CARBON CAPTURE PLANT UPDATES

Kline Consulting
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Green House Gas Technology Conference # 17
330 Presentations
500+ E-Posters
All Aspects of Carbon Capture, Reduction, and Storage

Main Take-Aways

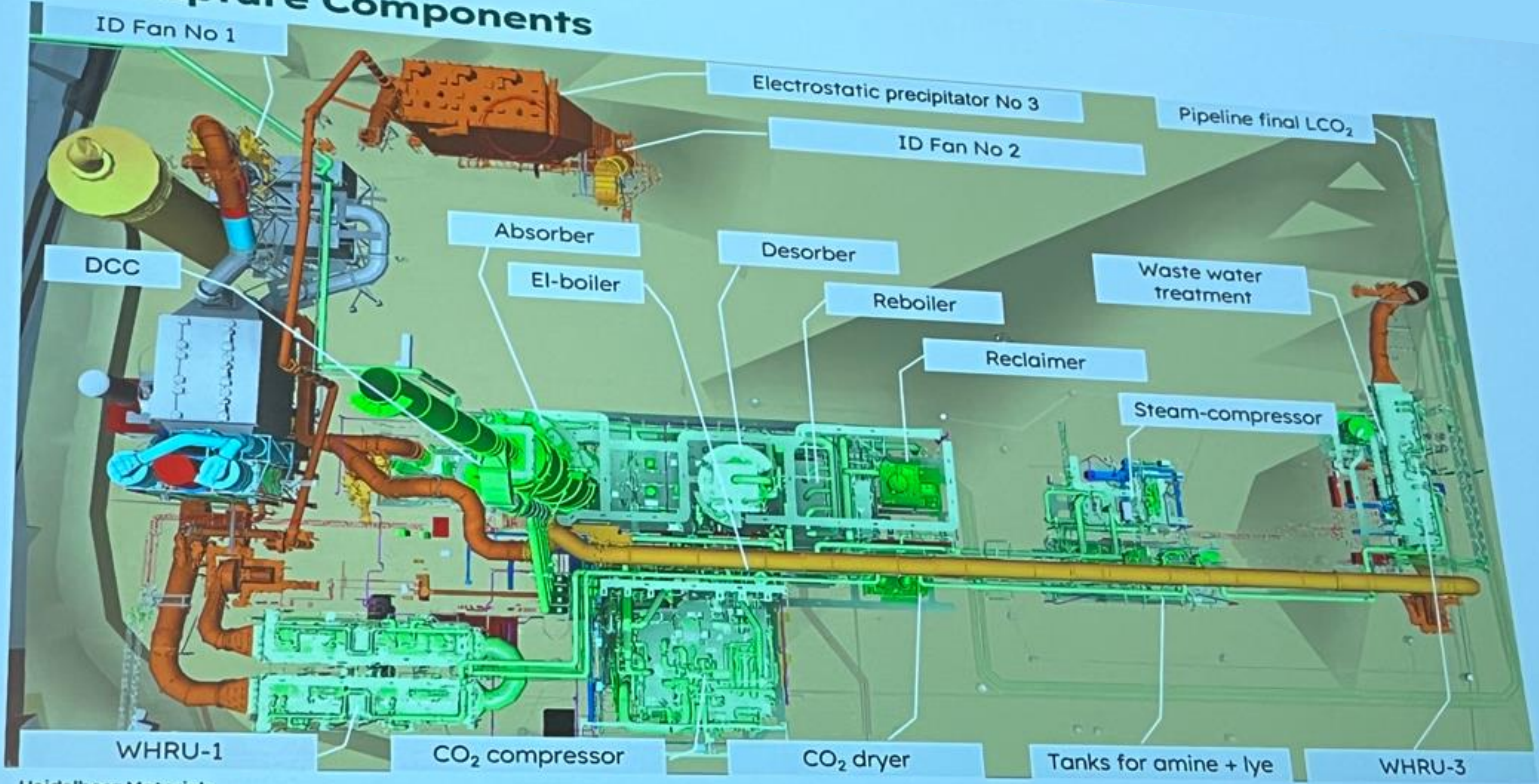
- There is a lot going on in many different industries
- Progress is being made
- But not fast enough

CCUS Projects	Operational	Under Construction
The Americas	27	18
Europe	5	10
Asia	1	4

- For most cement plants, getting to net zero will require steps beyond just carbon capture
- US DOE – 18 operating projects, 220 announced projects

