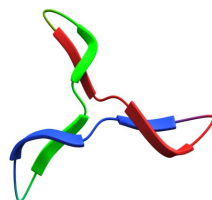


Evaluating Anthropogenic Sources of CO₂ for use in EOR or Storage Projects

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October 1, 2020



Carbon Management and CO₂ EOR

Setting the Stage

- CO₂ EOR has been historically supply-limited in some U.S. regions (recent market dynamics notwithstanding)
- Potential oil reserves and CO₂ storage with current and next generation CO₂ EOR are substantial
 - Caveat: EOR recently competing for capital with other production technologies (e.g., hydraulic fracturing, horizontal drilling)
- CO₂ EOR provides a path to significantly reduce CO₂ emissions from anthropogenic (man-made) industrial sources



Session Outline

- Anthropogenic CO₂ Sources and End Use
- Factors affecting CO₂ value
- Components of CO₂ Costs
- Summary



Stationary Anthropogenic CO₂ Sources

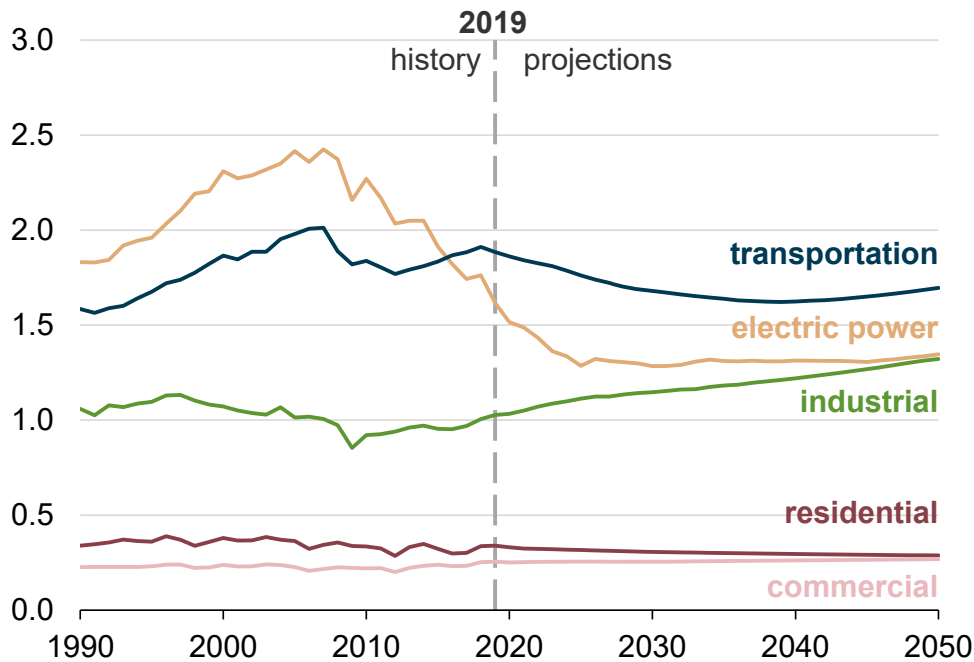
- Combustion
 - Power plants, process heaters, boilers
- Natural Gas Processing
 - More than half of worldwide raw natural gas contains >4% CO₂ (and sometimes much more)
- Chemical Byproducts
 - Hydrogen, ammonia (fertilizer), cement, ethylene, ethylene oxide, iron & steel, coal to chemicals/fuels
- Ethanol Fermentation
- Other/Developmental Technologies
 - IGCC with shift reaction, NG to hydrogen for CC
 - Oxy-fuel combustion



