Costs of CO_2 pipeline transport for Dynamis case studies

European Conference on CCS Research, Development and Demonstration

February 2009

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- Experience with CO_2 pipelines
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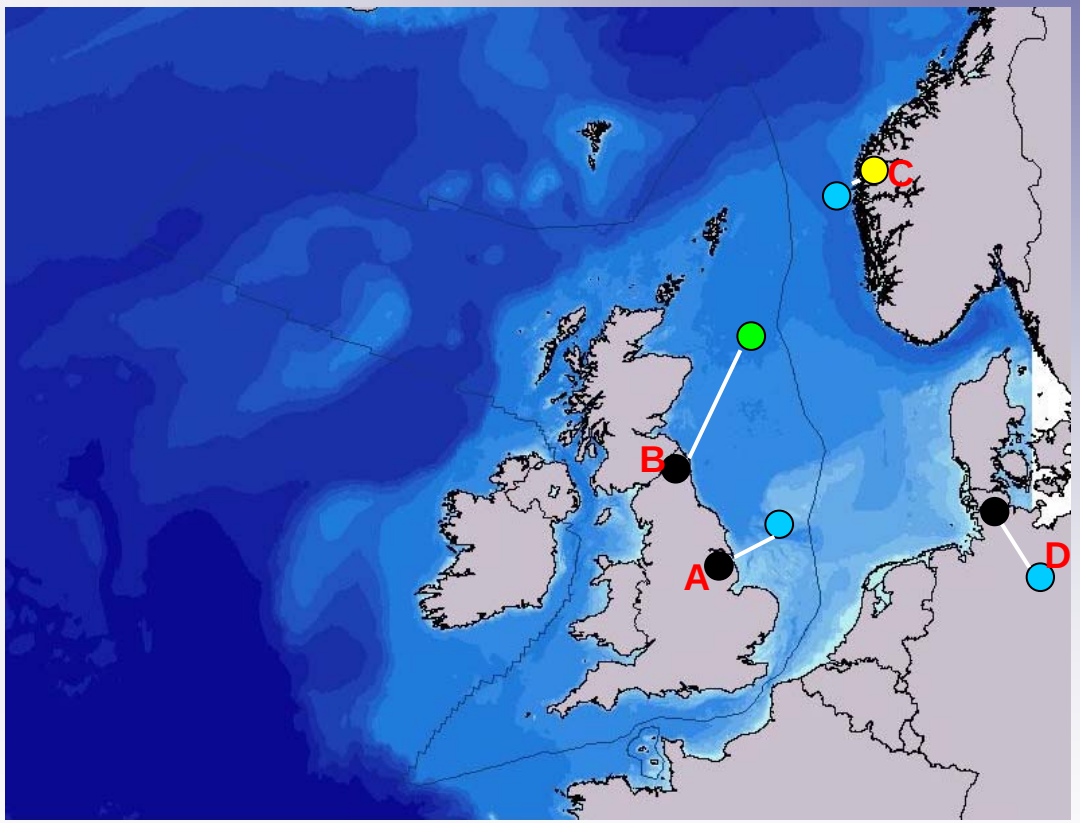
Scope of the work

SP3 work focuses on infrastructure for CO_2
- DYNAMIS CO_2 quality recommendation
- Routing and costing of CO_2 pipelines



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CO_2 quality recommendations

Compound	Concentration limit	Remarks
H_2S	200 ppm	Health and safety considerations
CO	2000 ppm	Health and safety considerations
SO_x	100 ppm	Health and safety considerations
NO_x	100 ppm	Health and safety considerations
H_2O	500 ppm	Technical limit
O_2	Aquifer <4 vol% (all non cond. gases), EOR >100 ppm	Technical limit; storage issue
CH_4	Aquifer < 4 vol%, EOR <2 vol% (all non cond. gases)	Like ENCAP
N_2, Ar, H_2	<4 vol% (all non cond. gases)	Like ENCAP
CO_2	> 95%	Result of other compounds in CO_2

