CO2 Capture Project®

CO_2 Capture Project (CCP) Phase 3 – Advancing to Deliver Results

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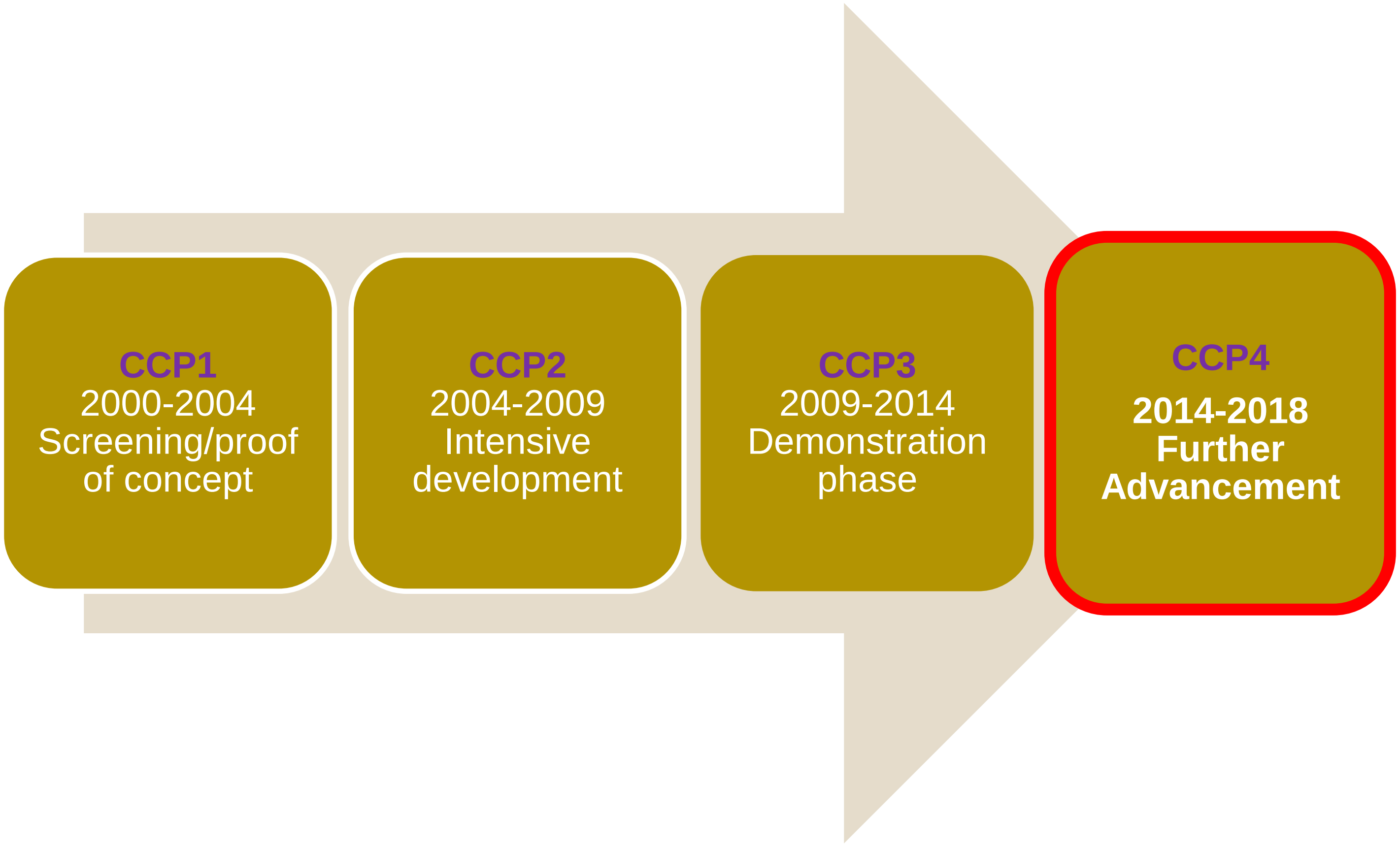
An Oil Refinery Scenario

