Cost of Transport
Large Scale and Post Demonstration

Dusseldorf 9th November 2011
Per Arne Nilsson
panaware ab
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Background - ZEP & CCS Cost project
EU CCS Demonstration Programme

Objective: Enable commercial availability of CCS

Three different challenges:

- **Capture** Technology Down the Learning Curve
- **Minimize Transport** Cost by Early Planning
- **Demonstrate Secure Storage** for Public Perception
Why is the ZEP Cost Report unique?

- Publicly available cost data on CCS are scarce

- New, live, in-house data provided exclusively by ZEP member organizations

- Over 100 contributors and nearly 2 years of work...

- Complete CCS value chains; individual reports analyse costs for:
  - Capture
  - Transport
  - Storage

- Establishes reference point for costs of CCS, based on a “snapshot” in time (CAPEX referenced to Q2 2009)
Main Messages

CCS will be cost-competitive with other low-carbon power technologies

(Will be covered in the next presentation)
Transport Costs
Approach, Assumptions & Networks
Approaches to transport cost estimation

**Bottom-up**
- Detailed component cost built into dimensioning model for specific CCS cases
- Focusing on material costs, operating expenses
- Static, detailed view on cost

**Top-down**
- Analyzing "the market", potential capture projects coming on stream in a coordinated mode
- Based on phased-in volumes, approximating required, optimal transport capacities
- Focusing on total CAPEX
- Dynamic volume development view, extrapolations on cost

**Integrated**
- Live, transport chain cost components, CAPEX and OPEX
- Simulated transport volume demands and network developments
- Integrating network scenarios and component costs
- Dynamic, generic view on cost and volume
ZEP: The costs of CO$_2$ transport - method

European conditions

Network & volume scenarios

Sensitivities Uncertainties

Definitions, assumptions & interfaces

Detailed CAPEX and OPEX data collection

First results

Iteration 1

Iteration 2

Final Report

Partner review

ZEP membership scrutiny
Key Assumptions

General
- exchange rates
- project lifetime
- cost of energy
- interest rates
- residual value
- inflation
- cost time stamp

Common CCS
- flow rates (volumes)
- annual production profile
- CO₂ purity
- interface conditions
  - inlet pressure/temperature
  - outlet pressure/temperature
- injection properties

Onshore pipeline
- custom installations
- flat topography, simple soil conditions
- unobstructed right of way
- pressures
  - inlet 100 barg
  - outlet 80 barg
  - maximum design 100 barg
- maximum CO₂ temperature 50°C
- booster pumping >200 km’s

Offshore pipeline
- custom installations
- 4 slot subsea template
- control cable
- pressures:
  - inlet 100 barg
  - outlet 60 barg
  - maximum design 250 barg
  - start 200 barg
- environmental factors
- market factors

Shipping
- custom ship design maximum 40’ m³
- buffer storage 0.8-1.0 * ship size
- offshore terminal submerged turret
- transport mode 7 bara & -55°C
- discharge conditions
  - pressure 60 barg
  - temperature 0°C
- direct injection
- no offshore buffer storage
- subsea template & control cable
# Collection of Component Costs - Example

<table>
<thead>
<tr>
<th>Source</th>
<th>Capture/Compression</th>
<th>Onshore pipeline</th>
<th>Pump</th>
<th>Launcher/Landfall</th>
<th>Offshore Pipeline</th>
<th>Template Storage</th>
<th>Offshore Pipeline</th>
<th>Template Storage</th>
<th>Control Cable</th>
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</thead>
<tbody>
<tr>
<td>Length</td>
<td></td>
<td>10 km</td>
<td></td>
<td></td>
<td>180 – 1 500 km</td>
<td>10 km</td>
<td>50 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>110 barg</td>
<td>110 → 100 barg</td>
<td>100 → 200 barg</td>
<td>200 barg</td>
<td>200 → 60 barg</td>
<td>60 barg</td>
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<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td>H</td>
<td>I</td>
</tr>
</tbody>
</table>

**Battery limits and cost zones for offshore pipeline**
**CO₂ Transport from Point-to-Point ...**

**Onshore spine**

- Source 10 Mtpa
- 10 km Pipeline onshore
- 180 km Pipeline onshore
- Storage

**Offshore spine**

- Source 10 Mtpa
- 10 km Pipeline onshore
- Pumping
- 180 km Pipeline offshore
- Storage
... to Complex Networks

Complex networks with onshore pipeline spine of 180 km and 500 km
More robust scenarios built in other studies...