Experience with CO_2 pipelines

- Experience with the transportation of CO_2 in pipelines:
  - Ca. 3100 km CO_2 pipelines using naturally occurring CO_2 for EOR in USA
  - With a capacity of 44 Mt/yr
- But CCS projects differ, because:
  - The CO_2 is from anthropogenic origin, the quality of the CO_2 differs
  - Both long distance onshore and offshore pipelines
- Gas and oil pipelines estimates give good indications of CO_2 pipeline costs
  - With the remark that CO_2 pipeline costs can be higher due to higher operating pressures and thicker pipeline walls

CO_2 and transport characteristics

- CO_2 characteristics:
  - Dense phase -> to increase density and reduce cost
  - Recommended CO_2 purity -> >95% (Dynamis SP3.1)

- Pipeline transport characteristics:
  - Continuous flow
  - Cheaper at shorter distances (compared to ship)

- Possible (re)use of existing pipelines

OCAP pipeline

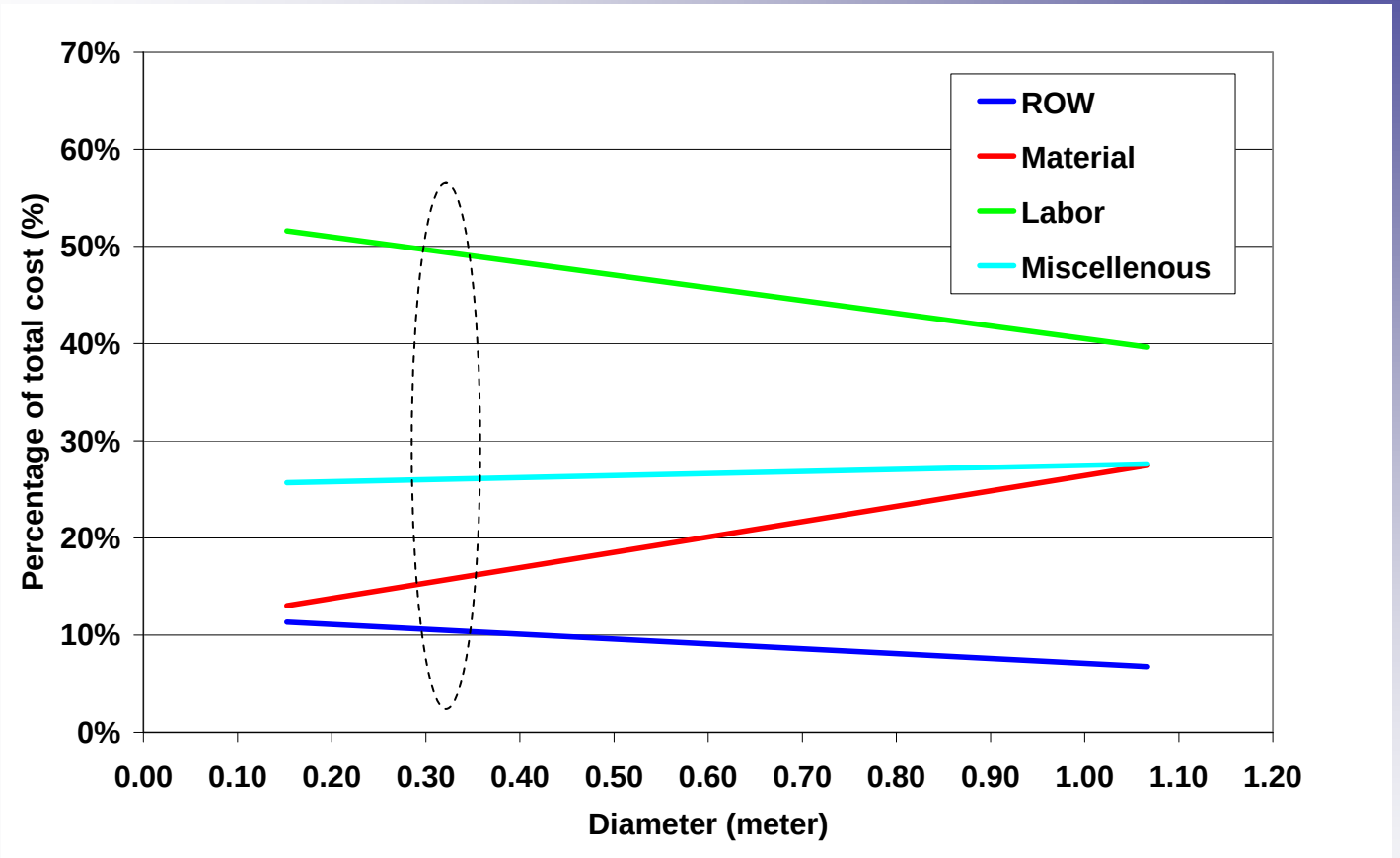
- Currently:
  - 44 kg/s
  - Gaseous, at 22 bars
  - No (additional) permits required
  - Risk assessment performed
- Suitable for higher pressures (after some limited modifications)