U.S. CO₂ Emission Sources

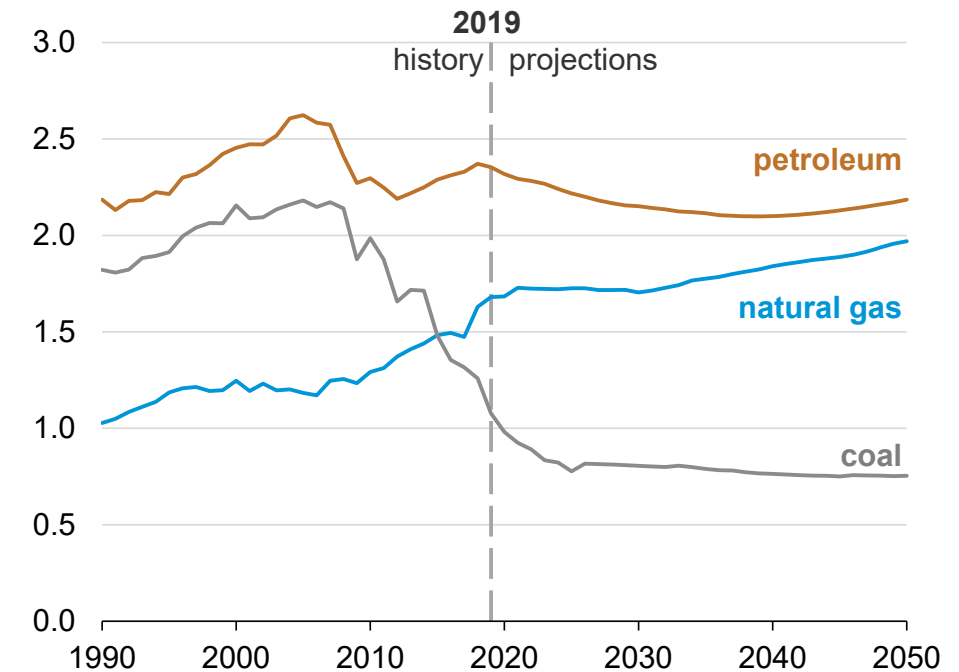
Energy-related CO₂ emissions by energy sector (AEO2020 Reference case)

billion metric tons



Energy-related CO₂ emissions by fuel (AEO2020 Reference case)

