CO_2 Capture Project

The Capture Program for Phase II (2004 – 2008)

NGO Meeting

Phoenix Park Hotel
Washington D. C., December 6, 2006
presented by
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CO_2 Capture Project

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Why focus on capture and geologic storage?

- Fossil fuels will be required to meet the worlds energy needs for the foreseeable future
- Possible to achieve material reductions in CO2 emissions & provide a bridge to a lower carbon future
- Applicable to broad range of industry sectors
- Cost of decarbonising fossil fuels is currently too high
- Carbon sequestration is needed to make H2 possible in near/medium term with no/low GHG emissions
- Can provide a win ~ win for both energy security and environment

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CO2 Capture Project objectives

- Achieve major reductions in the cost of CO2 capture and storage:
  - 50% reduction when applied to a retrofit application.
  - 75% reduction when applied to a new build application.
- Demonstrate to external stakeholders that CO2 storage is safe, measurable, and verifiable.
- Progress technologies to:
  - ‘Proof of concept’ stage by 2003/4.
  - Ready for pilot/demo by 2008/9

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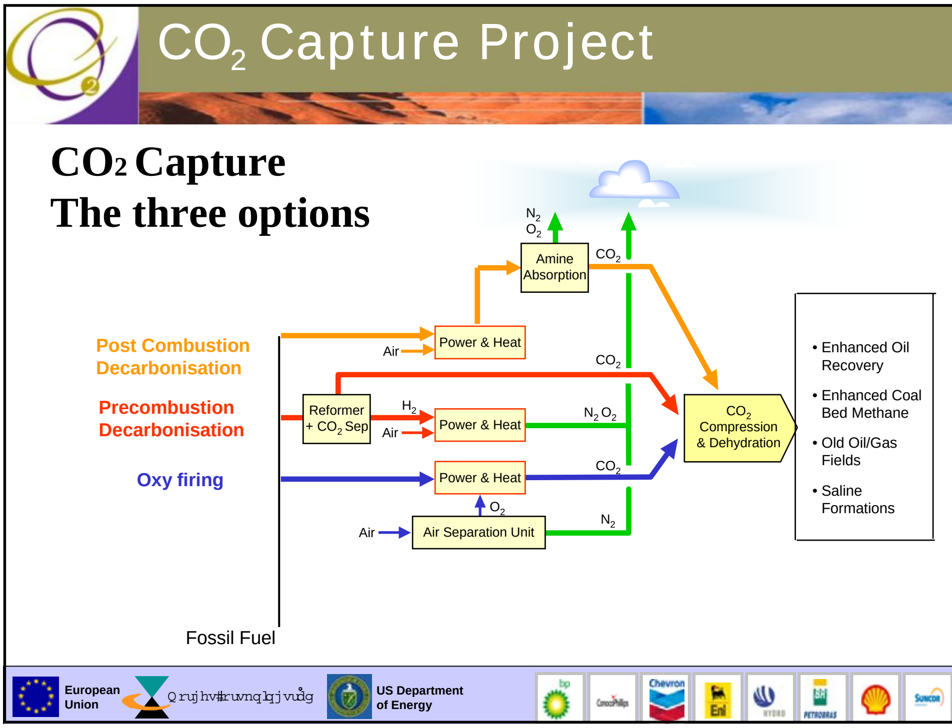
CO2 Capture Project
CO2 Capture
The three options
Post Combustion Decarbonisation
Precombustion Decarbonisation
Oxy firing
Fossil Fuel
Air
Power & Heat
Amine Absorption
N2 O2
CO2
Reformer + CO2 Sep
H2
Air
Power & Heat
N2 O2
CO2
Power & Heat
O2
Air
Air Separation Unit
N2
CO2 Compression & Dehydration
• Enhanced Oil Recovery
• Enhanced Coal Bed Methane
• Old Oil/Gas Fields
• Saline Formations
