CO2 Capture Costs Putting the Pieces Together

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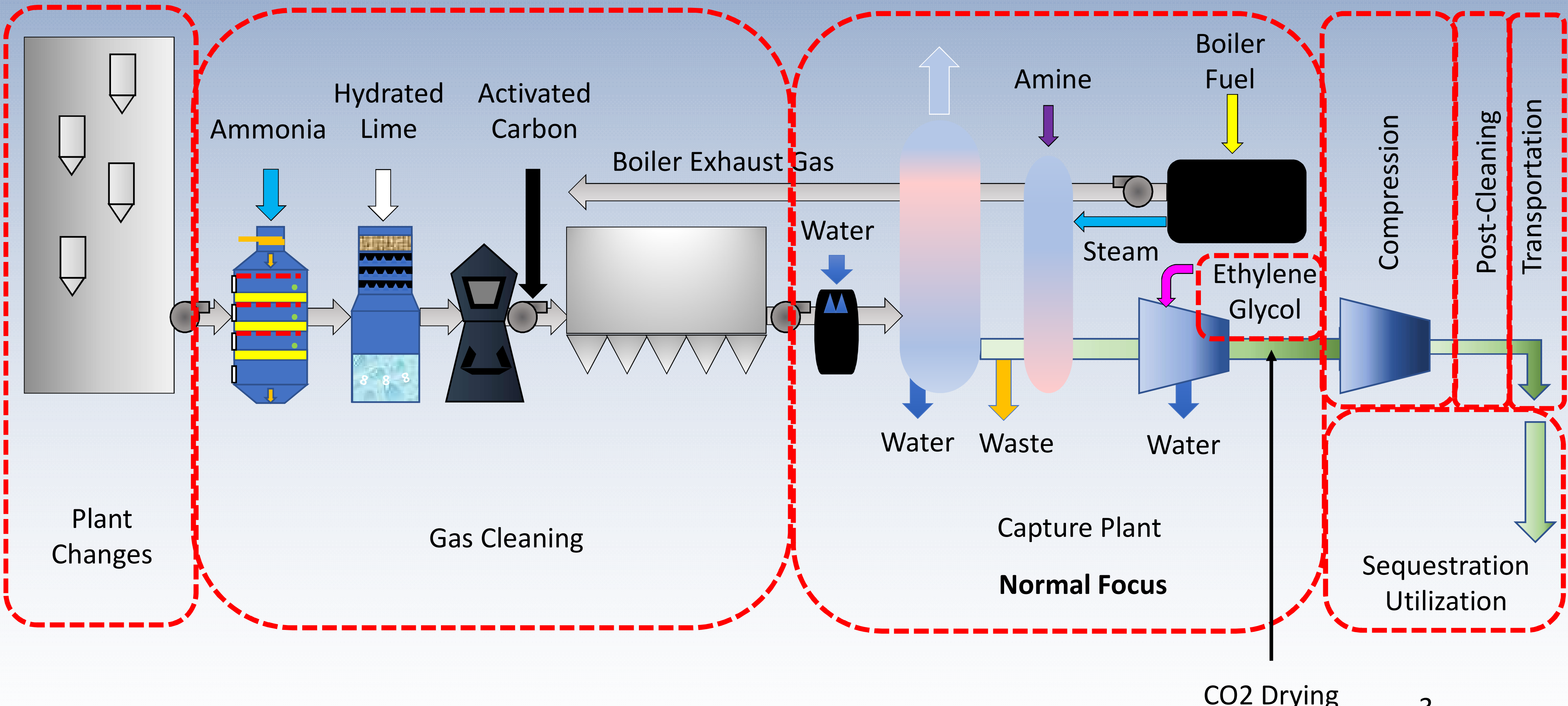
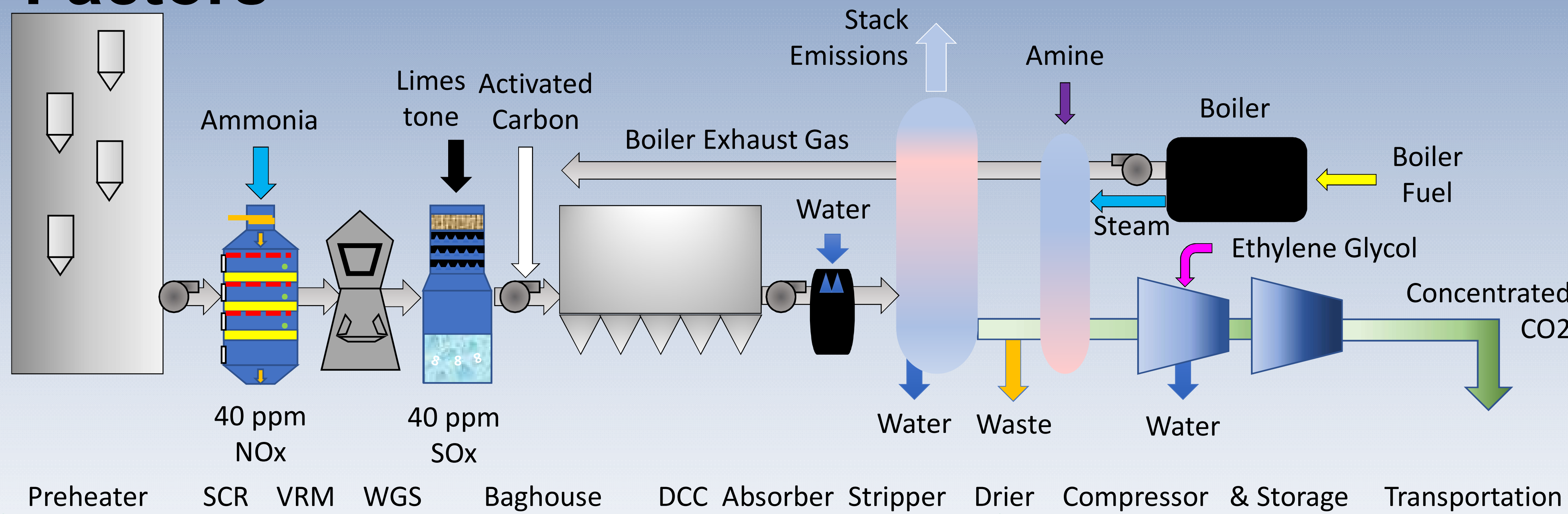
Carbon Capture = Costs of a New Plant

Most of what you hear is optimistic !