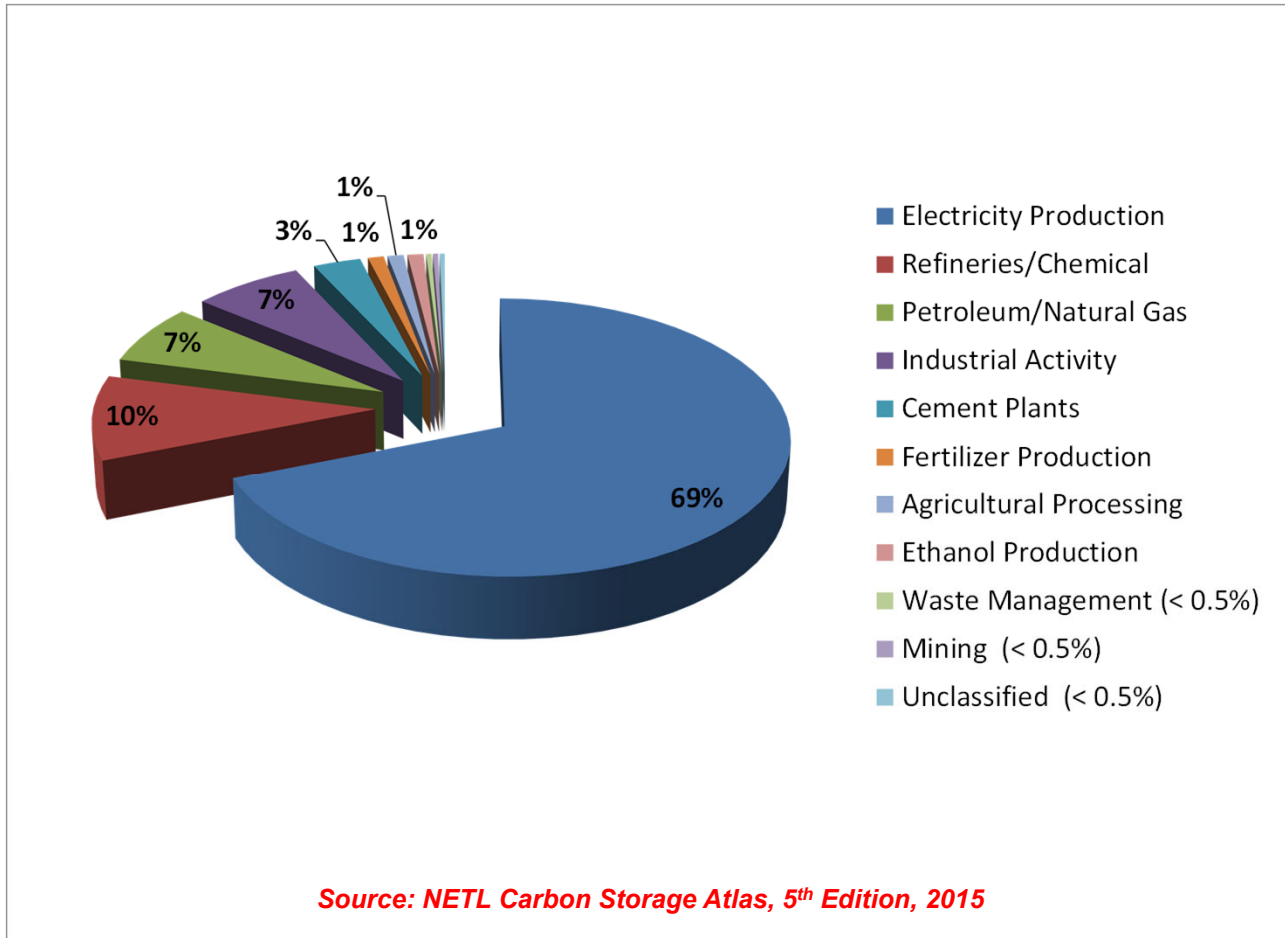
billion metric tons



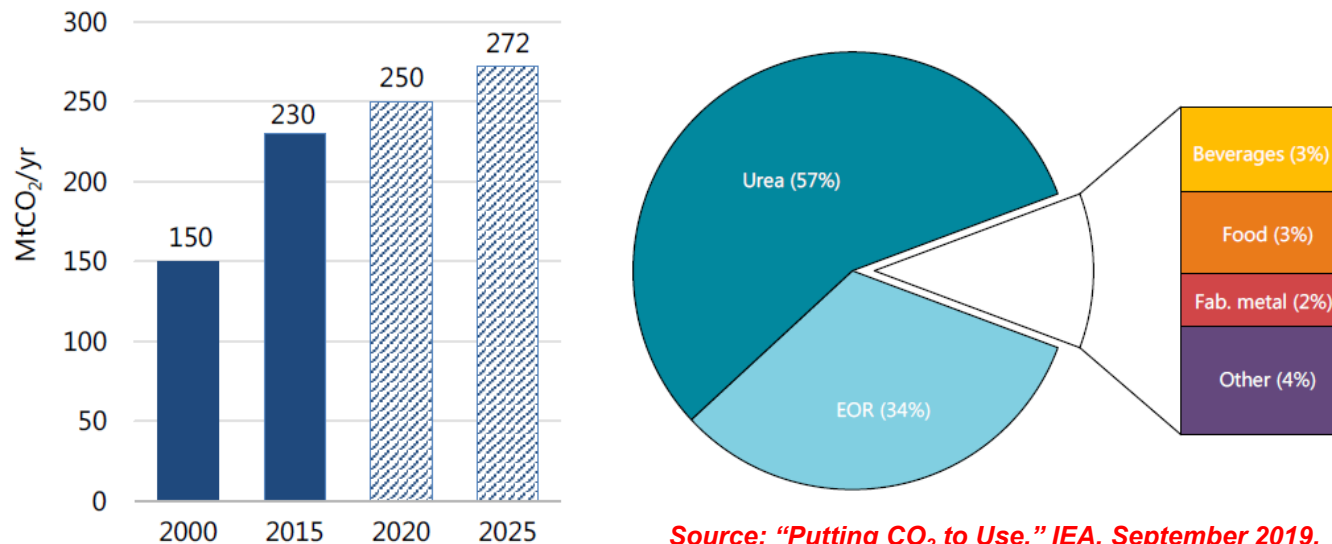
Source: U.S. EIA Annual Energy Outlook 2020



U.S. Stationary CO₂ Emission Sources - 2015



Current Global CO₂ Demand by End Use (2015 and projections)



Source: "Putting CO₂ to Use." IEA, September 2019.

