Integrated CCS for Kansas (ICKan): CO_2 source assessment
Preliminary design for capture from fossil fuel sources

Carbon Capture, Utilization and Storage in Kansas

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ICKan Project Phase 1: CO_2 Sources & Capture Options Assessment - Objectives

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Overall Objective

- Identify CO_2 emission sources and assess cost effective capture and compression options to provide 50 Million tonnes/CO_2 for the ICKan project CO_2 utilization and storage network

Specific Objectives

- Identify large single point CO_2 emissions sources (e.g. power plants and industrial CO_2 emissions) in Kansas state that can deliver the targeted captured CO_2 volumes for the ICKan EOR utilization /geological storage sites
- Obtain data from the source facilities for preliminary assessment of CO_2 capture and compression
- Perform conceptual design to assess CO_2 capture and compression costs.

Identified CO_2 sources for ICKan and characteristics

CO_2 Source	Key drivers	Challenges
Coal fired power plant Lead source: Westar's Jeffrey's Energy Center, St. Marys, KS (other coal plants available)	- Large single point source - Partial capture from one of the three-trains can enable meeting ICKan target	- Cost of capture - Economic incentives - Contaminant & issues related to specific site design (aerosols) - Coal vs wind power economics in region
Refinery CHS SMR Hydrogen Plants (other sources, e.g. FCC boiler within refinery)	- Intermediate CO_2 volumes - Can contribute to ICKan target - Could promote economics with access to CO_2 pipeline	- Non-SMR CO_2 sources distributed in site - Low pressure steam availability
Ethanol (Corn-based Fermentation plants)	- Significant number of lower volume but higher CO_2 concentration source ideal for pipeline aggregation - Bio-based may contribute to CO_2 footprint	- Cost of specific contaminant removal if required (e.g. O_2, aldehydes, alcohols, H_2S/COS) - Low volumes and longer distances to market/storage sites

Pathways of CO_2 capture.
Linde's technology portfolio.

