The crucial role of ships in establishing a Nordic CCS infrastructure

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Effective processes for a climate friendly future

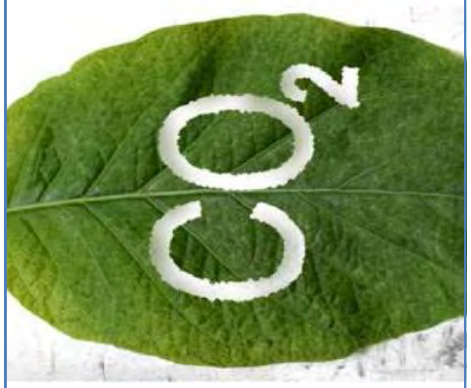
Powder technology

- Transport
- Storage
- Handling
- Separation
- Characterization

Energy

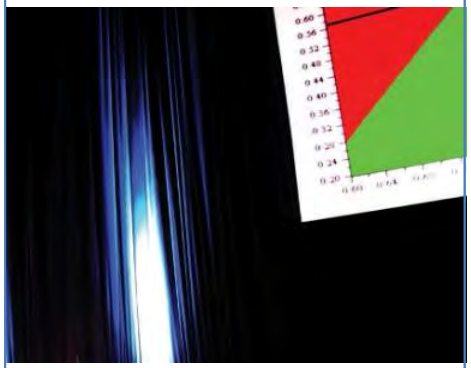
- CO_2 capture combined with bioenergy
- Biogas
- Combustion and environment
- Modelling and flow
- Energy effective processes
- Calculation of cost-optimal energy utilization

CCS*



- Post-combustion capture technology
- CO_2 transport and infrastructure
- Degradation of amines
- Early phase cost estimation
- Solutions for energy-producing and energy-intensive industry
- CO_2-lab

Smart Manufacturing



- Multivariate
  - analysis/diagnostics
  - modelling
  - simulation
  - optimization
- Understanding/ hypothesis
- Verification
- Implementation

* Carbon capture and storage

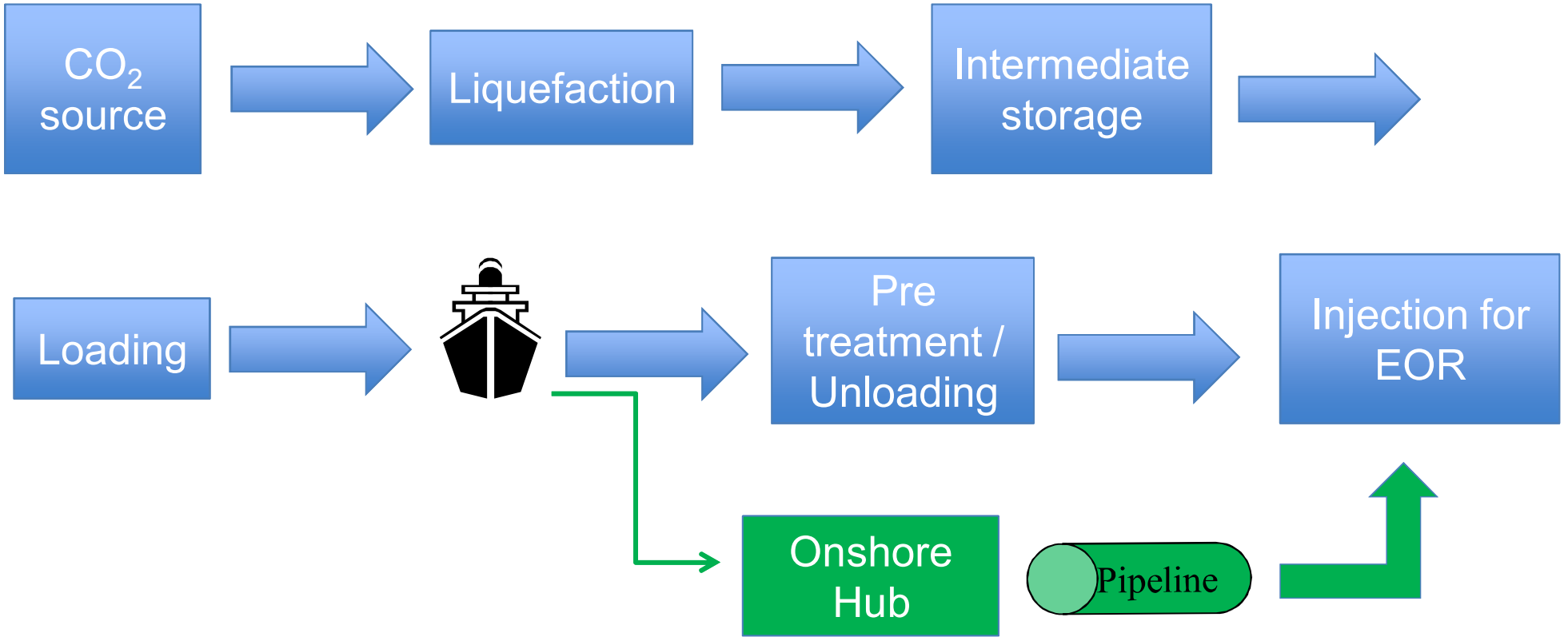
Existing CO_2 ship

Food grade CO_2 transport

M/T Yara Gas III alongside the quay near Yara's ammonia plant in Porsgrunn,
Capacity: 1200 t of liquefied CO_2 in 2 tanks of 600 tons capacity each
Ship type: Converted container vessel

Photo: Larvik Shipping

Ship based CCS chain



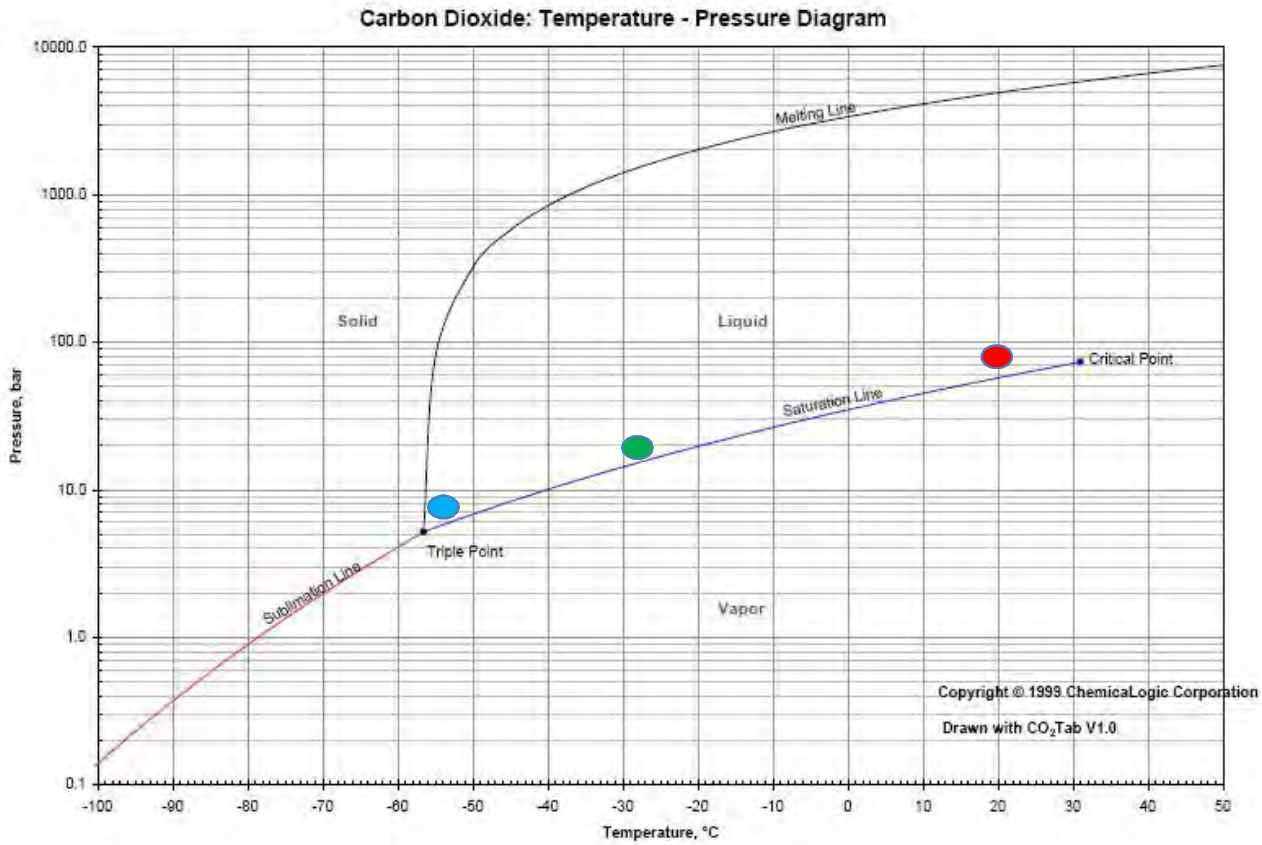
Ship based CO_2 transportation alternatives