Heidelberg Brevik

Carbon Capture Components



Heidelberg Brevik

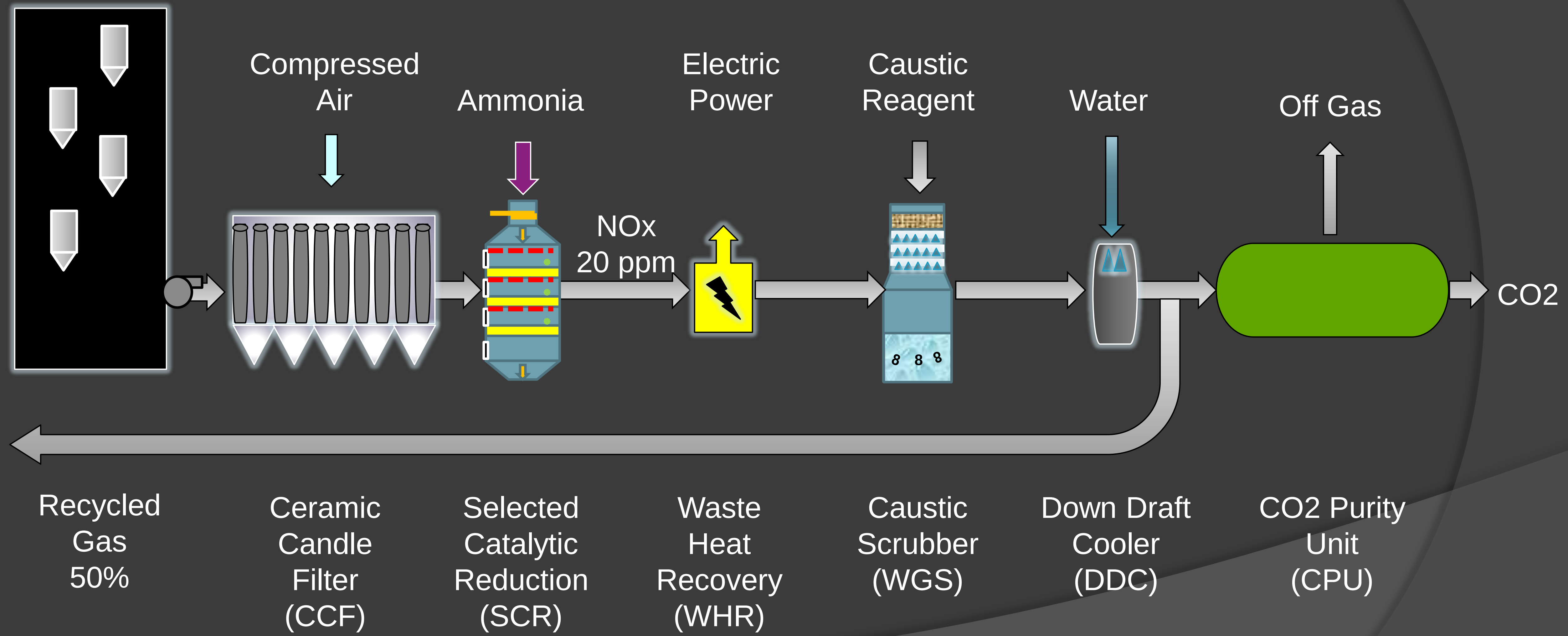
- Heidelberg Brevik plant nearing completion
  - 88% complete after 45 months
  - 10 months behind schedule
  - 1,000,000+ man hours so far
- Brevik using Aker's (now Schlumberger) proprietary liquid sorbent
- Capture 400,000 tons per year of CO2 (~50% of total CO2)
- Capacity selected due to no additional fuel burning
- 46 MW of heat recuperation in 9 shell in tube heat exchangers (preheater & cooler) – modular design + heat recuperated from compressor
- Shipped 700 km in 7,500 ton ships then pumped 100 km for North Sea EOR
- Ship loading at 800 tons-CO2 per hour

Original Budget	30.1 bn NOK	Norway 20.3 bn NOK
	3.4 bn USD	2.3 bn USD
2023	2.6 bn NOK	0.3 bn USD