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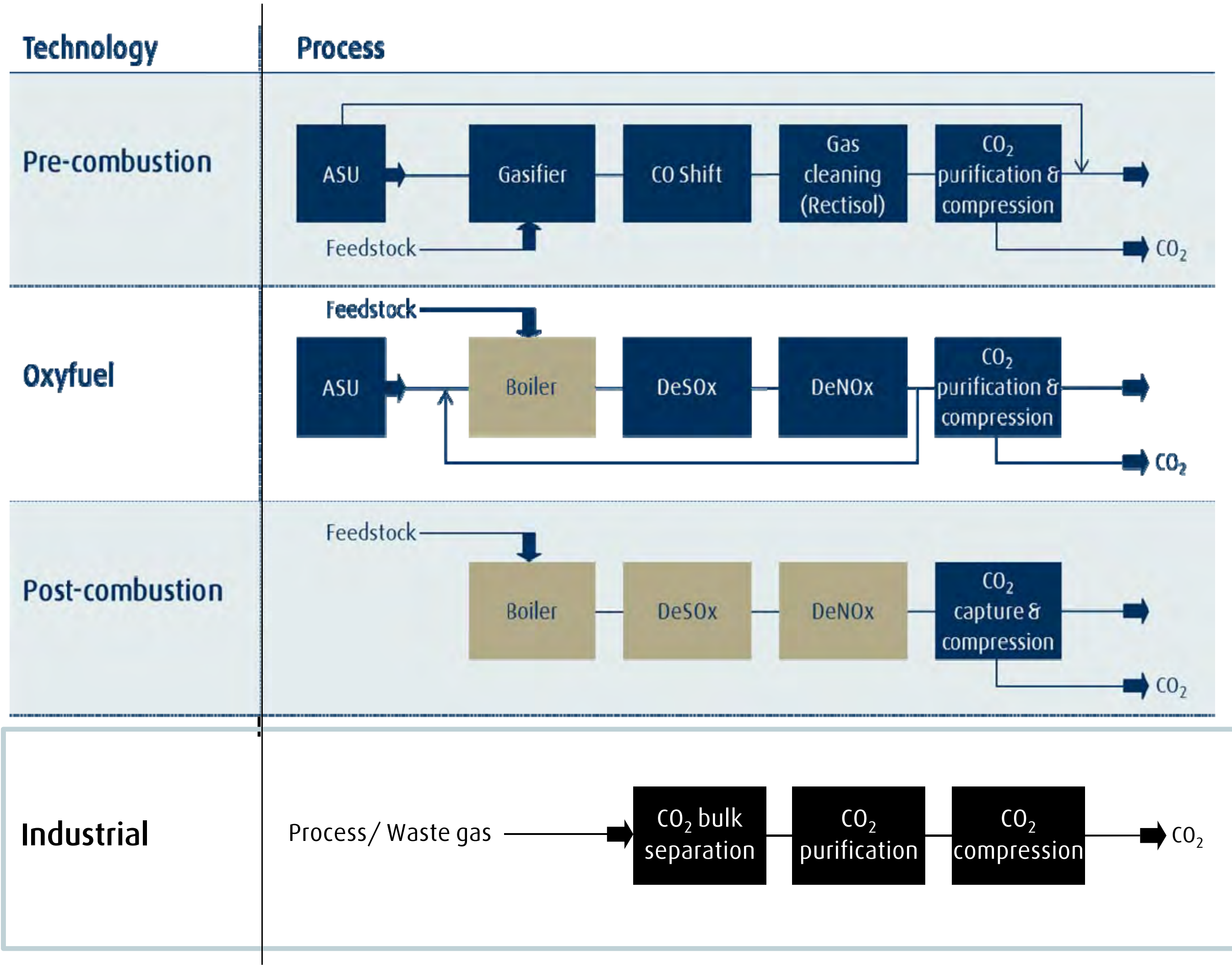

Solvent based capture is focus of this presentation:

- Applicable to new or retrofit plants
- Capture all or part of flue gas
- Applied at large scale in other applications
- Novel solvents (e.g. OASE® blue) stable in presence of flue gas contaminants & O_2
- Significant progress made toward the capture cost goal
- Recent successful large scale implementations (Boundary Dam, Petronova) provide confidence for future projects

BASF OASE® blue technology roadmap.
Adopted & optimized for PCC applications.

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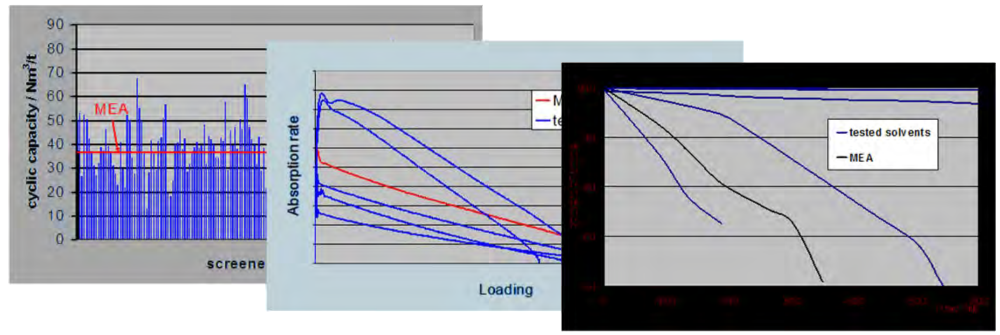
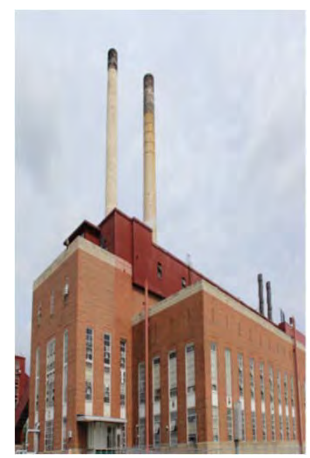
Equilibria