- Ships carrying liquiefied CO_2
  - Industrial experience exists
- Barges
- Ships carrying compressed CO_2
  - Cylinders or Coiled-up pipeline
  - No existing practical experience

Ship transport of CO_2 (1)

- Ships or barges carrying
  - liquefied CO_2
  - compressed CO_2

- Liquefied
- Compressed
- Commercial



Ship transport of CO_2 (2)

- Commercial maritime transport of CO_2
  - Ongoing for years
  - Small quantities
  - CO_2 is used for food and beverages, cleaning, fire extinguishers etc.
  - Transport conditions are;

    15 – 18 bar, -22 to -28ºC (liquefied)

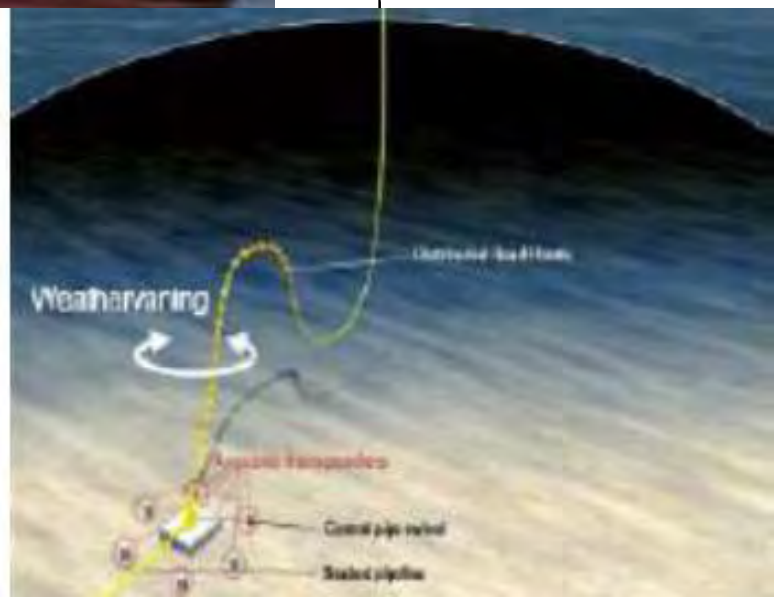
Ship size and installations on land

- Optimal size of ship vary with transporting distance and CO_2 volume
  - 10000 – 50000 tons of cargo?
- CO_2 to be liquiefied (7 barg, -50˚C, <50 ppm H_2O)
- Need of intermediate storage tanks, capacity about +50% of ship
- Need of loading facilities

Onshore hub, pipeline to subsea installation

Offshore unloading to buoy, platform

Offshore unloading to subsea installation



Ship transport of CO_2 (3)

- Large scale CO_2 transport for storage in saline aquifers and for EOR
  - Larger quantities than current volumes
  - Effective transport will have to take place close to the triple point of CO_2;

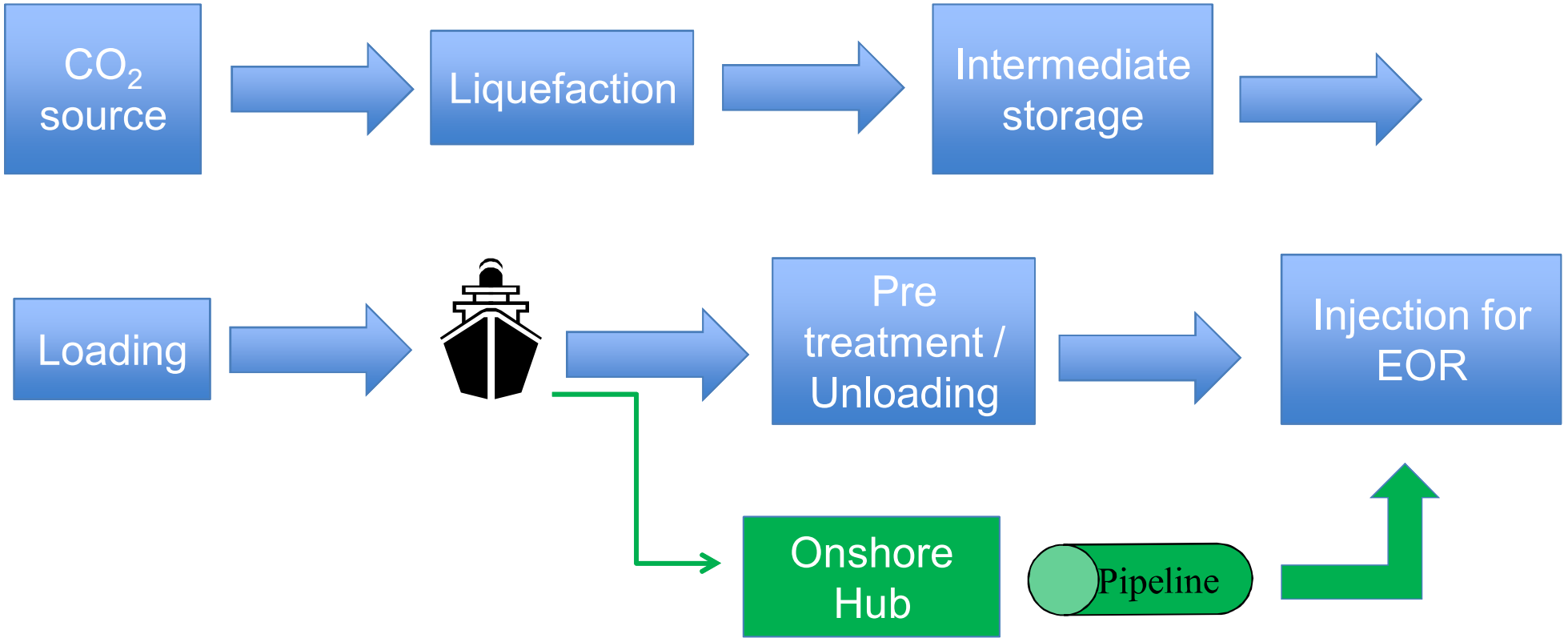
    7 – 8 bar and -50ºC, < 50 ppm water
  - Pressure increase 0.1 to 0.2 bar/day due to thermal leakage
  - Capacity of available ships is currently between 10 000 and 40 000 t
  - Optimal ship size depend on volumes and distance
  - Not proven at this scale