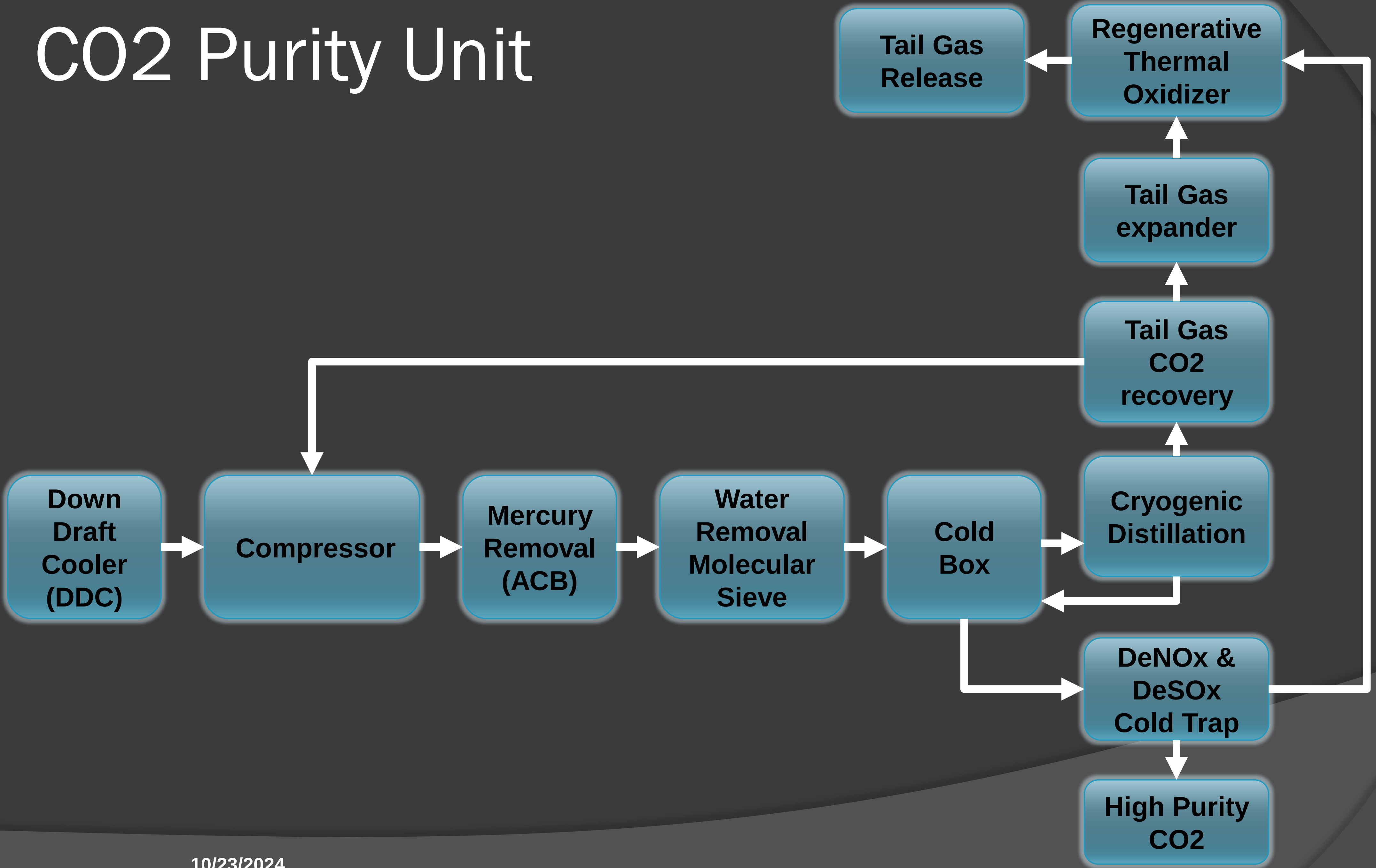
Heidelberg Geseke Project

- **2,700 mtpd clinker**
- **1,050,000 mtpy cement**
- **750 kg-CO_2 / t-clk with 15% (to 90%) biogenic fuel**
- **Pre-dry alternative fuels**
- **96% O_2 for combustion – 80%v CO_2 in exhaust gases**
- **CCS – Second generation oxy-fuel combustion**
- **700,000 t-CO_2 / year captured**
- **New 5 stage precalciner kiln line**
- **3.3 GJ/t-clk / 790 kCal/kg-clk / 2.85 mn BTU/ston-clk**
- **FID – Q1, 2025 – Start-Up in 2029/30**
- **Other Oxy-Fuel Projects – 250 tpd Denvya / 450 tpd CI4C**

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

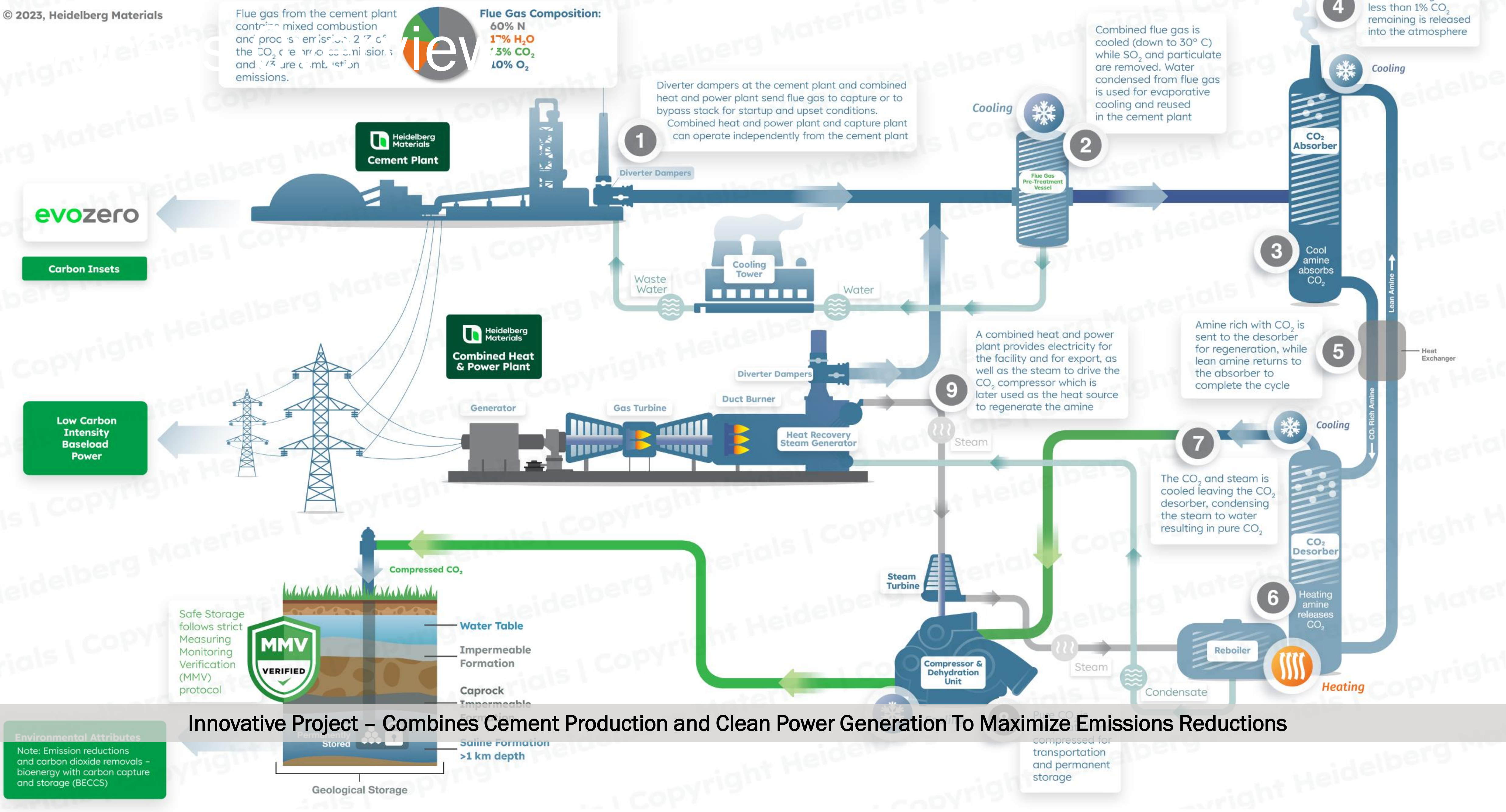
CO2 Transport

- 350 km (+/-) from plant to Wilhemshaven (seaport)
- Ship transport to North Sea
- Initially by rail
  - 13 bar
  - 35 Degrees C
  - 4,500 tons of storage
  - 38 X 60-ton rail cars per day (2,280 tons-CO_2/day)
- Future
  - Pipeline to port (10 years to build)
- **The capture of biomass CO_2 provides offsets to take to net zero**

