InnoSepra

Transformational Sorbent-Based Process for a Substantial Reduction in the Cost of CO_2 Capture (DE-FE0031722)

NETL Carbon Management Meeting

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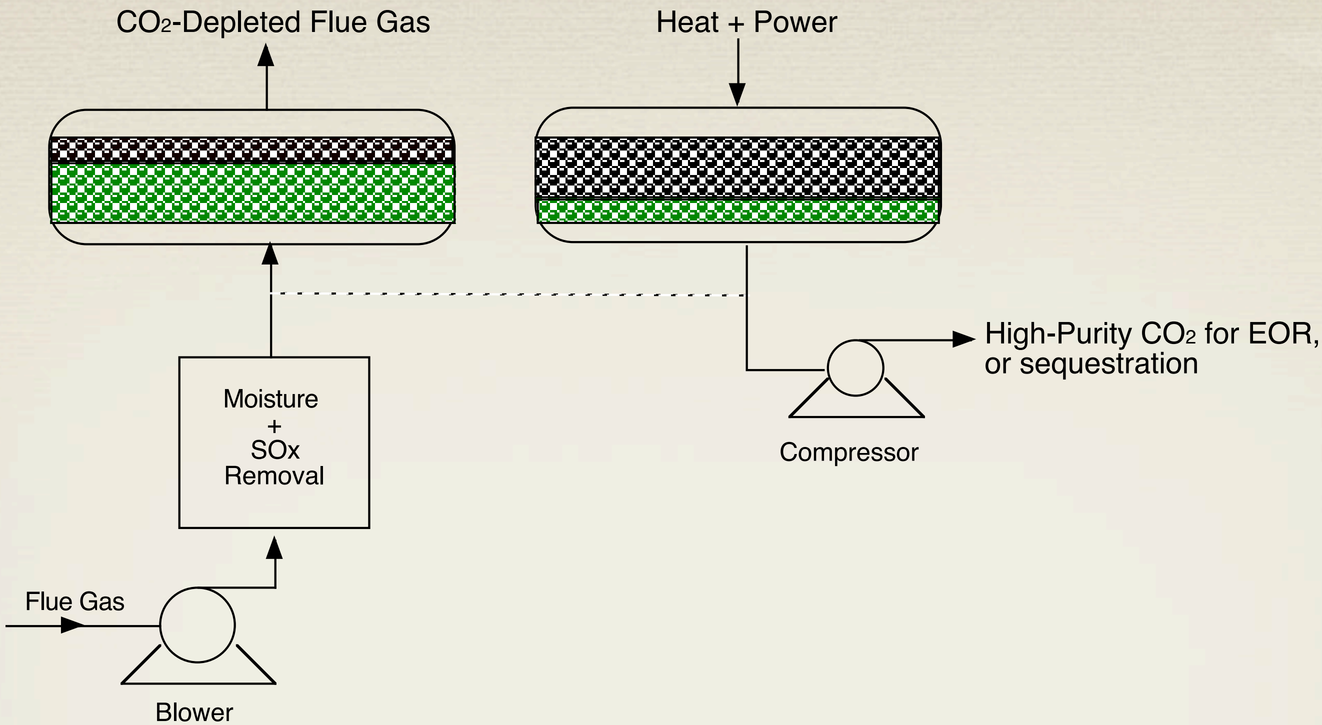
Executive Summary

- CO_2 Capture with physical sorbents, low heats of adsorption (~0.8 GJ/MT)
  - High purity CO_2 (>98%) at high recovery (>90-95%)
    - Up to 99% recovery possible with some process modifications
  - The estimated energy requirement (excluding compression) of 1.6 GJ/MT of CO_2, needed at about 110^{o}C
    - 40% lower than Cansolv and 57% lower than MEA based on absolute energy requirement
    - 66% lower than Cansolv and 73% lower than MEA based on lost work analysis (160^{o}C steam extraction temperature for amines)
  - Potential for about 45% reduction in the capital cost, and up to 50% reduction in the capture cost for CO_2 meeting pipeline specs
    - <$30/MT capture cost without any increase in LCOE or any loss in power output
  - Lab scale testing, process simulation, and a preliminary TEA during BP1; bench scale testing at TCM and a final TEA during BP2