Kinetics

Stability



Lab. & Mini plant (2004)	Pilot: 0.45 MWe (2009)	Pilot: 1.5 MWe (2014-2016)	Large Pilot (proposed): 10+ MWe (2017-2020)
• Ludwigshafen, Germany • Solvent selection & performance verification	• Niederaussem, Germany • Process opt., materials & emissions testing	• Wilsonville, AL (NCCC) • Design improvements, emissions confirmation	• Abbott power plant, UIUC, Champaign, IL • Full value chain demo.



Linde-BASF progress toward lowering the cost of capture

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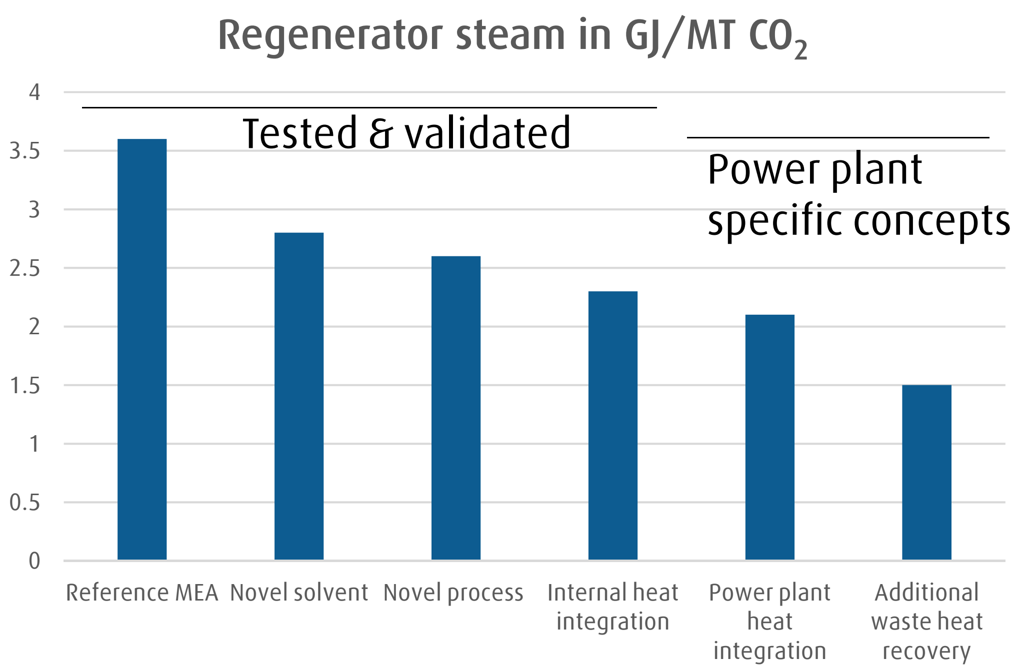
Reducing low pressure steam consumption:



Capex reduction:

- High capacity structured packing (smaller diameter absorbers)
- Higher pressure regeneration (Reduced CO_2 compressor cost)
- Novel lower cost equipment (e.g. reboiler, inter-stage heater)

Electrical energy reduction:

- CO_2 compression power by operating at higher regenerator pressure

Other features for lower Opex:

- Reduced solvent inventory
- Fast dynamics for load following

Westar Jeffrey's Energy Center: A large power plant CO_2 source capable to deliver the entire CO_2 capture volume required for ICKan through partial capture installation

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Power plant facts:

- 3 x 800 MWe power plants located in St. Marys, KS with a total nameplate annual CO_2 emissions of 12.5 million tonnes.
- Power plants built in the 1980's but fitted in the past decade with selective catalytic reduction (SCR) based NOx removal, activated carbon sorbent based Hg removal and scrubber based flue gas desulfurization (FGD)

