CO₂ Capture Project

Post Combustion Technology Overview

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CO_2 Capture Project

Cooperating For A Better Environment

US Dept. of Energy
National Energy Technology Laboratory
David Hyman, Program Manager

EU DG Research
Directorate-General Research
Program Manager: David O'Brien

Norges forskningsråd
The Research Council of Norway
Program Manager: Hans-Roar Søarheim

EU DG Energy and Transport
Directorate-General Energy and Transport
Program Manager: Vassilios Kougionas

Joint Industry Partnership (JIP)

www.co2captureproject.org

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Technology Areas Reviewed by the CCP

- **Absorption Processes**
  - Traditional Amine based – conventional and low cost designs.
  - Membrane based – using proprietary solvents.

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- **Adsorption Processes**
  - PSA – using novel materials.
  - ESA – using carbon fiber composite mol sieve.

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- **Other Processes**
  - Cryogenics
  - Compact Equipment Designs
  - Novel Concepts

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Operating Scenarios and Key Studies

North European Refining and Petrochemical Complex.
- Amine Baseline Study to capture 2 million tpa CO_2 from heaters and boilers across the complex - with Fluor

- **Alaska Open Cycle Gas Turbines.**
  - Amine Baseline Study to capture 2 million tpa CO_2 from 11 open cycle gas turbine sets - with Fluor
- **Norwegian 400MW power plant**
  - Amine Baseline study to capture 1 million tpa CO_2 from power plant exhaust gases – with Fluor
  - Amine Low Cost and Integrated Designs to capture 1 million tpa CO_2 from power plant exhaust gases - with Nexant
  - Amine + Membrane system to capture 1 million tpa CO_2 from power plant exhaust gases – with Mitsubishi/Kvaerner

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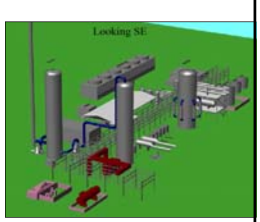
Key Outcomes – Absorption Based Technologies

- **Baseline studies…**
  - Have established the technical feasibility and costs of post combustion CO_2 capture using amines across three scenarios.
  - Highly energy intensive process…
  - Technology largely proven (albeit not at this scale) and available today for retrofit.
  - Requires coincidental removal of SO_x and NO_x
  - It is high capital cost.



- **Key Issues are…**
  - Low CO_2 concentration in flue gas
  - Low pressure flue gas
  - Large volumes of flue gas being handled

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Key Outcomes – Absorption Based Technologies

Amine Absorption Low Cost and Integrated Designs

•Nexant Low Cost Design
Identify ideas for design simplification/cost reduction of post combustion CO_2 capture using amines (retrofit emphasis)

•Nexant Integrated Design
Identify ideas for design and integration of post combustion CO_2 capture with new build CCGT.

•Combination MHI & Nexant (CCP 'BIT')
Application of design philosophy from Nexant (simplified and integrated studies) in conjunction with MHI's KS-1 solvent.

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The Elements of BIT

- Scenario = Onshore, 400-MW CCGT in Norway (Statoil)
- Recover 2850 tonne/day CO_2 for EOR
- Reference Plant = 30 wt.% MEA, refinery/API standards (Nexant, Inc.)
- Low-Cost Capture Plant through Value-Engineering (Nexant, Inc.)
- Integrated Power + Capture Plant (Nexant, Inc.)
- BIT = Integrated Power + Capture Plant with MHI's KS-1 (CCP)

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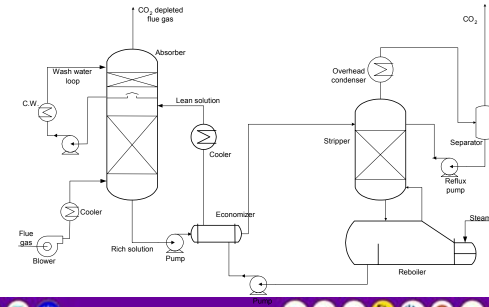
Reference Capture Plant



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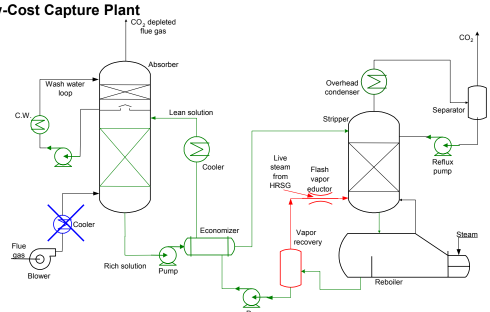
Low-Cost Capture Plant



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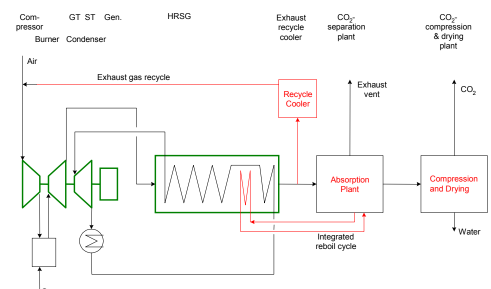
BIT Integrated (Note: Solvent switched to KS-1)



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Summary of Cost and Performance (by CCP)

	Net Power (MW)	Efficiency (%)	USGC Capex ($MM)	USGC Opex ($MM/yr)	USGC CO_2 Avoided Cost ($/tonne)
Uncontrolled	392	57.6	284	13	**N/A**
Base Capture	322	47.3	418	26	**60.0**
Low-Cost Capture	332	48.8	366	24	**44.7**
Low-Cost Integrated	335	50.6	345	24	**35.1**
BIT	**357**	**52.5**	**352**	**21**	**28.2**