A Joint Workshop organized by IEA Greenhouse Gas R&D Programme (IEAGHG) and
IEA Industrial Energy-related Technologies and Systems (IETS)

CO_2 Capture Project (CCP) – History

CCP4 "*Advancing CCS technology deployment and knowledge for the oil and gas industry*"



CO_2 Capture Project (CCP) – Teams

CCP3 Team Overview

The project consists of four work teams, supported by Economic Modeling:

- **Capture**: aiming to reduce the cost of CO_2 capture from a range of refinery, in-situ extraction of bitumen and natural gas power generation sources, supported by **Economic Modeling:** building a fuller picture of the integrated costs for CCS
- **Storage Monitoring & Verification (SMV)**: increasing understanding and developing methods for safely storing and monitoring CO_2 in the subsurface
- **Policy & Incentives**: providing technical and economic insights needed by stakeholders, to inform the development of legal and policy frameworks
- **Communications**: taking rich content from the ongoing work of the other teams and delivering it to diverse audiences including government, industry, NGOs and the general public

Capture Program – Refinery Scenario

The Refinery Scenario

Refinery Scenario

Technology demonstration

- **Oxy-fired Fluid Catalytic Cracking (FCC) Pilot Plant demonstration**
  - Vacuum Gas Oil & Atmospheric Residue Feeds

Development projects

- **Capture of CO2 from refinery heaters using oxy-fired technology**
- **Membrane Water Gas Shift (MWGS)**

Economic evaluation

- **Hydrogen production for chemical use (Steam reforming)**

Heavy Oil and NGCC Scenario

Technology demonstration

- **Oxy-fired Once Through Steam Generators (OTSG)**
  - 50 MMBTU/hr OTSG retrofit

Economic evaluation

- **Natural Gas Combined Cycle (NGCC) power station (400 MW)**

Field demonstration of Fluid Catalytic Cracking (FCC) oxy-firing capture (Petrobras)

Refinery Scenario

•*Image courtesy of Petrobras*

- Field demonstration of Fluid Catalytic Cracking (FCC) oxy-firing capture technology at Petrobras, Brazil
- FCC is one of the main sources of oil refinery CO_2 emissions (20-30%)
- Aim: to evaluate operability, test start-up and shut down procedures and obtain data for scale-up

FCC Testing Unit

FCC Large Scale Pilot Unit

Typical pilot plant		Test unit		Full scale unit
Catalyst inventory	x 150 →		x 280 to 2000 →	
Feed flow rate	x 200 →		x 580 to 2000 →	

Capacity: Cat. Inventory = 300 kg; feed flow rate = 200 kg/h (30 bpd) VGO; 1t/d CO_2 emission

•*Image courtesy of Petrobras*

Refinery Scenario – FCC Summary & Conclusions

FCC Summary and Conclusions

- The technical viability of oxy-firing an FCC unit was demonstrated on a large scale pilot test unit
- The results have shown the CO_2 content in flue gas to be over 94% (dry basis). For industrial application the purity is expected to be even higher
- Two oxy-combustion conditions have been tested: *same heat balance* and *same inert flow rate*. The first showed very little impact in product slate while the second showed a gain in feed conversion. Alternatively, the feed rate may be increased by about 10% while keeping constant conversion
- Corrosion inside the recycle compressor was observed, indicating the need for adequate handling of the gas and use of resistant material for long-term operation

Refinery Heaters and Boilers – Oxy-firing of process heaters (John Zink Company)

Background and Objectives

Background

- In CCP Phase 1, oxy-firing showed potential
  - Lower energy requirements: flue gas contains mostly CO_2 and water (minimal nitrogen and O_2 separation)
- ASU cost is significant - investigated ion transport membrane to generate O_2

Objectives

- Assess the feasibility of utilizing conventional process heater burners for oxy-firing
- Confirm the feasibility of oxy-firing in process heaters by conducting single burner testing with flue gas recycle
- Construct computational fluid dynamics (CFD) models to simulate oxy-firing in typical multi-burner heater geometries

