CO₂ Capture Project

Oxyfuel Technology Overview

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NETL Carbon Sequestration Conference
May 19, 2004

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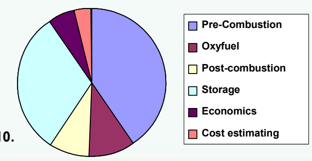
THE CAPTURE MISSION

- Assess technical/economical potential of technologies under development.
- Fund R&D for technologies able to reduce capture costs to the 20-30 US$/ton range by 2008-2010.

TOTAL FUNDING ~ 25 MMUS$



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The CCP Case Studies

	Fuel	Source	Sink	Location
A	Gas or Liquid Hydrocarbon	Heaters and Boilers	Offshore EOR	European Refinery
B	Natural Gas	GTCC - Power Generation	Offshore EOR	Norway
C	Natural Gas	Gas Turbines, small	Onshore EOR	Alaska North Slope
D	Solid/liquid gasification	Cogen	Onshore EOR	Western Canada

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Oxyfiring: Combustion with “pure” oxygen

- Oxyfiring not currently used in typical large combustion systems because of:
  - Expensive air separation system
  - Necessity of flue gas recycle to moderate temperature.
- In the perspective of CO_2 capture, oxyfiring has the unique advantage to generate an effluent stream almost exclusively composed by CO_2 and H_2O resulting in cheap and easy capture.

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Oxyfuel: The Background

- Cryogenic air separation is a mature technology with very little possible improvement.
- Large R&D ongoing Projects to develop novel “breakthrough” technologies for air separation with the target of commercialization by 2008-2010.
- Research in the field largely independent from “greenhouse gases” concerns.

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Scope of Work

- Definition of an Oxyfuel Baseline by application of “state-of-the-art” technologies to the European Refinery Scenario.
- Investigation of the technical/economical potential of novel technologies or equipment, particularly:
  - Novel technological solutions for boiler revamping or new-building, maintaining cryogenic air separation (heaters have more uncertainties).
  - Advanced thermodynamic cycles for oxyfiring in power generation systems.
  - Novel air separation technologies for application to conventional boilers/heaters systems.
  - Novel technologies integrating steam or power generation systems and novel techniques for oxygen supply.

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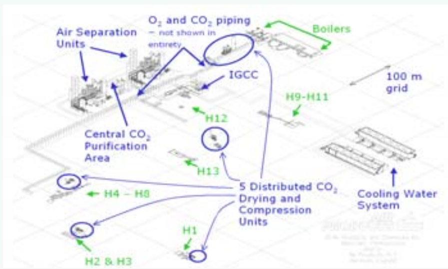
The Oxyfuel Baseline(1)



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The Oxyfuel Baseline(2): Economics

	Post Comb. Baseline	Case 1: Cryogenic O_2 Base Case	Case 2: Cryogenic O_2 & offset steam	Case 3: Cryogenic O_2 & offset steam via H_2
Captured CO_2 (MMtons/year)	2.0	1.88	1.69	2.33
Avoided CO_2 (MMtons/year)	1.4	1.65	1.57	1.99
CO_2 Captured Cost (US$/ton)	55	38.0 (- 30.9%)	36.1 (- 34.4%)	33.8 (- 38.5%)
CO_2 Avoided Cost (US$/ton)	78	43.2 (- 44.6%)	38.9 (- 50.1%)	39.3 (- 49.6%)
Power Export (MWe)	Utility Neutral	10.7	3.4	(0.3)

- Alignment by the CEM Team for Case 1 resulted in :
  - CO2 capture cost: 44.4 US$/ton
  - CO2 avoided cost: 49.3 US$/ton

  ⇒ Further 10$ reduction if NOx credit is accounted for.

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The Oxyfuel Baseline(3): Main Conclusions

- Conversion of heaters and boilers to oxyfiring is technically feasible.
- Economic optimum for oxygen purity of 95%.
- Transport of concentrated O_2 raises additional (manageable) safety issues.
- One order of magnitude reduction in NOx emissions is also achieved.
- The Oxyfuel Baseline is applicable with consistent saving compared to any other available options, and low technical risk, so that implementation in Countries applying high level of Carbon Tax may be considered.