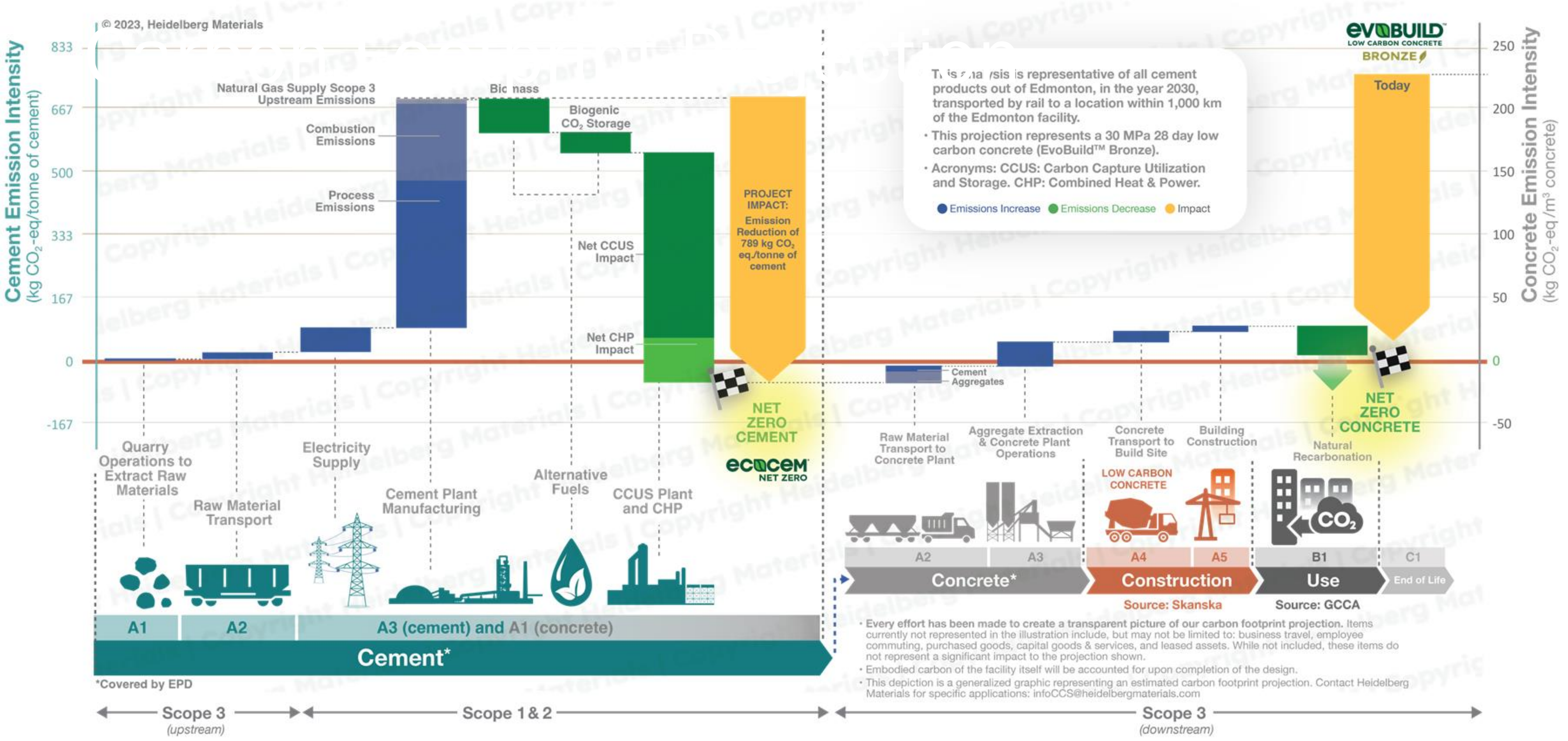
Heidelberg Edmonton Project

- Precalciner kiln system
- 780,000 tpy CO_2 emissions from cement plant
- Added two combined heat & power units 120 MW total
  - ~30 MW to power cement plant
  - ~30 MW to power CCS plant
  - Balance for green energy sale / carbon credits
- Will capture CO_2 from the cement plant and the two natural gas fired CHP units + ~220,000 tpy CO_2
- Getting ready for permitting, testing emissions now
- 50% AF garbage and biogenic
- Inline compressor to 2600 psi CO_2 into a 10 inch pipeline connected to the Alberta Carbon Trunk Line for EOR