- EOR currently dominates the demand for externally sourced CO₂.
 - 70 – 80 Mt CO₂/yr
 - *Urea (fertilizer production) is internal CO₂ re-use via ammonia production*
- CO₂ EOR occurs mostly in North America
- 1.7% Annual Growth Rate Projected in Demand (IHS Markit, 2018)



Factors Affecting CO₂ Value

Economic Attractiveness

- Quantity (ton/day, tonne/yr, or MMscfd)
- Source Purity (and impurities) and Pressure
- Distance Between Source and Sink
- Reliability/Availability
- Cost of Electricity
- Rate of Return and Numerous Other Project Specific Economic Factors
- Government incentives (tax credits, taxes, etc.)





Source: NRG Energy Case Studies, Petra Nova, Carbon capture and the future of coal power.

NRG/JX Petra Nova CO₂ Capture Project near Houston, Texas

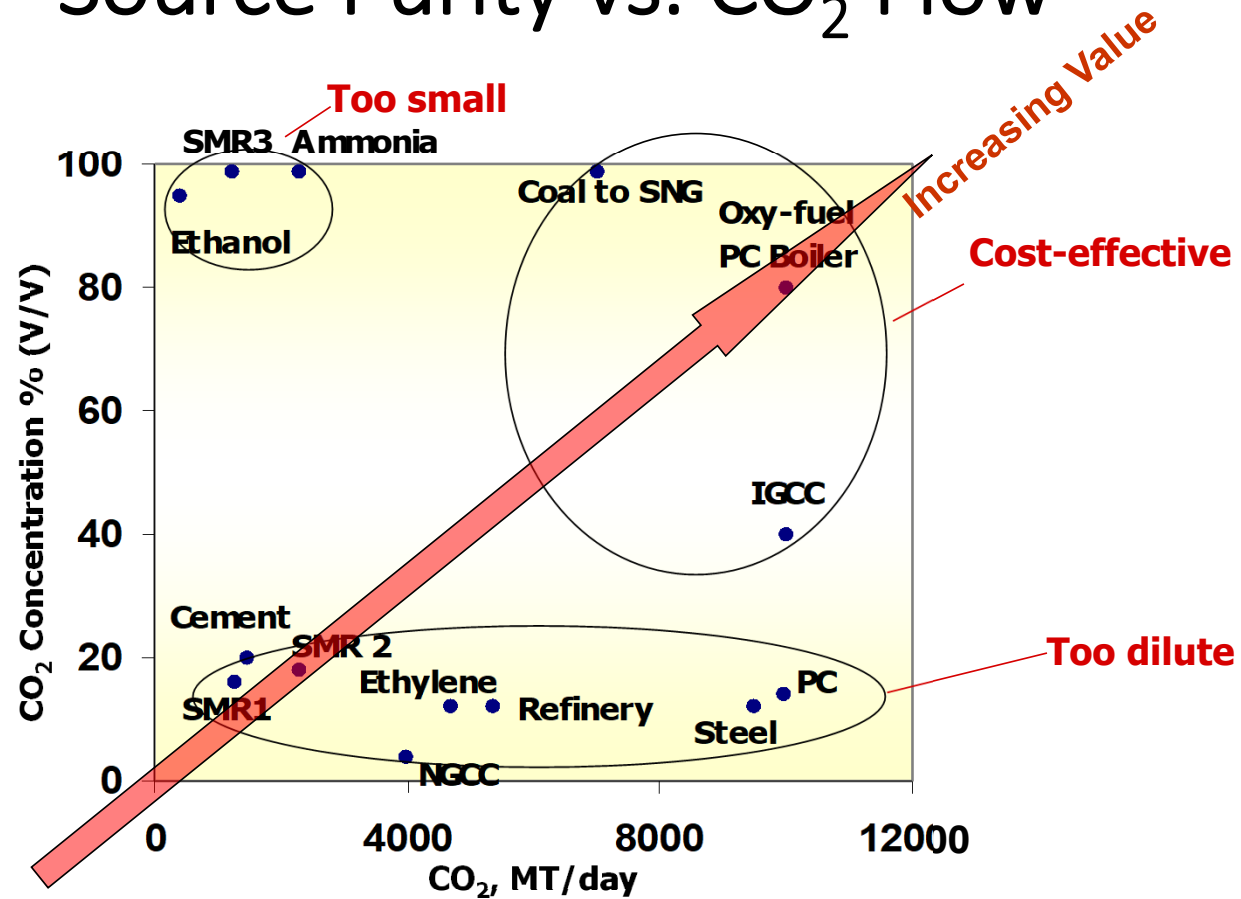
Air Products Steam Methane Reformer Project in Port Arthur, Texas



Source: Air Products and Chemicals, Inc.