Safety – ship transport of CO_2

Hazard	LNG	LPG /LNH3	Liquefied CO2
Toxic	No	No	No
Carcinogenic	No	No	No
Asphyxiant	Yes (in confined spaces)	Yes (in confined spaces)	Yes (in confined spaces)
Others	Low temperature (-160 Deg C)	Moderately low temperature (-50Deg C)	Moderately low temperature (-50Deg C)
Flammability Limits in Air (%)	5-15	2-10	Non-flammable
Storage Pressure	Atmospheric	Often pressurised	Pressurised
Behaviour if spilt	Evaporates forming a visible 'cloud' that disperses readily and is non-explosive, unless contained	Evaporates forming an explosive vapour cloud	Solidifies to 'dry ice' (if no sufficient heat around) and then sublimates as surrounding temperature increases

The UK P&I Club, 2005

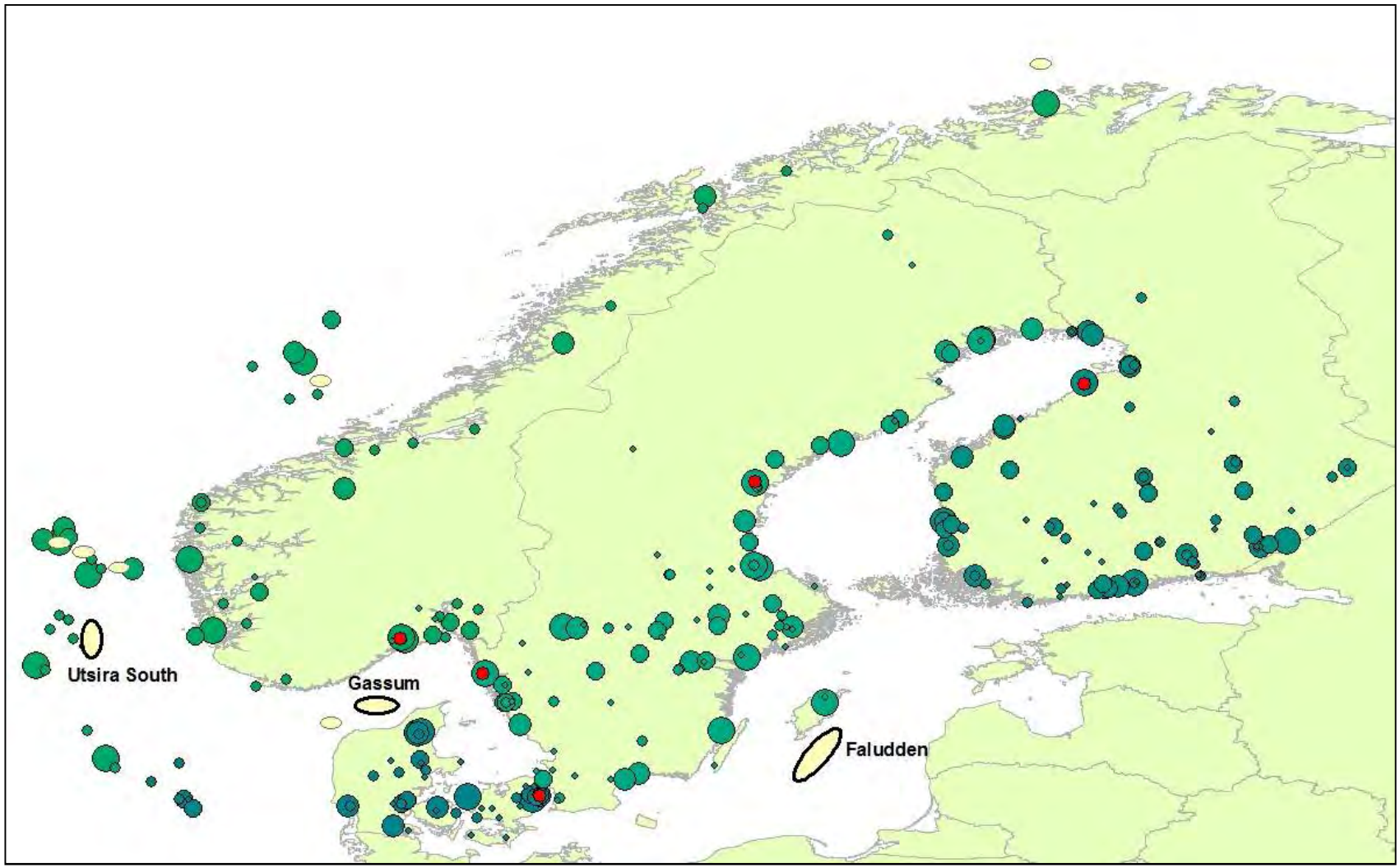
Ship based CCS chain



EOR vs. aquifer storage

- EOR
  - Limited injection period
  - CO_2 injection rate is gradually reduced
    - Produced CO_2 is re-injected
    - Offset options must likely be in place
  - Needs reliable supply of CO_2
  - Considered to be a stepping stone for implementation of CO_2 storage in saline aquifers

CO_2 sources and possible storage sites in the Nordic region



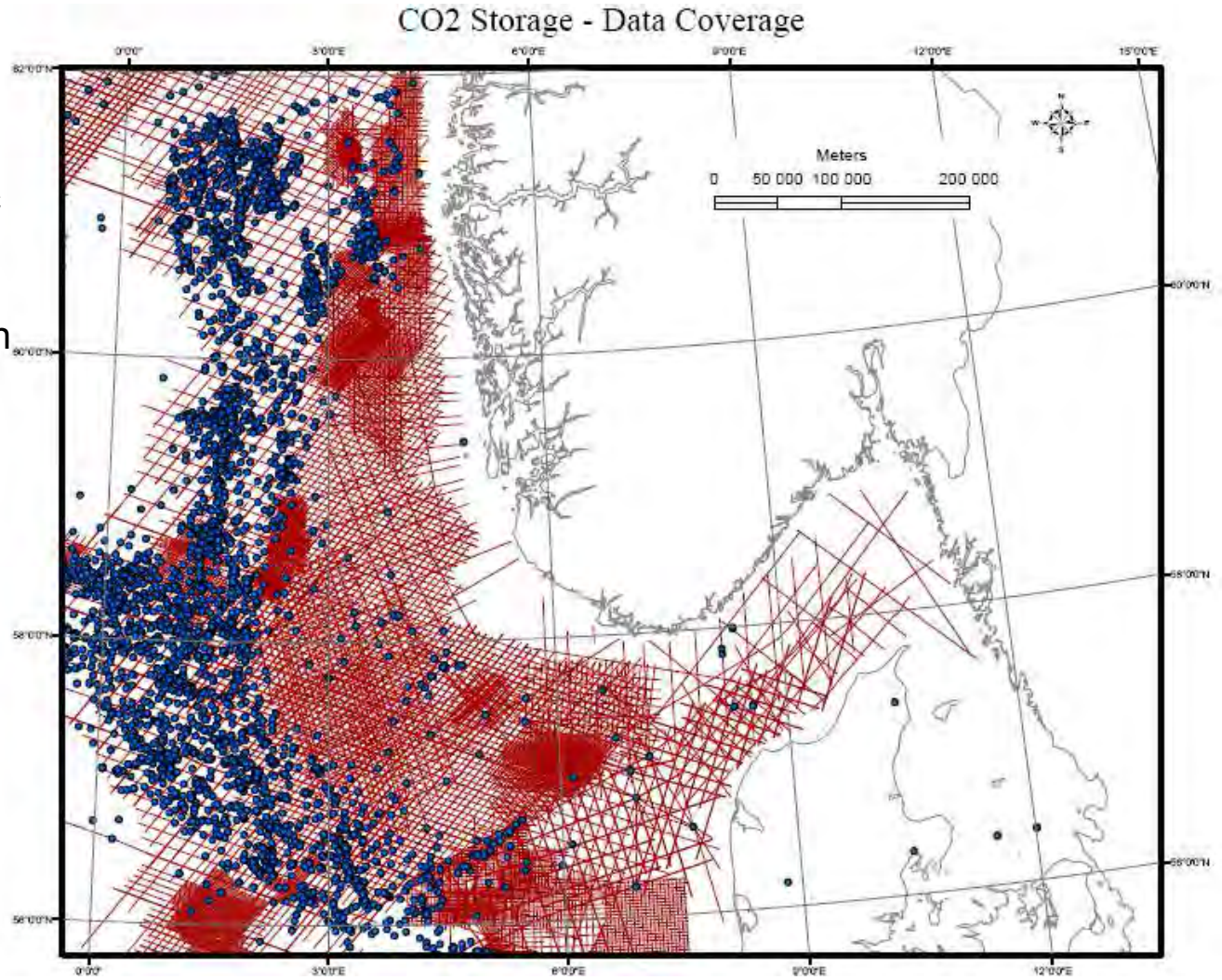
Green: Fossil sources, Red: biogenic sources,
Yellow: Possible storage sites