Heidelberg Materials Edmonton CCUS Project

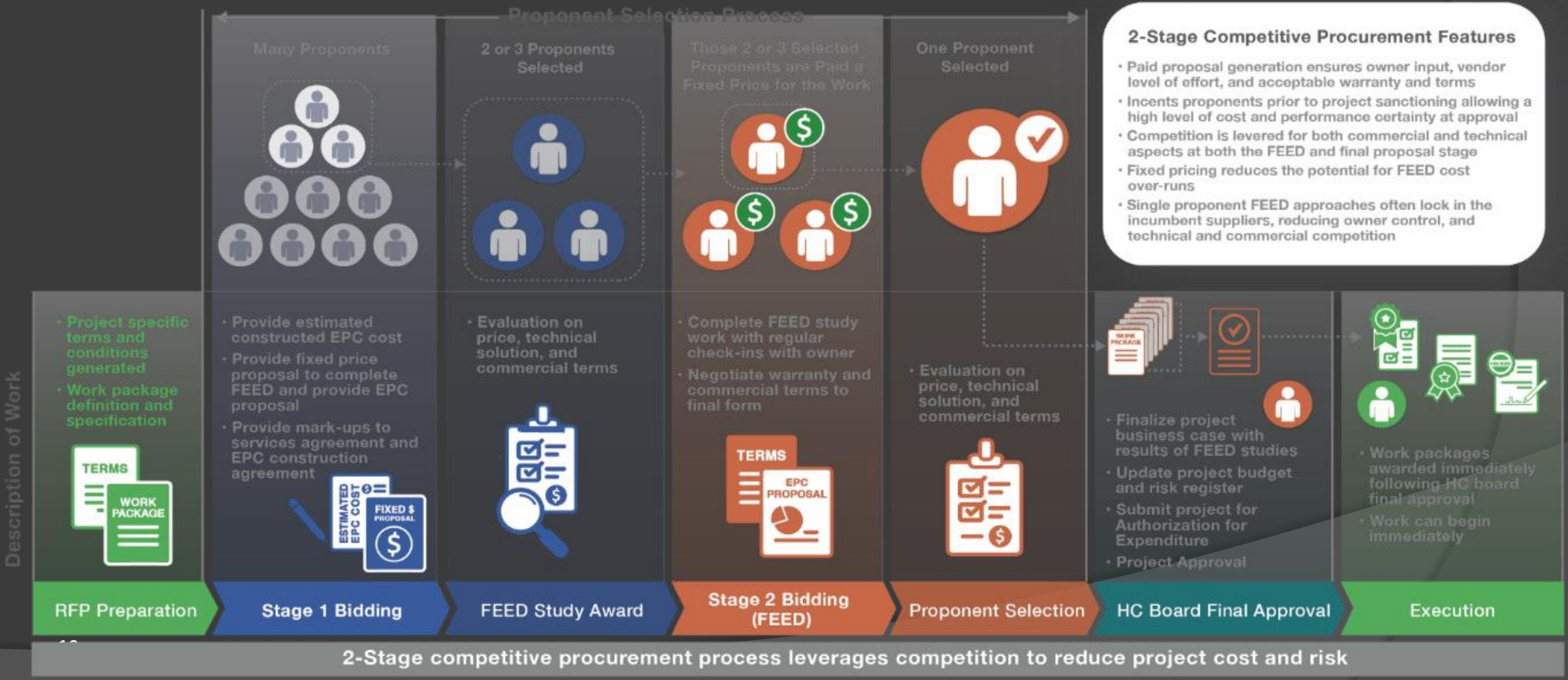


Innovative Project – Combines Cement Production and Clean Power Generation To Maximize Emissions Reductions



Produces The World’s First Net Zero Cement, Without Offsets, Enabling Net Zero Concrete