Economics of pipelines (1)

- Costs depend on the length and size of the pipe, terrain conditions and number and complexity of artworks, condition of the CO_2 and level of impurity, steel price, cost of labour...

- Cost shares for US land pipelines with diameter between 0.21m and 0.91m are:
    - Installation / labour: 45%
    - Material: 26%
    - Miscellaneous : 22%
    - Permits, Rights of way : 7%

Economics of pipelines (2)



With increasing pipeline diameter the proportion of material costs and miscellaneous cost increases, while the proportion of the other components decreases

Economics of pipelines (3)

- Historical pipeline investment costs of pipelines are given as:
  - 0.6 – 1.0 M€/m/km for onshore pipelines through 'uncomplicated' terrain excl. art works
  - 1.0 -2.0 M€/m/km for offshore pipelines

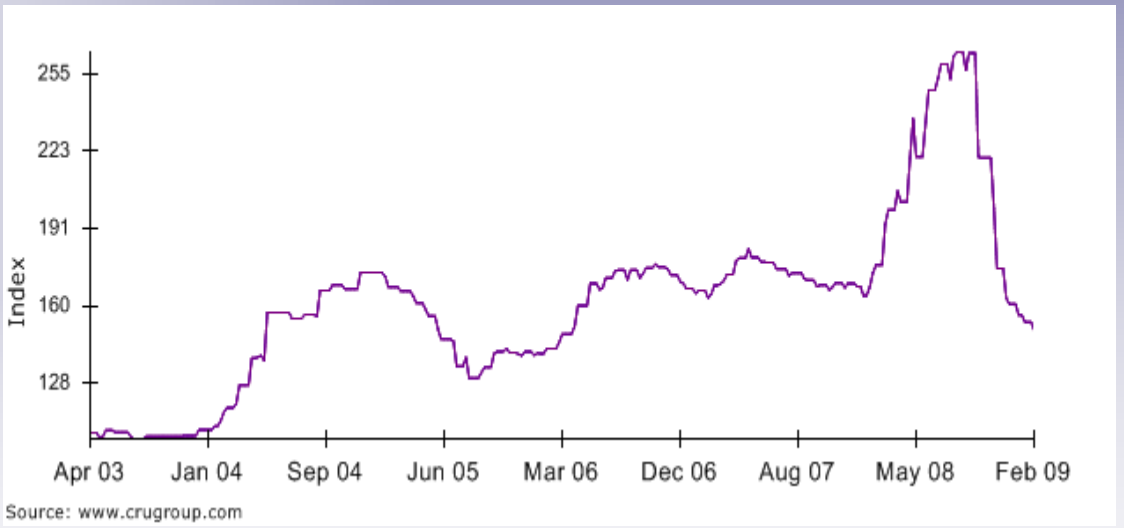
- Pipeline costs of existing CO_2 pipeline projects:
  - Snøhvit: 2.3 M€/m/km (subsea, arctic circumstances)
  - Weyburn: 0.5 M€/m/km (long distance, desert area)

- In the last years pressure on the market showed substantial increase in costs (material, labor)

Material cost (1)

- Current practice: carbon steel for transportation of 'dry CO_2'
- For (very) short transportation distances and wet CO_2 stainless steel might be economic

