ZEP
The Zero Emission Power Plant Technology Platform

MIT, Cambridge, 1st of November 2006
Lars Strömberg
Vattenfall AB
Stockholm/Berlin
What is the ZEP
What is the ZEP?

- The Zero Emission Platform is an initiative within the European Union to get a common view on
  - Present status of the CCS technology
  - Examine the GAPs and hinders to develop CCS to a commercially available option in 2020 and beyond
  - Create a strategic research agenda
  - Define a deployment route
- The work has been performed by more than 100 persons nominated from different parts of society
- The result is presented in form of
  - Reports from five different working groups
  - A Strategic Research Agenda
  - A Strategic Deployment Document
## The Working Groups

<table>
<thead>
<tr>
<th>Working Group</th>
<th>Leads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture and Power Plant Technology</td>
<td>Lars Stromberg, Vattenfall</td>
</tr>
<tr>
<td></td>
<td>Johannes Heithoff, RWE</td>
</tr>
<tr>
<td></td>
<td>Anderas Pistauer, Siemens</td>
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<tr>
<td>CO₂ Capture and Use</td>
<td>Tore Torp, Statoil</td>
</tr>
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<td></td>
<td>Niels-Peter Christenssen, GEUS</td>
</tr>
<tr>
<td>Infrastructure and Environment</td>
<td>Graeme Sweeney, Shell</td>
</tr>
<tr>
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<td>Paul Friswold, Bellona</td>
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<tr>
<td>Market Regulation and Policies</td>
<td>Francoise Gigier, EdF</td>
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<td>Pietro Di Zanno, Air Liquide</td>
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<tr>
<td>Communication and Public Acceptance</td>
<td>Philippe Lacour-Gayet, Schlumberger</td>
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<tr>
<td></td>
<td>Gabriela von Goerne, Greenpeace</td>
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The Groups

The working groups have worked with the perspectives of different stakeholders. In all 105 stakeholders from:

- The research community
- NGOs
- Equipment manufacturers
- Oil and gas industry
- Power industry
The results
Content of the WG1 report

1. Capture and Power plant technology overview
2. Benchmarking the technologies
3. Market potential for different technologies
4. Overall development goals by 2020 and after 2020
5. The R&D Gaps
   1. Power plant efficiency increase
   2. Post combustion capture
   3. Pre combustion capture
   4. Oxyfuel combustion
   5. Emerging and new capture technologies
6. The way forward. Route Map and time frame
7. Barriers for deployment and actions to remove them
8. Conclusions and recommendations for action
Key points - Technology Options

Three technologies seems capable to fulfil the primary target to 2020

- All largely contain known technology and components
- All need optimization, scale up and process integration
- Power process efficiency increase is always a supporting activity
Parallel R&D routes needed

- Development of the three main technologies for the 2020 target
  - Several large scale pilot and demonstration plants, optimized, with full process integration
  - Supporting R&D to reach lower costs, increase process efficiency and achieve better availability
- R&D for new and emerging technologies for deployment after 2020
  - Many routes to examine
  - Assessment to prioritize the technologies capable to overtake the leading role from any of the three main candidates.
Key Points – Development need

• Generally known technology and components

• Process integration, optimization and scale-up

• The last steps in the development process are long, very expensive and need support
## Key Points – Development need

### Post-combustion

#### Overall Status

<table>
<thead>
<tr>
<th>Component</th>
<th>Conceptual Investigations and Laboratory Tests</th>
<th>Pilot Plant</th>
<th>Demonstration Unit</th>
<th>Ready for Deployment</th>
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<tr>
<td>Full process integration and optimization for power</td>
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#### Component Status

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<td>Boiler and power process</td>
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<td>DeNOX process</td>
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<td>CO2 capture process</td>
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<tr>
<td>Capture process optimization incl. new solvents and scale-up</td>
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<td></td>
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<tr>
<td>CO2 processing</td>
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### Key Points – Development need

**Pre-combustion**

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<tbody>
<tr>
<td>Full process integration and optimization for power</td>
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#### Component Status

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<td>Coal Gasification</td>
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<td>Natural gas reforming</td>
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<td>Syngas processing</td>
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<td>CO2 capture process</td>
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<tr>
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<tr>
<td>High efficiency, low emission</td>
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<td>H2 Gas Turbine</td>
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## Key Points – Development need

### Oxy-fuel

#### Overall Status

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#### Component Status

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<tr>
<td>Air separation unit</td>
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<td>Combustion process and boiler</td>
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<td>Water/steam cycle, particle removal</td>
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<tr>
<td>Desulphurization</td>
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<td>Flue gas condensation</td>
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<td>CO2 processing</td>
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### Benchmark