From: Kjärstad & al. 2014. NORDICCS project, pres. at GHGT 12

Data coverage in the North Sea and Skagerrak/Kattegat

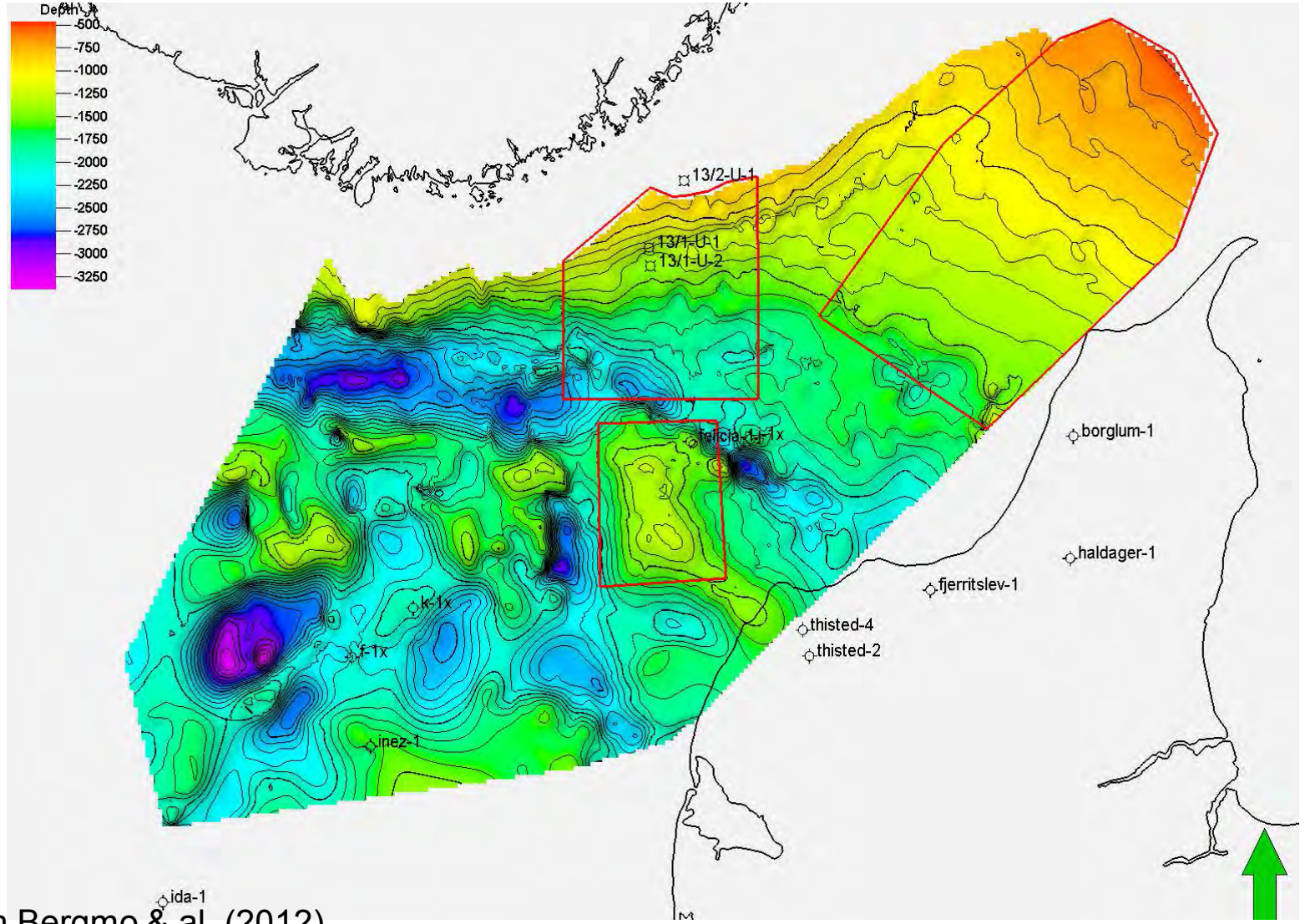
Red lines: Seismic datasets

Blue dots: Location of wells



From Faleide & al. 2011

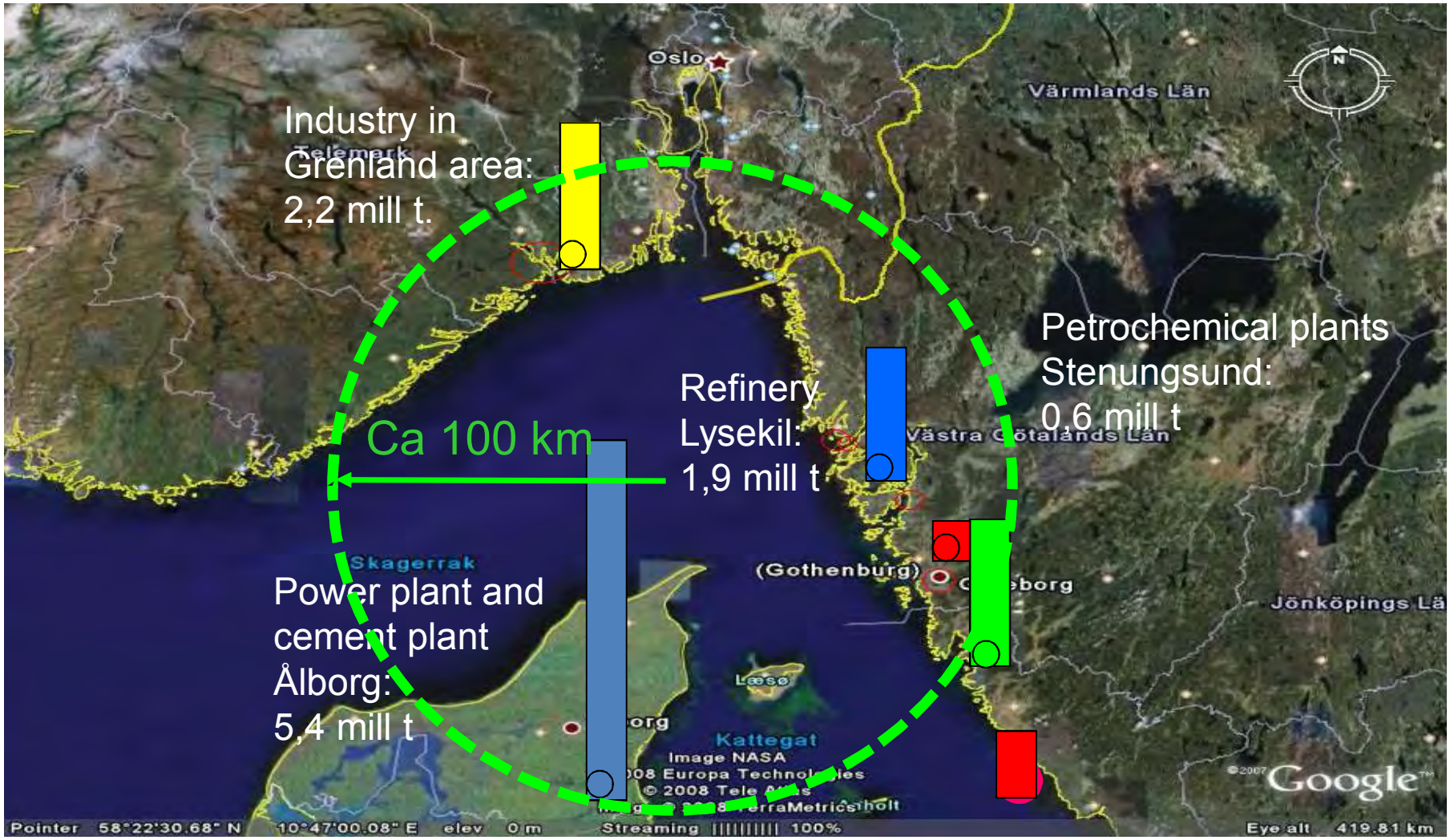
Depth contour map of top Gassum formation and examined storage models