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Novel boilers optimized for Oxyfiring of fuel gas or oil

- A few studies were commissioned to different Technology Providers to investigate potential savings achievable by optimization of boilers for oxyfiring:
  - High Pressure Boiler – Mitsui Babcock.
    Expected savings by reduced volume and power consumption.
  - Staged Combustion Boiler – Mitsui Babcock.
    25% reduction in fuel gas recycle at the expense of doubled footprint.
  - Zero recycle Boiler – Alstom/Praxair.
    No fuel gas recycle by using higher grade materials.
- No potential for consistent reduction in capture costs.

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Advanced Oxyfuel Thermodynamic Cycles (1)

- Evaluation by SINTEF of three different power generation concepts from the scientific literature based on stoichiometric oxygen combustion of Natural Gas and claiming high thermodynamic efficiency, to avoid the penalties related to air compression for separation and flue gas recycle:
  - Water Cycle, using water injection rather than Flue Gas Recycle to control combustion temperature.
  - Graz Cycle, similar to Water Cycle, with steam injection in the combustor.
  - Matiant Cycle, based on high temperature turbine and heat exchangers.

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Advanced Oxyfuel Thermodynamic Cycles (2)

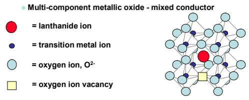
- Main conclusion is that the high efficiency claimed by all of the studied cycles are related to features requiring significant developments in gas turbine / steam cycle equipment, e.g.:
  - High temperature operation (turbine inlet at 1500°C or heat exchanged at 1000°C).
  - Low vacuum condensing (0.06 bara).
- All the cycles were about the same efficiency when compared on consistent bases.
- Turbine vendors not willing to engage in very expensive development without clear market perspectives.

Novel Technologies for Air Separation

- Different Consortia are developing ionic transport membranes for air separation with DOE and EU-funding for commercialization by 2008-2010.

Ion Transport Membranes (ITM)
Oxygen Permeable Ceramics

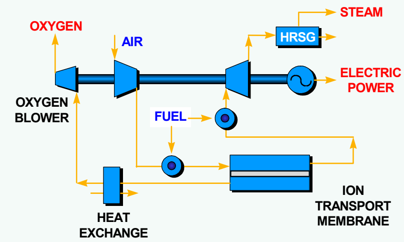
Typical ITM
- Multi-component metallic oxide - mixed conductor



Vacancies built into the oxide by ion substitution
- Mobile at >700°C

Oxygen permeates at high flux and 100% selectivity
- Dependent on integrity of seals and membrane

Application of ITM (Air Products) in European Refinery



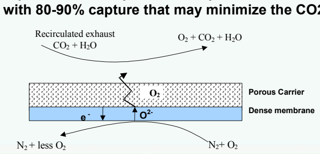
Economics of ITM in European refinery

Case	GT	O_2 reqd. Te/day	Total Power Reqd. (MW)	Export Power (MW)	CO_2 Captured ($x 10^6$ te/yr)	CO_2 Avoided ($x 10^6$ te/yr)
1	2 x V94.2	6626	54.7	446.2	1.89 / $33.5	1.71 / $37.0
2	2 x V94.2	3828	26.4	289.9	1.09 / $25.1	1.43 / $20.0
3	1 x V94.3	6051	71.3	121.4	2.62 / $28.5	2.06 / $38.1

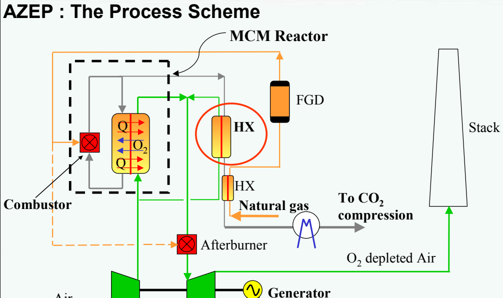
- CCP alignment of Case 1 at about 30 US$/ton.
- Process scheme not fit for revamping unless there is market for power export.
- Promising option for new-built including CCGT systems for power generation.

Novel integrated equipment - AZEP (Advanced Zero Emission Power)

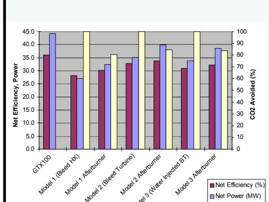
- AZEP is developed by Alstom/Norsk Hydro in the frame of a 3-years EU-funded Project started in January 2002.
- Technology is applicable to the CCP power generation Case Studies.
- Alaskan scenario was selected for the CCP study, since it is composed by relatively simple and small turbine systems.
- While the original concept calls for complete CO2 capture, the CCP study also includes options with 80-90% capture that may minimize the CO2 avoided costs.