Carbon Capture Cost Boundaries



Carbon Capture System ($1bn)– 2 Main Cost Factors



Cost is a Function of Gas Quality & Flow

Heat Consumption, Fuel Type, Elevation, & Inleakage

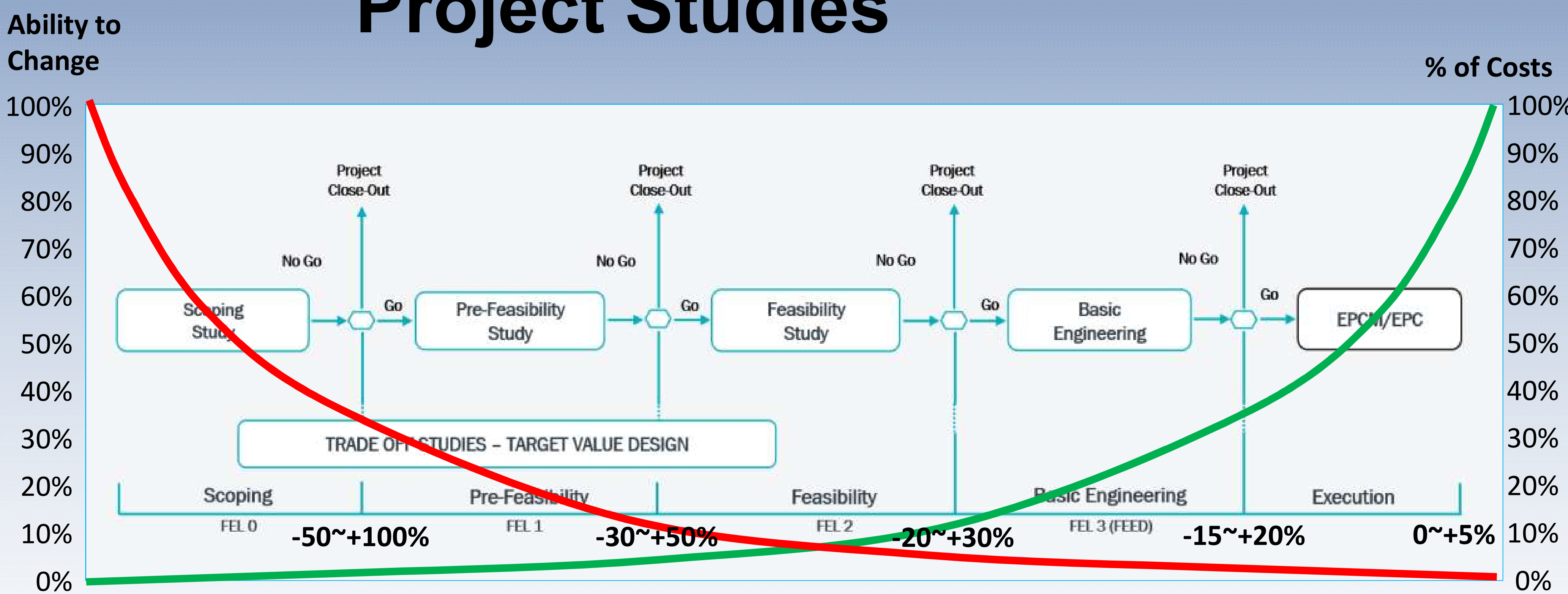
25~34% of Costs

Cost is a function of CO_2 Captured

CO_2 from fuel, calcination, & boiler

66~75% of Costs

Project Studies



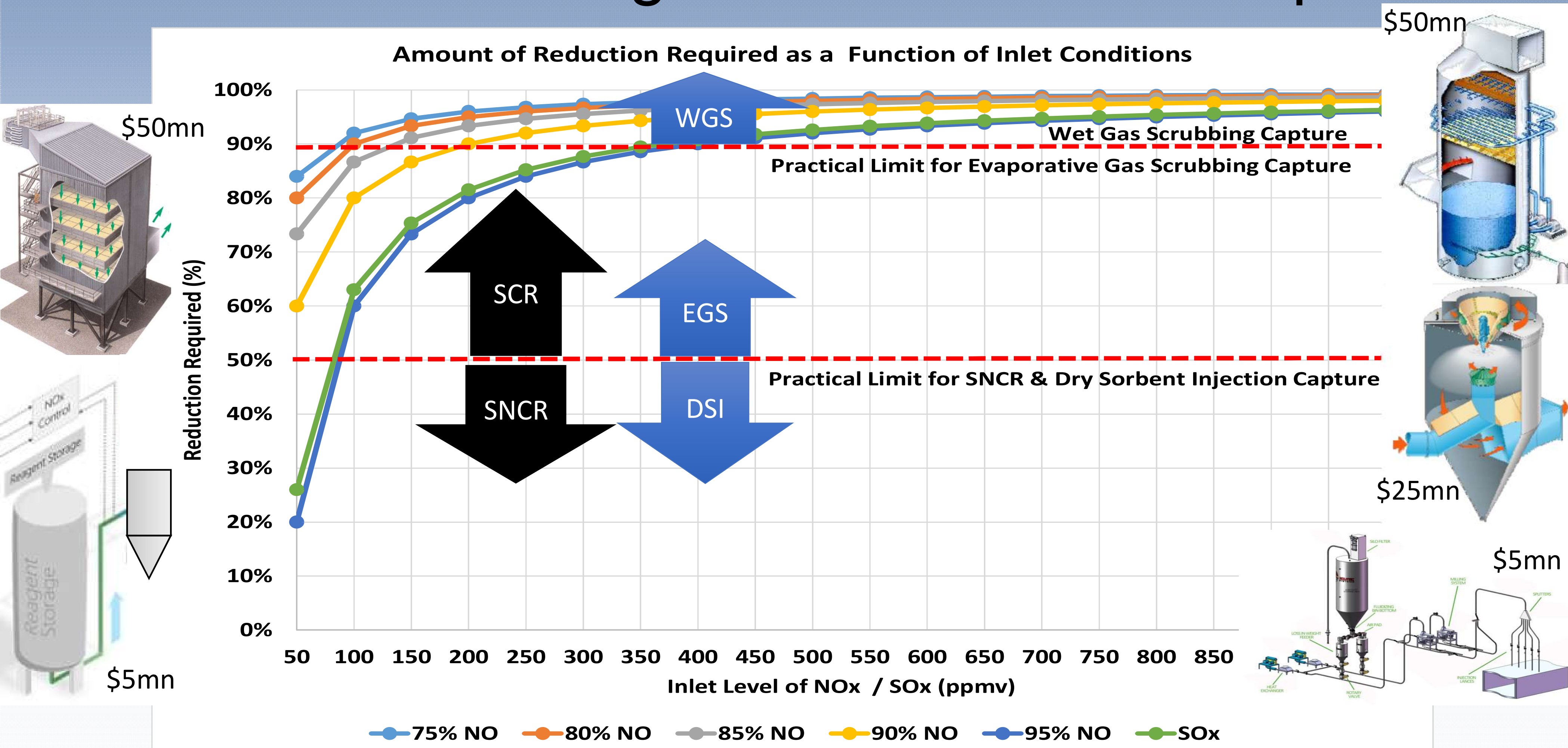
If the Costs are too high, don't study in more detail, change the scope

Plant Modifications

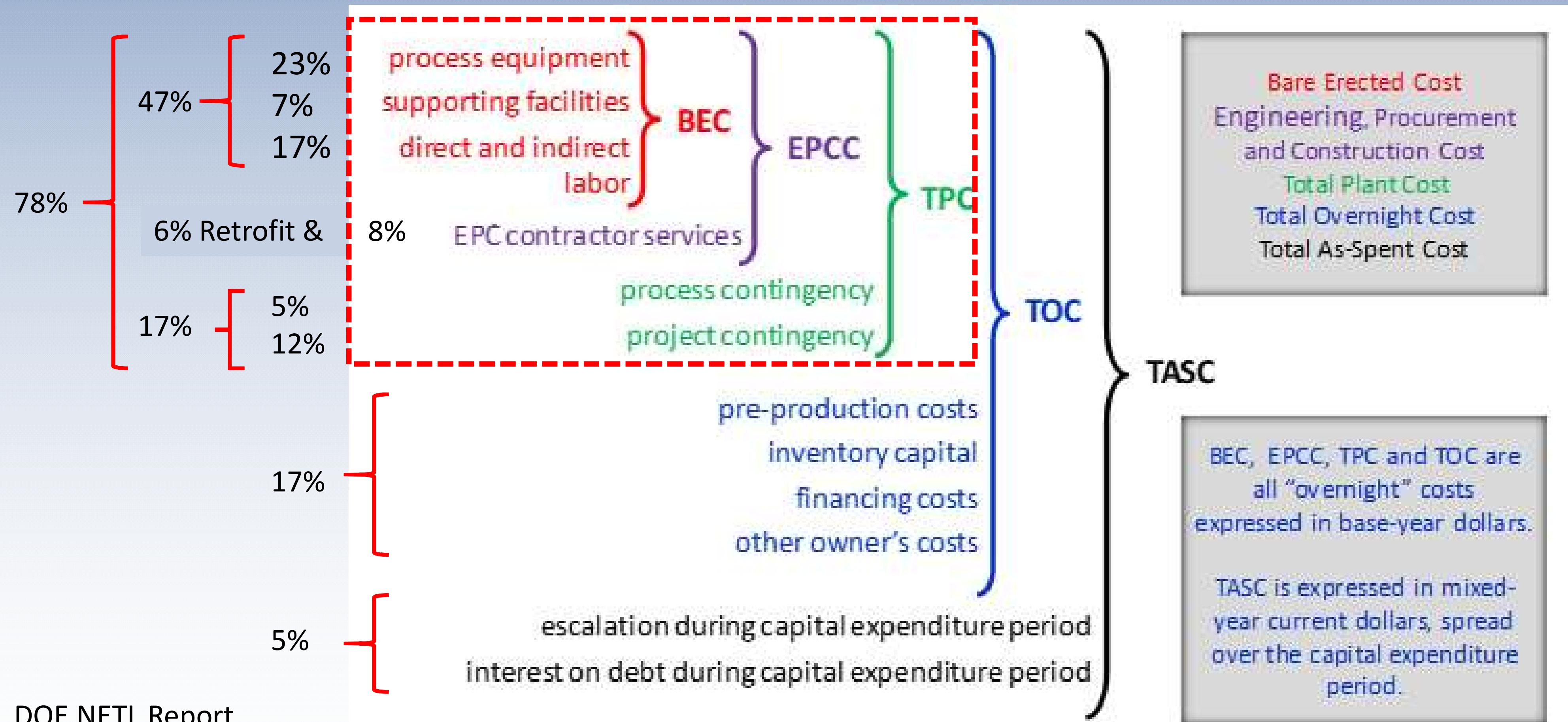
- Incoming power + 100 to + 400 kWh/t-cem [1]
  - Incoming power lines
  - Substation(s)
- Fuel Availability (Solid & Gas) + 0 to +4.0 GJ/t-clk [1]
- Water Supply + 1 mn gpd / +4 mn lpd [2]
  - Pre-cleaning
- Construction Site – 10+ acres / 2.5+ Hectares [2]
  - Clearing
  - Leveling
  - Fencing, etc.
- Plant changes, roads, access gates, fencing, security, etc.