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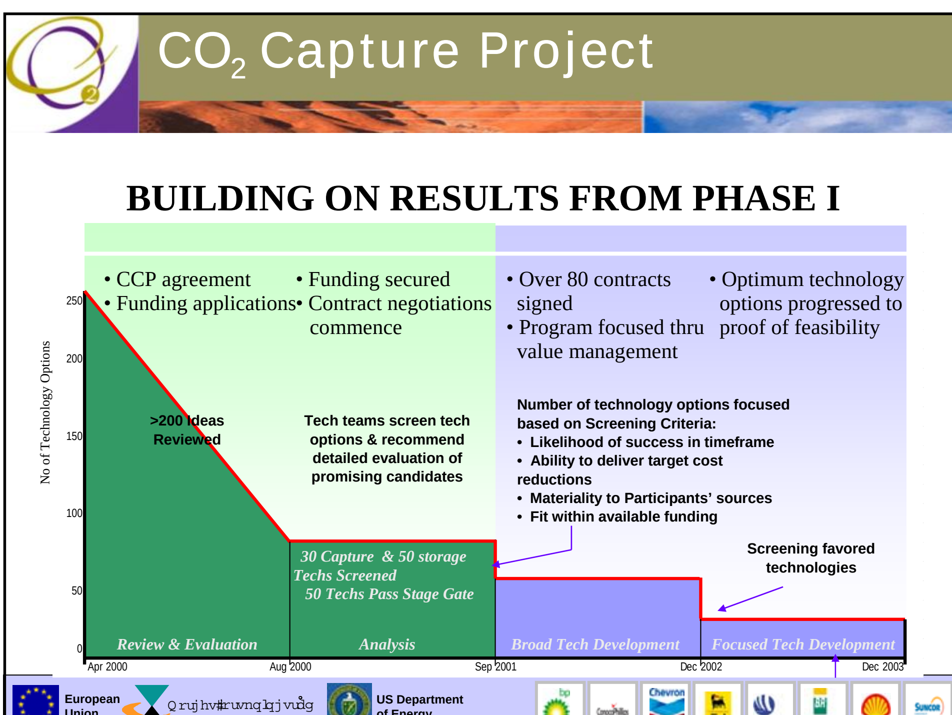
CO2 Capture Project
BUILDING ON RESULTS FROM PHASE I
• CCP agreement
• Funding applications
• Funding secured
• Contract negotiations commence
• Over 80 contracts signed
• Program focused thru value management
• Optimum technology options progressed to proof of feasibility
No of Technology Options
250
200
150
100
50
0
>200 Ideas Reviewed
Tech teams screen tech options & recommend detailed evaluation of promising candidates
Number of technology options focused based on Screening Criteria:
• Likelihood of success in timeframe
• Ability to deliver target cost reductions
• Materiality to Participants' sources
• Fit within available funding
30 Capture & 50 storage Techs Screened
50 Techs Pass Stage Gate
Screening favored technologies
Review & Evaluation
Analysis
Broad Tech Development
Focused Tech Development
Apr 2000
Aug 2000
Sep 2001
Dec 2002
Dec 2003
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- **Phase I favored technologies achieved:**
  - ✓ **Proof-of-Feasibility**
    - **Concept successfully tested at the lab scale**
    - **Critical items for development identified.**
  - ✓ **Potential for consistent reduction in CO_2 Capture costs compared to currently available technology.**

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Scenario	**Fuel**	**CO_2 Source**	**CO_2 Sink**	**Capture Target (MM tonne/yr)**
Grangemouth Refinery in Scotland	Gas and Fuel Oil	Flue gas from heaters and boilers	Offshore EOR	2.0
Norway 385-MW power plant in Karsto, Norway	Gas	Flue gas from turbine outlet	Offshore EOR	1.1
Alaska Eleven 30-MW single cycle gas turbines.	Gas	Flue gas from distributed turbines	Onshore EOR	1.8
Canada Gasification plant	Pet Coke	Syngas from gasifier	Onshore EOR	6.8