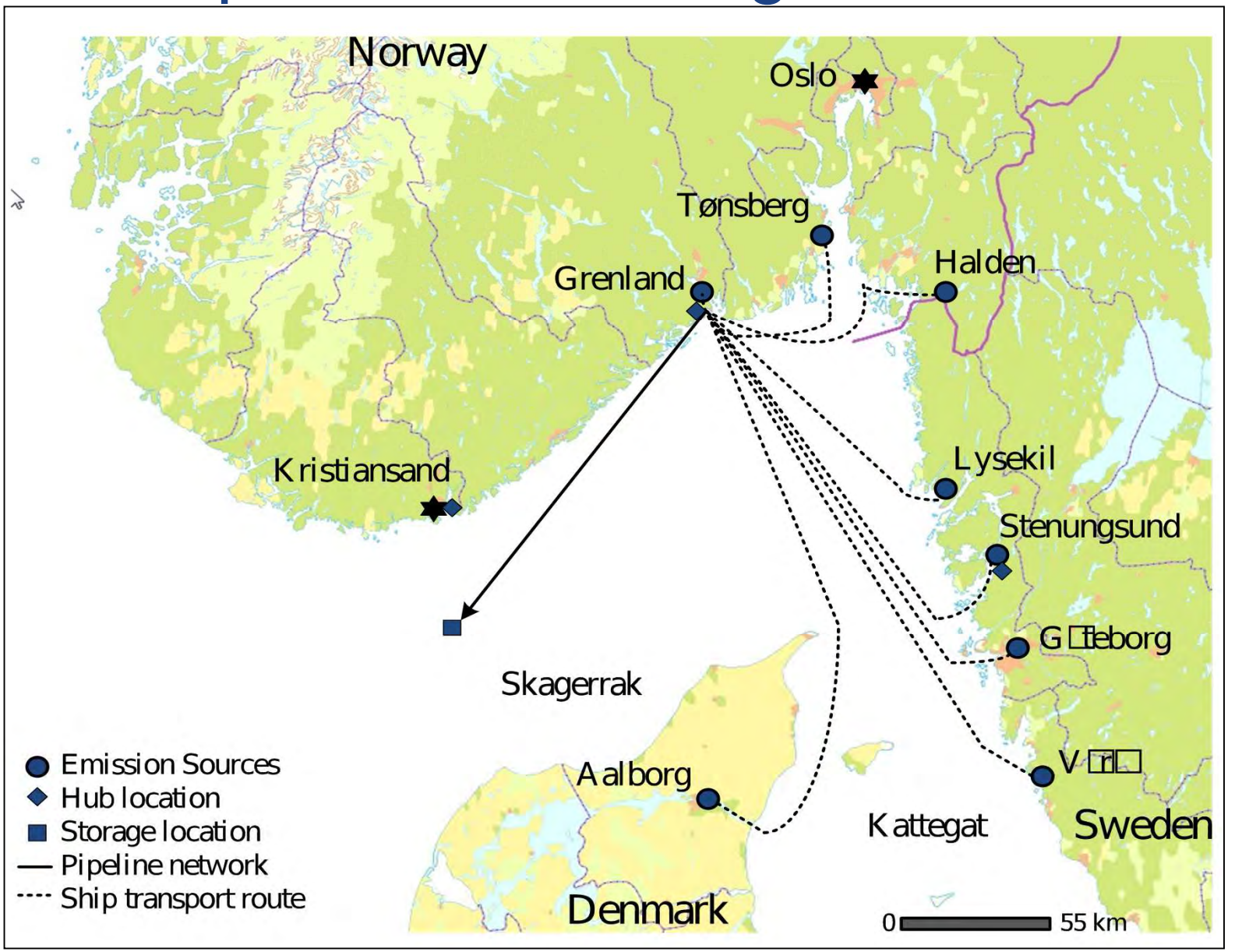
From Bergmo & al. (2012)