[1] – ECRA 2022 technology papers
[2] – US DOE NETL 2023 Cement Plant Retrofit

Gas Cleaning ahead of Carbon Capture



DOE CCS Project Cost Breakdown



DOE NETL Report

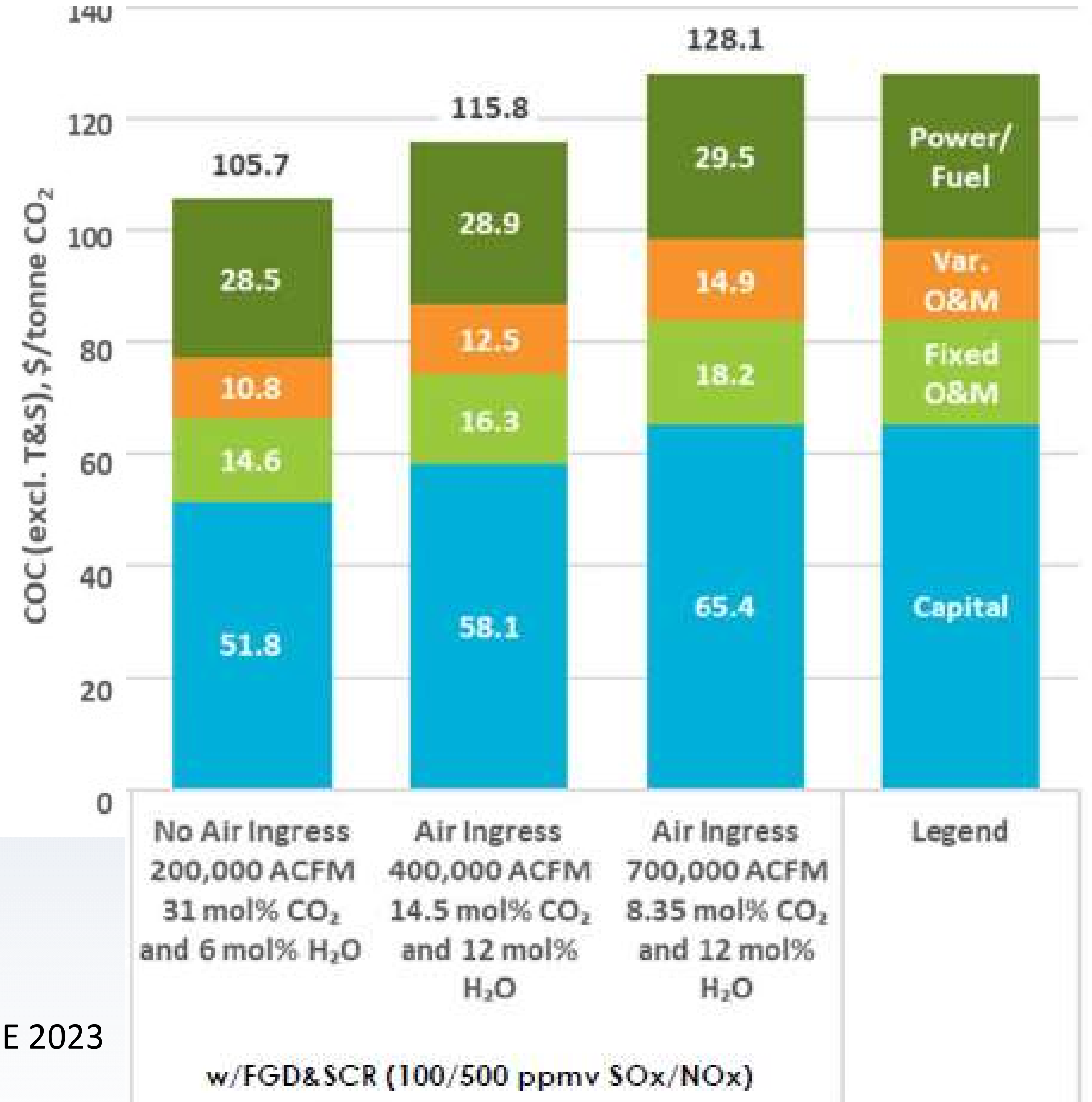
DOE Results

Selected Cases

No Air Ingress = Preheater Exit Gases

Air Ingress 400,000 ACFM = VRM with low leakage

Air Ingress 700,000 ACFM = VRM with high leakage and / or Cooler exhaust



Basis: 1.371 mn tpy clinker – coal fired pyro line with natural gas fired boiler for stripping

Includes CO2 drying and compression

Excludes Post-Cleaning, Transportation & Storage

"Remains Optimistic"

DOE Presentation @ IEEE 2023

DOE NETL Report

DOE NETL Report Financial Assumptions

Exhibit 2-3. Financial assumptions for retrofit capture at cement plant

Financial Parameter	Value
Fixed Charge Rate	7.91%
TASC/TOC Ratio	1.118
Capital Charge Factor	8.84%
Debt/Equity Ratio	42/58
Operating Life/Depreciation Period	30 years
Interest on Debt	8.82%
Levered Return on Equity	4.90%
Weighted Average Cost of Capital	6.56%
Capital Expenditure Period	3 years
Capital Distribution	1st year – 10% 2nd year – 60% 3rd year – 30%

DOE NETL Report

Project Cost Breakdown by Cost Type

Cost Type - *CM95-B-S100N500 at 250°F with air in-leakage up to 400,000 ACFM*	Costs	% of Total
Equipment Costs	$207,247,000	23.3%
Material Costs	$58,364,000	6.5%
Direct Labor Costs	$145,026,000	16.3%
Bare Erected Costs (BEC)	**$431,169,000**	**48.4%**
Owner's Costs	$71,861,000	8.1%
Process Contingency	$39,530,000	4.4%
Project Contingency	$104,406,000	11.7%
Total Project Costs	**$626,434,000**	**70.3%**
Retrofit Costs	$31,322,000	3.5%
Total Retrofitted Project (TPC)	**$657,756,000**	**73.8%**
Start-Up & Commissioning	$139,472,000	15.6%
Total Overnight Costs (TOC)	**$797,228,000**	**89.4%**
Escalation & Interest	$94,091,000	10.6%
Total As Spent Costs (TAS)	**$891,319,000**	**100.0%**

Project Cost Breakdown by Area (DOE)

Area - ***CM95-B-S100N500 at 250°F with air in-leakage up to 400,000 ACFM***	**Costs**	**% of Total**
Feed water & Misc. BOP	$41,712,000	6.3%
Flue Gas Clean-Up & CC	$496,991,000	75.6%
Ductwork & Stack	$32,520,000	4.9%
Cooling Water System	$15,590,000	2.4%
Accessory Electric Plant	$30,162,000	4.6%
Instrumentation & Control	$7,149,000	1.1%
Improvements to Site	$2,310,000	0.4%
Total	**$626,434,000**	**95.2%**
Retrofit	$31,322,000	4.8%
Total with Retrofit	**$657,756,000**	**100.0%**

Operating Costs (DOE)

Cost Item - CM95-B-S100N500 at 250°F 400,000 ACFM	**Comments**	**Annual ($ mn)**	**$ / t – CO2 Avoided (1,104,478 t-CO2)**
Operating Labor	11.5 people (maint. separate)	$6.60	$5.97
Property Taxes & Insurance		$13.16	$14.41
Fixed Costs		$19.75	$17.88
Natural Gas ($4.42 / mn BTU)	3.86 mn BTU / t-clk	$23.43	$21.21
Power ($60 / MWh)	135 kWh / t – clk	$11.67	$10.56
Maintenance Materials	0.96 % TPC	$6.31	$5.72
Water Consumption ($0.00224/gal)	1,053,000 gallons / day	$0.74	$0.67
Water Treatment Chemicals ($647.04/ton)	3.1 tons / day	$0.64	$0.58
Amine Solution	Proprietary	$4.01	$3.63
Tri-Ethylene Glycol ($8/gal)	286 gallons / day	$0.71	$0.64
Lime ($188.23/ton)	13 tons / day	$0.24	$0.21
Ammonia 19% ($352.93/ton)	10.5 tons / day (19%)	$2.48	$2.25
SCR Catalyst ($176.46 / ft3)	0.4 ft3 / day	$0.04	$0.03
Waste Management	4 Streams	$0.06	$0.06
Variable Costs		$65.49	$59.29
Total All Costs		$85.24	$77.17

DOE NETL Report

$62.17 / ton-clinker

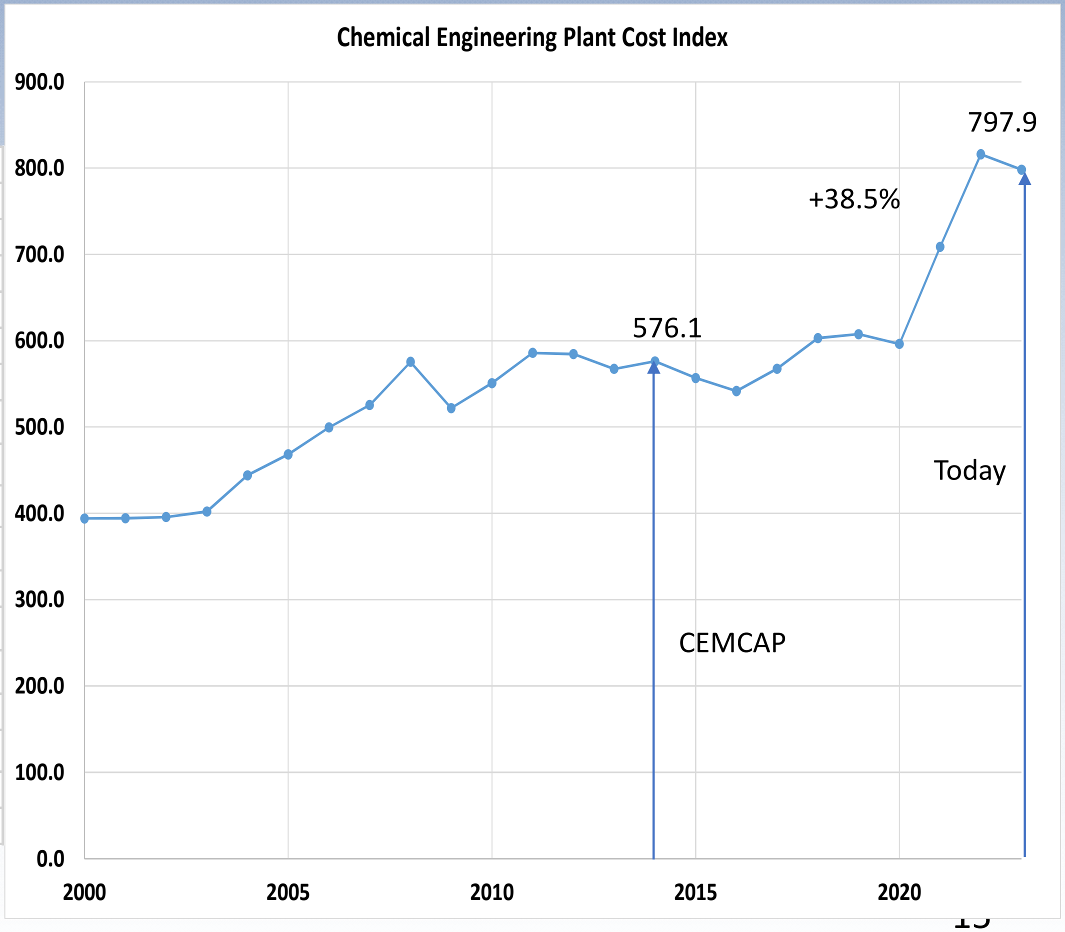
Wastes Generated

• SCR Catalyst waste	0.7 ft3 / day
• Triethylene glycol waste	287 gallons / day
• Thermal reclaimer waste	1.69 tons / day
• Pre-scrubber blowdown waste	0.03 tons /day