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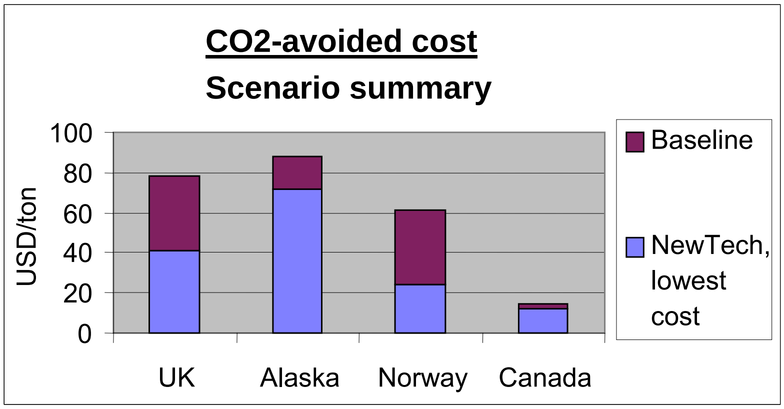

Main conclusions from Phase I
Post-Combustion

- **Low chances that development of a single novel technology may result in achievement of cost targets.**

- **Post-Combustion may be a winner if several improvements of different nature are simultaneously applied to existing technology:**

  - **Novel solvents with higher load and lower regeneration heat.**
  - **Integration of CO_2 capture in new-built power stations, including partial recycle of combustion exhaust to the combustion chamber.**

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Main conclusions from Phase I
Pre-Combustion

- It is considered as the most promising option for future development.
- Additional cost of CO_2 capture is moderate since syn-gas is produced at relatively high pressure.
- Two routes were followed in Phase I:
  - Integration of CO_2 separation and Water Gas Shift
  - Novel technologies for hydrogen production
- Evaluations showed that, while both routes have potential to achieve cost reduction targets, the development of novel technologies for hydrogen production may reduce the cost to the lowest level in the long term.

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Main conclusions from Phase I
Oxy-firing

- This approach shows the highest potential for processes of combustion at atmospheric pressure.
- Adoption in gas turbine systems would need development of tailored machinery for higher temperature to minimize the need for CO_2 recycle or use of temperature moderating fluids.
- Oxyfiring would greatly benefit by availability of cheaper oxygen through development of novel air separation technologies.
- Chemical Looping Combustion identified as a high potential approach.

The Targets of Phase II

- **Achieve significant progress for each technology:**
  - **Scaling-up successfully operation by at least one order of magnitude.**
  - **Addressing and solving critical issues identified in Phase I**
- **Confirm or improve economical evaluations of Phase I.**
- **At least one technology ready for field demonstration.**

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The Timeline of Phase II

- **2004**
  - **Selection of Technology Portfolio.**
  - **Preparation of Project Proposals.**
  - **Submission to Governmental funding entities (Oct-Dec).**
- **2005-2006**
  - **Approval of Project Proposals.**
  - **Start Technical Program.**
  - **Definition of further needs**
  - **Prepare additional proposals.**
- **2007-2008**
  - **Run technical Program to completion maintaining stage gate approach.**
  - **Update economical evaluations.**
  - **Continue monitoring of novel concepts and competing technologies.**

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The Technology Portfolio
Main Features

- Technologies with different "time to market" in a sequenced approach:
  - Short Term (by 2010)
  - Mid-Term (2010-2012)
  - Long Term (by 2015)
- A gradual reduction of capture cost is expected , but short term technologies may achieve a breakthrough for specific applications.
- Emphasis on Pre-Combustion technology, but continuation of most promising Post-Combustion and Oxy-firing Projects.

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Phase II Projects

Project Acronym	Co-Funder	Starting Date	Duration	Total Budget
CACHET	European Union	April 2006	36 months	13.4 MM €
HMR – BIT in CLIMIT	Norwegian Research Council	June 2005	36 months	46.0 MM NOK (~ 6 MM €)
CLCGASPOWER	European Union	January 2006	30 months	2.1 MM €

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CACHET
Technical Targets

- Develop in parallel to "ready-for-pilot" several novel hydrogen production and pre-combustion CO2 Capture Technologies.