Large CO_2 point sources in the Skagerrak / Kattegat region

Total emissions from large point sources: Approx 13 mill tonnes CO_2/year



Combination of ships and pipelines: An example from the Skagerrak area



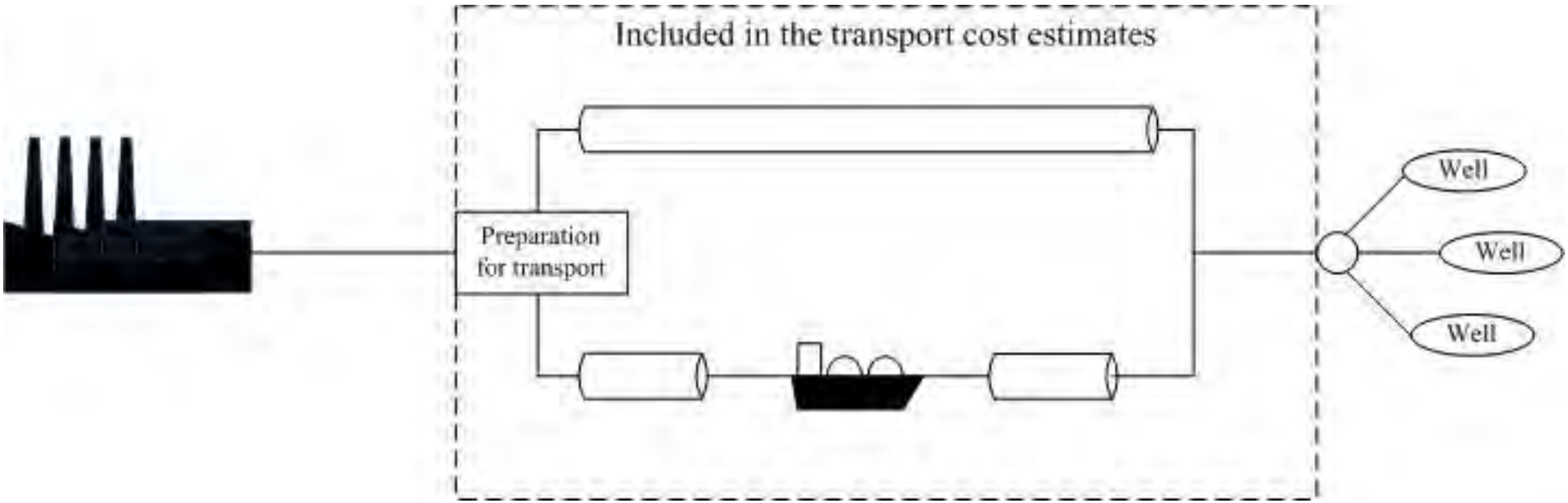
© map: Mareano

Transport cost estimation for this case: Assumptions

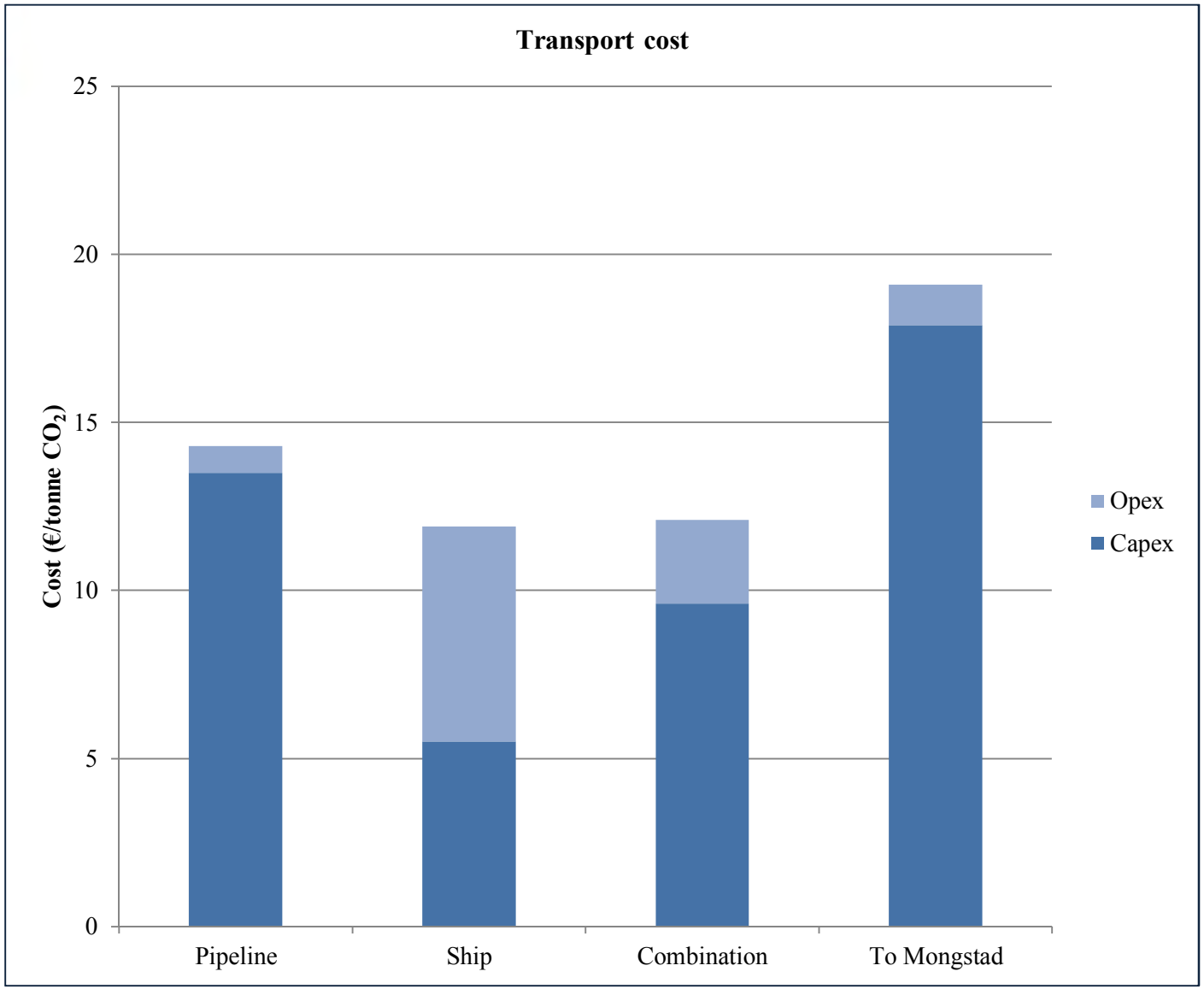
- 14 Mtonne CO_2 annually
- 100% utilization (not realistic from day 1)
- 8% rate of return
- Project lifetime 25 years, 1 year construction and 24 years of operation
- Mode of transportation:
  - Ship, liquefaction plant, (onshore pipeline) intermediate storage, conditioning for permanent storage
  - Pipeline, compression

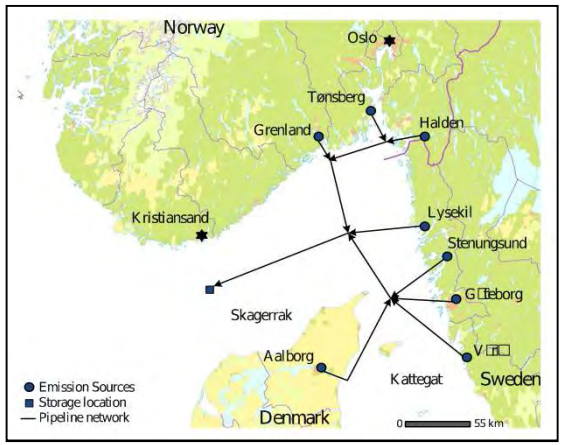
- The estimation method used gives an accuracy of ± 30% (factor estimation)

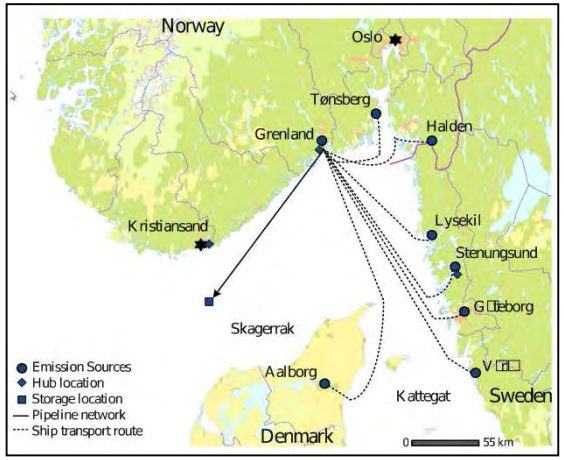
Transport

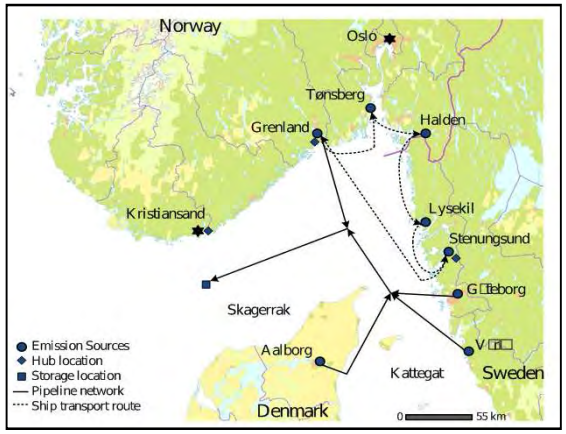

Included in the transport cost estimates
Preparation for transport
Well
Well
Well