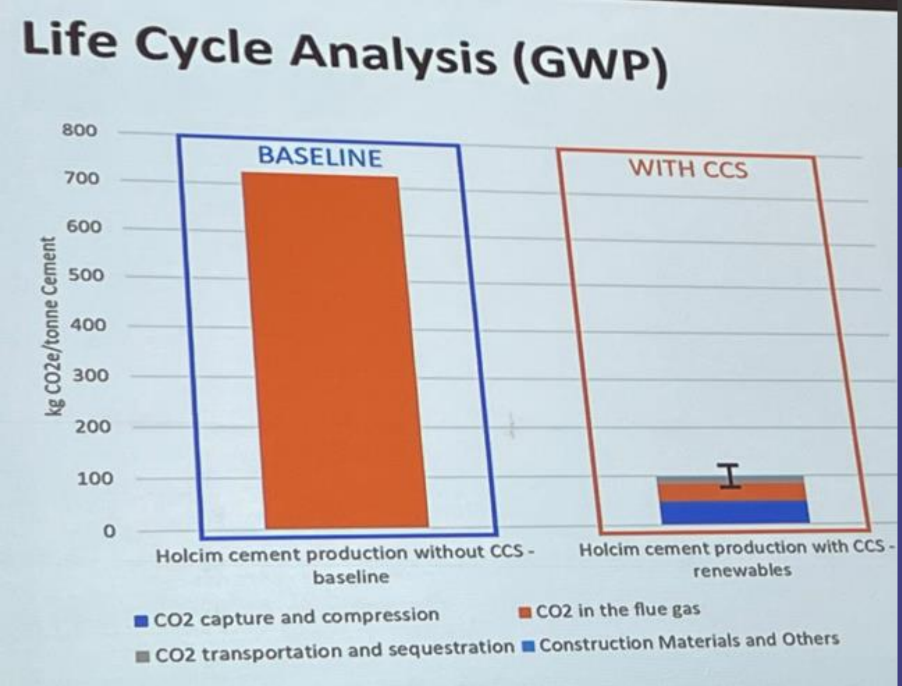
Project Procurement Strategy

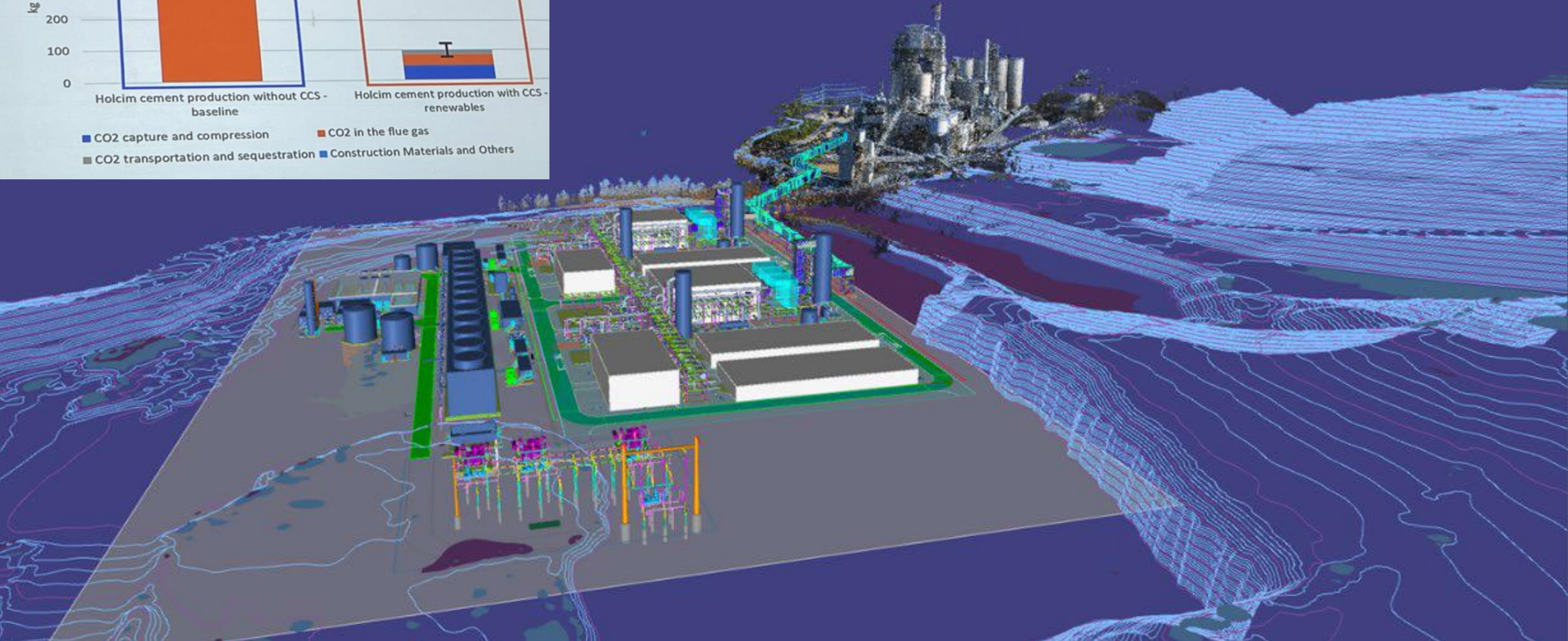


Holcim – Saint Genevieve

- Largest plant in the US with 4.5 mn tons per year of cement production increasing to 5.3 mn tons per year
- CO_2 20.3% by volume, wet
- FEED study - $5 mn / 26 months
- Air Liquide Cryocap Project
- Pressure swing absorption pretreatment with cryogenic distillation afterwards for 95% capture (all electric no chemicals)
- >95% pure CO_2 at pressure of 2215 psi & <49 C for pipeline transportation 60~80 miles
- 25 acres required for CCS plant, sited in the quarry
  - Vibration from quarry blasts requires special attention
- Final study due out next year

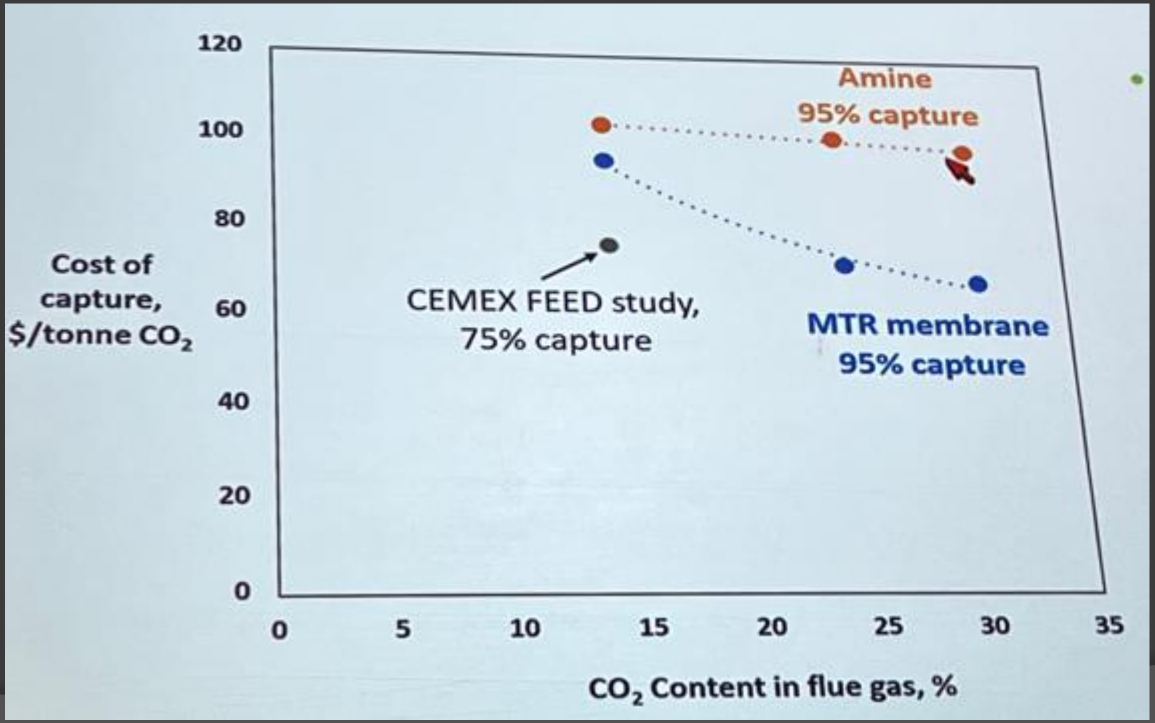
HOLCIM St. Gen.