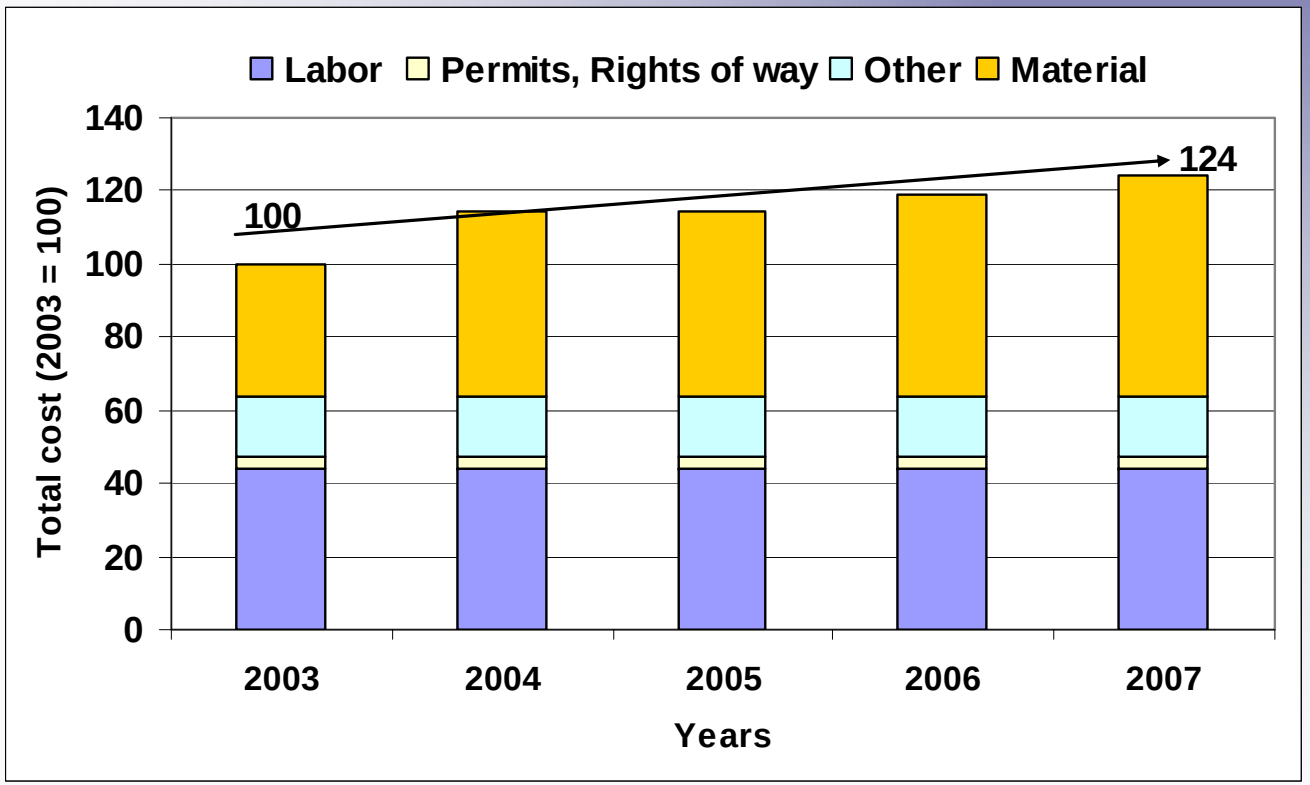
- Steel prices:
  - 'stable' in period '94 – '03
  - Increasing since 2003
  - Almost doubled in 4 years
  - Steel prices currently decline



Source: www.cruspi.com

Material cost (2)

- 2003 pipeline investment cost set to 100%
- Steel prices increase according to price index of steel



Base construction cost

- Estimation of CO_2 transportation cost based on base construction cost of
  - 1.7 €/m/km for land pipelines and
  - 2.7 €/m/km for sea pipelines

- Conservative estimates

Estimating CO_2 pipeline cost

Steps in calculating CO_2 transportation cost (€/tCO_2):

1. Determination of alternative pipeline trajectories, considering:
   - avoidance of urban areas
   - the possibility of following existing pipeline corridors
   - Make use of existing gas or oil terminals