Capture opportunity:

- Partial CO_2 capture installation (~583 MWe flue gas) from one of the three power plants can satisfy the entire ICKan CO_2 integrated capture, compression and storage target over a 20 years project period
- Solvent based post-combustion capture likely technology option for implementation by 2025 due to technology maturity and capture capacity

Capture challenge:

- Not fitted with baghouse; potential aerosol in flue gas causing solvent carry-over and losses
- Concerns about the long term power plant utilization capacity with increasing wind power coming online

Overall integrated project economics:

- Sources of waste heat to generate low pressure steam for solvent regeneration, thereby reducing parasitic power consumption (e.g. full capacity waste heat utilization for partial CO_2 capture)

Westar Jeffrey's Energy Center: Preliminary CO_2 capture assessment/Design basis

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CO_2 product:

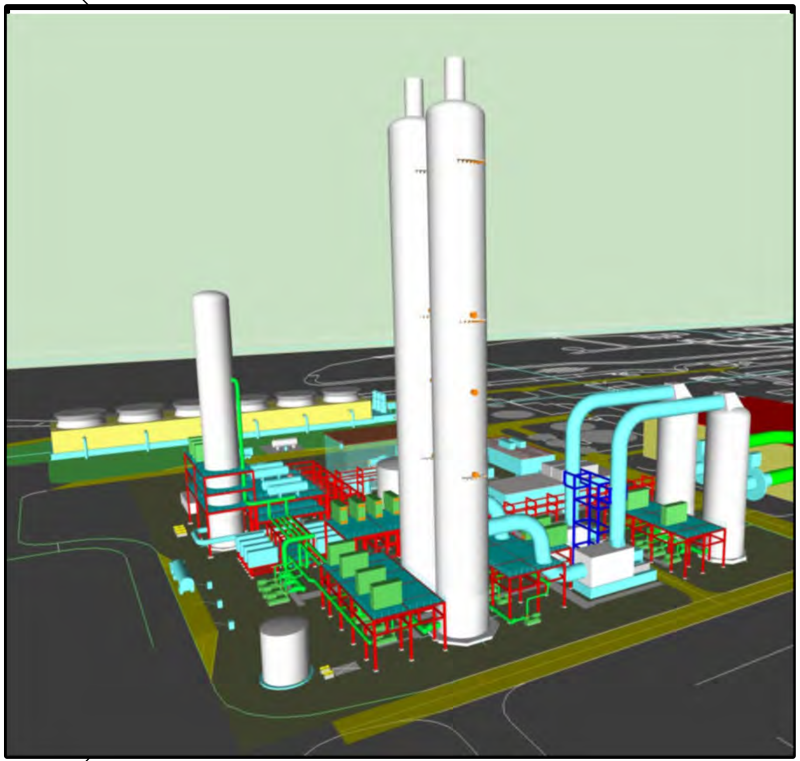
- 2.5 million MT (20 yrs) or 7500 MTPD
- 90% capture efficiency
- 99.7+% purity (<100 ppmv Oxygen)
- 150 bars delivery pressure at site boundary

Flue gas processed:

