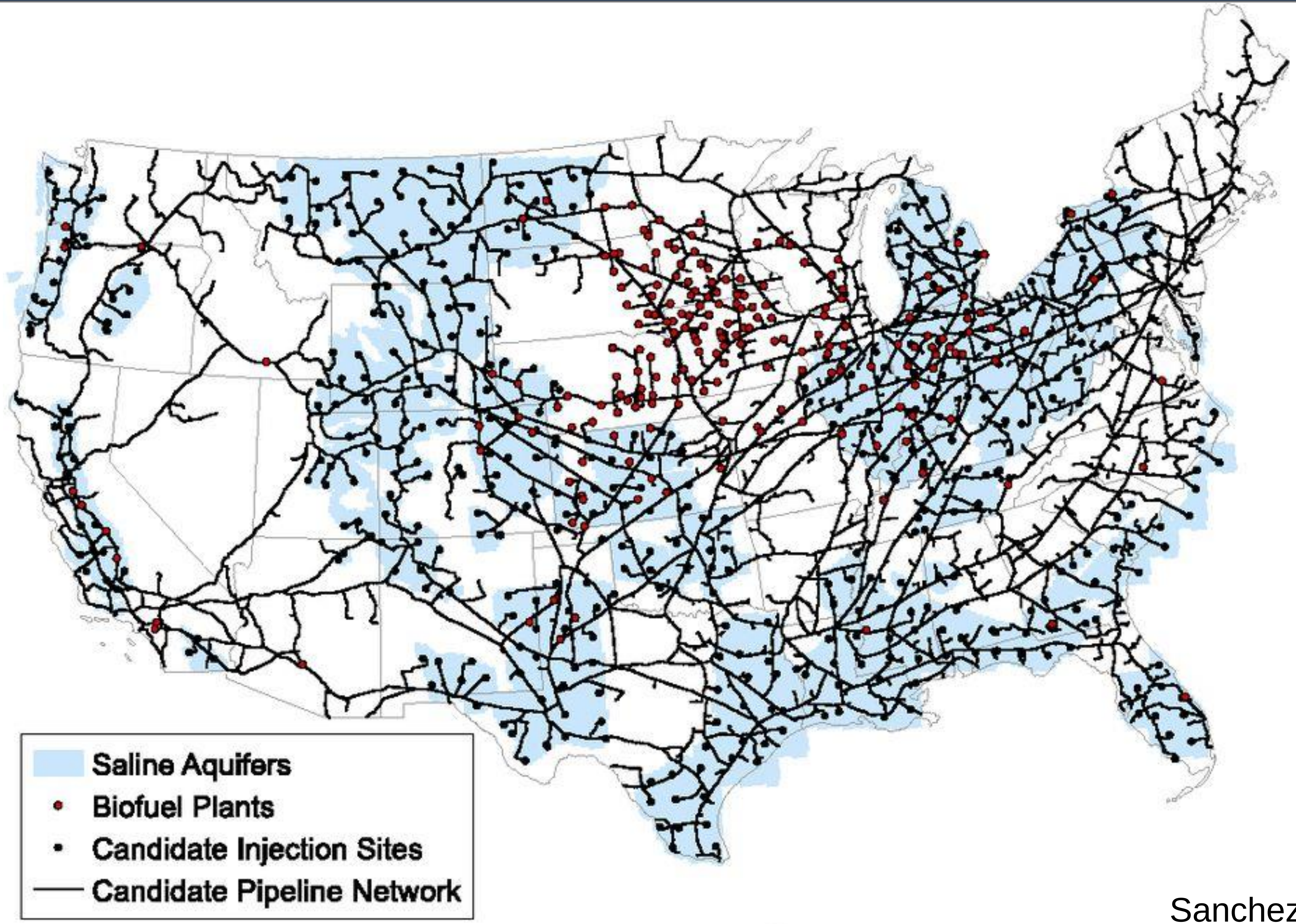
Contour plot of modeled abatement costs and scales for CO_2 capture, dehydration, and compression for biorefineries (N=216)

Sanchez et al. *PNAS* (2018)