Cost Escalation & CemCap Study

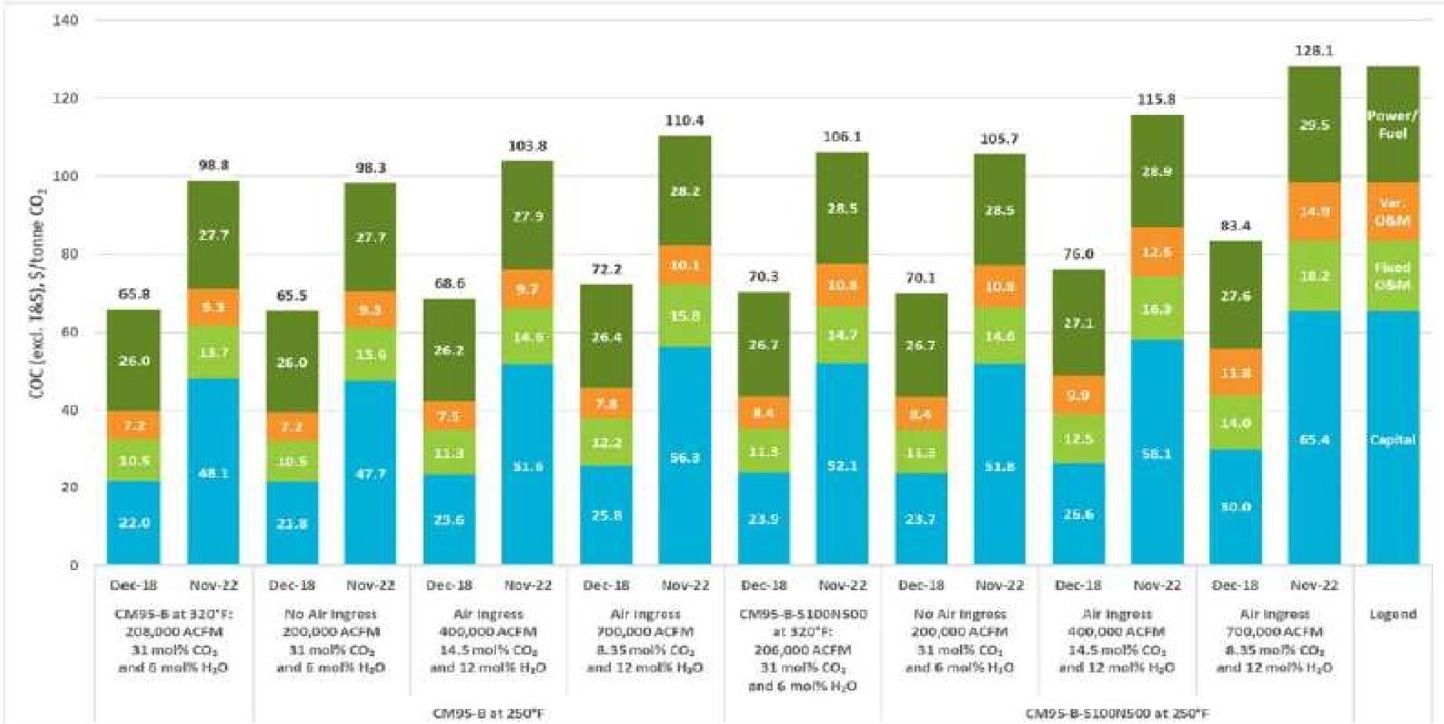
Opex	Costs		Units
Raw Meal Price	€	5.00	€ / t - clk
Coal Price	€	3.00	€ / GJ - LHV
Natural Gas Price	€	6.00	€ / GJ - LHV
Power	€	58.10	€ / MWh
Cost of Steam produced from a natural gas boiler	€	25.30	€ / MWh
Cost of steam produced from waste heat	€	8.50	€ / MWh
Carbon Tax	€	-	€ / t - CO_2
Cooling water	€	0.39	€ / m^3
Process water	€	6.65	€ / m^3
Ammonia solution for SNCR	€	130.00	€ / t - NH_3
MEA solvent	€	1,450.00	€ / t - MEA
Ammonia solvent	€	406.00	€ / t - NH_3
Sulfuric acid	€	46.00	€ / t - H_2SO_4
Sodium hydroxide for flue gas desulfurization	€	370.00	€ / t - NaOH
Membrane material replacement	€	7.87	€ / m^2
Other variable O&M	€	1.09	€ / t - clk
Cost of labor per person	€	60,000.00	€ / year

Adapted from CEMCAP Study



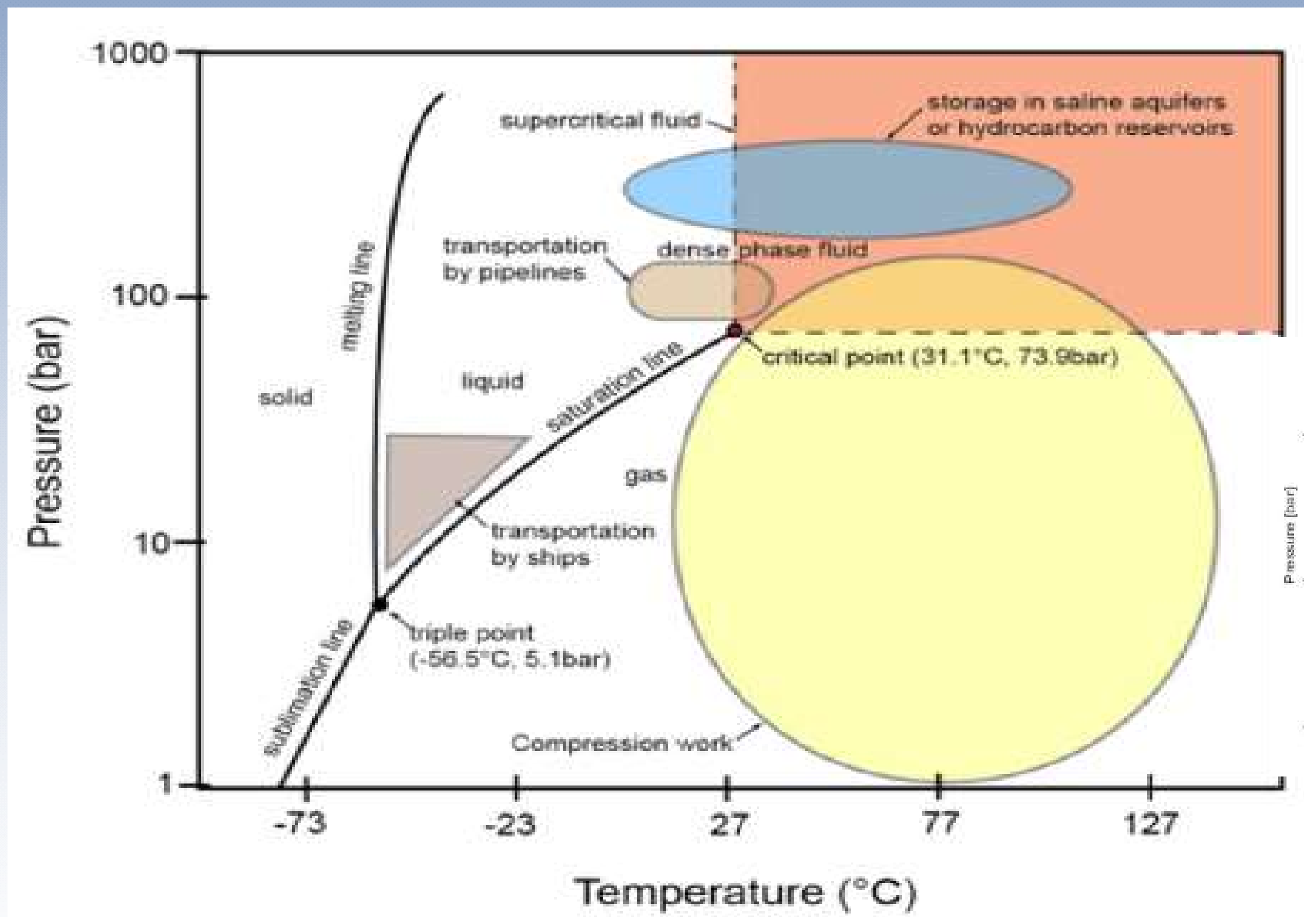
Cost Comparison: 2018 vs 2022 US Dollars