Source Purity vs. CO₂ Flow



SMR1 – SMR/PSA plant syngas; SMR2 – SMR/PSA plant flue gas
 SMR3 – SMR/Amine plant CO₂; PC – pulverized coal power plant



CO₂ Capture Costs by Source

Industrial Process	Reference Plant Capacity	CO ₂ Source Stream	CO ₂ to Product Ratio (tonne CO ₂ /tonne Product)	Source Stream CO ₂ Concentration (mol%)	Source Stream CO ₂ Partial Pressure (psia)	CO ₂ Available for Capture (M tonnes CO ₂ /year)		Breakeven Cost of Capturing CO ₂ (\$/tonne CO ₂)
						Reference Plant	All U.S. sources	
High Purity Sources								
Ethanol	50 M gal/year	Distillation gas	0.96	100	18.4	0.14	40	30
Ammonia	907,000 tonnes/year	Stripping vent	1.9	99	22.8	0.458	6	27
Natural Gas Processing	500 MMscf/d	CO ₂ vent	N/A ¹	99	23.3	0.649	27	18
Ethylene Oxide	364,500 tonnes/year	AGR product stream	0.33	100	43.5	0.122	1	25
Coal-to-Liquids (CTL)	50,000 bbl/d	AGR product stream	N/A ²	100	265	8.74	-	9
Gas-to-Liquids (GTL)	50,000 bbl/d	AGR product stream	N/A ²	100	265	1.86	-	9
Low Purity Sources								
Refinery Hydrogen	59,000 tonnes/year	PSA tail gas	10.5	44.5	8.9	0.274	68	118
Iron/Steel	2.54 M tonnes/year	Plant Total COG PPS COG/BFG ³	2.2	N/A	N/A	3.9	49	99
				23.2	3.4	2.75		99
				26.4	3.9	1.16		101
Cement SCR/FGD Sensitivity	992,500 tonnes/year	Kiln Off-gas	1.2	22.4	3.3	1.14	80	100 127
Coal-fired power plants	550 MW	Flue Gas	NA	13.5	2.0	4.13	2,545 ⁴	77 ⁵⁶

Source: NETL "Post Combustion Capture Analysis Update", August 2018





CO₂ Pipelines in the United States

Source: National Petroleum Council (NPC) "Carbon Capture, Use, and Storage (CCUS) Report", August 2019



CO₂ Pipeline Costs

Pipeline Name	Green	Greencore	Seminole	Coffeville	Webster	Emma
Company	Denbury	Greencore Pipeline Company	Tabula Rasa Energy	Perdure Petroleum	Denbury	Tabula Rasa Energy
Year Constructed	2009/2010	2011/2012	2012	2013	2013	2015
Length (miles)	320	232	12.5	67.85	9.1	2
Diameter (inches)	24	20	6	8	16	6
Total Cost (\$/mile)	\$3,044,000	\$1,372,700	\$480,000	\$928,500	\$3,190,000	\$750,000
Unit Cost (\$/inch-mile)	\$126,823	\$68,635	\$80,000	\$116,062	\$199,176	\$125,000

Source: National Petroleum Council (NPC) "Carbon Capture, Use, and Storage (CCUS) Report", August 2019



Summary

- CO₂ availability for EOR has generally been limited on historical basis
- Higher oil prices than today could lead to increased demand for CO₂ for EOR
- EOR creates a path or a bridge to storage of man-made CO₂
- Not all man-made CO₂ is created equal – important factors include quantity, source pressure, purity, and impurities, transport distance, and daily reliability and long term availability.



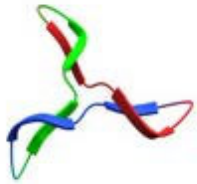
Questions & Discussion

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