Courtesy of Sean McCoy, Univ. of Calgary

Optimal spatial capture, transportation, and sequestration networks for sequestration credits **of \$30, \$60, and \$90 / tCO_2**, at the scale of the United States, and focusing on the Midwest United States



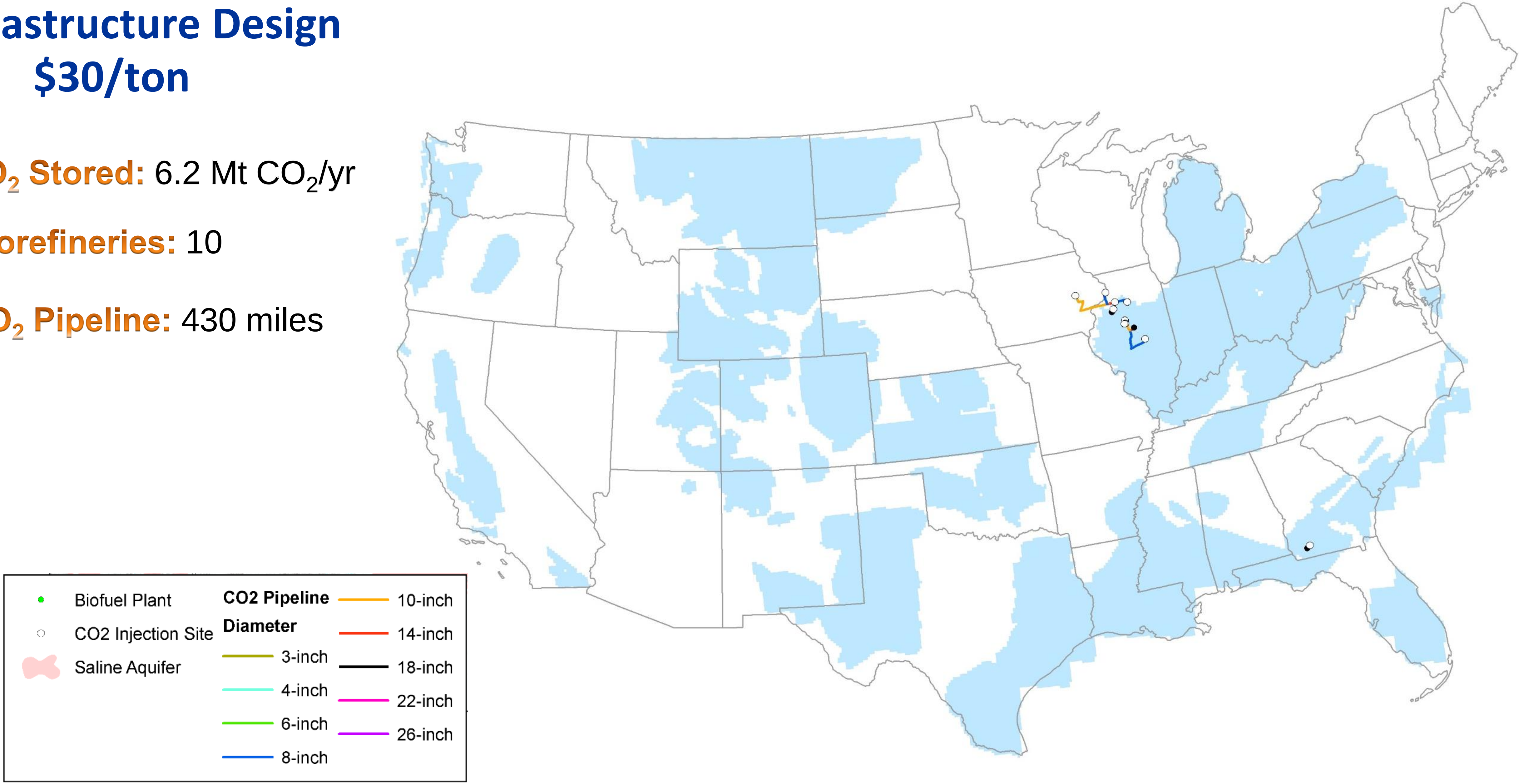
Sanchez et al. *PNAS* (2018)