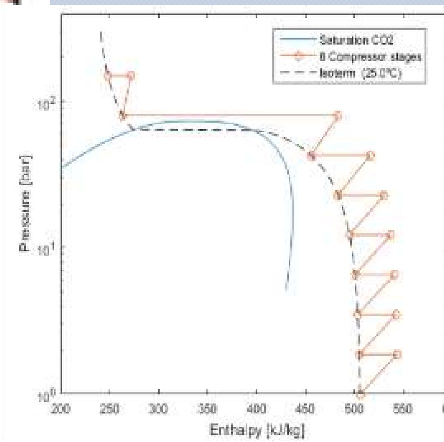
- Increases in cost of money, escalation resulted in cost of capture increases ~50% (+)
- Increases in utility pricing (i.e. natural gas, auxiliary power) had minimal impact



Compression Levels

6 to 8 stages of compression with inter-stage cooling

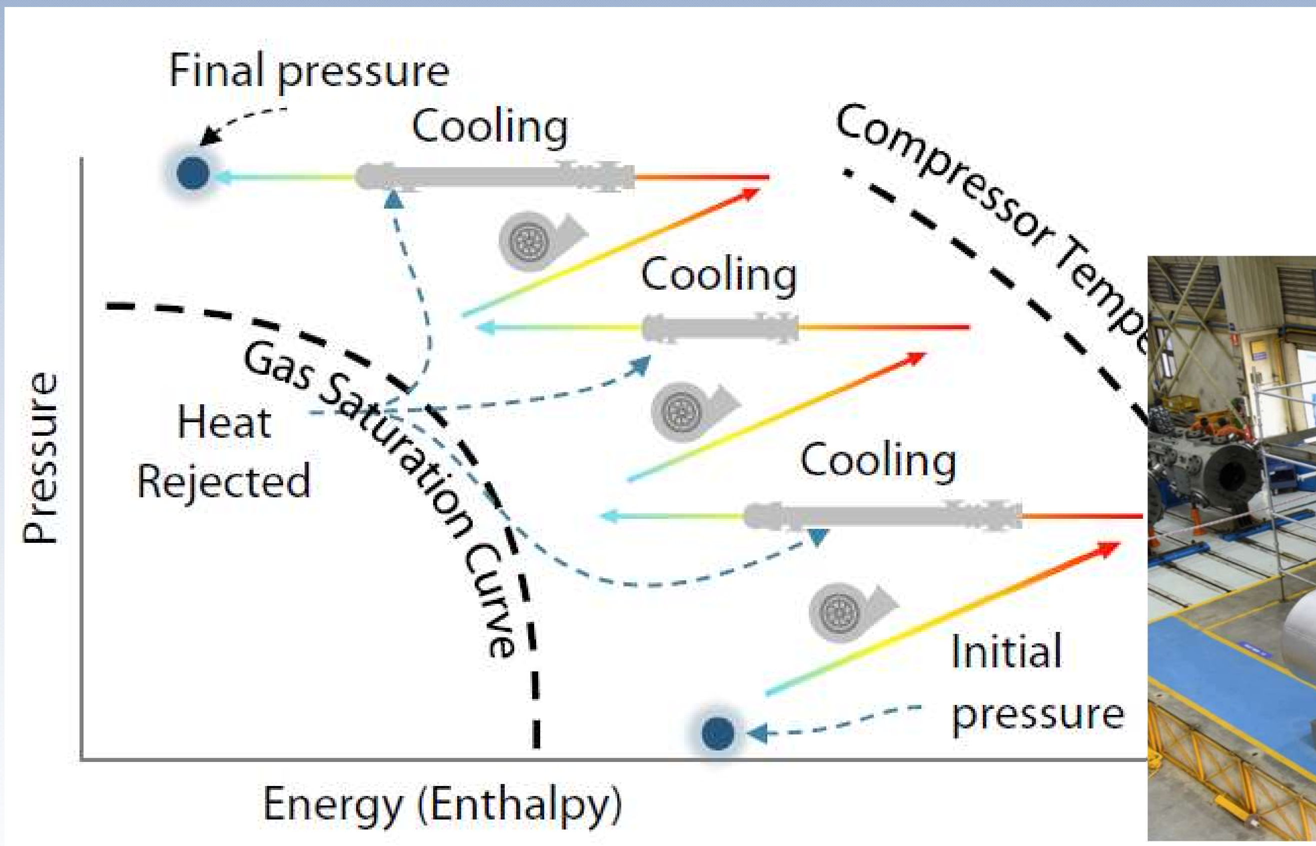




https://iopscience.iop.org/article/10.1088/1755-1315/167/1/012031/pdf

Multi-period, multi-objective optimisation of the Northern Lights and Stella Maris carbon capture and storage chains, Fraga et. al. 2024

Multistage Compression with Cooling



Siemens

Notes:
a – as SO2
b – excluding methane
c – g/m3
d – ppmw
e – liters / m3
f – lbs / mn cfm
g – gallons / mn cf
h – ppm (w or v not specified)
j – volume %
k - C2+
l – ppmv
m – aliphatic only

Note: France has additional requirements

Specifications for CO2 used for EOR and / or Sequestration

		Projects				Pipelines						Ship Transport	
	Units	Teeside n	CarbonNet Lower n	CarbonNet Upper n	Dunkerque n5	Kinder Morgan n1	Dynamis n	Weyburn field supply n	Canyon Reef n2	Cortez (KM) n2	Holcim Florence n3	Kinder Morgan n	Brevik Project n4
Carbon dioxide	Vol%	>=95	>93.5%	100%	>95	>=95	>95.5	<96	>95	>95	>95	>99.7%	
Acetaldehyde	ppmv				<20								<=20
Amine	ppmv				<10								<=10
Ammonia	ppmv	<50			<10								<=10
Argon	Vol %	<=1			<0.4		<4					<0.3	
Cadmium & Thallium	ppmv				<0.03								<=0.03
Carbon Monoxide	ppmv	<2000	<=900	<=5000	<750		<=2000 h	<1000			<4250	2000	<=100
Formaldehyde	ppmv				<20								<=20
Glycol						0.3 g			<4E-05 e		0.3 g		
Glycol liquid	Vol %					0							
Hydrocarbon Dew Point	Deg C					-28.9			-28.9				
Hydrocarbons	Vol%	<=2	<=0.5 b		<1200 m	<5		<2.3 k	<5	1~5	<5		
Hydrogen	Vol %	<=1			<0.75		<4				<1	<0.3	<=50
Hydrogen Sulfide	ppmv	<=200	<=100	<=100	<9	<20	<200 h	<9000	<1500 d	<2	<20	200 h	<=9
Mercury	ppmv				<0.03								<=0.03
Methane Acquifer	Vol %						<4						
Methane EOR	Vol %	<=1			<1		<2 j	<0.7				<0.3	
Nitrogen	Vol %	<=1			<2	<4	<4	<0.03	<4	<4	<4	<0.3	
Nitrogen Oxides	ppmv	<100	<=250	<=2500	<10		<= 100				<1		<=10
Oxygen Acquifer	ppmv	<10			<40	<10 d	100~1000				<10		<=10
Oxygen EOR	ppmv							<50	<10 d		<10		
Particle Size	Um	<10											
Particulates	mg/Nm3	<=1									<1 d		
Sulfur Oxides	ppmv	<100	<=200 a	<=200 a	<10		<= 100				<1		<=10
Sulfur Total	ppmw				<20 l	<35		<=35	<=1450		<35		
Temperature	Deg C					<=48.9			<=48.9		<48.9		
Total Non-Condensable	Vol %	<=4	<=2	<=5	<4		<=4						
Water Free	ppmv	<=50	<=100	<=100	<40	0	<=500 h	20		30 f	30 f	50 h	<=30
Water Vapour Phase						<0.48 c	<=200 h		<0.48 c				