2. Collection of information on trajectory specific conditions such as:
   - # of principal crossings (river, roads)
   - # of km through residential area, cultivated area etc.
   - Sea depth

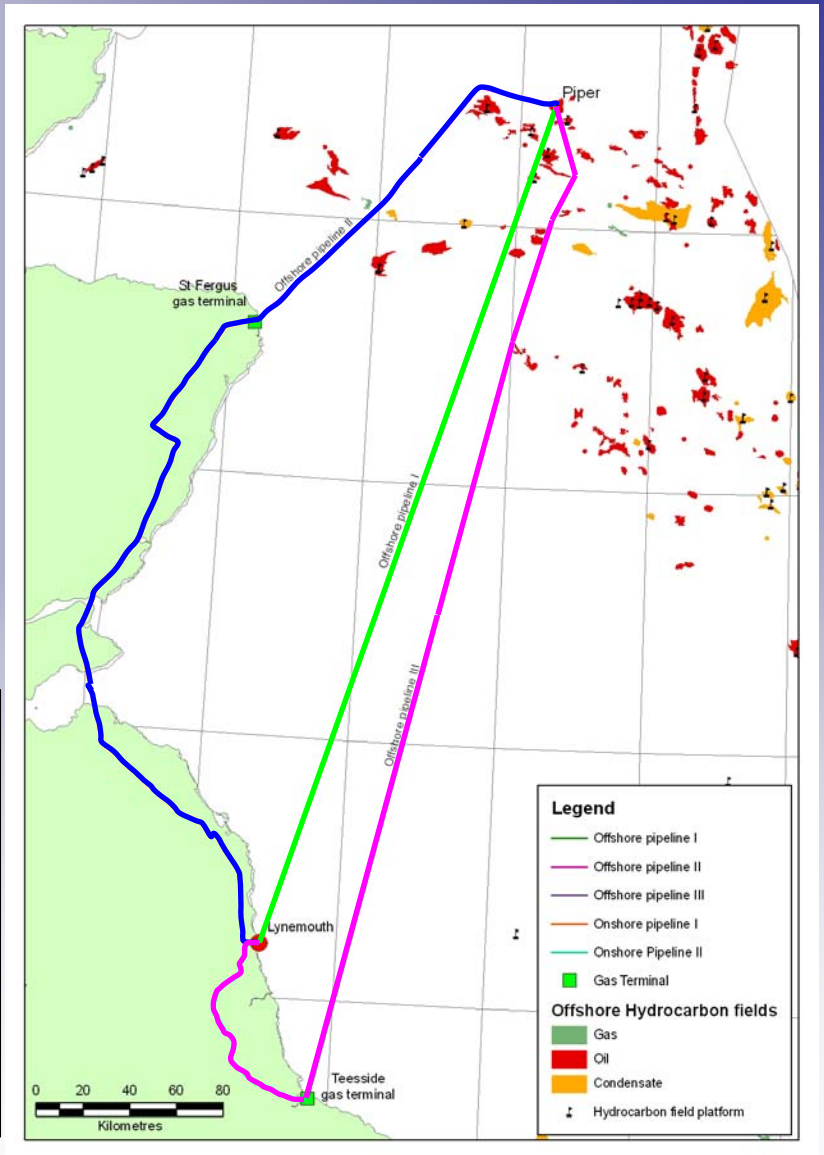
Example – case study

Candidate plant site Progressive Energy Ltd.:

- Capture location: Lynemouth
- Storage location: Piper field

- 2.5 Mt CO_2/y
- diameter pipeline 0.34 m

Length (km)	Principal crossings (#)			Sea Depth (m)	Cost (€/tCO_2)
	Main roads	Rail	Waterway		
377 km offshore	-	-	-	0 -150 m	22.6
331 km onshore 177 km offshore	32	16	182	0 -150 m	48.5
106 km onshore 440 km offshore	5	66	47	0 -150 m	42.0



(BGS, 2008)