Heater Performance Modeling (OnQuest, FRNC-5)

Objective: Identify feasible operating conditions in typical process heating in oxy-fuel mode

- Overall heater efficiency
- Maximum film temperature and tube metal temperature limitations
- Radiant / convection heat absorption ratio
- Flue gas recycle requirements

Results:

- Without flue gas recycle, high levels of excess oxidant would be required
- Conditions with 0.5 - 2 wet vol% O_2 concentration in flue gas, recirculation rate 72%
- Oxy-firing provides a ~14% improvement in heater efficiency compared to ambient air base case
- Met maximum film and tube metal temperature constraints; small changes to radiant/convection section duty split; minimized O_2 use

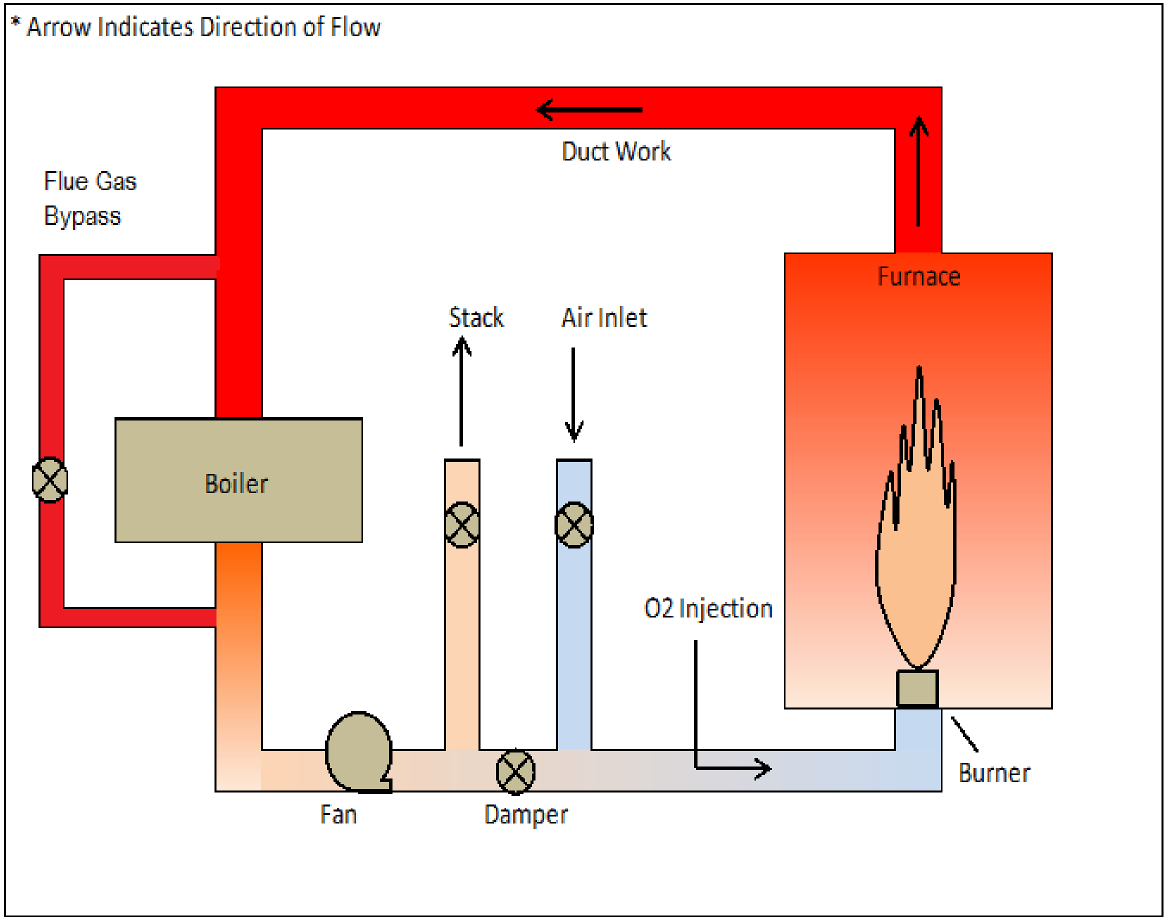
Single Burner Test Furnace

- Two John Zink burners tested
  - PSFG: low NO_x diffusion flame burning with staged fuel injection
  - COOLStar: ultra low NO_x diffusion flame burner with internal flue gas recirculation and staged fuel injection
- Test furnace cooled by single-pass water tubes in radiant section; no convection section
- Measurements: flame appearance, flame stability, flame length, incident heat profile, stack emissions, CO/O_2 measurements upstream of burner, temperature

Furnace for burner tests (courtesy of John Zink Co.)

Single Burner Tests

- External boiler to cool flue gas prior to recirculating fan (carbon steel)
- Oxidant:
  - Ambient Air (baseline)
  - O_2 (5.2% O_2 in flue gas and 1.3% O_2 in flue gas)