Presentation Outline

- Background on the Proposed Technology
- The DOE Project Summary (Objectives, Timeline, Budget, Key Activities)
- Project Partners
- Key Results from Budget Period 1
- Key Budget Period 2 Tasks and Budget Period 2 Status
- Summary

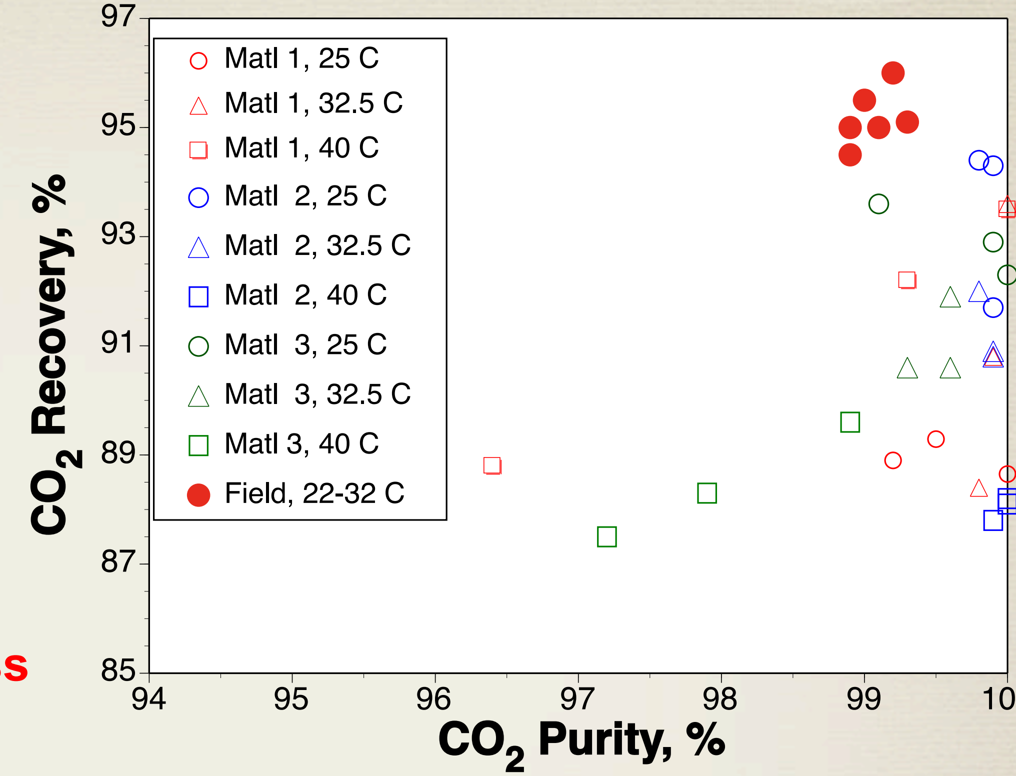
InnoSepra Process Overview



- **Flue gas pretreatment for NO_2 and SO_X removal to sub-ppm levels, removal of substantial amounts of aerosols**, and moisture removal to ppm levels
  - NO_2, SO_X and aerosol removal demonstrated at pilot scale; applicable to solvent capture
- Physical sorbents with a very high surface area (>10 million m^2/m^3), low heats of adsorption (0.8 GJ/MT of CO_2)
  - Adsorption at 25-40°C, regeneration at 90-110°C, high net CO_2 capacity (>8-wt%)
  - Pipeline quality CO_2 (>98% purity, <1 ppm H_2O and SO_X, <10-ppm O_2), >90% recovery
- Key innovation is ***the novel combination*** of process, sorbent regeneration and materials
  - Performance similar to or better than amines, much lower regeneration energy requirement