<table>
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<tr>
<th>Financial and other boundary conditions</th>
<th>Natural gas</th>
<th>Hard coal</th>
<th>Lignite</th>
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<tr>
<td>Fuel price €/GJ (LHV)</td>
<td>5,8</td>
<td>2,3</td>
<td>1,1</td>
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<td>Plant size MWe (Ref)</td>
<td>420</td>
<td>556</td>
<td>920</td>
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<td>Specific investment €/MWe (Ref)</td>
<td>471</td>
<td>1058</td>
<td>1278</td>
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**Common input**

<table>
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<tr>
<th>Life time</th>
<th>Years</th>
<th>25</th>
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<td>Wacc</td>
<td>%</td>
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Baseline

Electricity generation cost for large power plants in operation by 2020 (ZEP WG1)

**Chart:**
- **Y-axis:** EUR/MWh
- **X-axis:** Hard coal, Lignite, Natural Gas
- **Legend:**
  - No capture
  - Pre-combustion
  - Post-combustion
  - Oxyfuel

**Note:**
Power generation cost without CO2 transport and storage cost
Benchmark

Avoidance cost for large power plants in operation by 2020 (ZEP WG1)

Note: CO₂ Avoidance cost without transport and storage cost

- Pre-combustion
- Post-combustion
- Oxyfuel

Power plant and CCS technology improvement potential

- Hard coal
- Lignite
- Natural Gas
Barriers

- General barriers
  - Create a worldwide market for CCS
  - Commercial availability to storage facilities
  - Availability of educated people, in universities, administration and industry

- Technical barriers
- Infrastructural barriers
- Institutional and organizational barriers
- Regulatory and legal barriers
  - Permissions and acceptability
  - ETS
Action to remove the barriers

- Facilitate research and development work in identified areas.
  - Concentrated efforts on prospective technologies, both on an integrated level and basic R&D for support
- Create a level playground concerning market, and commercial framework for the industry
- Create a unified legislation, update regulations, standards, guidelines and permission processes to include CCS
- Make the individuals involved in legislative activities, permission processes, and the public, knowledgeable about the technology.
WG1 Roadmap

Necessary to enable commercial application by 2020

- Demonstrate in full scale for coal/gas
- System simplification and cost reduction
- Improved solvents

R&D to realize next generation

- Develop new solvent based capture systems
  - Establish European solvent system vendor
  - Capitalise on R&D infrastructure
- Non-water based solvents
- Break through concepts
- Highly integrated schemes
- Sorbents and systems
- Calcination/carbonation
- Antisublimation
- Membranes

R&D to create future more optimal solutions

- Undiluted Low NOx high H2 combustors
  - New gasification schemes
  - New reforming schemes
  - Improved hot gas clean-up
- H2 membranes
- Micro-channel reforming
- SER (Sorbent Enhanced Reforming)
- CLC reforming
- Integrated H2 production utilising new reactor types

Targets

- Avoidance cost <20€/ton
- Reduced investments
- Reduced O&M costs
- Minimized energy requirements
- High availability
- Sustainable fossil fuel power generation
- Several industrial plants with CCS put to work

Necessary to enable commercial application by 2020

- Demonstration of full scale plants for ZEIGCC/ZEIRCC
  - System simplification and cost reduction
  - Develop designated H2 combustion turbines

- Demonstrate at large scale for coal and gas
  - Gain basic experience in the design of such plants
  - Build designated oxy-fuel turbine system
  - Economy of scale for Cryogenic O2 prod.

- Improve radiation/heat transfer tools
  - Oxygen Sorbents
  - High temp. O2 prod.
  - High temperature HEX
  - New integrated reactor systems

- Step change in mixed flow turbine dvs (100= °C)
- New control system logics
- CLC (Chemical Looping Combustion) for coal
- New cycles

Several industrial plants with CCS put to work

2006 2010 2020

SINTEF-2006
Working group 1

SRA
(Charles Soothill, Alstom)

SDD
(Gardiner Hill, BP)
Strategic Research Agenda

• CO\textsubscript{2}-The Global Challenge
• The Key Questions
• SRA-key points
  • Technology Options
  • Storage & Transport
  • Environment and the Public
• The R&D Roadmap
• Key Recommendations
• The Way forward
The Global Challenge

CCS, together with improved energy conversion efficiency, is a near-term solution to reducing CO$_2$ emissions on a massive scale. Its rapid deployment will help avoid the catastrophic consequences of climate change.