- Fuel:
  - Tulsa natural gas
  - Simulated refinery fuel gas



Result of Single Burner Tests

- No burner modification required for either burner; minimum to maximum heat release
- Transition from air to oxy-fire operation demonstrated
- Satisfactory turn down with both burners and both fuels at 72% flue gas recycle
- FGR rate and O_2 concentration are important operating parameters:
  - Large FGR can push combustion process to flammability limit, especially under low O_2 conditions
  - A less "reactive" fuel, e.g. natural gas, may need a higher percentage of oxygen in the oxidant during oxy-firing
- Significant reduction in NO_x emissions
- To make oxy-firing effective in process heaters, proper sealing would be essential to minimize air ingress
  - Even under certain low draft test conditions, N_2 concentrations as high as 11% was measured in the recirculated flue gas

Development of Pd-Alloy Membrane for CO_2 Capture and H_2 Recovery (Pall Corporation)

Background

Capturing CO_2 from refinery heaters and boilers (H&Bs)

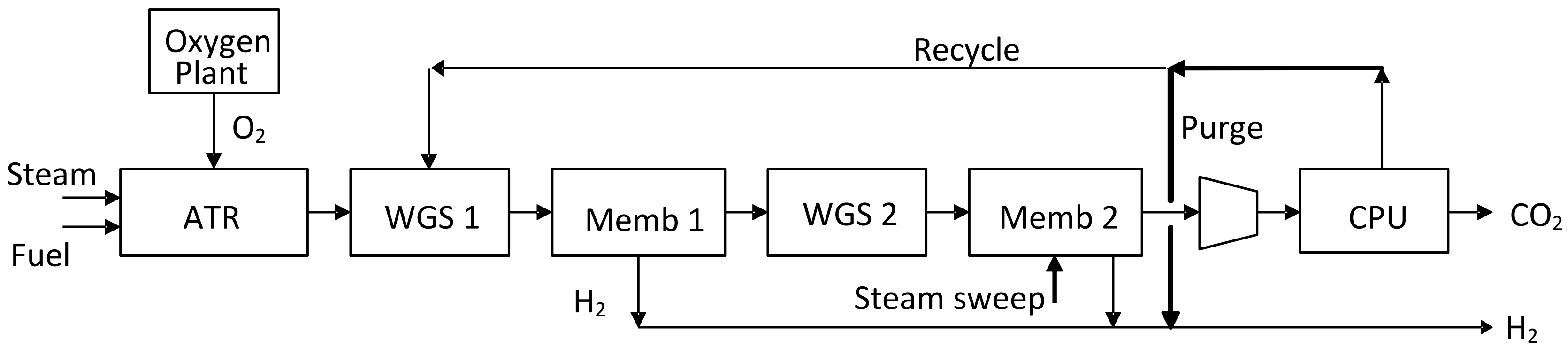
- H&Bs are a significant source of CO_2 in a refinery
  - They are usually scattered throughout a refinery
  - Post-combustion and oxy-combustion technologies are not generally practical in a space-constrained refinery
  - Pre-combustion capture technology with the production of low-carbon H_2 fuel in a centralized location provides an economical alternative for capturing CO_2 from H&Bs