Field Demonstration of First Generation CO_2 Capture Process

Pilot Plant for the First Generation Process



- NRG's Indian River, DE coal fired power plant, more than 8 weeks of testing
- 80-100 scfm flue gas, 22-32^{0}C feed, 50-ppm SO_2, 10-12% CO_2
- 8-10.5 wt% net CO_2 capacity in the field
- >94% CO_2 recovery, 98.5- 99.5% CO_2 purities, pipeline / EOR quality gas (<10 ppm oxygen and moisture)

Comparison with MEA for the 1st Generation Process

- The absolute energy requirement is 2.1 GJ/MT, about 40% lower than MEA; effective energy requirement (based on loss work analysis) is 1.1 GJ/MT, about 68% lower (lower steam extraction temp.)
- The CO_2 capture system capital cost, using DOE Lang factors, is about 38% lower compared to MEA for a 550 MW plant process
  - **About $246 MM for InnoSepra vs. $397 MM for MEA on the same basis**
- The parasitic power load is
  - **About 99 MW for InnoSepra, 18% of the plant output**
  - **About 154 MW for MEA, 28% of the plant output**
- The capture cost is $38/MT vs. about $74/MT for MEA (19.5% capital+maintenance charge, $64/MWh for the lost power output)
  - **About 48% reduction vs. MEA**

The Second Generation InnoSepra Process
(The Current DOE Project)

Second Generation InnoSepra Process

- A breakthrough regeneration method has allowed reduction in the absolute energy requirement to 1.6 GJ/MT (based on lab testing and process simulation) at about 110^{o}C
  - **The process is also simpler, significant capital savings over the first generation process**
- Effective parasitic load of 0.96 GJ/MT based on a steam extraction temperature of 160^{o}C (74 psia) for MEA and Cansolv
  - **About 67% lower than Cansolv, and about 73% lower than MEA**
  - **Less than 16% of plant's output for CO_2 capture and compression**
- The technology is to be demonstrated at the bench scale in 2022 at TCM (Technology Centre Mongstad)

The DOE Project (FE0031722)

- Objectives: >90% CO_2 recovery, >95% purity with a potential pathway for <$30/MT capture cost by 2030
- The total project budget is U.S. $4 million ($3.13 MM DOE, $0.87 MM match including significant match from TCM)
- In the first budget period (May 2019 to March 2021) we
  - **Optimized the sorbent and the regeneration process through lab testing, Monte Carlo simulations, and process simulation**
  - **Did a detailed design and costing of the bench unit, a preliminary TEA, and a HAZOP addressing TCM integration issues**
- In the second budget period (April 2021 to Dec 2022) we will
  - **Construct and field test the bench unit (500 Nm^3/hr scale)**
  - **Carry out a detailed engineering design, and a techno-economic evaluation for a commercial scale unit (550 MW power plant)**

Project Participants

DOE/NETL

- Project oversight, feedback, funding

InnoSepra

- Technology development at lab and bench scale, coordinate with partners, project management and reporting