Transport costs



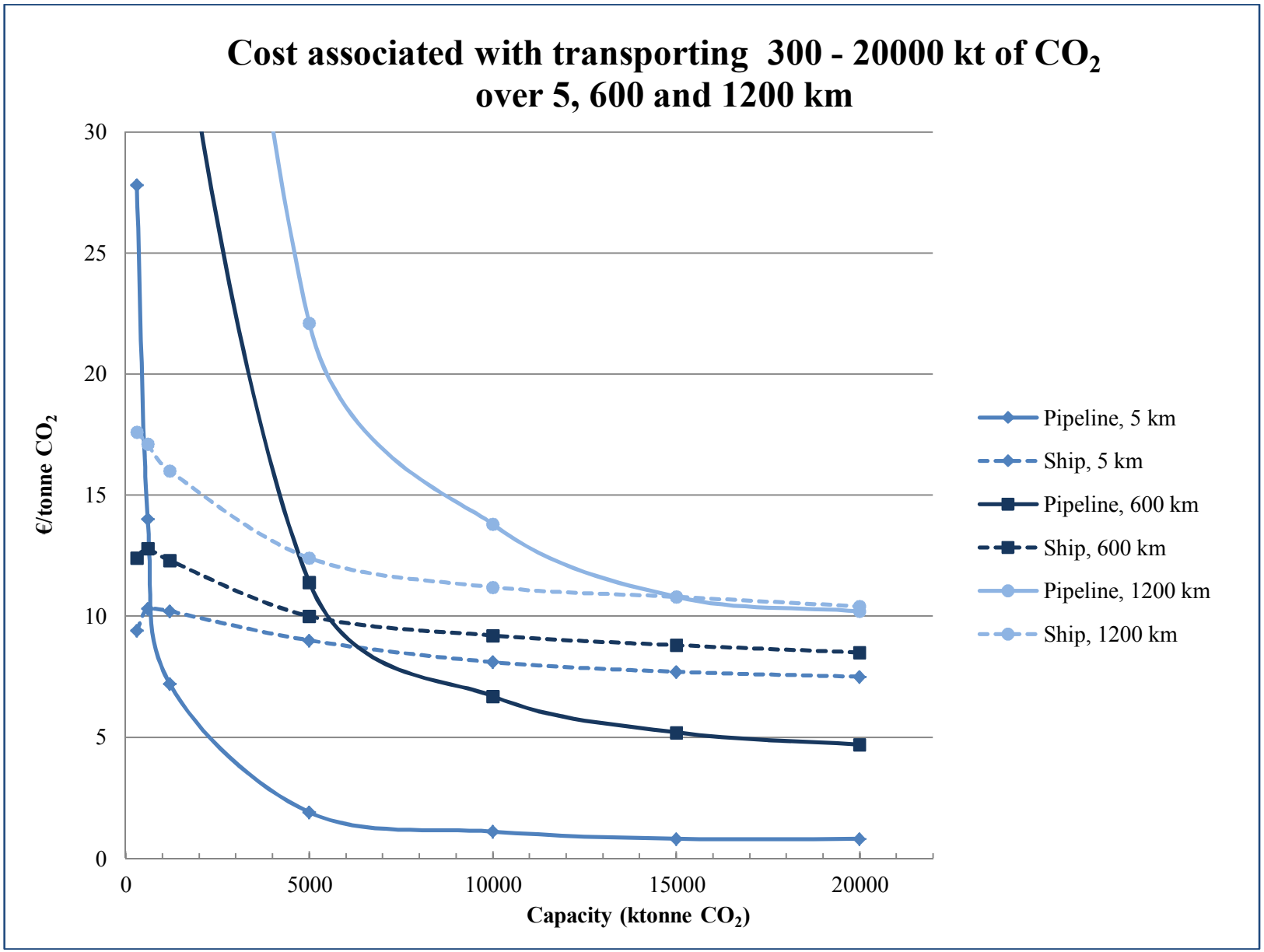






From: Mathisen & al., 2012

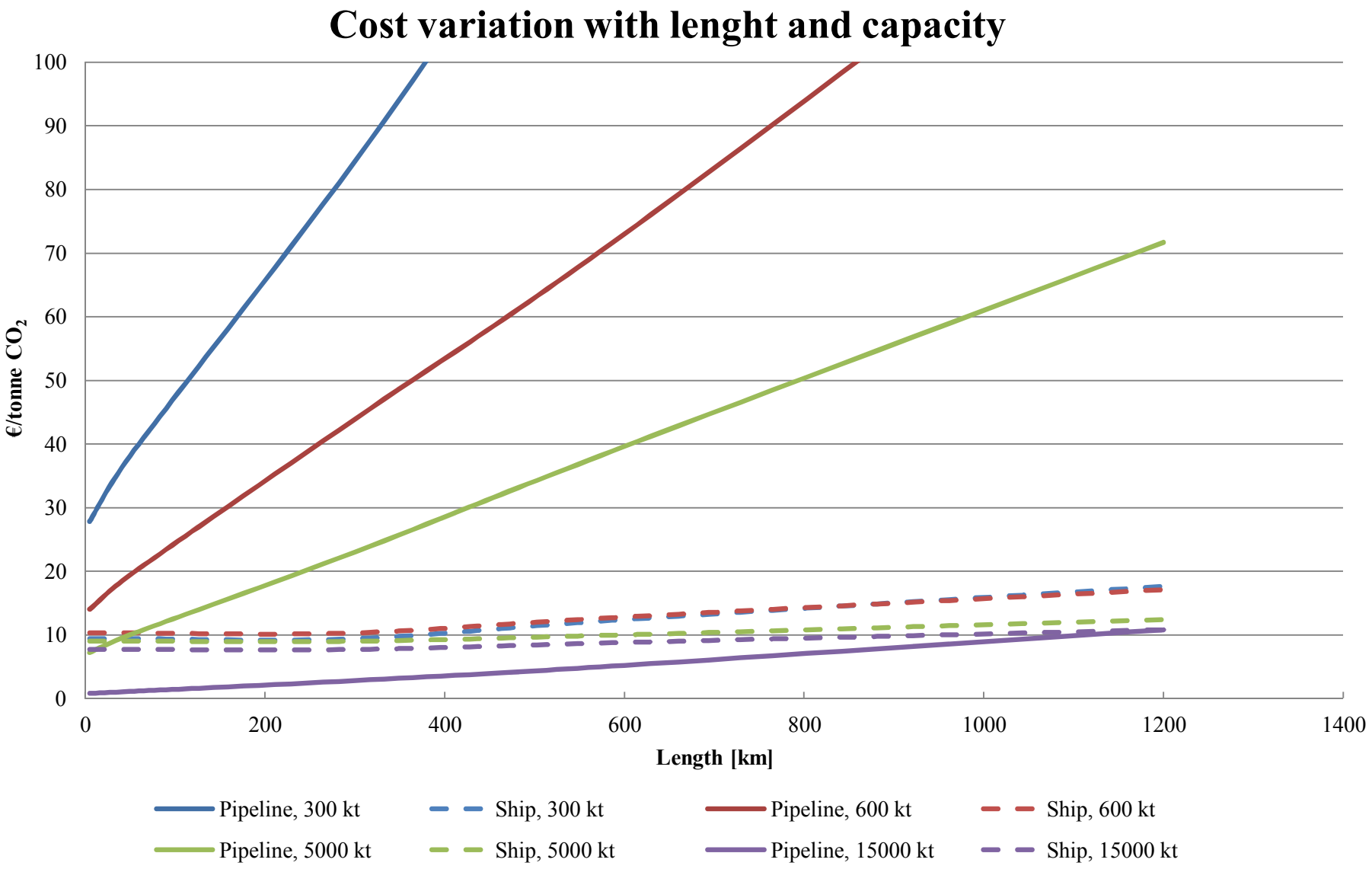
Relative transport cost vs capacity



Transport cost – ramp up

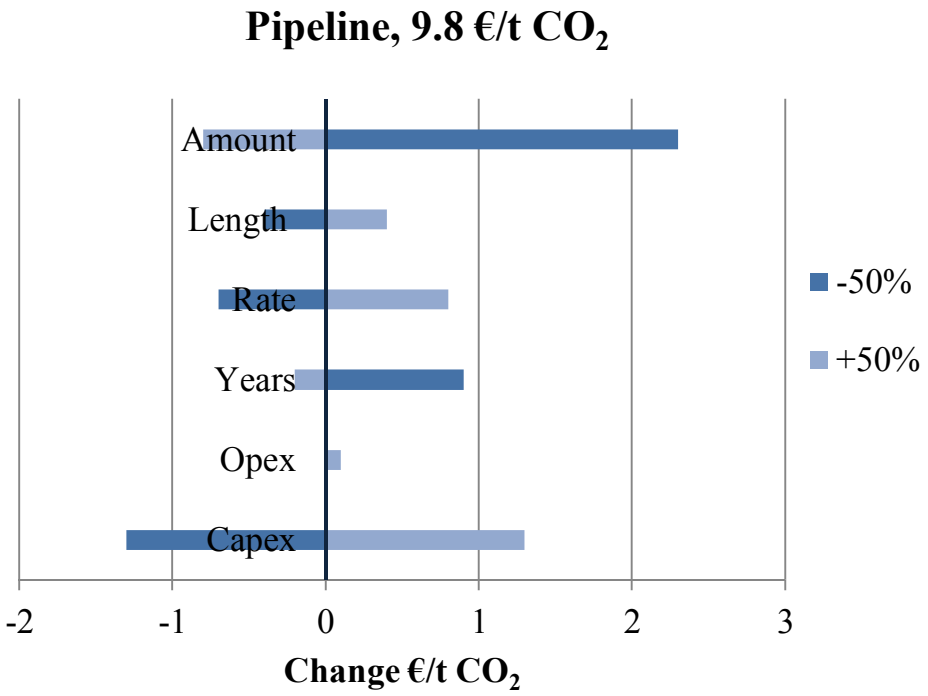
- Unless building strict one-to-one pipelines, 100% capacity utilization from day 1 is very unlikely
- Alternative solutions:
  - Replace pipelines concurrently with increasing CO_2 volumes
  - Parallell pipelines
  - One oversized pipeline from day 1
    - Challenges:
      Reasonable knowledge of future CO_2-volumes
      Who to pay for redundant capacity until full volume
  - Ships

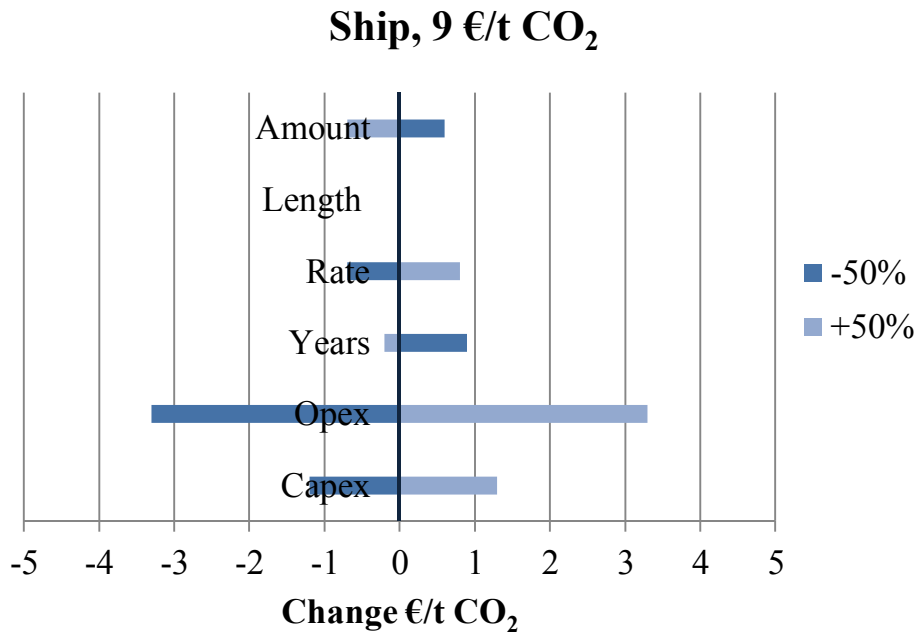
Transport cost generic comparison (1)



Transport cost generic comparison (2)

- Sensitivities
  - Which parameters have the biggest influence on transport cost?
  - Assumption: 5 Mt CO_2 to be transported 500 km





CO_2-transportation, ships vs. pipelines

Pipelines		***Ships***	
+	**-**	**+**	**-**
Low Opex	*High Capex*	*Low Capex*	*High Opex*
Onshore needs: Compression	*Relatively low flexibility*	*Large flexibility (volume and route)*	*Onshore need for intermediate storage and liquefaction plants*
Can be built both onshore and offshore	*Low potential for re-use*	*Re-use potential*	
	Large sunk cost	*Lower sunk cost*	
		Short delivery time (2 years ?)	

Cost impact of the main elements of the CCS chain

Part of CCS chain	Eur/tonne	Significant cost parameter
Capture	50-60	Energy cost
Transport-ship/pipeline	12	Liquefaction plant, storage and volume
Transport-pipeline	14	Volume, utillity
Storage	9	Number of injection wells

Maturity assessment – chain

Element	Maturity
Liquefaction	Proven for other pressure/temperature
Storage tanks-steel	Proven
Loading equipment: Loading arms, flexible hoses etc.	Proven for CO_2
Refrigerated CO_2 ship transport	Proven for LPG and ethylene down to - 104 ˚C CO_2 ship (-50 ˚C, 8 bar only in studies)
Ship transport of compressed CO_2	A few literature studies
Utilizing the cold	Very few literature studies
Unloading arm – to storage tank or ship	Proven for other pressure/temperature
Unloading buoy- to injection	Proven for oil/ NG
Heating before injection	Literature studies
CO_2-EOR	Literature studies on offshore, proven for onshore oilfields

Conclusions

- To transport CO_2 by ship introduces flexibility into the CCS chain
- As a start-up method ships are advantageous as compared to pipelines
- Cost of ship transport does not vary much with volume and distance, but..
  - Pipelines are more economical for larger volumes over shorter distances