Producing low-carbon H2 in a refinery

- Steam methane reformers (SMRs) are widely employed for producing <200 MMSCFD H2
- For larger H_2 quantities, such as for H&Bs, autothermal reformers (ATRs) provide certain advantages, e.g. a single source of CO_2 available at high pressure.
- CO_2 removal in aMDEA® solvent is the conventional technology
- CO_2 separation using H_2 membranes has several advantages:
  - High purity H_2 stream can be obtained at a suitable pressure (1–2 barg)
  - CO_2 stream is available at high pressure, thus reducing the compression energy
  - Removal of H_2 at high temperature improves the equilibrium in the WGS reaction

Background (cont'd)

Process Configuration



- ATR produces the syngas containing H_2, CO, CO_2, H_2O
- Two membrane stages are preceded by a high temperature shift reactor to convert CO into H_2 and thus increase the overall H_2 recovery in the membranes
- The retentate from the membrane unit is processed in a cryogenic purification unit (CPU) to recover a high purity CO_2 product stream
- Overall targeted H_2 recovery is 90% with purity >95 mol%

Project Objectives and Methodology

Project Objectives

- Evaluate the performance of Pd alloy-based membranes in separating H_2 from simulated syngas
- Use the performance data along with a model to design and cost a commercial scale membrane system for producing 5,000 MMBtu/h (LHV) of low-carbon H_2 fuel stream in an ATR process while producing a purified CO_2 stream at high pressure suitable for sequestration

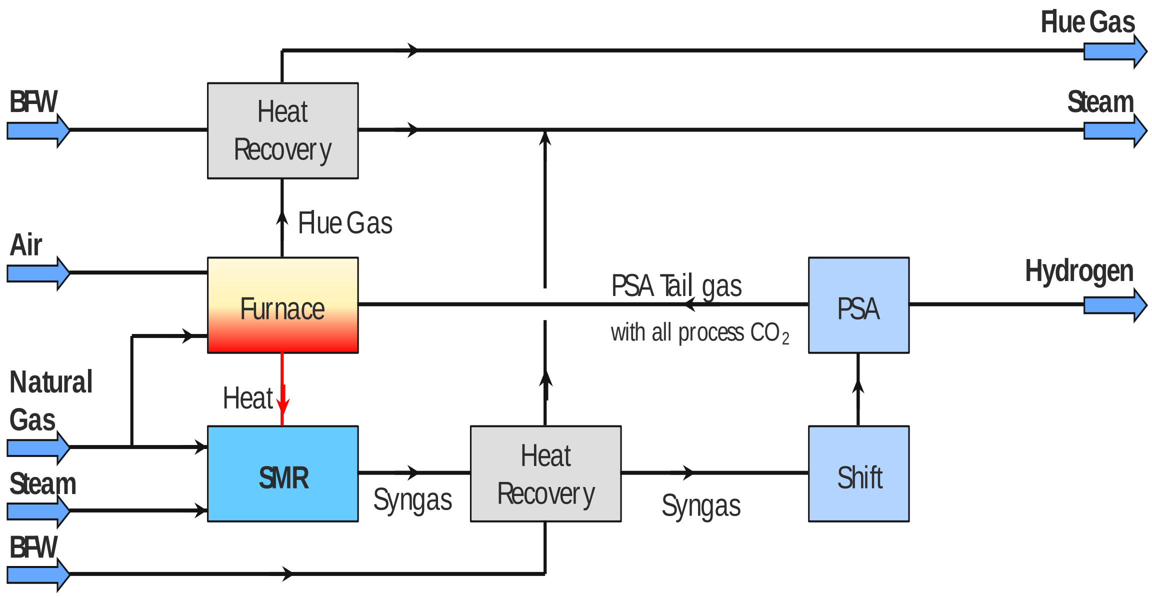
Methodology

- Perform experiments on Pd alloy-based membranes/modules to develop and calibrate a simulation model
- Use the performance data for design and costing of a commercial scale membrane module system