Infrastructure Design
$30/ton

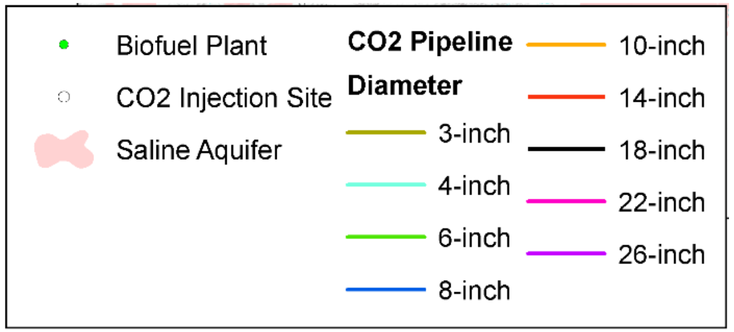
CO_2 Stored: 6.2 Mt CO_2/yr

Biorefineries: 10

CO_2 Pipeline: 430 miles



$30/ton


Biofuel Plant
CO2 Injection Site
Saline Aquifer
CO2 Pipeline Diameter
3-inch
4-inch
6-inch
8-inch
10-inch
14-inch
18-inch
22-inch
26-inch

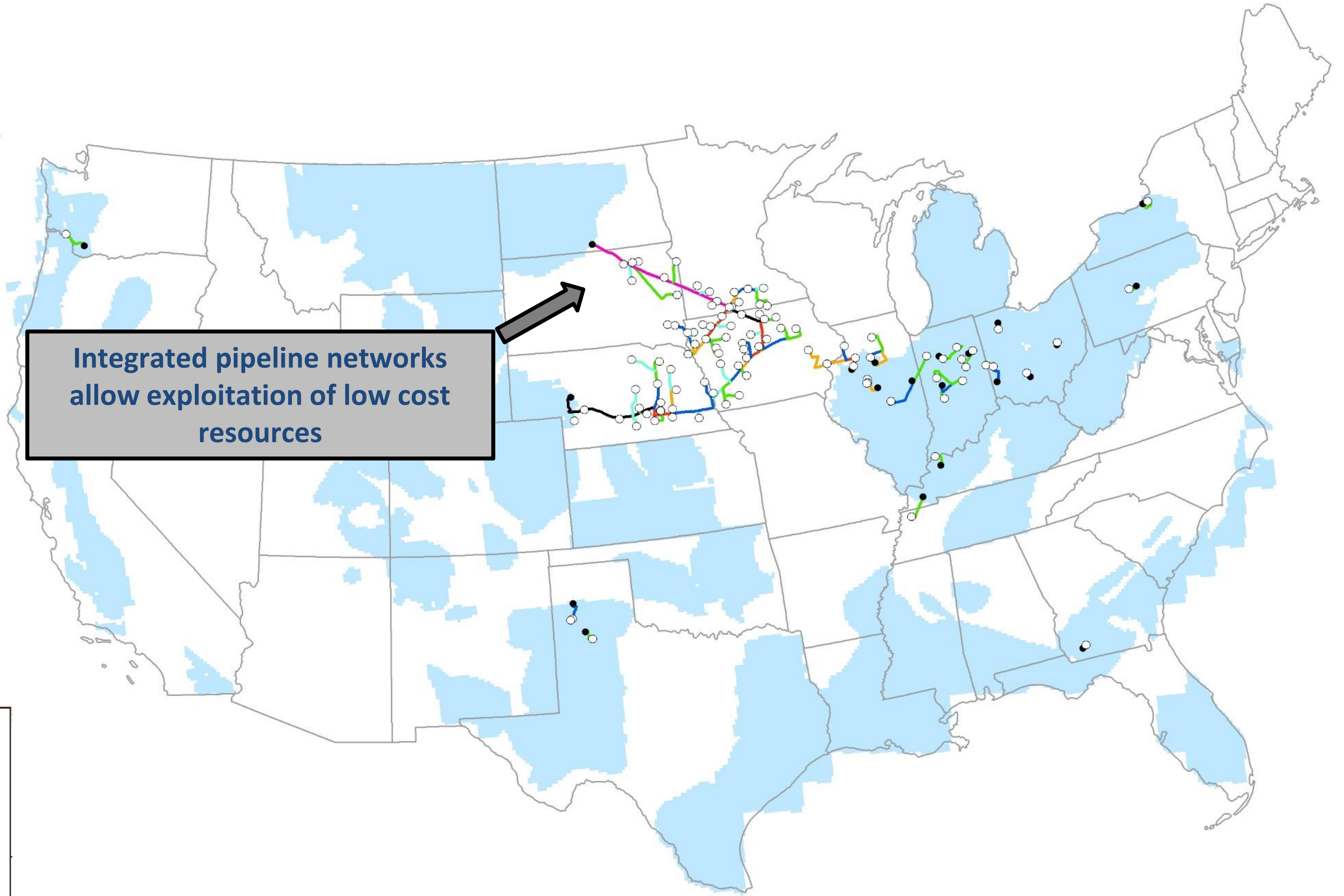

B
$30

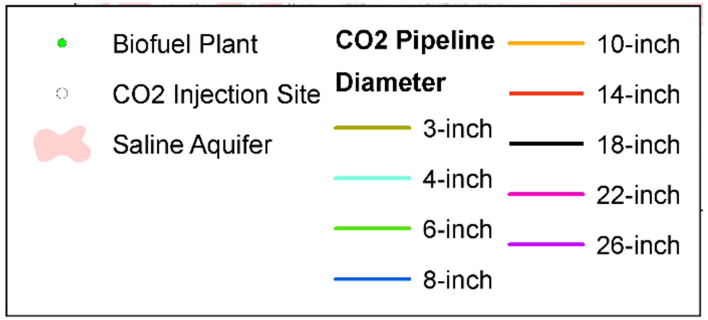
$60/ton

CO_2 Stored: 30.4 Mt CO_2/yr

Biorefineries: 106

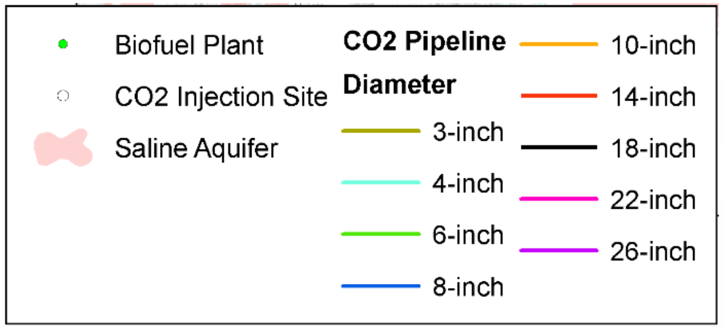