- There is industrial experience with ship transport and handling of CO_2
- FPSOs seem to be an interesting option for offshore unloading in combination with ships, however, not without challenges

Why are ships crucial in establishing a Nordic CO_2 infrastructure?

- Flexible source-to-storage solutions
  - Including combination with pipelines
- Avoiding long pipelines from Baltic and westwards
- Economy
  - Avoiding large up-front capex
  - Can also be combined with CO_2-EOR
  - Smooth transition towards larger pipeline infrastructure
  - Ships may be re-built and re-used
- Faster road to implementation of CCS

Probably not a future CO_2 tanker

Thank you for your attention

Ship transport challenges

- There are proposed solutions for all elements in the chain
  - However, some of these are unproven
- Offshore discharge conditions
  - Conditioning of the CO_2 onboard ship, injection temperature and pressure
  - Flow rate capacity of the injection well and reservoir
- Periodic flow of CO_2 into the reservoir
- High operational cost

- Questions regarding the purity of CO_2
  - Different quality requirements for transport, storage and for EOR?

Elements

Element	Maturity	Status	Development potential
Liquefaction	Proven for other pressure/temp	Performed by the food industry with different pressure and temp and LNG without the same conditions.	Requires lot of energy, Unknown regarding impurities, need optimization
Storage tanks-steel	Proven	Yara and other have large CO2 tankers on shore. LNG without pressure, LPG with pressure	Cost and material, inslulation – boil off
Storage tanks – new materials	Some literature	Storage in rocks, carbonfibre etc	Unknown costs, depends on environmental if it is possible
Storage tanks- mobile tanks	studies	Barges	
Loading equipment **Loading arms, flexible hoses etc**	Proven	In daily use	Material, pressure?
Cryogenic CO2 ship transport	Proven for higher pressure/temp (ethylene ship) CO_2 ship (-50C, 6 bar	Done by Yara today (til -25, 18 bar) small ships LNG(low temp) and LPG transported on large ships	Boil-off, utilizing the cold
Dedicated ship- compressed CO2	Few studies	Not planned for CO2	
Combined ship - cold	Studies	In combination with LNG	Cleaning of the ship utilizing the cold
Loading/un loading arm – to storage tank or ship	Proven	In daily use	
Unloading buoy- to injection	Proven for oil/ NG	In daily use, but not for CO2.	Periodic injection The pressure / temperature, costs, extreme weather
Heating before injection	Not executed	Heat exchangers on land or ship?	Icing, space
EOR	studies	Proven onshore in US with compressed CO2	Costs, corrosion