Steam Methane Reforming - Hydrogen Plants Techno-Economic Evaluations (Foster Wheeler Energy)

Background

- Hydrogen production is energy intensive
- CO_2 emission from Hydrogen plants can contribute up to 20% of refinery emissions
- Steam Methane Reforming (SMR) is the industrial workhorse to produce hydrogen
- CO_2 from SMR unit is produced from two sources:
  - High pressure in main process stream - Reforming and shift steps (50-60% of total)
  - Low Pressure in flue gas stream - Fuel combustion in the reformer furnace (40-50% of total)



CCP3

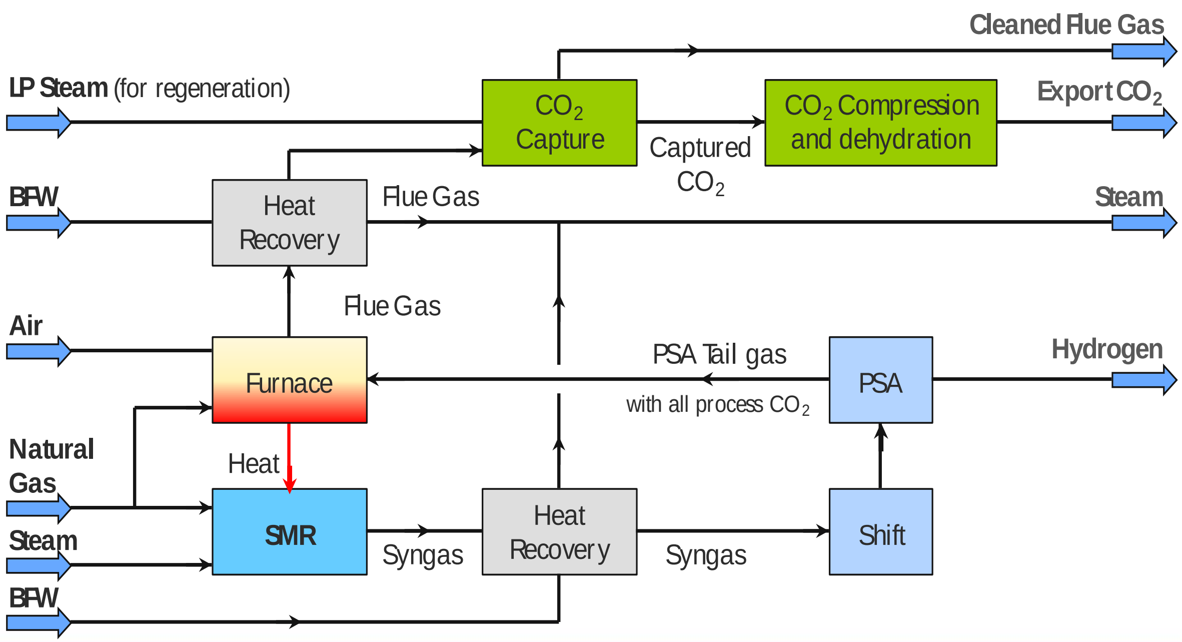
Background (cont'd)

Objectives

1. To identify the process scheme with 90% overall CO_2 capture from the SMR unit
2. Conduct techno-economic feasibility analysis with Foster Wheeler for the identified scheme/technology for a 50,000 Nm^3/hr hydrogen plant

Process Scheme

Post combustion with 90% capture from the reformer flue gas with 18-22 vol% CO_2



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Premises – Design and Economics

Design

- 50,000 Nm^3/hr hydrogen plant with Pressure Swing Adsorption (PSA)
- 5% flue gas bypass to stack
- Remainder 95% flue gas is sent to absorber with 90% capture from this feed
- MHI-KS1 – current state-of-the-art technology is used for post combustion capture
- Stand-alone steam boiler package supplies the steam required for Capture plant
- Power needed is imported over the fence
- Captured CO_2 is dehydrated and compressed to 150 barg for pipeline transport