But:- we must demonstrate:-
- Reduced CO2 capture and plant costs
- The safety of CO2 geological storage
The Key questions

1. Can CO2 from fossil plant be captured effectively?
2. How can captured CO2 be safely transported?
3. Can the capture and long term storage of CO2 be achieved at reasonable cost?
4. Is CO2 storage safe?

The SRA proposes RD & D priorities and a technology roadmap to address these issues
1. Demonstration of long term safety and monitoring is vital for CO2 storage.
2. Numerous storage options exist - but room for more innovation and better mapping of capacity in EU.
3. Optimise the benefits & use of CO2 (EOR, NGPS)
4. Transport options are well understood, but safe, efficient & cost effective routes must be identified
1. Adopt **zero tolerance** to major CO2 leaks and establish mitigation plans.

2. Determine impact on the **full** ecosystem

3. Develop **advanced** studies & models for CO2 infrastructure.

4. Transport options are well understood, but **safe**, efficient & cost effective routes must be identified

5. Public acceptance of CCS is prerequisite and will be addressed
Building the Road to Success

- R&D to facilitate commercialisation by 2020
- Storage demo
- New concepts R&D
- Pilot & demo tests
- Development of new concepts
- Commercial plants
- Integrated projects with CCS
- R&D to optimise solutions
- ZEP as standard
- Implementation of novel concepts

CO2 avoided
The Key Recommendations

1. Implement 10-12 integrated, large-scale CCS demonstration projects Europe-wide
3. Support long-term exploratory R&D in advanced, innovative concepts for implementation of next-generation technology by 2050
4. Maximising co-operation at national, European and international level
5. Strengthen and accelerate R&D priorities to support the Strategic Deployment
ZEP on the web

www.zero-emissionplatform.eu
Vattenfalls CO$_2$ free power plant project

Roadmap to realization - Pilot Plant and Demo Plant
<table>
<thead>
<tr>
<th>Year</th>
<th>Conceptual investigations</th>
<th>Laboratory Test</th>
<th>Pilot Plant</th>
<th>Demo-Plant</th>
<th>Commercial Plant</th>
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<tbody>
<tr>
<td>2006</td>
<td>• Theoretical Research</td>
<td></td>
<td>• Demonstration of the process chain</td>
<td>• Verification and optimization of the component choice, the process and reduction of risks</td>
<td>• Competitive in the market at that time</td>
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<tr>
<td></td>
<td>• Research</td>
<td></td>
<td>• Interaction of components</td>
<td>• Commercially viable incl. subsidies</td>
<td>• No subsidies</td>
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<tr>
<td></td>
<td>• Basic principles</td>
<td></td>
<td>• Validation of basic principles and scale-up criteria</td>
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<tr>
<td></td>
<td>• Combustion characteristics</td>
<td></td>
<td>• Long term characteristics</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Non-commercial</td>
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<tr>
<td>2015</td>
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<td>2020</td>
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The demonstration project timeline: Capture & Storage

- **Pre-feasibility study**: ¾ years
- **Feasibility study**: 1 ½ years
- **Pre-planning phase**: 1¼ years
- **Bidding phase**: ½ years
- **Detailed engineering**: 1½ years
- **Investigation phase**: Site characterisation, Long-term risk assessment, Baseline-monitoring 1¼ years
- **Planning phase**: Site design & Planning consent 1½ years
- **3 years of construction**
- **Approval procedure**: 3¼ years (pipeline), 4 ½ years probably needed
- **2 years (storage), Actual time needed uncertain 1½ years (capture)**
- **Order Investment decision Capture plant permit**
- **3 years of construction**
  - (production drilling, surface facilities)
- **Order Investment decision CO2 storage permit**

A = Early Consultations
B = Pipeline permit application submitted
C = Capture plant tenders sent out
D = Storage permit application submitted
E = Capture permit application submitted
Pilot Plant Lay out
<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
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<th>2011</th>
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<tbody>
<tr>
<td>Tasks</td>
<td>Planning for tender procedure</td>
<td>Permit planning</td>
<td>Detailed engineering</td>
<td>Erection</td>
<td>Commissioning</td>
<td>Operation</td>
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</table>

- **Ground Breaking**
Schwarze Pumpe power plant
Vattenfall oxyfuel pilot plant at Schwarze Pumpe Power station
Computer simulation of the new Vattenfall Boxberg R unit 660 MW- lignite
Computer simulation of Vattenfall’s new units in Hamburg 2 x 835 MW hard coal