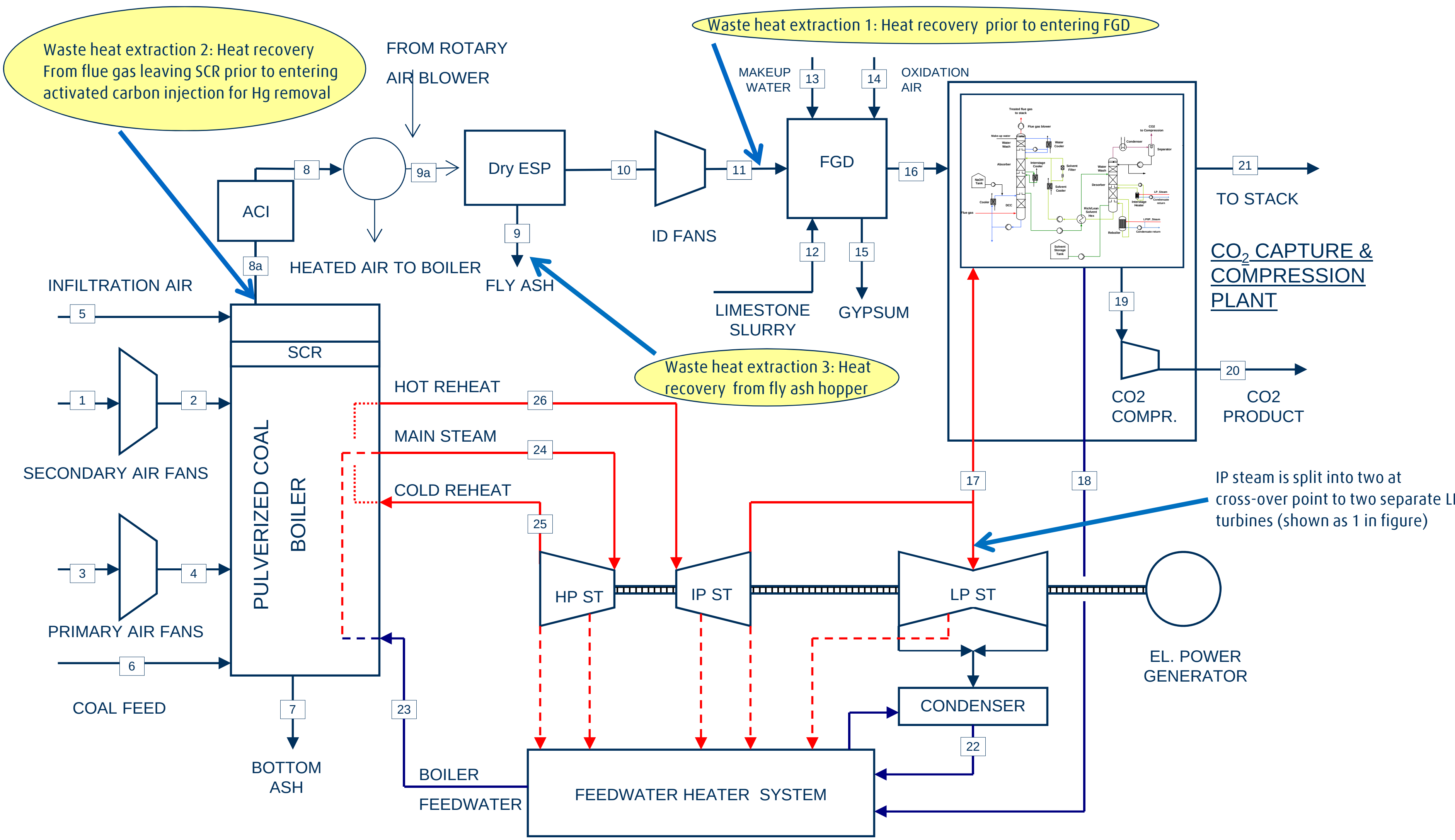
- Target flue gas flow rate: 2063 MT/hr (wet)
- Flue gas composition: CO_2 10.8% wet; 13.2%dry
  O_2 5.1% wet; 6.3% dry
- Target capture plant capacity: 583 MWe (~73% of Unit 1)

Operating requirements:

- Regenerator LP steam (4.8 bar): 1.16 tons/ton CO_2
- Electrical power: 129 kW/ton CO_2 (40 MW)
- Cooling water: 112 m^3/ton CO_2 (36,000 m^3/hr)



Power plant block flow diagram showing potential waste heat extraction to generate LP steam for PCC plant



CHS refinery: SMR H_2 plants can deliver cost effective CO_2 capture to partially meet the ICKan CO_2 capture volume target

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Steam Methane Reformer H_2 plant facts:

- 2 x ~40,000 Nm3/hr H_2 plant capacities. Plants incorporate PSA (Pressure swing adsorption) based H_2 purification with purge gas used as reformer fuel.
- Total name-plant CO_2 emissions with SMR furnace flue gases is ~760,000 Tonnes/year. This meets 30% of the ICKan CO2 capture and storage capacity over a 20 year project.