CO_2 Pipeline: 4,256 miles





$60/ton


C
$60

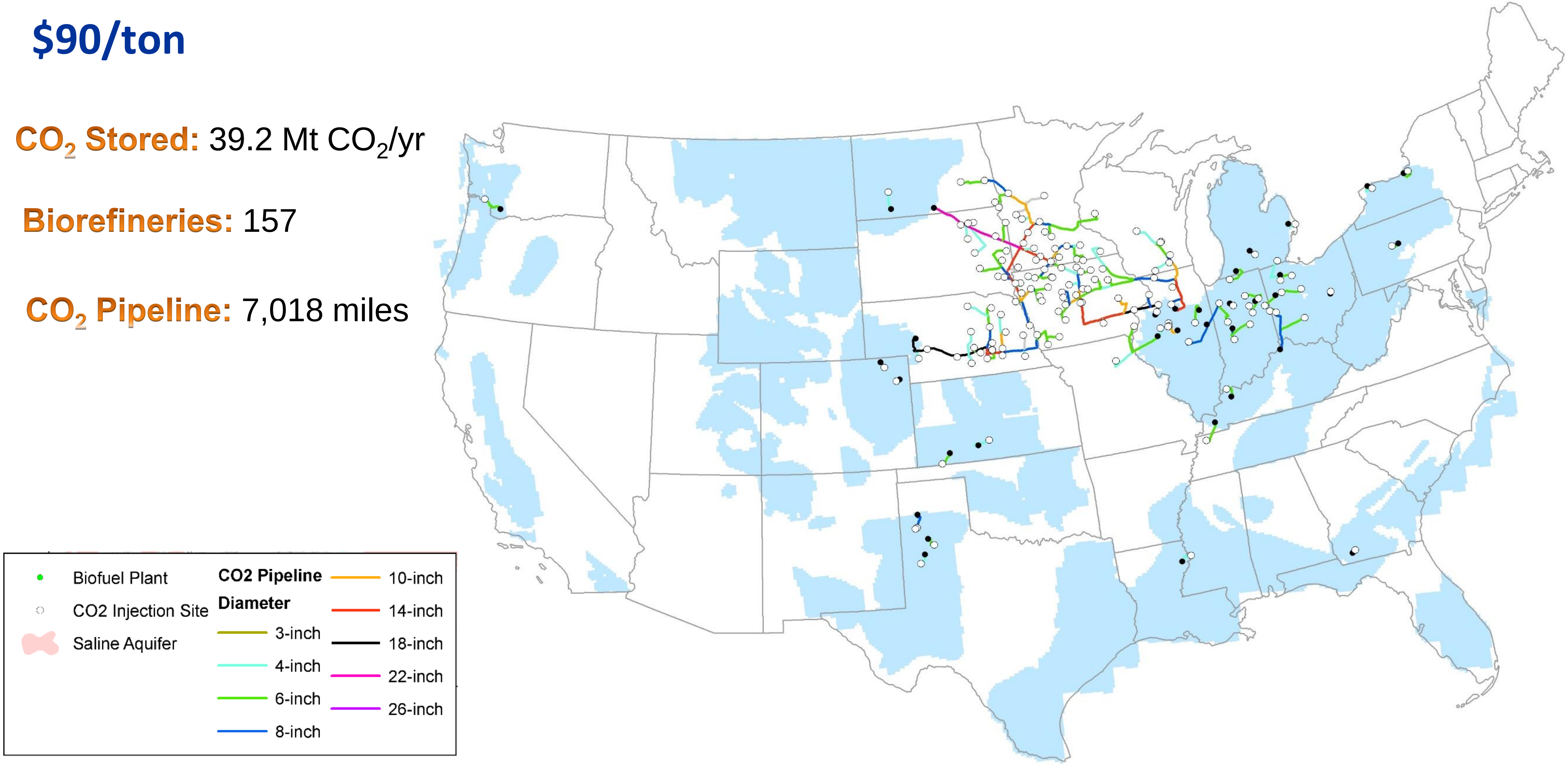

Biofuel Plant
CO2 Injection Site
Saline Aquifer
CO2 Pipeline Diameter
3-inch
4-inch
6-inch
8-inch
10-inch
14-inch
18-inch
22-inch
26-inch