Cemex Balcones

- Sargent & Lundy performed FEED study for Sargent & Lundy MTR Polaris membrane capture system
- Kiln 2 – 2,700 mtpd CO2 at 15% by volume



- Membranes use less water
- Membranes are less advanced
- Several other membrane projects / studies underway

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				

Lessons Learned – Heidelberg Brevik

- There is a lot to learn, the more you know, the more you know that you do not know
- CCS projects are extremely complex
- Information flow was too much, too fast – need to have an established knowledge management system
- Lack of people with expertise, hired from oil & gas industry (different mind set and vocabulary)
- Lack of standards and procedures
- Thousands of parts with specific standards and procedures
- FEED study must have a defined end point – different standards for pipelines, transport vessels, and projects

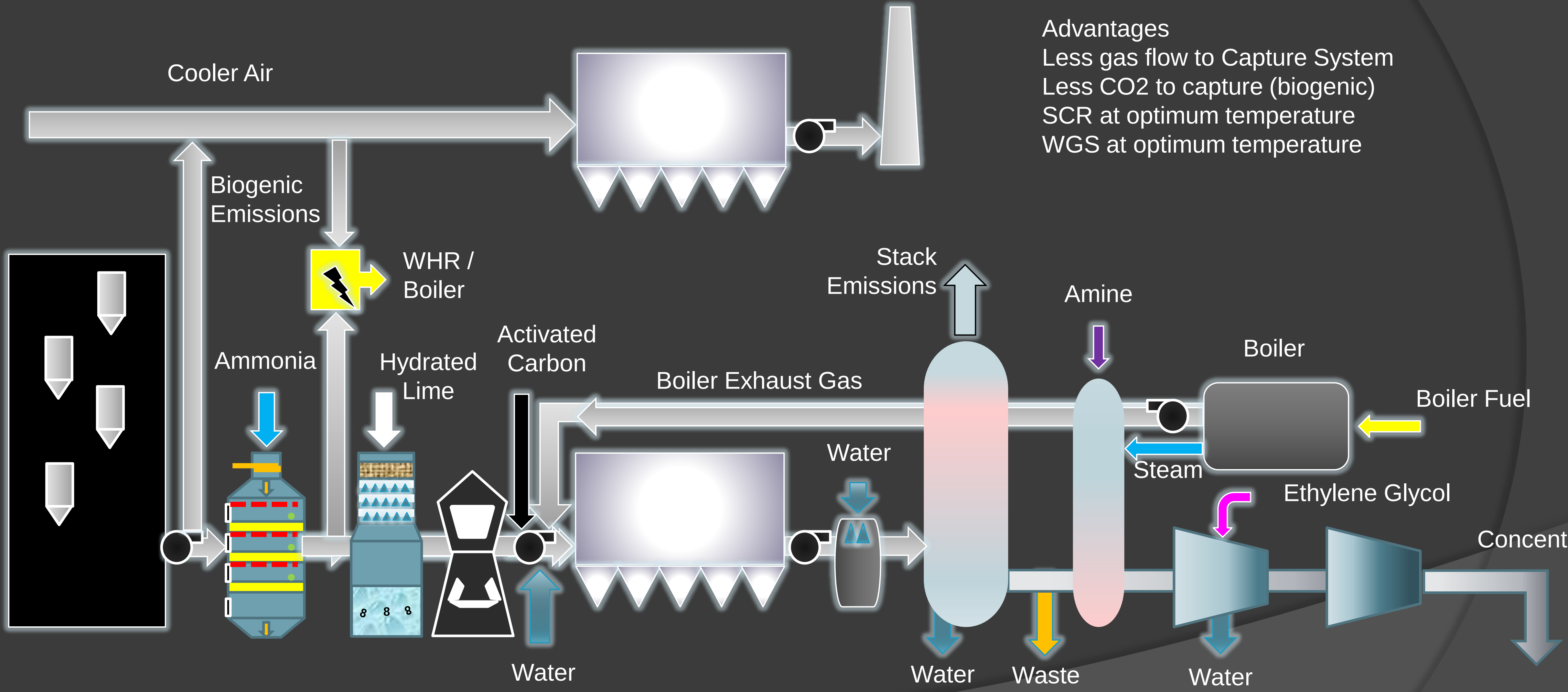
Lessons Learned – Heidelberg Brevik

- Need a disposal plan for off specification CO_2 (i.e. vent ships during loading)
- Heidelberg managed the civil and electrical, surprised by cost of scaffolding (7% of installation cost in Oil & Gas, 1% in Cement)
- Sequence of work very important, pipeline welding, thousands of pressure tests, touch up painting, & insulation
- Must be able to isolate subsystems for testing
- Need to keep all CO_2 piping dry
- Operator training for a year using a homebuilt simulator
- Heidelberg is now hiring 4 new engineers a year to specialize in carbon capture systems