Pipeline / Project Specification Sources

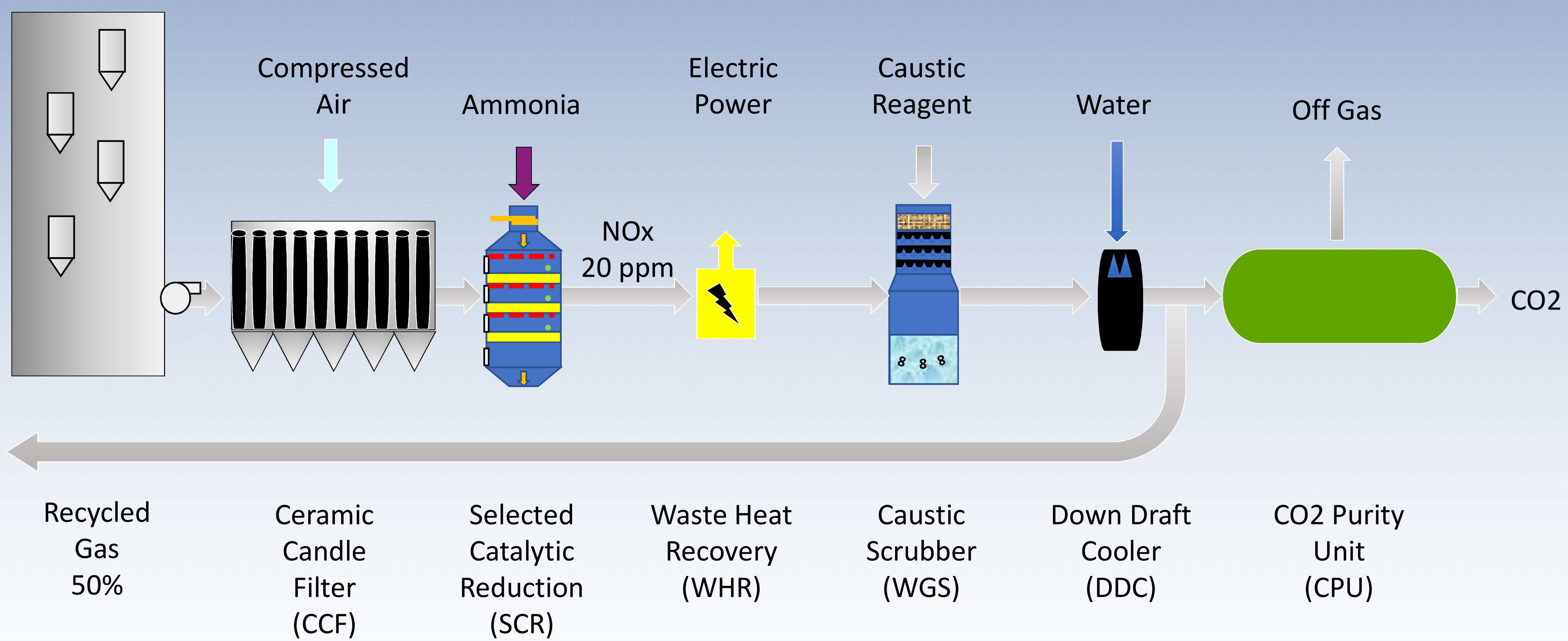
n	Pipelines - The safest way to travel for CO2 - Whole value chain carbon capture, utilization and storage
	Ken Havens, VP of Operations and Engineering, Kinder Morgan CO2, Company - 16-Oct-18
n1	https://www.ccusnetwork.eu/sites/default/files/TG3_Briefing-CO2-Specifications-for-Transport.pdf
	CCUS Projects Network - Briefing on carbon Dioxide Specifications for Transport
	1st report of the tematic Working group on:CO2 transport, storage, and networks - Dr. Peter A Brownsort 29-Nov-19
n2	https://pure.strath.ac.uk/ws/portalfiles/portal/133841084/Race_etal_JPE_2012_Towards_a_CO2_pipeline_specification_defining_tolerance_limits.pdf
	This is a peer-reviewed, accepted author manuscript of the following article: Race, J. M., Wetenhall, B., Seevam, P. N., & Downie, M. J. (2012). Towards a CO2 pipeline specification: defining tolerance limits for impurities. The Journal of Pipeline Engineering, 11(3), 173-190.
n3	LH CO2MENT Colorado Project, Final Report, Version 2, January 31, 2023 - Electricore, Ms. Deborah Jelen
n4	Emailed specifications from Brevik project, Adsorption assisted cryogenic carbon capture: an alternate path to steam driven technologies to cresae cost and carbon footprint
n5	GRTgaz Open Season Pour une Infrastructure de transport de CO2 a Dunkerque
	https://www.grtgaz.com/sites/default/files/2023-02/Proposition-specifications-co2-dunkerque.pdf

Gas Constituents Impacts on Pipelines

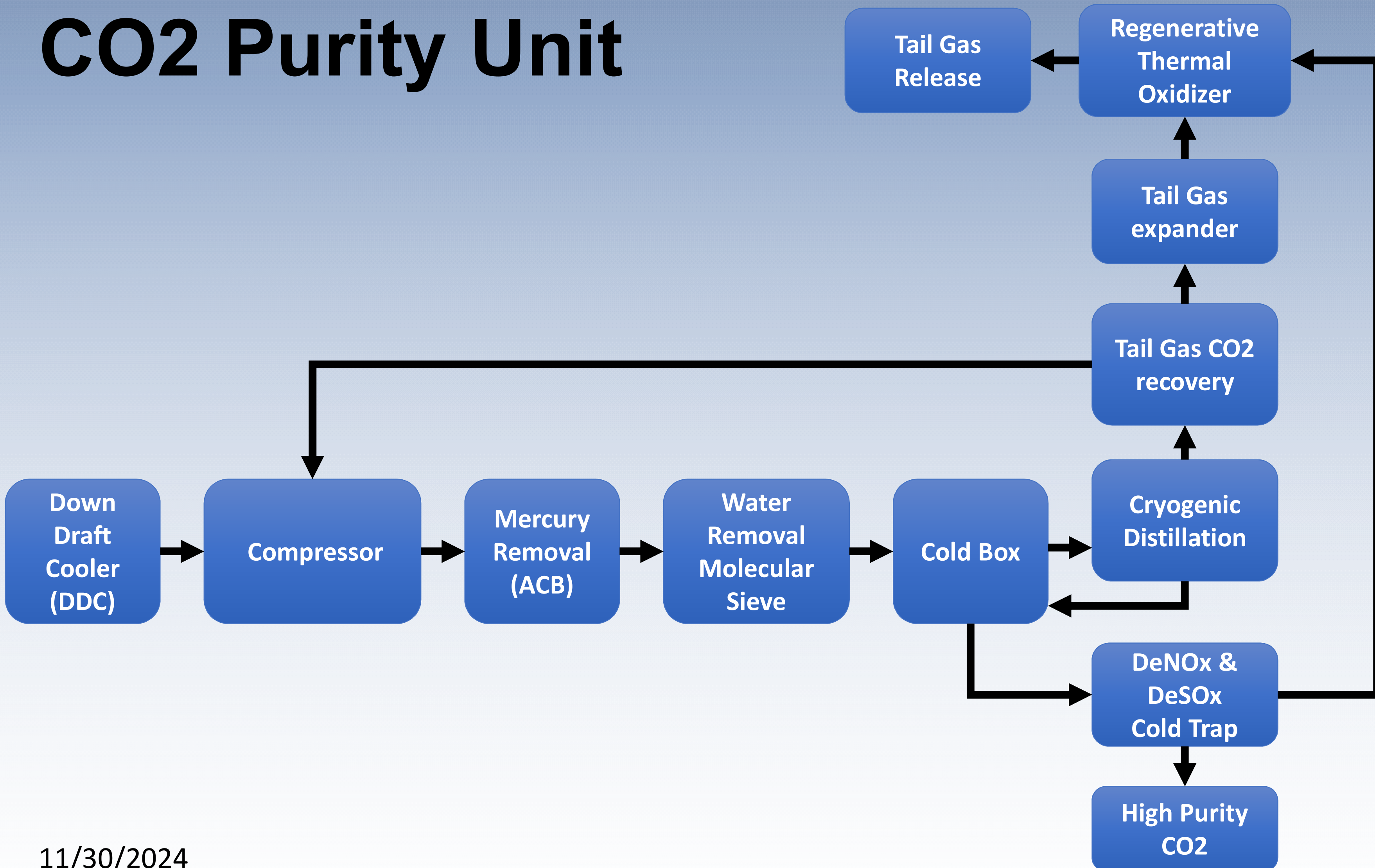
	Hydraulics (dense phase)	Hydraulics (gas phase)	Fracture Control	Water Solubility	Corrosion	Cracking	Hydrate Formation	Health & Safety
CO_2								Toxic in event of release
H_2O	Not Studied	Not Studied	Not Studied		Promotes corrosion	Promotes Cracking	Promotes Hydrate Formation	
SO_x	Increase critical pressure	Reduces operating pressure	Reduces saturation pressure	Decreases water solubility	Promotes corrosion	Effect unknown	Effect unknown	Toxic in event of release
NO_x	Increase critical pressure	Reduces operating pressure	Effect unknown	Decreases water solubility	Promotes corrosion	Effect unknown	Effect unknown	Toxic in event of release
H_2S	Increase critical pressure	Reduces operating pressure	Effect unknown	Increases water solubility	Effect unknown	Promotes cracking	Effect unknown	Toxic in event of release
CO	Increase critical pressure, reduces pipeline capacity, increases pressure drop, increases power consumption	Increases operating pressure	Increases Saturation Pressure	Effect unknown	Not Studied	Promotes Cracking	Effect unknown	Toxic in event of release
H_2		Increases operating pressure	Increases Saturation Pressure	Effect unknown	Not Studied	Effect unknown	Promotes Hydrate Formation	Effect unknown
Ar		Increases operating pressure	Increases Saturation Pressure	Effect unknown	Not Studied	Not studied	Effect unknown	Effect unknown
N_2		Increases operating pressure	Increases Saturation Pressure	Effect unknown	Not Studied	Not studied	Promotes Hydrate Formation	Effect unknown
O_2		Increases operating pressure	Increases Saturation Pressure	Effect unknown	Promotes corrosion	Not studied	Effect unknown	Effect unknown
CH_4		Increases operating pressure	Increases Saturation Pressure	Decreases water solubility	Not Studied	Not studied	Effect unknown	Effect unknown

Adapted from Race, et al. [3]

Geseke Flue Gas Cleaning



CO2 Purity Unit



Geseke Oxy-Fuel CCS Power Consumption

Raw Material Heating 5 kWh/t-clk

Raw Material Grinding 10 kWh/t-clk

Clinker Burning 40 kWh/t-clk

Clinker Grinding 55 kWh/t-clk

Product Handling 5 kWh/t-clk

Air Separation Unit 80 kWh/t-clk

Flue Gas Pretreatment 20 kWh/t-clk

Purification Unit 115 kWh/t-clk

CO2 Liquefaction 35 kWh/t-clk

Cooling & Utilities 15 kWh/t-clk

265 kWh/t-clk

115 kWh/t-clk

380 kWh/t-clk

Post Cleaning (w/o Oxygen Removal)

