CO_2 Infrastructure Study, a summary

Implementation of CO_2 transport in Europe

September 4, 2014

Goal and approach of the study

- Identification of technical, regulatory and economical requirements for building up a CO_2 infrastructure up to 2050

- Deduction of CO_2 amounts to be transported based on energy policy

- NB: specific details of the study are confidential; only general highlights are presented here, report will be public in the near future

Method

- The study analysed
  - expected CO_2 emissions up to 2050 within the boundary conditions for a prototype country
  - CO_2 emissions from power plants and energy-intensive industry
  - the required CO_2 infrastructure for pipeline and ship transport for offshore storage under the North Sea for the determined amounts of CO_2
  - models for implementation of a future CO_2 transport infrastructure
  - regulatory requirements
  - timing and costs of implementation of a transport infrastructure

- To account for varying flows and compositions, abstract clusters of CO_2 sources are considered

Boundary conditions of the analysis

Technical requirements of a CO_2 transport infrastructure cannot be seen separately from CO_2 sources and sinks:

- Influences from CO_2 sources:
  - CO_2 flow and annual amount
  - Composition of the CO_2 stream

- Influence from CO_2 storage:
  - Restrictions in flow rate
  - Continuity of flow

Analysis of emission political reduction targets

- Energy strategy states targets for
  - CO_2 emission reduction
  - Contribution of renewable energy sources to power generation
  - Energy demand reduction
  - Efficiency increases
- Targets are set for the years 2020 to 2050
- From these targets, minimum CO_2 amounts to be captured and transported are derived
- Relative shares in fossil energy mix assumed constant until 2050

In 2020 for example in a specific case, capture of 25 Mt/a is required; in 2050, 60 Mt/a.

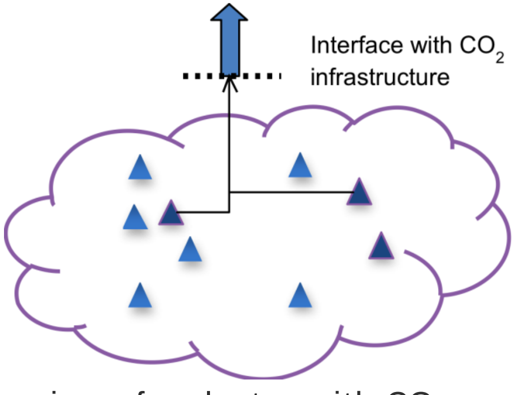
CO_2 sources and clustering – Challenges

Challenges of sizing CO_2 infrastructure:

- Multiple items are unknown for 2050 (such as the number of sources, specific availability of storage capacity, geographical spread of sources)
- Designing an infrastructure requires realistic input on:
  - Max. flow rate and annual capacity
  - Main components in CO_2 stream
- To investigate, abstract clusters are used, taken into account

the following factors:

  - Current state of art sources + capture
  - Clusters of industry and / or power generation
  - No geographical demarcation
  - Influence of RES
  - Influence of variations in operational types (day/night and baseload)