$90/ton

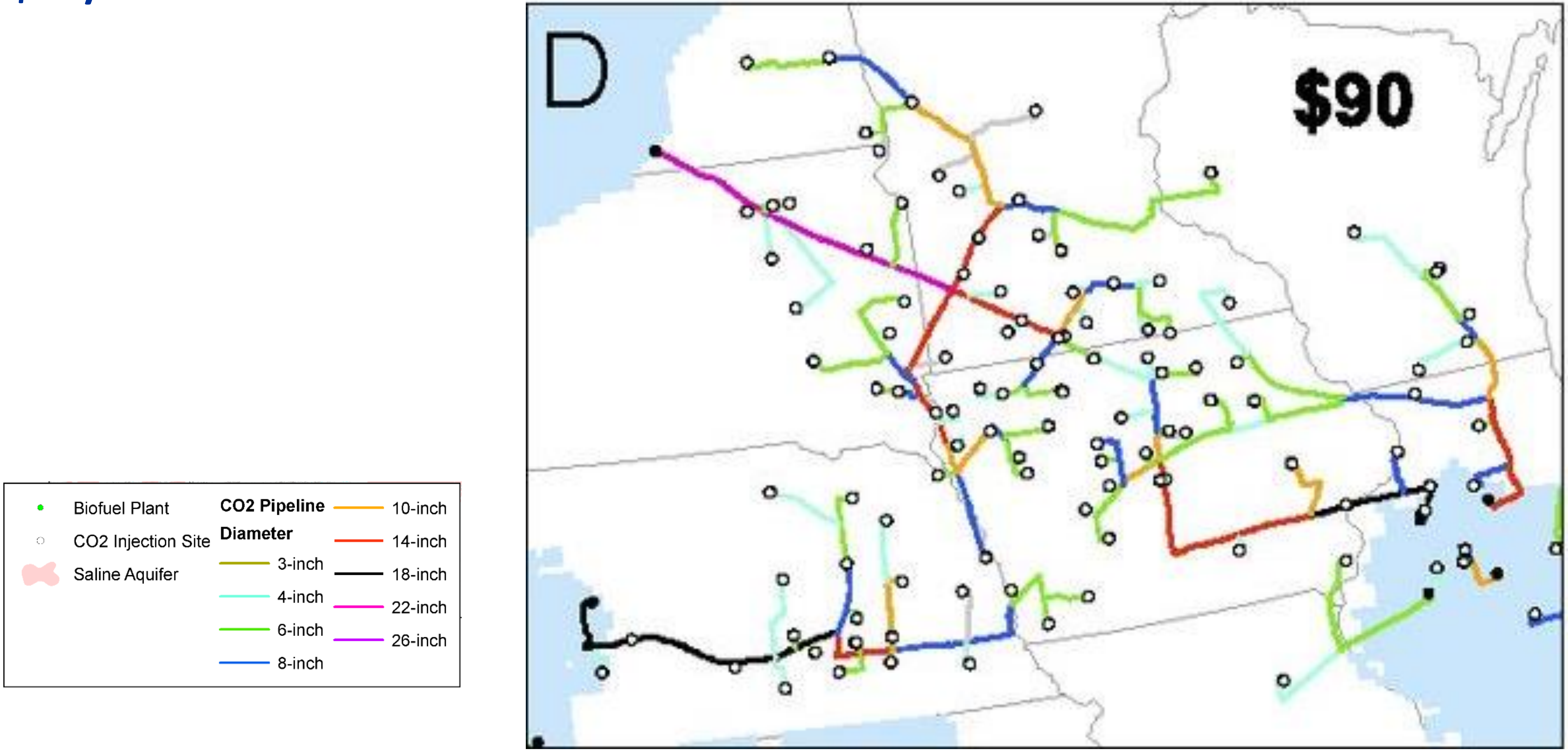
CO_2 Stored: 39.2 Mt CO_2/yr

Biorefineries: 157

CO_2 Pipeline: 7,018 miles



$90/ton


D
$90
Biofuel Plant
CO2 Injection Site
Saline Aquifer
CO2 Pipeline Diameter