Final Thoughts

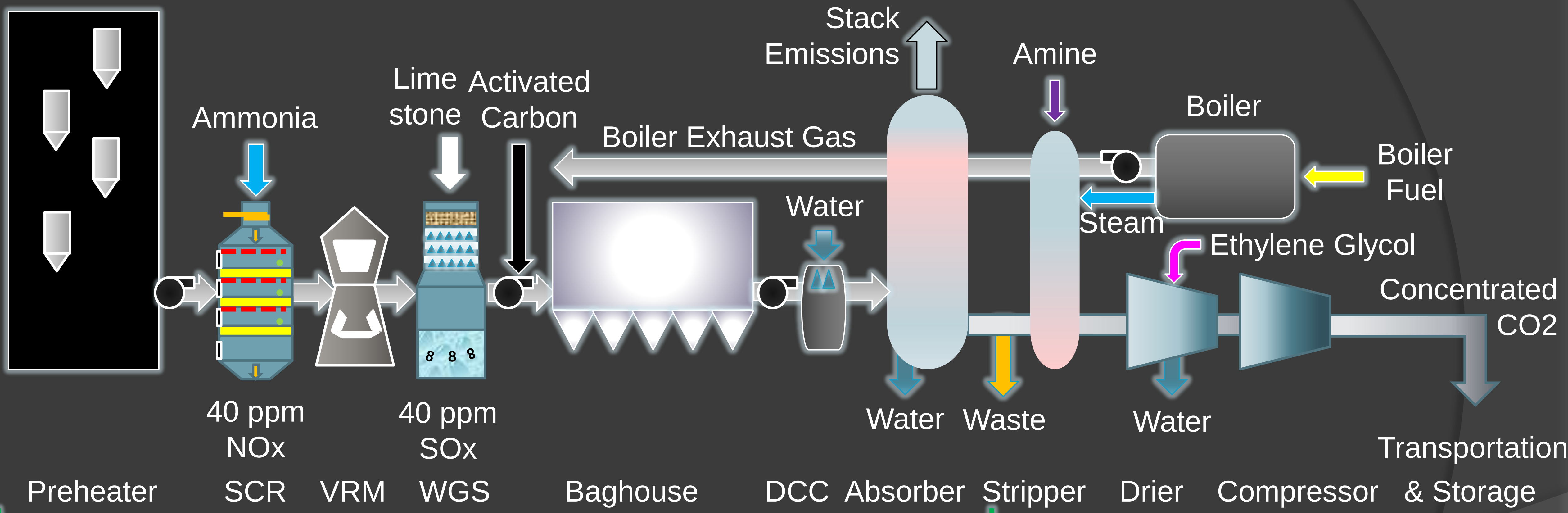
- Process mastery & clinker reactivity more important than ever
- Alternative fuels, especially biogenic fuels will become more valuable than fossil fuels
- Understand your unique situation and plan accordingly
- Start you plan early, but track what is happening elsewhere
- Bring in more technical people
- Move towards your final configuration

Cement Plant Reconfigured



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

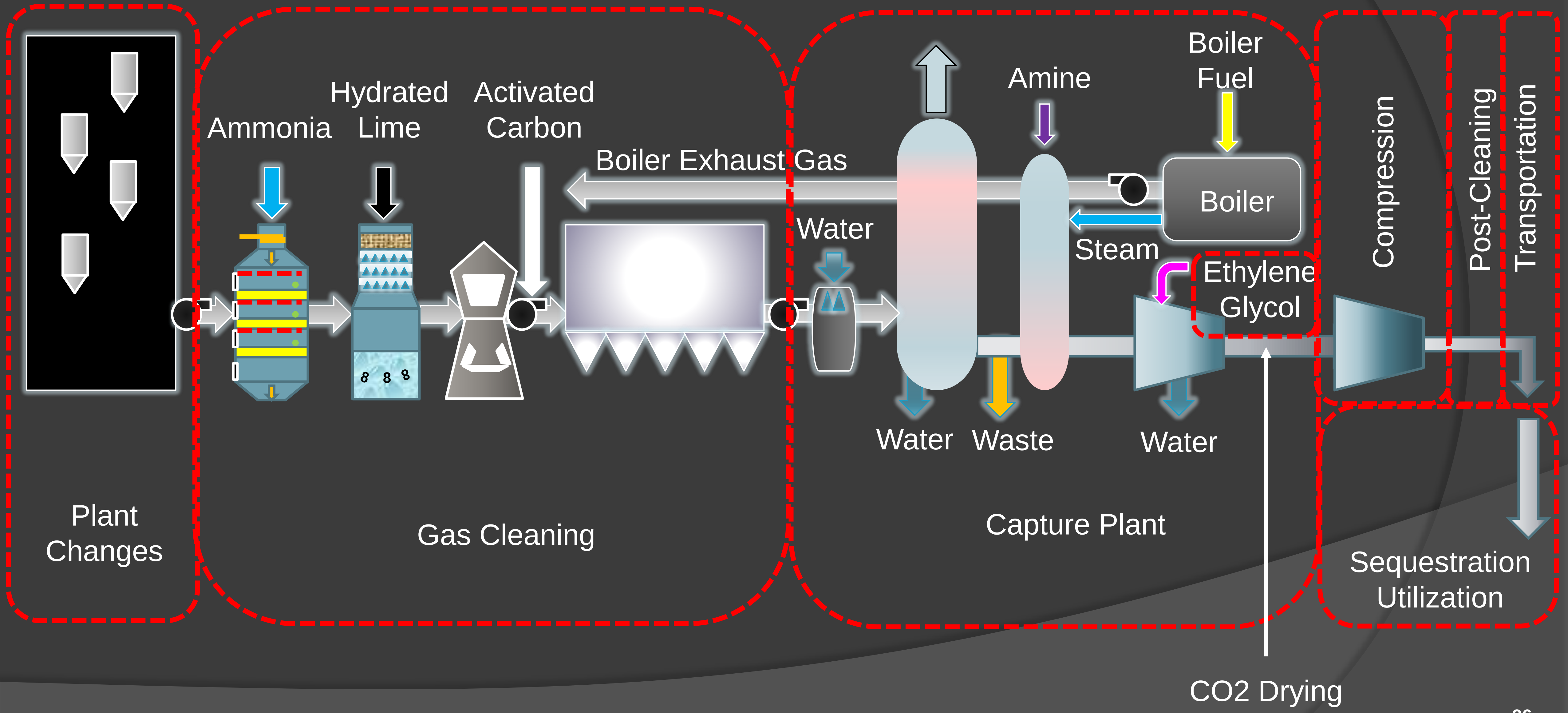
Carbon Capture System ($1bn)– 2 Main Cost Factors



Cost is a Function of Gas Quality & Flow
Heat Consumption, Fuel Type, Elevation, & Inleakage
25~34% of Costs

Cost is a function of CO2 Captured
CO2 from fuel, calcination, & boiler
66~75% of Costs

Carbon Capture Cost Boundaries



Questions ?

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