Capture Program – Heavy Oil Scenario

Oxy-fired Once Through Steam Generators (Cenovus)

Heavy Oil Scenario

- Capture from multiple Once Through Steam Generators (OTSGs) in the Canadian oil sands was studied in CCP3
- Cases were designed to provide the same amount of useful injection steam as the reference case

Image courtesy of Cenovus

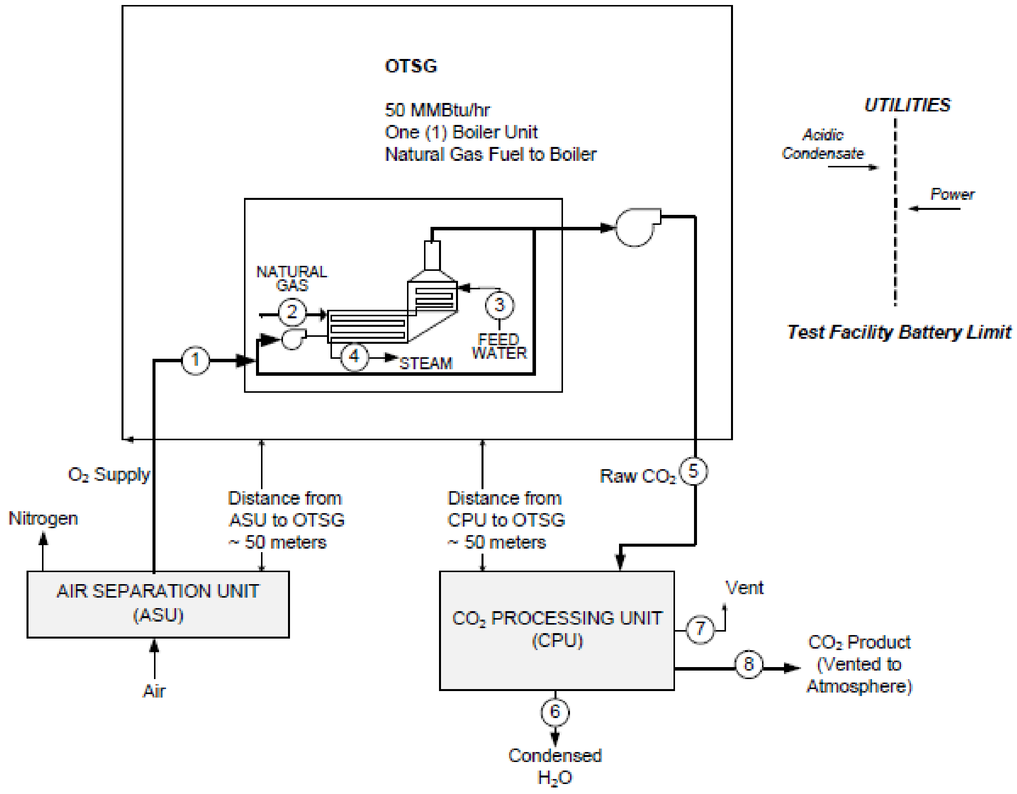
Once Through Steam Generator (OTSG)

Two Phase Project:

- Phase I (completed 2010): Develop design basis and cost estimates for test and commercial scale OTSGs
- Phase II (2011-present): Pilot oxy-fuel combustion on 50 MMBTU/hr test OTSG

Overall Objective:

- To demonstrate that oxy-fuel combustion is a safe, reliable and potentially cost-effective technology for CO_2 capture from once-through steam generators



Demonstration System Process Schematic

Heavy Oil Scenario – Summary and Conclusions

Results

- The best technology to capture CO_2 today appears to be post-combustion
- Although the CO_2 sources are large, the remote location complicates technology application and costs
- Capture from OTSGs is therefore one of the least economically viable CCS applications studied by CCP (levelized CCP3 capture cost 200 $USD/tonne)