3-inch
4-inch
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22-inch
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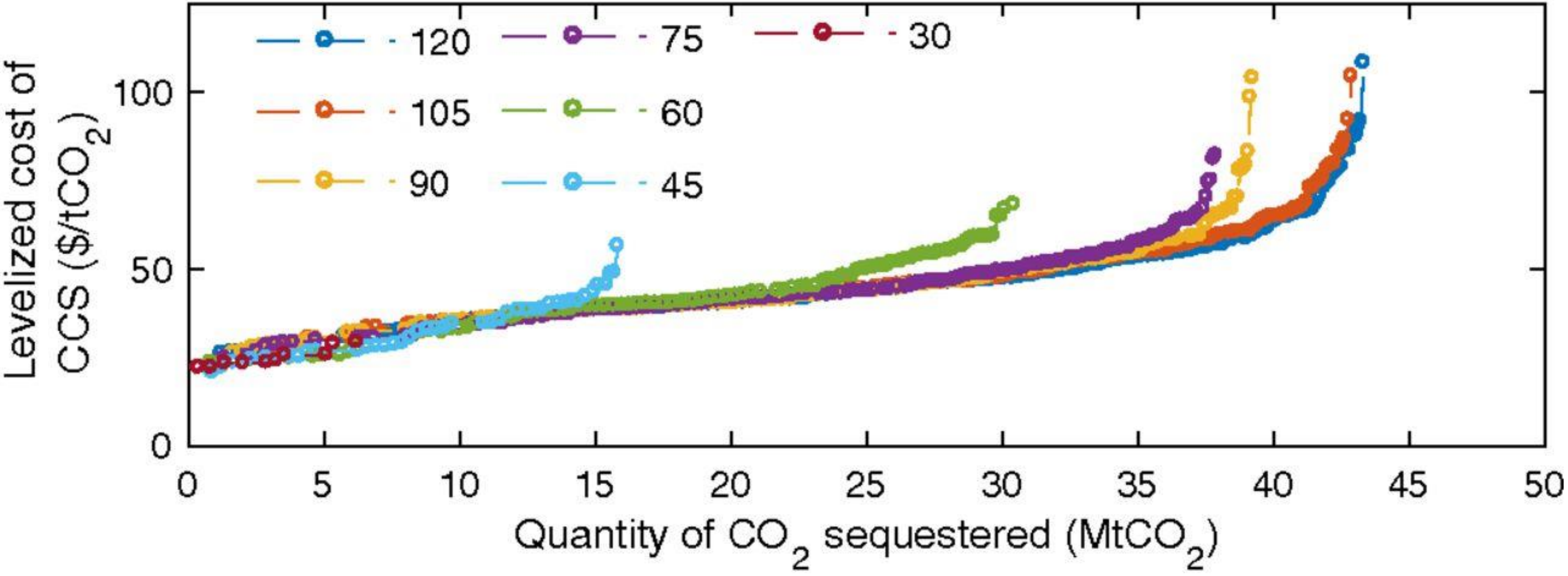
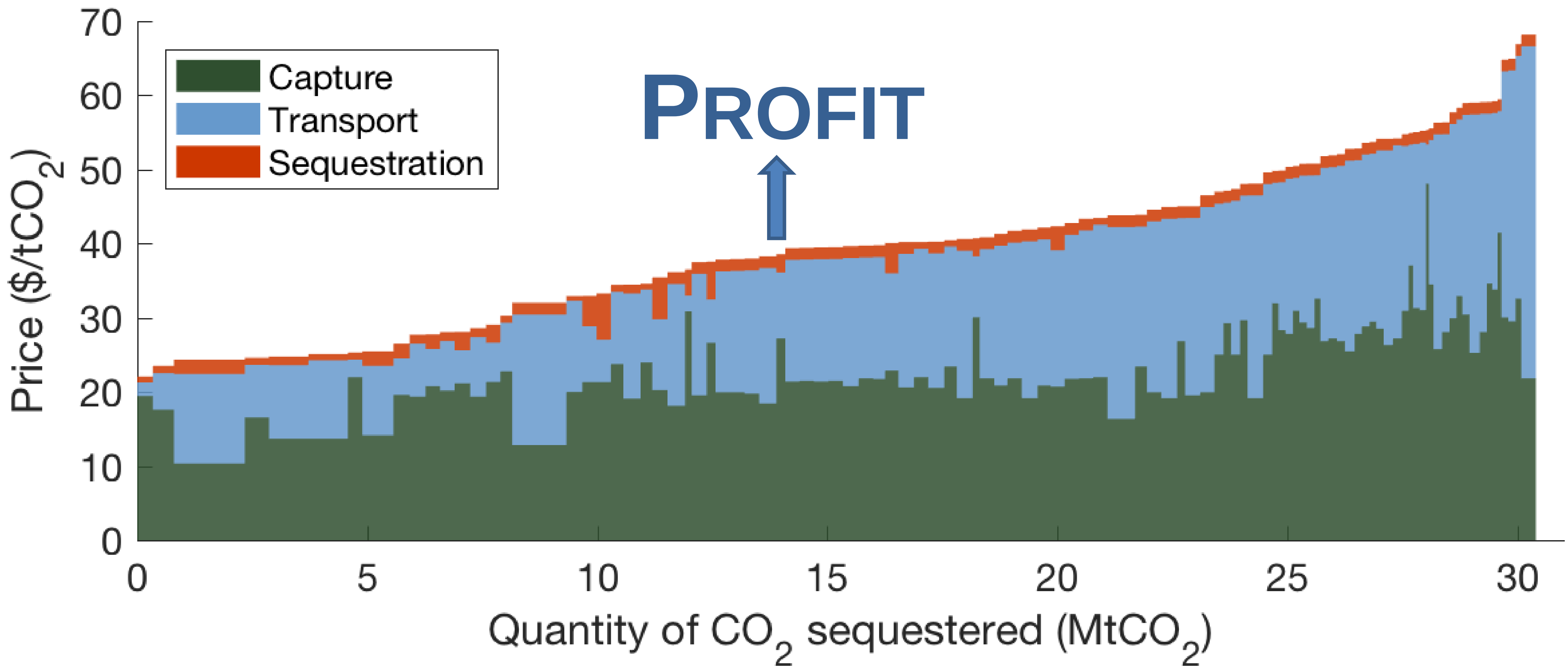