- Identify optimal process scheme through optimized integration of technologies driven by economic evaluation.

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CACHET Technologies

- CO2 separation technologies
  - Membrane Water Gas Shift (MWGS)
  - Sorption Enhanced Water Gas Shift (SEWGS)
- Novel Syngas/Hydrogen production technologies
  - Chemical Looping Reforming
  - One-Step Hydrogen
  - HyGenSys
  - Membrane Reforming

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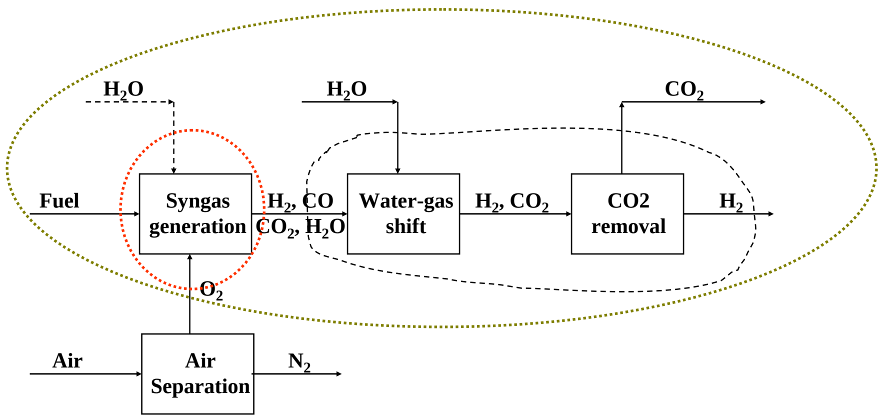

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Membrane Water Gas Shift

- Strategic Features
  - Mid Time to Market (2010-2012)
  - Mid Potential for Cost Reduction
  - Preferential application to heaters/boilers or steam turbine power generation from natural gas (Low pressure hydrogen product).
- Phase II development in CLIMIT
  - Assessed mechanical resistance of supported membrane to pre-combustion differential pressure.
- Phase II Expected Development in CACHET (SINTEF/ECN/Dalian)
  - Develop and test supported palladium membranes in the form of long tubes.
  - Build and operate a bench scale reactor module (12 tubes) with hydrogen production roughly equivalent to 15-30 kW.

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Sorbent Enhanced Water Gas Shift

- Strategic Features
  - Short Time to Market (by 2010)
  - Mid/High Potential for Cost Reduction
  - Preferential application to power generation from natural gas in combined cycle (High pressure hydrogen product).
- Phase II Expected Development in CACHET (Air Products/ECN)
  - Further optimization of adsorbent materials.
  - Build and operate a lab unit with 7 reactors in parallel to simulate the commercial operating cycle.

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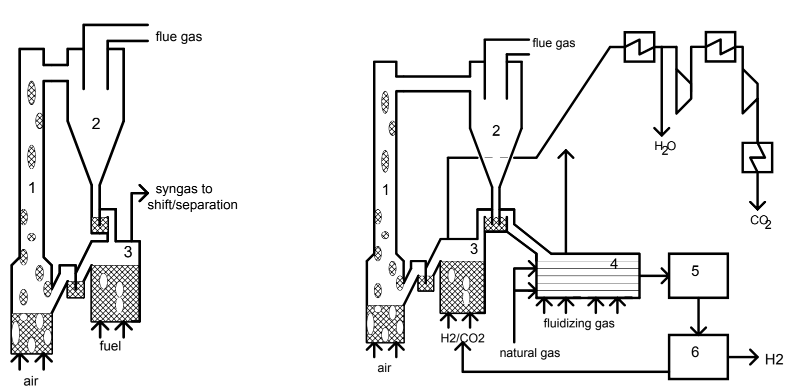
CACHET - Chemical Looping Reforming



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CACHET - Chemical Looping Reforming