Main Line Engineering

- Engineering design of the full scale plant, TEA, cost share

TCM

- Field testing, commercial feedback and cost share

Adroitech

- Monte Carlo Simulation, fabrication of structured sorbents

Adsorptech / Fabrication Partners

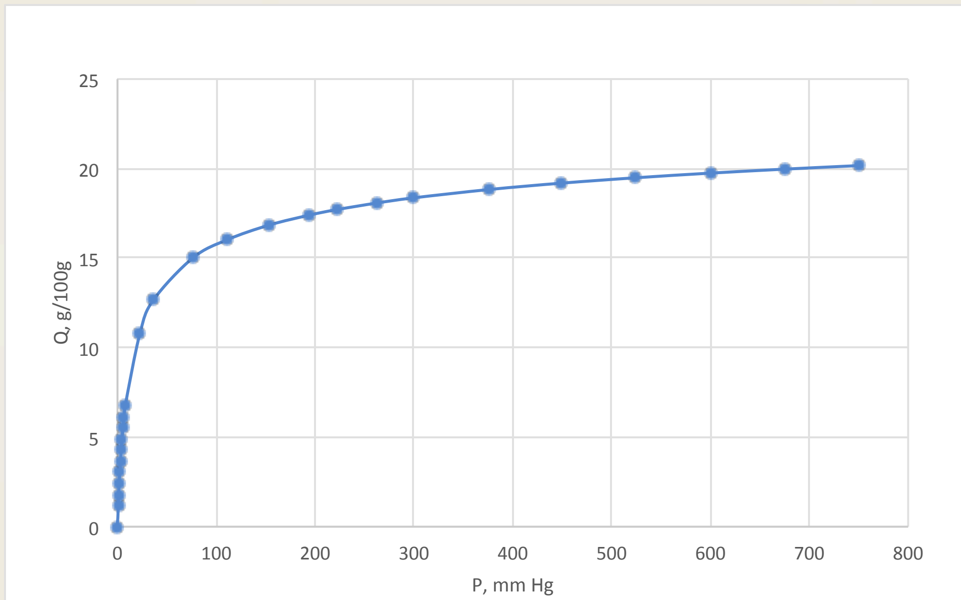
- Bench unit design and fabrication, cost share

Key Activities for BP1

- Monte Carlo simulations to identify the suitable sorbents
  - **Sorbent structure variation can provide absolute CO_2 capacities (15% CO_2 at 25°C) between 18-wt% (CO_2-N_2 separation factors of 15-20), and 12-wt% (CO_2-N_2 separation factor over 200)**
  - **Confirmed through microbalance and breakthrough testing**
- The regeneration process was optimized through cyclic testing
  - **No loss in performance after multiple cycles, >8-wt% net CO_2 capacity**
- Process simulation, integration with the host site, preliminary TEA
  - **A detailed process simulation confirmed a power penalty of <16% of plant's output**
  - **A new CO_2 compression cycle for up to 20% reduction in energy needed for CO_2 compression**
  - **A detailed HAZOP and test site integration with TCM**
  - **A preliminary TEA indicating the potential for a capture cost of about $30/MT**