120
75
30
105
60
90
45
Levelized cost of CCS ($/tCO2)
0
50
100
0
5
10
15
20
25
30
35
40
45
50
Quantity of CO2 sequestered (MtCO2)



PROFIT
Capture
Transport
Sequestration
Price ($/tCO2)
Quantity of CO2 sequestered (MtCO2)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30

Policy drivers
and
policy impacts

Carbon sequestration tax credits

- FUTURE Act (S. 1535):
  - Previous law: ~\$20/tCO_2 for permanent sequestration, \$10 for enhanced oil recovery, 500 kt/yr minimum, likely fully subscribed
  - Current law: up to **\$50/tCO_2 tax credit** (45Q) sequestered, 12-year duration
  - No credit cap, ~25 kt/yr minimum
  - Signed into law February 2018 after several years of effort

- Liken to sequestration credit

CARBON CAPTURE COALITION

Carbon Capture Coalition Launches to Further Adoption of Carbon Capture Technologies as a National Energy, Economic and Environmental Strategy

February 23, 2018 | News

National Enhanced Oil Recovery Initiative Adopts New Brand and Adds New Members

Low Carbon Fuel Standards

- California Low Carbon Fuel Standard
  - Uncertain price, currently $125 - **195/t$CO_2$** abated
  - Price cap: $200/ton
  - Limited market size
  - <u>Recently adopted</u>: quantification and permanence methodologies for CCS
  - <u>Recently adopted</u>: extension through 2030, with tightening of cap

- Additional markets: Oregon, British Columbia
  - Soon: Canada and Brazil


Low Carbon Fuel Standard credit price (October 2012-October 2018)
U.S. dollars per metric ton
eia
200
175
150
125
100
75
50
25
0
Oct 2012
Oct 2013
Oct 2014
Oct 2015
Oct 2016
Oct 2017
Oct 2018

Conclusions about U.S. Market Opportunities

- Low-cost CCS opportunities exist at biorefineries around the United States
- Aggregation of CO_2 in integrated pipeline networks enable cost-effective sequestration
- Near-term policy could be sufficient to incentivize up to ~45 $MtCO_2$/yr of sequestration

This financial opportunity can catalyze the growth of carbon capture, transport, utilization, and sequestration, improve the lifecycle impacts of conventional biofuels, and help fulfill the mandates of low-carbon fuel policies across the U.S.

Occidental Petroleum and White Energy to Study Feasibility of Capturing CO_2 for Use in Enhanced Oil Recovery Operations

June 19, 2018 09:00 AM Eastern Daylight Time

"The carbon capture project would be designed to be eligible for 45Q tax credits and California's Low Carbon Fuel Standard Carbon Capture and Storage protocol, both currently in development, demonstrating that these important incentives result in near-term investment, reduced CO2 emissions and jobs."

The Washington Post

Democracy Dies in Darkness

Energy and Environment

The world needs to store billions of tons of carbon. It could start in a surprising place.

By Chris Mooney April 23 Email the author

A wagon adds freshly gathered corn cobs to a pile on a farm near Hurley, S.D., in 2007. (Dirk Lammers/AP)

The corn-based ethanol industry could become a surprising leader in a technology that the world needs to fight climate change, an economic analysis published Monday suggests — a development that

Questions for audience

- Why haven't we seen more projects announced?
  - Uncertainty around 45Q implementation?
  - Stringency of California CCS protocol?
  - Permitting of CCS pipelines?
  - Lack of knowledge of CCS within industry?
- What could make this realistic?
  - Trucking of CO_2?
  - Smaller-scale utilization options?
  - Regional storage hubs?
- How much CO_2 is already captured for merchant markets?