- **Mid/Long Term time to market (2012/2015)**
- **CCP2 Expected Development (CLCGASPOWER Consortium)**
  - **Screening and optimization of solid carrier materials at the lab scale.**
  - **Engineering development will benefit from parallel CLCGASPOWER development.**

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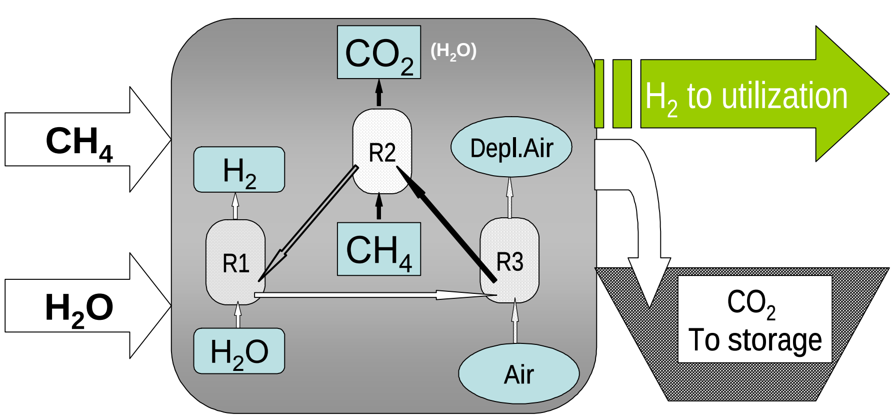
CACHET – One Step Hydrogen



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CACHET - One Step Hydrogen

- **Long Term time to market (~ 2015)**
- **CCP2 Expected Development (Eni)**
  - **Optimization of solid carrier materials at the lab scale, and scale-up of production with commercial manufacturer.**
  - **Reactor and Process scheme optimization**
  - **Hydrodynamic optimization through “mock-up” with continuous solid circulation.**

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CACHET - HyGenSys

- **HyGenSys is a novel reforming technology based on the Gas Heating concept (avoidance of furnace emissions) and strict integration with a gas turbine. In the power generation mode, hydrogen burning in the turbine is needed for zero emission.**
- **Short Term time to market (by 2010)**
- **CACHET Expected Development (IFP)**
  - **Process Optimization with turbine vendor.**
  - **Reactor mechanical design.**
  - **Hydrodynamic optimization through large “mock-up”**

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CACHET - Low Temperature Membrane Reforming

- Novel reforming technology based on the development of dense Pd alloy membranes to separate hydrogen as it is formed, able to operate at a temperature of about 600°C.
  - Long Term time to market (by 2015)
  - CCP2 Expected Development (ECN, SINTEF)
    - Development of suitable membranes at laboratory level.
    - Test in base module reactor (the same designed for MWGS).

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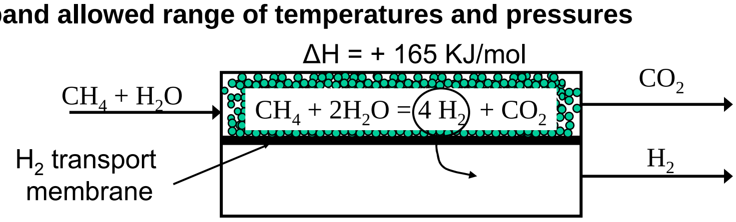
CLIMIT - Hydrogen Membrane Reforming

- Combination of reforming reactor and separation through ceramic membranes permeable to hydrogen at high temperature (> 800°C).
- Extract product gas (H_2) from reactor, no traditional CO_2 removal system required
- Drive equilibrium limited reactions towards completion
- Expand allowed range of temperatures and pressures