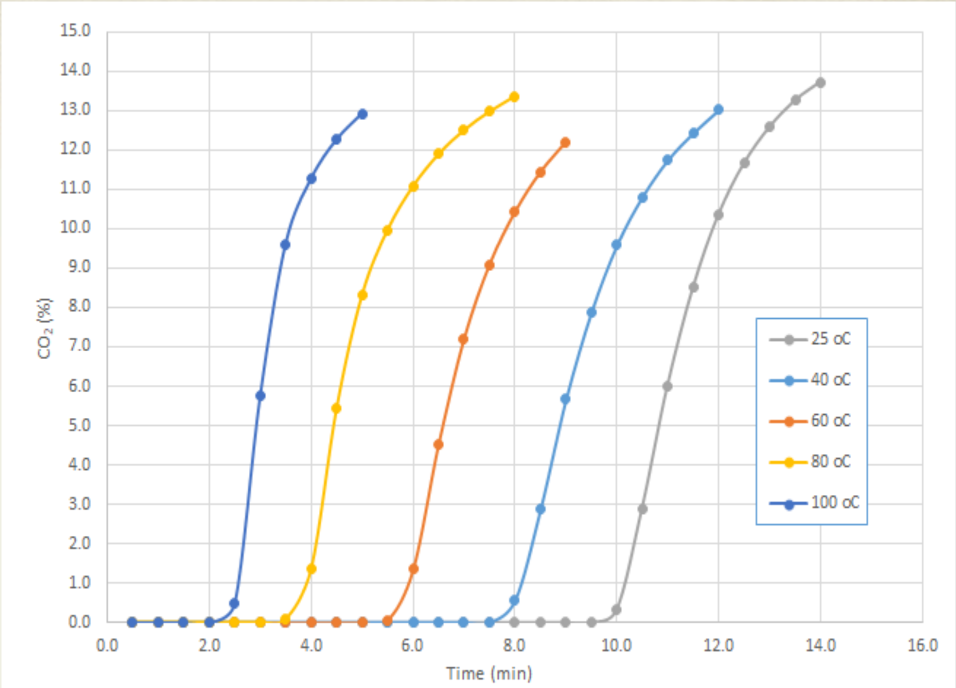
Identification of Suitable Materials

- A number of materials were identified based on Monte Carlo simulations and tested in the adsorption microbalance for CO_2 and N_2 capacities, and CO_2-N_2 separation
- A typical CO_2 isotherm (30^{o}C, Micromeritics ASAP 2020) is shown below

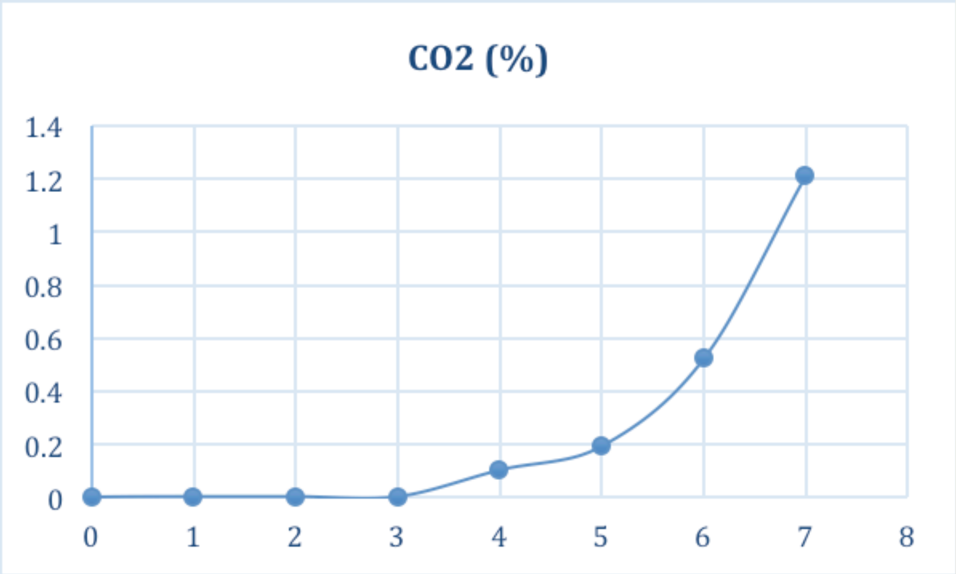


- Depending on the material structure CO_2 capacities between 12-wt% and 18-wt%, separation factors between 15 and 650 can be obtained
  - **High separation factors are associated with low CO_2 capacities**

Breakthrough Testing



Breakthrough Curves at Different Temperatures



Typical Breakthrough Curve (25°C)

Process Simulation Summary (Retrofit)

- Simulation of the CO_2 capture plant integrated with the coal-fired power plant with Aveva's Pro^{II} software
- The feed and product conditions (for a 550 MW SCPC plant) are:
  - **Flue gas: 2,138,000 kmol/hr, 57^{0}C, 100 kPa, 68.1% N_2, 13.5% CO_2, 15.2% water**
  - **Product CO_2: 9,517 kmol/hr, 99% CO_2, 15,270 kPa**
- Energy required for CO_2 capture and compression
  - **Pumps, blowers and compressors: 54.8 MW**
  - **Lost electrical output in LP turbine: 24.2 MW**
  - **Total loss in electrical output: 79 MW**
  - **Electrical output loss as a percent of total output: 14.4%**