	Compression & Dehydration Only (No O2 Removal) 2017$						
Facility Size (tonne / year)	246,000	383,000	400,000	450,000	1,000,000	3,000,000	6,000,000
Mn SCFD	13	20	21	23	52	156	312
US ton/day	743	1,154	1,206	1,358	3,017	9,052	18,104
Purchased equipment Cost ($mn)	$ 4.90	$ 7.30	$ 7.50	$ 8.00	$ 17.10	$ 26.40	$ 39.80
Total Installed Cost ($mn)	$ 15.30	$ 22.50	$ 23.10	$ 24.80	$ 53.00	$ 81.70	$ 123.50
Factor	3.122	3.082	3.080	3.100	3.099	3.095	3.103
Annualized Capital Costs ($mn / year)	$ 1.90	$ 2.80	$ 2.90	$ 3.10	$ 6.60	$ 10.10	$ 15.30
kWh/tonne CO2	112	112	112	112	112	76	76
Annual Operating Costs	$ 4.30	$ 6.60	$ 6.80	$ 7.50	$ 16.40	$ 30.10	$ 55.20
Total Annualized Costs ($/tonne-CO2)	$ 17.52	$ 17.11	$ 17.05	$ 16.69	$ 16.40	$ 10.02	$ 9.20

Trimeric Report

Cost influenced by pipeline & project / sequestration site specifications & local power costs

Post-Cleaning with Oxygen Removal

	EOR grade - Compression, Refrigeration, & Distillation (O2 Removal) 2017$						
Facility Size (tonne / year)	246,000	383,000	400,000	450,000	1,000,000	3,000,000	6,000,000
Mn SCFD	13	20	21	23	52	156	312
US ton/day	743	1,154	1,206	1,358	3,017	9,052	18,104
Purchased equipment Cost ($mn)	$ 10.70	$ 13.60	$ 14.00	$ 15.00	$ 32.10	$ 38.00	$ 58.00
Total Installed Cost ($mn)	$ 17.20	$ 23.70	$ 24.40	$ 26.10	$ 55.80	$ 86.00	$ 130.00
Factor	1.607	1.743	1.743	1.740	1.738	2.263	2.241
Annualized Capital Costs ($mn / year)	$ 2.10	$ 2.90	$ 3.00	$ 3.20	$ 6.90	$ 10.70	$ 16.10
kWh/tonne CO2	154	154	154	154	154	133	133
Annual Operating Costs	$ 3.30	$ 5.20	$ 5.40	$ 6.10	$ 13.50	$ 34.90	$ 69.80
Total Annualized Costs ($/tonne-CO2)	$ 22.00	$ 21.00	$ 21.00	$ 20.60	$ 20.40	$ 15.20	$ 14.30

Trimeric Report

Cost influenced by pipeline & project / sequestration site specifications & local power costs

CCUS Projects in the United States

CCS Facilities Currently Operating in the United States

Name of Facility	Date CCS Operations Began	Location	Type of Production	CO_2 Used for Enhanced Oil Recovery?	CO_2 Capture Capacity (Millions of metric tons per year)
Terrell	1972	Texas	Natural Gas Processing	Yes	0.5
Enid Fertiziler	1982	Oklahoma	Ammonia (Fertilizer)	Yes	0.2
Shute Creek	1986	Wyoming	Natural Gas Processing	Yes	7.0
Great Plains	2000	North Dakota	Hydrogen and Ammonia (Fertilizer)[a]	Yes	3.0
Core Energy	2003	Michigan	Natural Gas Processing	Yes	0.4
Arkalon	2009	Kansas	Ethanol	Yes	0.5
Century Plant	2010	Texas	Natural Gas Processing	Yes	5.0
Bonanza BioEnergy	2012	Kansas	Ethanol	Yes	0.1
Air Products	2013	Texas	Hydrogen	Yes	0.9
Coffeyville	2013	Kansas	Hydrogen and Ammonia (Fertilizer)[a]	Yes	0.9
Lost Cabin	2013	Wyoming	Natural Gas Processing	Yes	0.9
PCS Nitrogen	2013	Louisiana	Ammonia (Fertilizer)	Yes	0.3
Petra Nova	2017[b]	Texas	Electric Power	Yes	1.4
Illinois Industrial	2017	Illinois	Ethanol	No	1.0
Red Trail Energy	2022	North Dakota	Ethanol	No	0.2

Data source: Congressional Budget Office, using data from the Global CCS Institute. See www.cbo.gov/publication/59345#data.

CCS = carbon capture and storage; CO_2 = carbon dioxide.

a. Gasification of coal- or petroleum-based coke results in a mixture of hydrogen and other elements, which can be used to produce ammonia.

b. The Petra Nova CCS facility shut down in 2020 and reopened in 2023.

Congressional Budget Office Report

VDZ Study on CO_2 Infrastructure

- The study analysed the German requirements by the cement, lime and waste incineration industry
- About 4800 km of pipelines are needed by 2035
- Transporting a growing demand of CO_2
  - from 6.5 Mta in 2030
  - to 45.5 Mta by 2045
  - for a total of 500 Mt
  - Eventually, up to 21 Mta will be from AT, CH and FR (transit)
- Installation costs for the grid are estimated at € 14 bn
- Leading to 35 €/t CO_2 for the period under review, excluding transit quantities

https://www.vdz-online.de/fileadmin/wissensportal/publikationen/zementindustrie/VDZ-Studie_CO2-Infrastruktur-Deutschland.pdf

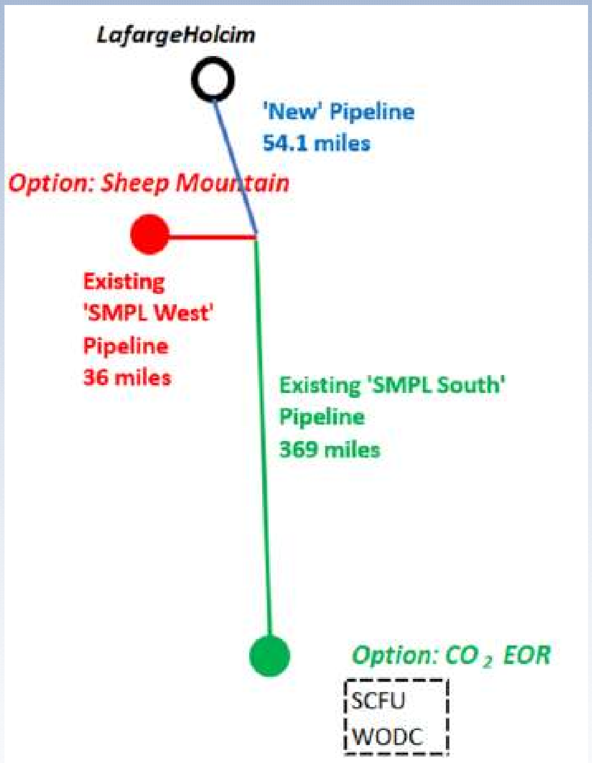
Cost of Some Pipeline Projects

Pipeline Name	Green Pipeline	Greencore Pipeline	Seminole Pipeline	Coffeyville Pipline	Webster Pipeline	Emma Pipeline
Company	Denbury Gulf Coast Pipelines, LLC (LA) & Denbury Green Pipeline - texas, LLC (TX)	Greencore Pipeline Company, LLC	Tabula Rasa Energy, LLC	Perdure Petroleum, LLC	Denbury Green Pipeline - Texas, LLC	Tabula Rasa Energy, LLC
State	LA/TX	WY/MT	TX	KS/OK	TX	TX
Pipeline Constructed (year)	2009/2010	2011/2012	2012	2013	2013	2015
Pipeline Length (miles)	320	232	12.5	67.85	9.1	2
Pipeline Diameter (inches)	24	20	6	8	16	6
Maximum Operating Pressure (psig)	2,220	2,220	1,825	1,671	2,220	2,319
Total Pipeline Cost ($/mile)	$3,044,000	$1,372,700	$480,000	$928,500	$3,190,000	$750,000
Pipeline Cost ($/diameter inch mile)	$126,823	$68,635	$80,000	$116,062	$199,176	$125,000
Notes	Extensive wetlands and marshlands crossed along with Gavelston Bay	Right of way on 65% private ranchland with 35% public and state lands		Construction issues with rock on lower section of pipeline, major boring requirements	Entire right of way within suburban high consequence area: more than 60% of pipeline was installed using horizontal directional drilling, which added significant cost to constitution	

Holcim Florence CO Pipeline estimate

- 4,750 mtpd CO2
- 12 inch pipeline (30 cm diameter)
- 0.375 inch / 9.5 mm wall thickness
- ANSI/ASME Class 900
- X-65 grade steel
- 54.1 miles / 87.1 km
- $112 mn ($2022)
- $2.07 mn / mile – $1.29 mn / km

Sequestration Costs
$34~48 / t-CO2 w/ PL
$5 to $20 / t-CO2



HOLCIM Florence FEED Study

Transportation Costs - US

CO_2 transport and storage costs in current 2019$/t$CO_2$ for various combinations of scale, transport distance, and monitoring assumptions in the United States.

CO_2 Scale and Distance	Low	Mean	High	High (with extra monitoring)
1 Mtpa, 0 miles	$9.7	$16.5	$23.2	$34.9
1 Mtpa, 100 miles	$12.6	$23.3	$34.0	$45.7
1 Mtpa, 500 miles	$24.1	$50.6	$77.2	$88.9
3.2 Mtpa, 0 miles	$5.3	$8.0	$10.7	$17.9
3.2 Mtpa, 100 miles	$6.5	$11.2	$15.9	$23.1
3.2 Mtpa, 500 miles	$11.6	$24.1	$36.6	$43.8
6 Mtpa, 0 miles	$4.4	$6.7	$9.1	$15.0
6 Mtpa, 100 miles	$5.2	$9.0	$12.7	$18.6
6 Mtpa, 500 miles	$8.7	$17.9	$27.1	$33.0
15 Mtpa, 0 miles	$4.0	$6.2	$8.4	$13.7
15 Mtpa, 100 miles	$4.5	$7.4	$10.4	$15.6
15 Mtpa, 500 miles	$6.3	$12.2	$18.2	$23.4

CO2 Transport & Storage Report

Sequestration Costs – US

U.S. storage cost range (2019$/t$CO_2$) under base monitoring assumptions.