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BIT Conclusions

- BIT evolved from several, independent CCP projects
- Significant Cost-Reduction Potential (~50%)
- Further engineering work with turbine vendor needed
- Pilot testing for cost-saving ideas needed
- Improvements in solvents can improve BIT further

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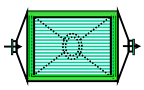
MHI / Kvaerner membrane contactor

- To develop an optimised process for CO_2 removal from flue gas
- By piloting the combination of Kvaerner's membrane contactor & MHI's KS-1 solvent technology

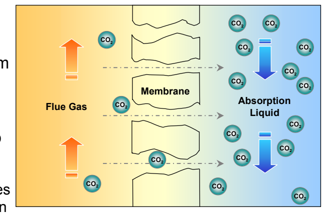
Kvaerner membrane + KS-1 solvent + MHI Nanko test facility = Pilot Demo in Japan



MHI / Kvaerner membrane contactor

- In the membrane gas/liquid contactor:

- Membrane physically separates flue gas containing 3 to 10% CO_2 from the KS-1 solvent
- Mass transfer of CO_2 occurs across the membrane due to absorption



Key Issue : Amine solvent migrates through the membrane requiring an additional flue gas clean up step.

Key Outcomes – MHI/Kvaerner Membrane

- Capital cost saving (versus conventional absorber/desorber equipment) are small and within the accuracy of the estimating technique.
- The principal advantage with this combination lies in the lower energy consumption of the KS-1 solvent (25% lower than MEA). Lower operating cost.
- The membrane system has a much smaller footprint and a much lower weight than conventional equipment. It will have an advantage where space and weight are at a premium….offshore.
- Reduction (versus baseline) in Cost of CO_2 Capture is 19%. Majority of this comes from operating cost reduction.

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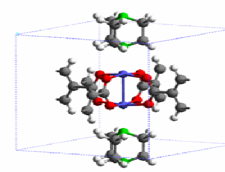
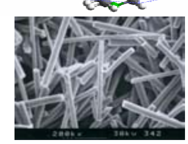
Key Outcomes – Adsorption Based Technologies

Two key Studies undertaken by the CCP

- SRI : Self Assembled Nanoporous materials.
  - Uses Copper Dicarboxylate materials.



- ORNL : Electric Swing Adsorption
  - Uses Carbon Fiber Composite Molecular Sieve material.



Self-Assembled Nanoporous Materials for CO_2 Capture

- SRI has synthesized copper terephthalate 3-D complexes, based on literature data, for use as CO_2 sorbents in a PSA system.
- Surface area: 20-1200 m^2/g
- Pore size distribution: over 90% with pores less than 20 Å (in a 450 m^2/g sample).
- SEM Surface morphology: multilamellar structure.
- Selectivity of the material for CO_2 over N_2: 8.

Carbon Fiber Composite Molecular Sieve - ORNL

- ORNL has synthesized CFCMS materials from isotropic pitch derived carbon fibers and phenolic resin.
- System surface area: 1300 -1700 m^2/g
- Pore size typically 2.0 nm
- Fibrous structure where;
  - Fiber diameter – 10 micron
  - Fiber Length – 10 to 1000 micron
- CO_2 loading circa 1wt% at typical flue gas pressures

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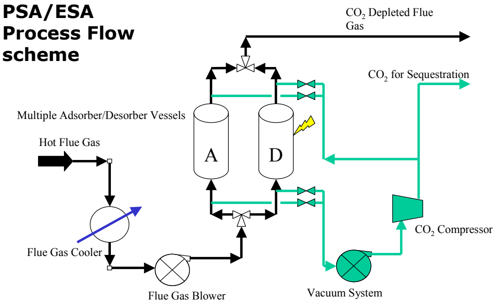
PSA/ESA Process Flow scheme



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SRI : Self-Assembled Nanoporous Materials for CO2 Capture….. Key Outcomes

- Simulation of a two-bed PSA system designed for a 400 MW gas fired power plant.
- Adsorption at exhaust gas pressure; desorption under vacuum.
- Recovery of 34.1% CO_2 at 67.9% purity.
- Sorbent weight: / Cost (per ton CO_2 captured):

Sorbent weight	Cost (per ton CO_2 captured)
SRI powder; 2,881 kg/bed;	SRI powder, $ 406.5
SRI granulated; 5,549 kg/bed;	SRI granulated, $495
HISIV; 1,440 kg/bed.	HISIV, $ 393.

- Power requirement for CO_2 capture: 1 GW.

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ORNL : CFCMS material used with ESA for CO2 Capture….. Key Outcomes

- CCP Internal engineering and cost review (Post Combustion at commercial scale) suggests 'no cost reduction potential' versus baseline amine technology.
- Low CO_2 loading on CFCMS requires multiple large Adsorber vessels and large CFCMS quantities.
- CFCMS pressure loss high – requires significant reduction for commercial feasibility.
- Requirement for substantial flue gas blower and regeneration vacuum systems – with attendant high cost.

Adsorbent systems all seem to suffer the same key problems;

- Low CO_2 loading due to low operating pressure
- Requirement to operate desorption under vacuum conditions

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Other Processes and Novel Concepts

- Cryogenic Processes were rejected for study early on;
  - Drying
  - Freezing
- CO2 hydrate briefly considered but cooling needs and partial pressure requirements appeared to make this impractical.
- Compact Equipment (Rotating Absorber/Desorber) was considered but development cost and schedule did not match available funds or timing for the CCP.
- Novel Chemistry approaches have been considered more recently, with pH swing and melting point swing processes planned for future evaluation.