Techno-Economic Evaluation Summary

550 MW SCPC Power Plant, 3.2 MM MT/year of CO_2 Captured

	MEA Capture	1st Generation InnoSepra Process	2nd Generation InnoSepra Process
Indicative Capital, U.S.$MM	397	250	215
Power Loss Due to Steam Extraction, MW	87	32	24
Electrical Power (compression, auxiliaries), MW	67	67	**55**
Total Power Loss, MW	154	99	**79**
Power Loss as % of Base Output	28	18	**14.4**
CO_2 Capture Cost at the plant gate, $/tonne	62	36	**31**
CO_2 Capture Cost including TS&M, $/tonne	67	41	35

- 19.5% capital + maintenance charge, $64/MWh replacement power
- A capture cost below $25/MT even with doubling of capital cost for a capital charge of 10% (ION Eng C3DC2: 7.7%, Svante CO2Ment: 11.6%) and a replacement power cost of $35/MWh (DOE: $30/MWh, Svante: $40/MWh)

Key Tasks for BP2

- Bench Unit Fabrication, Shipping and Installation
- Bench Unit Testing
    - **Parametric testing**
    - **Continuous testing at optimized conditions**
- Field testing report
- Detailed Engineering Design, Capital and Operating Costs, and the Final Techno-Economic Analysis for a 550 MW SCPC plant using DOE's Rev 4 guidelines (Retrofit and Greenfield)

Current Status for BP2

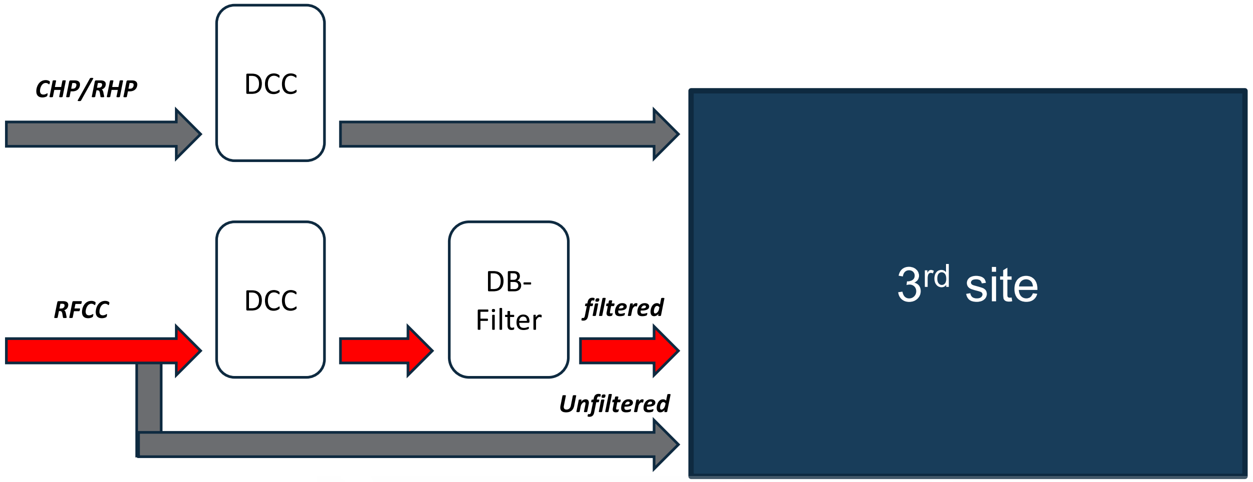
- Detailed engineering design of bench unit nearly complete
- Regular meetings with TCM to ensure that the design meets the sight requirements as well as shipping requirements
- Will go out for fabrication quotes soon
- Testing in Q2-Q3 (2022) per current schedule