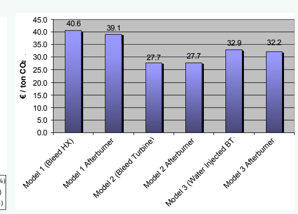


AZEP : The Process Scheme



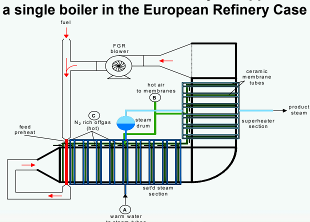
AZEP : Technical/Economical output





Praxair advanced boiler

➢ Praxair is developing an advanced boiler, incorporating the OTM membranes in the frame of a DOE-funded Project whose target is achieving Proof-of-concept by 2006. The CCP and the DOE co-funded a study for application of the concept to replacement of a single boiler in the European Refinery Case Study.



Praxair advanced boiler: economic results

➢ Boiler capital cost ~ 40% higher than conventional boilers.

➢ Total capital ~ 60% lower than conventional boilers with Post-combustion capture.

➢ Rough estimate based on Praxair data on CO2 capture cost at 15-20 $/ton.

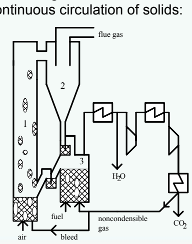
➢ Concept still at an early stage of development: commercialization expected by 2009-2010.

Chemical Looping

➢ Chemical Looping is a new combustion technology based on oxygen transfer from combustion air to the fuel by means of a metal oxide acting as a solid carrier. Core of the technology is a two-reactors system with continuous circulation of solids:

❖ Fuel reactor: $4MeO + CH_4 \Rightarrow 4Me + 2H_2O + CO_2$

❖ Air reactor: $4Me + 2O_2 \Rightarrow 4MeO$



Chemical Looping (2)

➢ Technology under development in a two-year Project co-funded by DOE and EU with a budget of 1.5 MM€ (1/2002 – 12/2003).

➢ Consortium formed By BP (Coordinator), Alstom Boilers, Chalmers University, Vienna University and CSIC (Consejo Superior de Investigaciones Scientificas).

➢ Achieved proof-of-feasibility of the Technology through successful operation of a pilot unit reproducing the features of future commercial units, at Chalmers. Alstom developed PFD, main equipment sizing and preliminary economic evaluation.

➢ R&D activity was limited to atmospheric pressure applications using Natural Gas as fuel. This technology may however be also applied to the typical pressure of combined cycles for power generation (20-30 bars), as studied in a DOE funded Project (outside CCP).

➢ Commercialization expected by 2008.

Chemical Looping: main technical achievements

➢ Proof-of-feasibility on pilot unit with continuous solid circulation and Ni- based carier, including:

❖ Reversible reduction/oxidation of the solid and oxygen transfer.
❖ Almost complete methane combustion (99.5% at 800°C).
❖ No gas leakage between reactors.
❖ CO2 purity > 98% (impurities by equilibrium CO and H2).
❖ Achieved solid circulation rate and reaction rate according to the hypotheses for economical evaluation.
❖ No significant particle attrition or chemical decay observed.

Oxyfuel Key Messages

➢ Oxy-firing offers the benefit to generate a flue gas stream containing only CO2 and H2O, making capture easy and inexpensive.

❖ Oxy-firing can be practiced today using conventional air separation, along with flue gas recycle, in retrofit or new-built boilers and heaters at a cost of CO2 avoided about 30% less than the Post-Combustion Baseline.

❖ In the longer term (2008-2010), CO2 avoided cost through Oxy-firing might be substantially reduced by advanced air separation technologies based on high temperature ceramic membranes, to the 20-30 $/ton range.

❖ CCP identified Chemical Looping as a technology with the same potential for cost reduction than ceramic membranes in the 2010 time frame and co-funded a EU Project which achieved Proof-of-Feasibility through pilot plant operation.

❖ An additional benefit of Oxy-firing is the drastic reduction (>90%) of NOx emissions.

❖ Application with (gas) turbines requires further significant development to deal with the high temperature from this process.