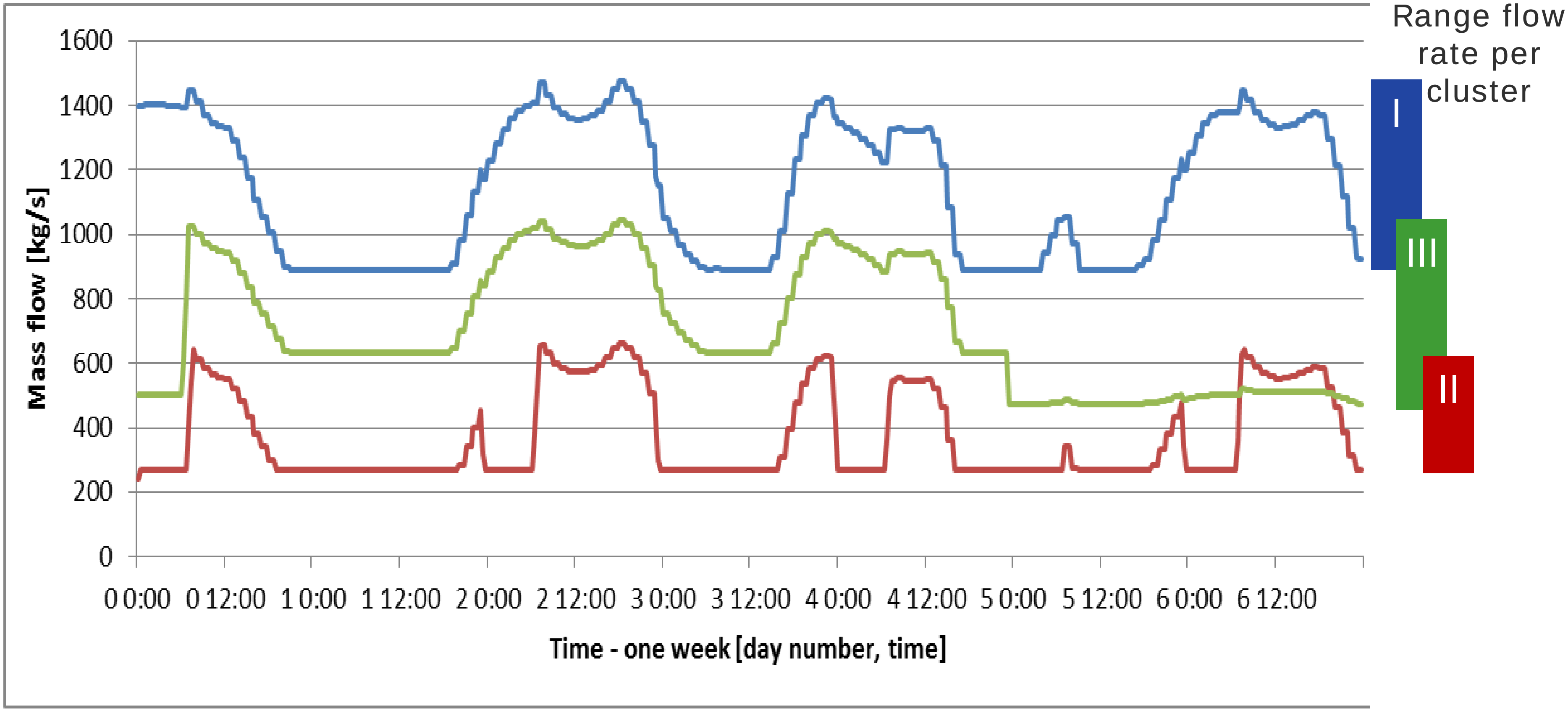
Overview of a cluster with CO_2 sources, the collection network and the system boundary with long-distance transport

Examples of CO_2 sources and clusters

- Three theoretical clusters are defined, consisting of the following sources:

Cluster	I	II	III
Description	High concentration of sources in industry and power	Only centralised power generation	Dispersed industrial sources and power plants
Type of source:	**# of sources**	**# of sources**	**# of sources**
Coal	6	4	5
IGCC	3	0	1
NGCC	3	0	1
Steel	7	0	1
Cement	5	0	7
Refinery	1	0	1
Total CO_2 amount per cluster (Mt/a)	**36**	**12**	**22**

CO_2 clustering - Results flow calculations



– The clusters show similar patterns based on the impact of renewable energy sources on power generation

– Utilization rate of clusters 60-80 %.

DNV·GL

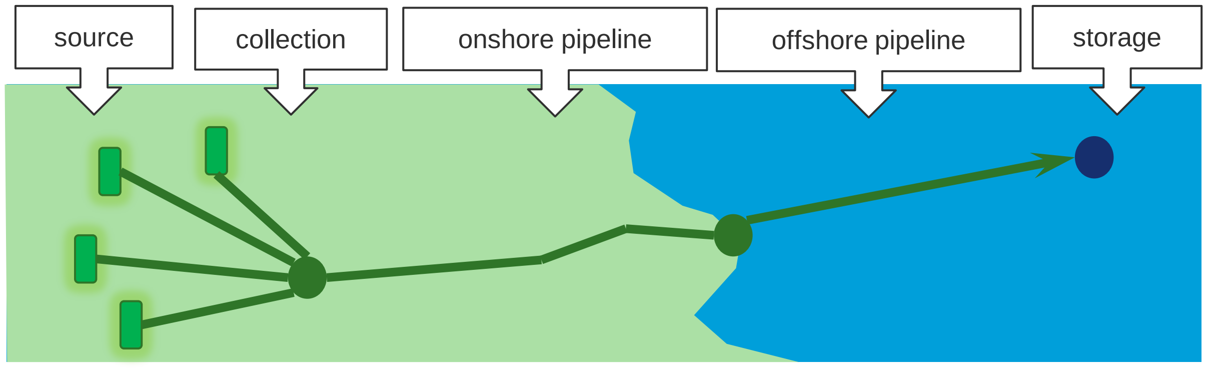
CO_2 quality requirements for transport

- Basis is carbon steel pipeline
- Free water due to condensation is to be avoided