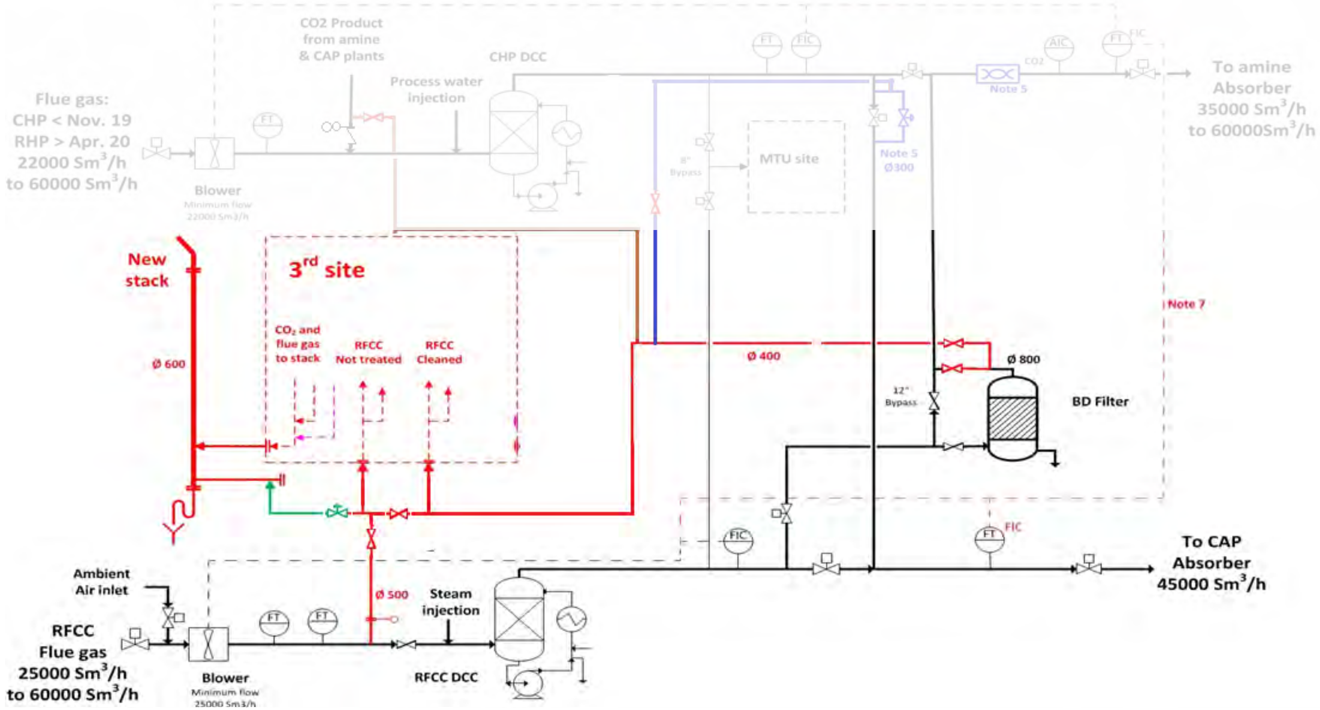
InnoSepra – TCM interface and utilities

Image of TCM test bay for emerging technologies

The flue gas - RFCC

Component	unit	Value
CO_2	mol%	13-14.5
SO_x	ppmv	5
NO_x	ppmv	100
Particles	mg/Sm^3	<0.5