One North Sea study
“Very High scenario 2050”
May 2010

CO₂Europipe
Reference scenario 2030
September 2011

Feasibility Study for Europe-wide CO₂ Infrastructures
2050 Mid CO₂ Capture Scenario
October 2010

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but more detailed and reality based cost element analysis in ZEP

- Pipeline data from both existing CO₂ pipelines and...
- ... in comparison with hydrocarbon networks
- Data from current (2010) demonstrator projects
- Detailed interface definitions with Capture and Storage experts
- Shipping data from live projects and LPG tonnage
- Process (compression, regas and liquefaction) from vendors and projects
Cost Predictions
Scale effects are real (total cost €/t)

Point-to-Point **180 km**

€/t

15
10
5
0

2.5 10 20 Mtpa

onshore pipeline
offshore pipeline
ship

Point-to-Point **500 km**

€/t

25
20
15
10
5
0

2.5 10 20 Mtpa

onshore pipeline
offshore pipeline
ship
Selected Networks:
20 Mtpa, 2 sources, 2 offshore storages

Ship spine
- Source 10 Mtpa
- Pipeline onshore 10 km
- Liquefaction Buffer storage
- 180, 500, 750, 1500 km
- Pipeline offshore 10 km
- Storage

Offshore spine
- Source 10 Mtpa
- Pipeline onshore 10 km
- Pumping
- 180, 500, 750, 1500 km
- Pipeline offshore 10 km
- Storage

Onshore spine
- Source 10 Mtpa
- Pipeline onshore 10 km
- Pumping
- 180, 500, 750, 1500 km
- Pipeline offshore 10 km
- Storage
Network costs:
20 Mtpa, 2 sources, 2 offshore storages

CAPEX (M€)

Spine (km) OPEX (M€ p a)

<table>
<thead>
<tr>
<th>Spine (km)</th>
<th>CAPEX (M€)</th>
<th>OPEX (M€ p a)</th>
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<tr>
<td>Ship 1 500</td>
<td>4000</td>
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<tr>
<td>Ship 750</td>
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<tr>
<td>Ship 500</td>
<td>2000</td>
<td>100</td>
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<tr>
<td>Ship 180</td>
<td>1000</td>
<td>50</td>
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<tr>
<td>Offshore 1 500</td>
<td>800</td>
<td>180</td>
</tr>
<tr>
<td>Offshore 750</td>
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<td>Offshore 500</td>
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<td>3</td>
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<tr>
<td>Onshore 180</td>
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Unit cost (€/t)

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<th>Ship 1 500</th>
<th>Offshore 1 500</th>
<th>Onshore 1 500</th>
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<td>16.3</td>
<td>11.3</td>
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<td>3.4</td>
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<tr>
<td>2.5</td>
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Pipeline sensitivities

Pipeline
% changes in cost per ton

Sensitivities for offshore pipeline 10 Mtpa and 500 km
Volume Ramp-up Sensitivity

Ramp up transport cost
500 km, increasing by 2 Mtpa to maximum 20 Mtpa
Conclusions
Adding up, for Europe, we speak BIG numbers...

Infrastructure investment required is massive, yet overall numbers remain the results of highly approximate extrapolations, only, so no guarantees issued on this.

<table>
<thead>
<tr>
<th>report</th>
<th>year</th>
<th>CAPEX (b€)</th>
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<tr>
<td>Arup/EUC</td>
<td>2010</td>
<td>7 - 20</td>
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<td>ZEP</td>
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<td>40 - 50</td>
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<td>CO₂ Europipe</td>
<td>2011</td>
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Illustration: Arup, EUC, DG ENER, Infrastructure study Oct 2010; High Scenario 2050
Key Conclusions

Early strategic planning of large-scale CO$_2$ transport infrastructure is vital to reduce costs

- Capital expenditure appears prohibitive and provides high risk – combining pipelines and ships can reduce risk

- Clustering plants to a transport network can achieve significant economies of scale – in both transport and storage

- Large-scale CCS requires the development of a transport system equivalent to the current hydrocarbon transport infrastructure

- Greatly reduced long-term costs can be ensured with early strategic planning
## Acknowledgements - Working Group Participants

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<thead>
<tr>
<th>Name</th>
<th>Country</th>
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