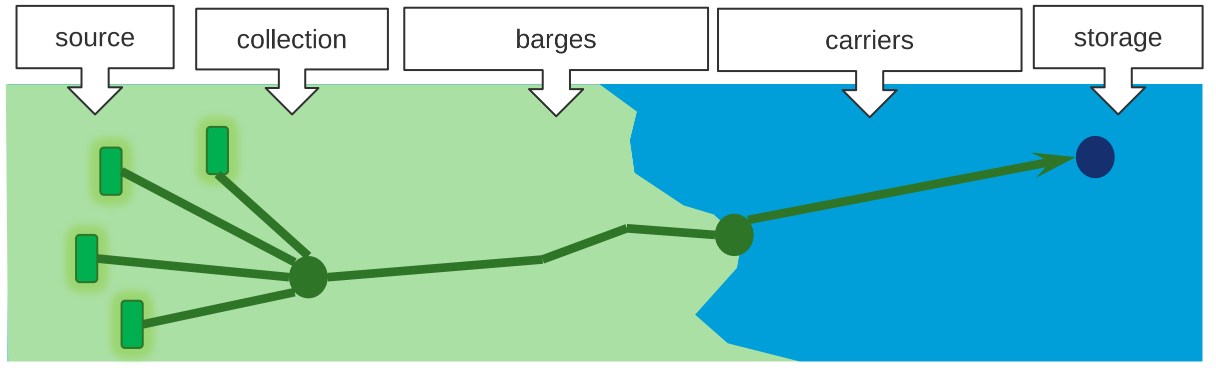
- The following is to be considered:
  - Determination of allowable water content
  - Possible interaction between impurities
  - Possible interaction resulting from mixing of different CO_2 flows

CO_2 transport options - Two modes of transport

- Two transport scenarios are investigated:
  - **Pipeline** network, onshore and offshore (50 km collection pipelines)



  - **Barges** for inland waterways, carriers for offshore transport



CO_2 transport options - Typical transport infrastructure size and capacity

Sizing examples based on 60 Mt CO_2 to be transported annually:

Pipeline Transport

- 60 Mt/a is equivalent to theoretical continuous flow of 1.900 kg/s
- Variations in flow require a higher peak capacity of around 3.000 kg/s
- 350 km onshore and 100 km offshore

Shipping

- 70-150 barges (6.000 t) for 350-700 km
- 25-35 carriers (25.000 t) for offshore

- Maximum depends on amount of installations in 2050, and their utilization and is subject to optimisation
- Not all sources can be connected to the transport infrastructure

Pipeline transport network development

- A national pipeline network could develop according to the following schedule
- Cost-optimal pipeline diameters are chosen.

	Annual amount of CO_2 captured	Required capacity	Pipeline configuration to meet capacity			
year	Mt/a	kg/s				
2020	25	1,100	32"	24"		
2030	28.8	1,260	32"	24"		
2040	39.9	1,750	32"	24"	28"	
2050	59.4	2,610	32"	24"	28"	32"

Economics and implementation – CO_2 transport costs and investment order of magnitude

- Construction of CO_2 transport capacity is ahead of operation by at least 5 years.
- Investment schedule shows when the required technical installation should be **in place** (rough estimates (± 50 %) of the upfront investments for the infrastructure)

	CAPEX (million €)	
Capacity installed	Pipelines onshore and offshore	Inland barges and offshore carriers
by 2020	2000	2000
2020-2030	100	1500
2030-2040	1000	2000
2040-2050	1000	3000
total	**4100**	**9000**

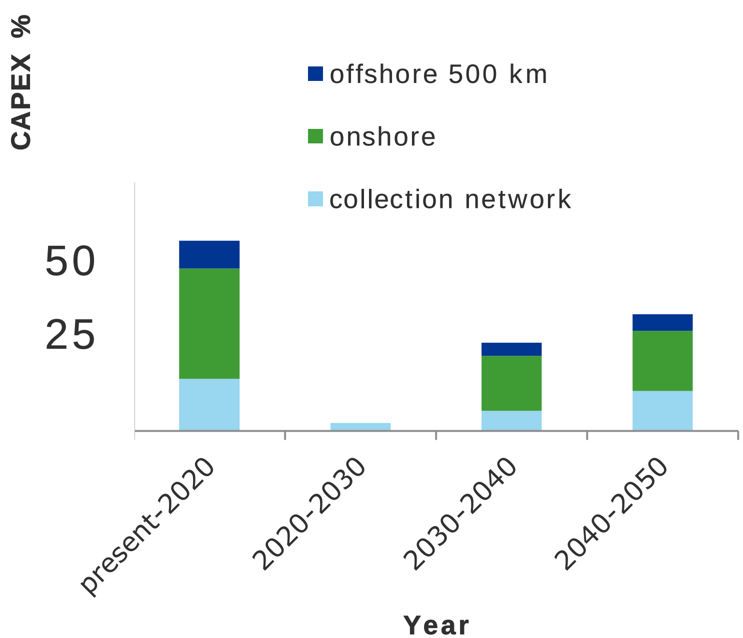
- For a system to be in place by 2020, construction must start by 2015 at the latest

Note: Expansion of the natural gas network took 6 years (Gasunie, the Netherlands). For Nord Stream, it took 5 years from start of the design to commissioning of the pipeline. Construction of the BBL (natural gas pipeline between the Netherlands and the UK) started in 2004 and commissioning took place in 2006.