Rate Mtpa CO_2	Low	Mean	High
1	$9.74	$16.47	$23.20
3.2	$5.25	$8.00	$10.75
6	$4.36	$6.73	$9.09
15	$4.05	$6.24	$8.44

U.S storage cost range (2019$/t$CO_2$) under extra monitoring assumptions.

Rate Mtpa CO_2	Mean	Mean with Extra Monitoring	Extra Monitoring-Only Costs
1	$16.47	$28.14	$11.67
3.2	$8.00	$15.14	$7.14
6	$6.73	$12.67	$5.95
15	$6.24	$11.49	$5.25

CO2 Transport & Storage Report

Notes:

1~3.2 Mtpa CO2 would represent small to large individual plants or a combination of individual plants with other nearby sources

3.2~6 Mtpa CO2 would most likely represent shared pipelines or small hubs

6~15 Mtpa CO2 would most likely represent large hubs or sequestration end points

"By default, **USDOE (2017) assumes stringent monitoring requirements** that we determined to reflect the high end of the CO2 storage cost range and which we refer to as "extra" monitoring assumptions."

Satartia Mississippi

The price of CO_2 Pipelines just went up – in the US at least !!

45 hospitalized in a town of 50 people, No deaths

$3.95 Million Total Costs
$2.9 Million Penalty

Denbury Failure Report

24 inch pipeline Designed for 150 bar and operated at 96.5 bar at the time.

5 million liters of liquid CO_2 released (Investigative report feels this number may be low)

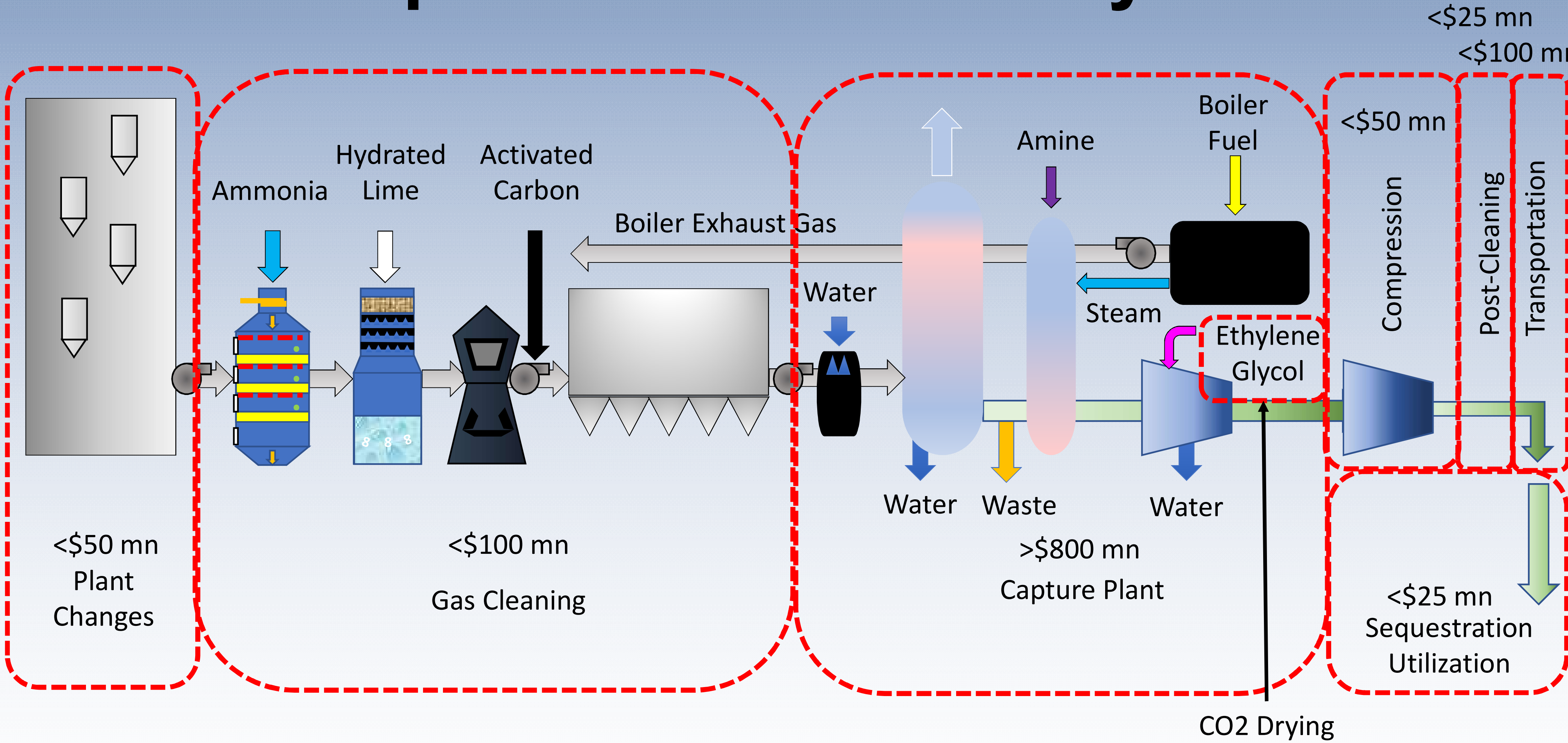
2.76 million m^3 at 21 ^oC

Carbon Capture Cost Check List

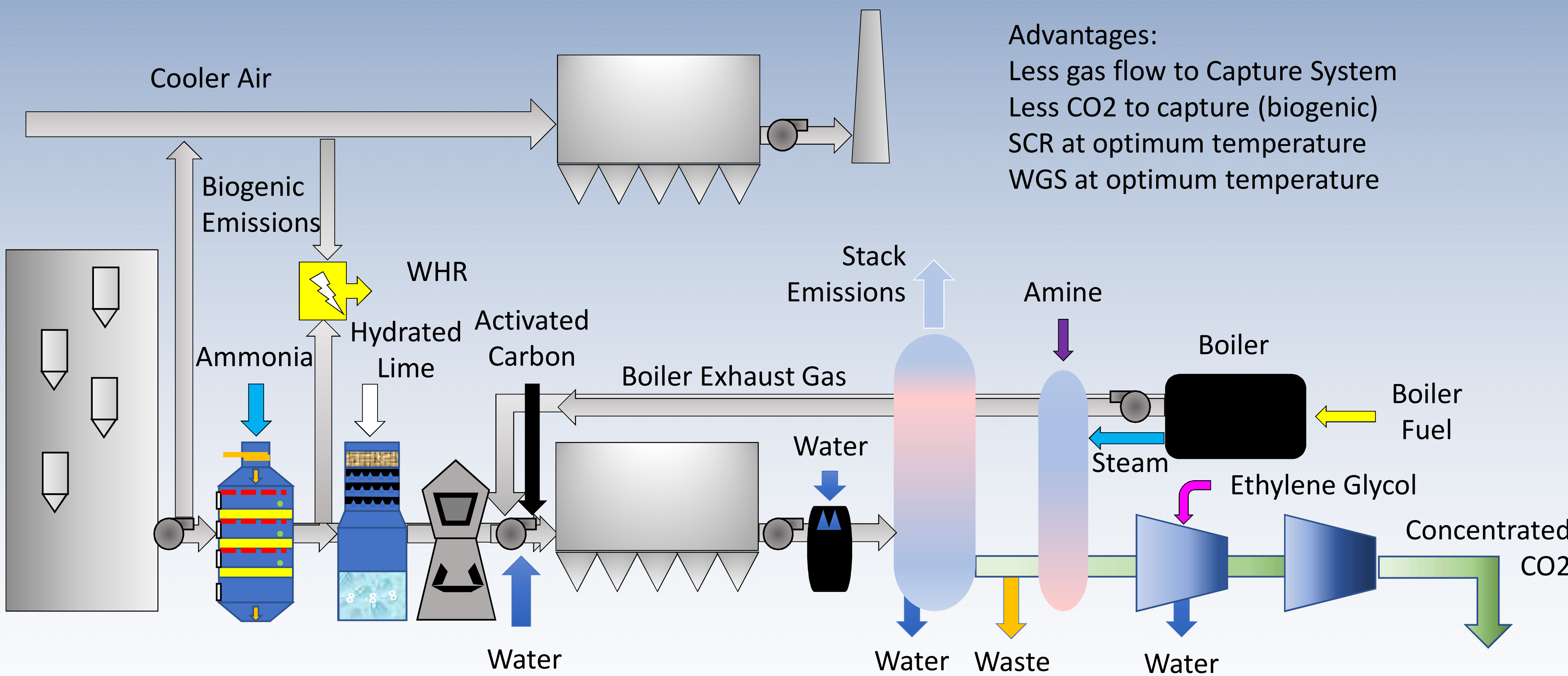
- ❑Permitting
- ❑Plant modifications
- ❑Gas precleaning
- ❑Carbon capture
- ❑CO2 dehydration
- ❑Compression
- ❑CO2 purification
- ❑Transportation
- ❑Sequestration
- ❑Training
- ❑Stakeholder Management

Keep in mind that construction costs vary in different parts of the world

Carbon Capture Cost Summary



Cement Plant Reconfigured



Advantages:
Less gas flow to Capture System
Less CO2 to capture (biogenic)
SCR at optimum temperature
WGS at optimum temperature

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Questions ?

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