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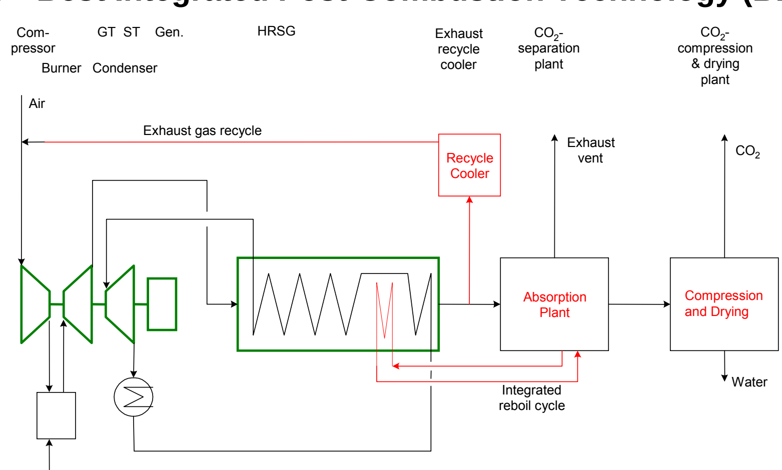
CLIMIT - Hydrogen Membrane Reforming

- **Strategic Features**
  - **Long Time to Market (2015)**
  - **High Potential for Cost Reduction (< 30 $/ton CO2 avoided)**
  - **Application to Power Generation from Natural Gas**
- **Phase II Expected Development (Hydro)**
  - **Develop membranes in the form of monoliths.**
  - **Successfully test at the laboratory level 2X2 cm monoliths.**
  - **Fabricate 7x7 cm monoliths that will form the base unit for pilot**
  - **plant (25 kW).**
  - **Review and optimize process scheme including collaboration with turbine vendor**

CO_2 Capture Project

CLIMIT - Best Integrated Post-Combustion Technology (BIT)



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CLIMIT - BIT

- Strategic Features
  - Short Time to Market (2008-2010)
  - High Potential for Cost Reduction (< 30$/ton CO_2 avoided)
  - Application to Power Generation from Natural Gas
- Phase II Expected Development (General Electric, Nexant, ...)
  - Assess feasibility and constraints of flue gas recycle to combustor (Phase I positively concluded – July 2006).
  - Evaluate use of novel solvents.
  - Review and further optimize the Phase I process scheme.

CLCGASPOWER

- Co-Funder: European Union
- Type of Project: STREP
- Duration: 30 Months (Started January 1st, 2006)
- Total Budget: ~ 2.8 MM$ (subject to exchange rate)
- Single Technology Development of Chemical Looping Combustion by a Consortium formed by:
  - Chalmers University of Technology
  - Alstom Boilers
  - CSIC
  - Shell
  - Vienna University of Technology
  - Tallinn University of Technology

Chemical Looping Combustion

- **Strategic Features**
  - **Mid Time to Market (2010-2012)**
  - **High Potential for Cost Reduction**
  - **Application to gas fired boilers/ steam turbine power generation**

- **CCP2 Expected Development**
  - **Assess long time resistance (both chemical and mechanical) of oxygen carriers tested in Phase I.**
  - **Scale-up from 10kW to 200kW pilot unit c/o Vienna University of Technology.**
  - **Prepare concept design for demo unit (20-50 MW).**

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The Time Sequenced Portfolio

Technology	Type	Time to Market	Preferred Application
Membrane Water Gas Shift	Pre-Combustion CO_2 Separation	Medium	Hydrogen fired Heaters & Boilers
Sorption Enhanced Water Gas Shift	Pre-Combustion CO_2 Separation	Short	Power Generation via Hydrogen Fuel
HyGenSys	Pre-Combustion Hydrogen Production	Short	Power Generation via Hydrogen Fuel
CLR/One Step H_2	Pre-Combustion Hydrogen Production	Long	Power Generation via Hydrogen Fuel
Hydrogen Membrane Reforming	Pre-Combustion Fuel Hydrogen	Long	Power Generation via Hydrogen Fuel
BIT	Post-Combustion	Short	Power Generation
Chemical Looping Combustion	Oxy-firing	Medium	Zero emission boilers

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The CCP Capture Team

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Suncor: Cal Coulter, Stephen Kaufman

Team Leader: Ivano Miracca, Eni

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