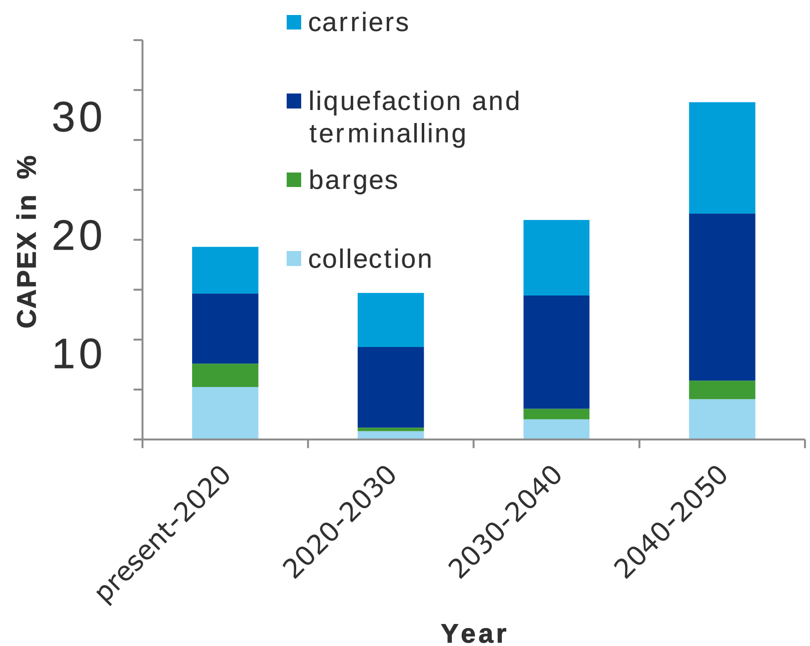
Economics and implementation – Pipeline and shipping infrastructure investment requirements

- In the below chart it is shown how should be invested in order to be prepared for the transportation of CO_2.
- Investment for capture installations and storage locations comes on top of this.

Investment in pipeline network



Investment in barge and carrier network



DNV·GL

Economics and implementation – Prerequisites for CO_2 transportation

- Approach for CO_2 transport infrastructure setup:
  - Parallels with utilities and services investigated
  - Applicability of business model concepts to CO_2 transport assessed

- For large-scale deployment of a CO_2 transport infrastructure the following prerequisites are determined:
  - Stakeholders with enough incentive to participate
  - Sufficient mitigation of uncertainties (e.g. stable investment climate, third-party access, public acceptance, appropriate safety level)
  - Goal setting by government requires an active role in the implementation

- Probable business model will include:
  - Single infrastructure, resulting in a natural monopoly
  - A regulator to mitigate risk and tariff
  - Third party access to the infrastructure, resulting in excess capacity

Economics and implementation – Prerequisites for CO_2 transportation

- CCS is an economic option:
  – After implementing transitional measures for first demonstration plants and
  – When a level playing field with other low carbon technologies is created

- Given the high investments needed and the high risk involved, political choices will have to be made for transitional support schemes
- In the long term, the targeted CO_2 emission reduction must be driven by emission trading only in competition between low carbon technologies without market interventions

Conclusions:

- CCS is an important option in order to reach CO_2 emission reduction targets
- Analysis of a set of reduction targets leads to capture requirement of around 60 Mt/a in 2050.
- North Sea storage capacity is sufficient.
- Large-scale long-distance CO_2 transport infrastructure will be required.
- Fluctuating CO_2 flows lead to infrastructure design layout based not on average flow (utilization 60 to 80 %) but on maximum capacity required.
- Technical design and operation of transport infrastructure is mature, but needs to be adjusted to fit the European situation.
- A CO_2 composition for transport needs to be specified.
- For safety-related design calculations, experimental model validation is needed.

Some political recommendations:

Regulatory issues present a number of challenges to successful implementation of CCS :

- National CCS law needs to be extended to cover CO_2 transport by ship and on large-scale, in order to keep these options open.
- National CCS law needs to be extended to cover CO_2 transport and storage at the scale of tens of Mt/a
- To reach emission reduction targets, investments in CCS would need to be done immediately.

- Without proper government policy and careful planning of government participation a successful implementation is hardly possible.
- Transboundary CO_2 transport can be realized through bilateral and multilateral agreements. The EU CCS directive provides the necessary framework.
- Ratification of the 1996 London Protocol[1] by all treaty partners is recommended. However, it is unclear when the ratification process is complete.
- The CO_2 transport terms of use can be supervised by the regulator.

[1] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter

www.dnvgl.com

SAFER, SMARTER, GREENER