Dynamis EI H_2 CO_2

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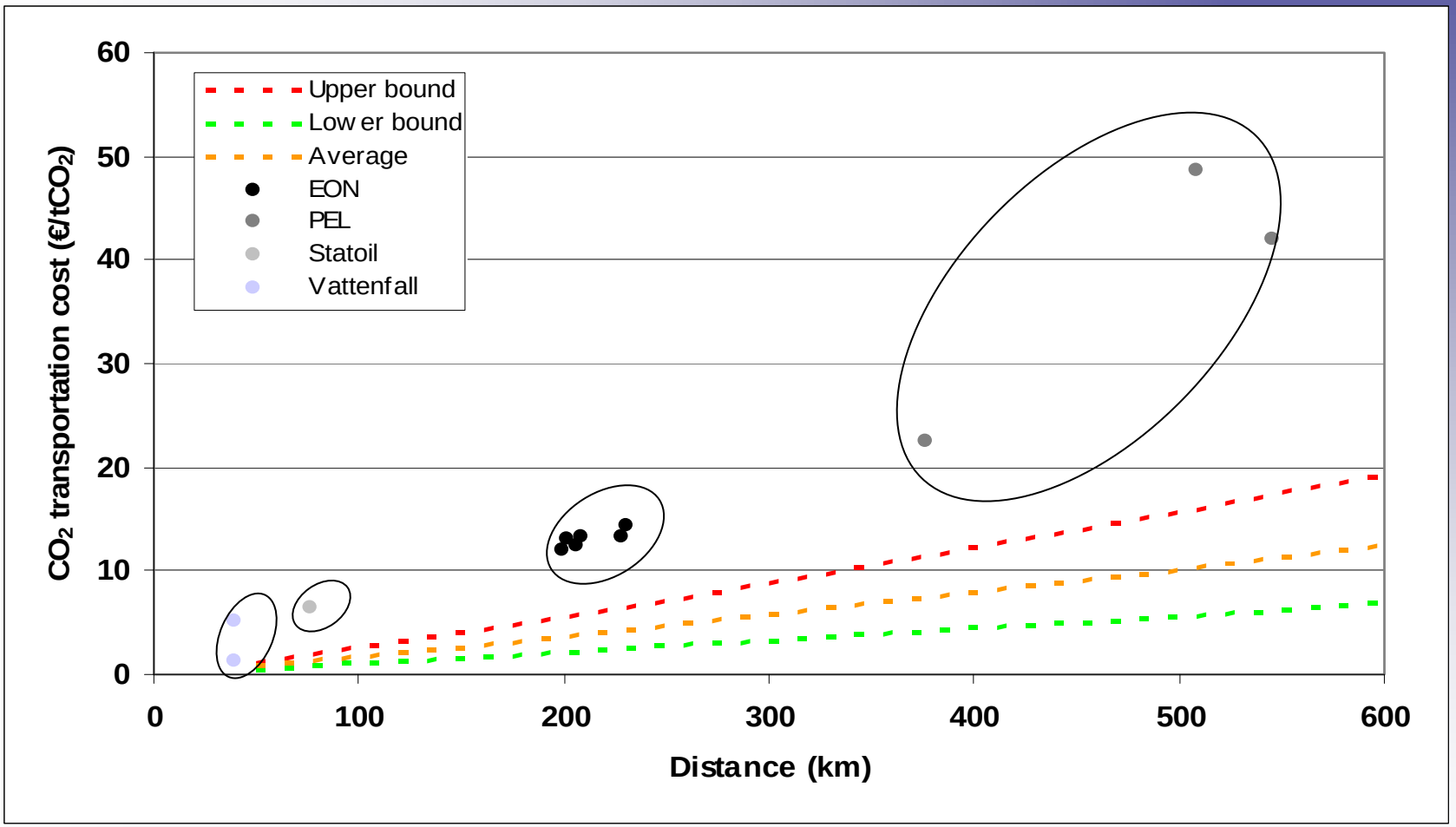
CO_2 transportation cost



Conclusions

Main conclusions:

- Current pipeline cost are significantly higher compared to the high estimates of other studies
- Used data suggest considerable spread of costs
- Sensitivity analysis suggests that up scaling of the activities from 2.5 Mt CO_2/year leads to large cost reduction