Economic Modeling (Foster Wheeler Energy)

Economic Evaluation – Key Assumptions

Calculated capture and avoidance costs include transportation and storage

Base Assumptions	Units	Value	Source
Fuel Gas Price – US	USD/GJ	4.50	Gulf Coast Public Data
Electricity Price - US	USD/MWh	70.00	Gulf Coast Public Data
Fuel Gas Price – AB	USD/GJ	4.50	
Electricity Price - AB	USD/MWh	60.50	
Time Horizon	Years	25	CCP Assumption
Power Intensity	tCO_2 /MWh	0.60	Gulf Coast Public Data
Steam Intensity for WHB FCC	tCO_2 /t	0.19	CCP Generated Figure
Heat to Produce Steam for FCC	GJ/t	3.13	CCP Generated Figure
CO_2 Transportation and Storage *	$/t	9.1	CCP Generated From Published Data

- Post-combustion steam consumption for solvent regeneration in the range of 2.7- 3.0 GJ/ton of CO_2
- *Storage costs – based on the WASP Study – Porous brine-filled aquifer http://www.ucalgary.ca/wasp/reports.html
- Transport costs based on capital costs factored from NETL data

CCP3 Economic Results

Application Scenario and Case Description	Fuel	CO_2 captured	CO_2 capture	CO_2 avoided	CO_2 capture cost	CO_2 avoided cost
Units		t/h	%	%	$/t	$/t
Refinery - US Gulf Coast						
FCC - Post Combustion	Carbon	55.5	85.5	65.5	94.2	112.9
FCC Oxyfuel Retrofit	Carbon	64.8	100.0	83.5	108.3	129.7
Fired Heater - Post Combustion	Fuel gas	26.6	85.0	65.0	118.6	156.5
Fired Heaters Pre-Combustion	Fuel gas	284.0	90.0	76.0	111.1	160.1
Refinery SMR with Post-Combustion	Nat gas	58.4	85.5	65.5	95.9	123.3
Oil Sands Steam Generation - Fort McMurray						
OTSGs - Post-Combustion	Nat gas	67.4	90.0	76.0	170.7	237.9
OTSGs CLC	Nat gas	63.3	100.0	86.0	195.7	236.4
Gas-Fired Power Generation - US Gulf Coast						
NGCC - Post-Combustion	Nat gas	126.1	85.5	73.7	97.9	113.6

- Post-combustion solvent-based technology is still the most economic (or close second)
- CO_2 avoidance costs are very high, especially for the Heavy Oil (oil sands) scenario due to the Alberta location
- The economic assumptions, such as fuel cost, location factor, imported power cost/CO_2 footprint, process scale/configuration, all have an impact on the costs

Capture Summary and Conclusions

- Three scenarios pertinent to the oil and gas industry were targeted in CCP3
  - Post-, pre- and oxy-combustion technologies were investigated at lab, bench, pilot and demo scale
  - Supplemented by independent technical and economic assessments
- Significant amount of knowledge was obtained in CCP3
- CO_2 avoidance costs are very high, especially for the Heavy Oil scenario due to the location
- The economic assumptions, such as fuel cost, location factor, imported power cost/CO_2 footprint, process scale/configuration, all have an impact on the costs

CCP Conclusions

CCP Conclusions

- CCS is the only technology that could enable continued large-scale use of fossil fuels in a tightly constrained world
- Post combustion capture technologies have seen some recent improvements, but what does the future look like versus alternatives, and will this achieve the end goal?
- Commercial complexity exists along the value chain, within an uncertain business and policy environment
- Significant government funding is required for demonstration, and transitional support is needed for wider deployment to achieve learning curve cost reduction
- There are some promising technology solutions to dramatically reduce capture costs & effectively verify safe/secure storage at scale, so R&D needs to continue
- CCP looks to build on its experience & expertise, welcome new partners and collaborate with others to ensure success

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Questions?

End