Capture opportunity:

- Solvent based post-combustion capture from the reformer furnace flue gas will result in maximum CO_2 emissions reduction (~90% of total emissions from SMR H_2 plants).
- Sorbent based (pressure or vacuum swing adsorption) capture from syngas or purge gas are likely technology options for partial capture (~50-60% of total SMR H_2 plant emissions) as they are more cost effective than solvent based due to relatively smaller capture capacity.

Capture challenge:

- Non-H_2 plant refinery CO_2 emissions distributed and in smaller amounts
- Unfavorable steam balance necessitating separate generation of low pressure steam for CO_2 capture plant
- Current lower H_2 plant loading may affect scale of CO_2 capture

Overall integrated project economics:

- Shorter distance (access pipeline) to EOR and/or storage sites targeted.
- Additional steam generation for refinery needs combined with LP steam for solvent regeneration may be attractive.

CHS refinery SMR H_2 plant CO2 capture: Preliminary assessment and design basis

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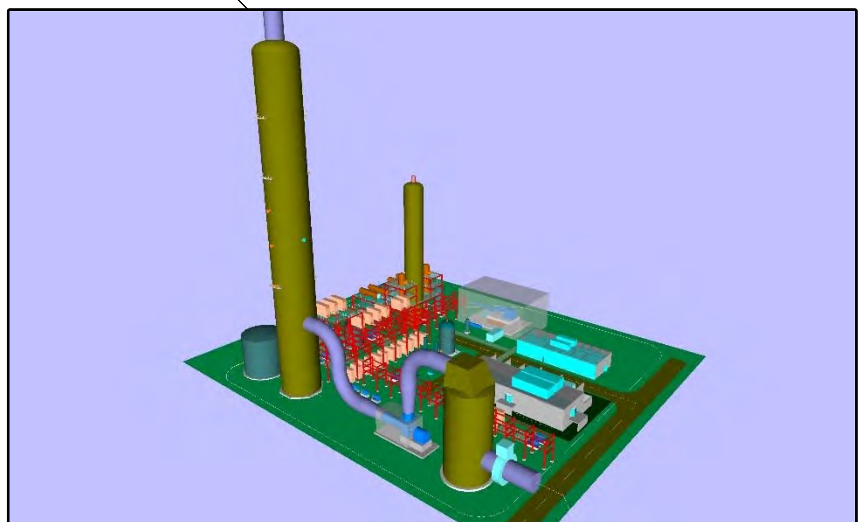
CO_2 product:

- 1872 MTPD (~13.6 million tons over 20 yrs)
- 90% capture efficiency
- 99.7+% purity (<100 ppmv Oxygen)
- 150 bars delivery pressure at site boundary

Flue gas processed (mixed from 2 SMR's):

- Target flue gas flow rate: 362.7 MT/hr (wet)
- Flue gas composition: CO_2 15.8% wet; 19.1%dry
  O_2 2.2% wet; 2.7% dry
- Target capture plant capacity: 100% of available SMR H_2 plant furnace flue gases (2 plants)



Operating requirements:

- Regenerator LP steam (4.8 bar): 1.17 tons/ton CO_2
- Electrical power: 123 kW/ton CO_2 (9,600 kW)
- Cooling water: 115 m^3/ton CO_2 (9000 m3/hr)

Questions?

Thank you for your attention!

Back-up slides

Linde has performed number of large scale studies/ process concepts and engineering assessment tailor-made based on end-customer requirements

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