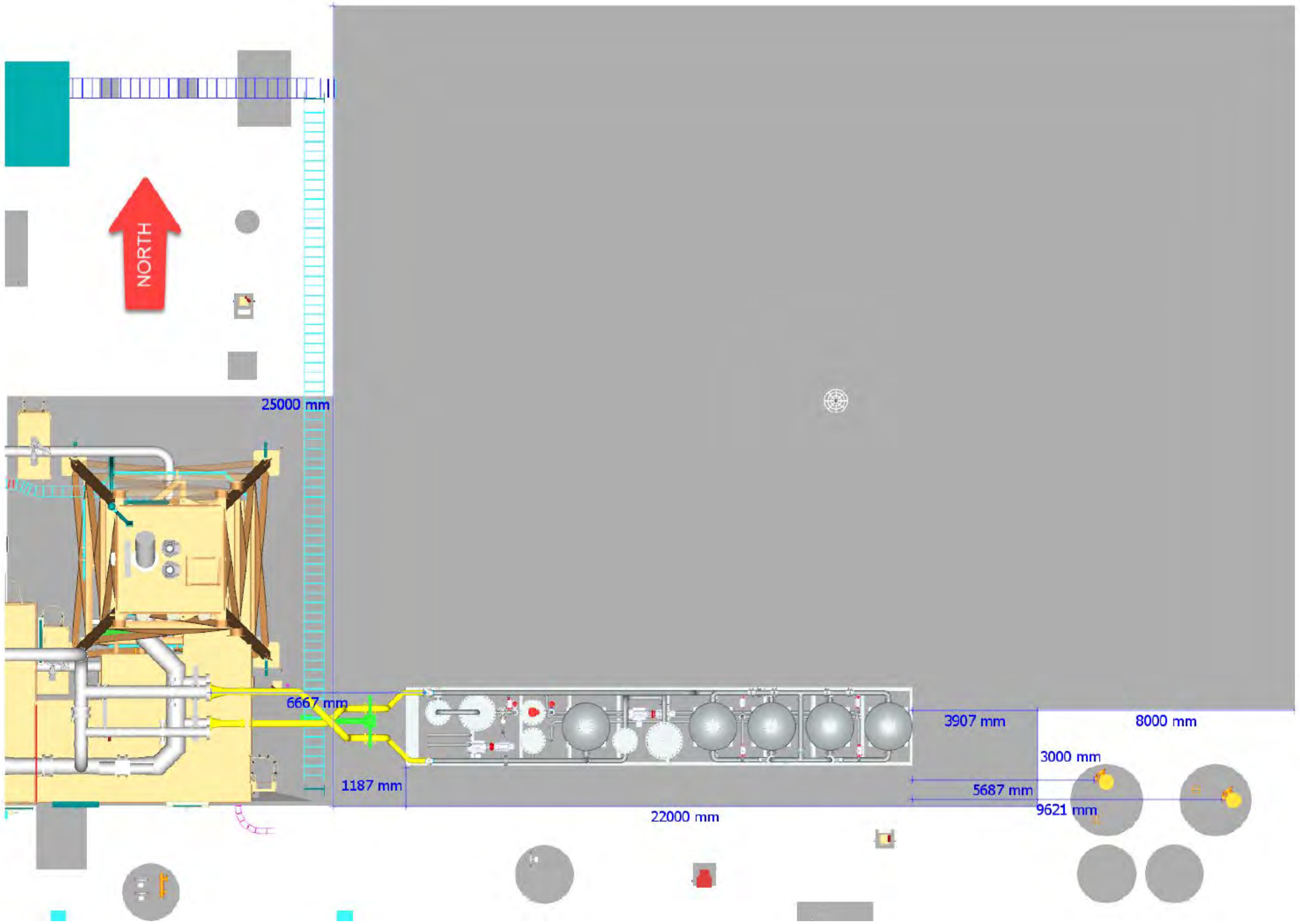




InnoSepra - Solid sorbent CO2 capture

1. Only electrical power consumption
   – No steam at site
2. Cooling water and flue gas condensate
   – Sea water return line

Utility	Unit	value
RFCC Flue gas	Sm^3/h	200-500
Seawater for cooling	m^3/h	3-6
Instrument air	Sm^3/h	5-10
Electric Power	kW	200



3D model of temporary linear design at TCM

Summary

- The InnoSepra CO_2 capture technology has the potential for a significant reduction in the CO_2 capture cost for the power plant and industrial flue gases
- It is possible to obtain very high recovery (90-95%), and high purity (>98%) CO_2 with physical sorbents while meeting the EOR/sequestration product specifications
- Potential to reduce the parasitic power required by more than 65%, and the capital required by about 45% leading to about 50% reduction in the CO_2 capture cost for the coal-based power plant flue gas
    - **After demonstration at the bench scale and further process optimization the process has the potential for a capture cost below $30/MT with no increase in LCOE and no loss in power output**