Solutions for CO_2 transport

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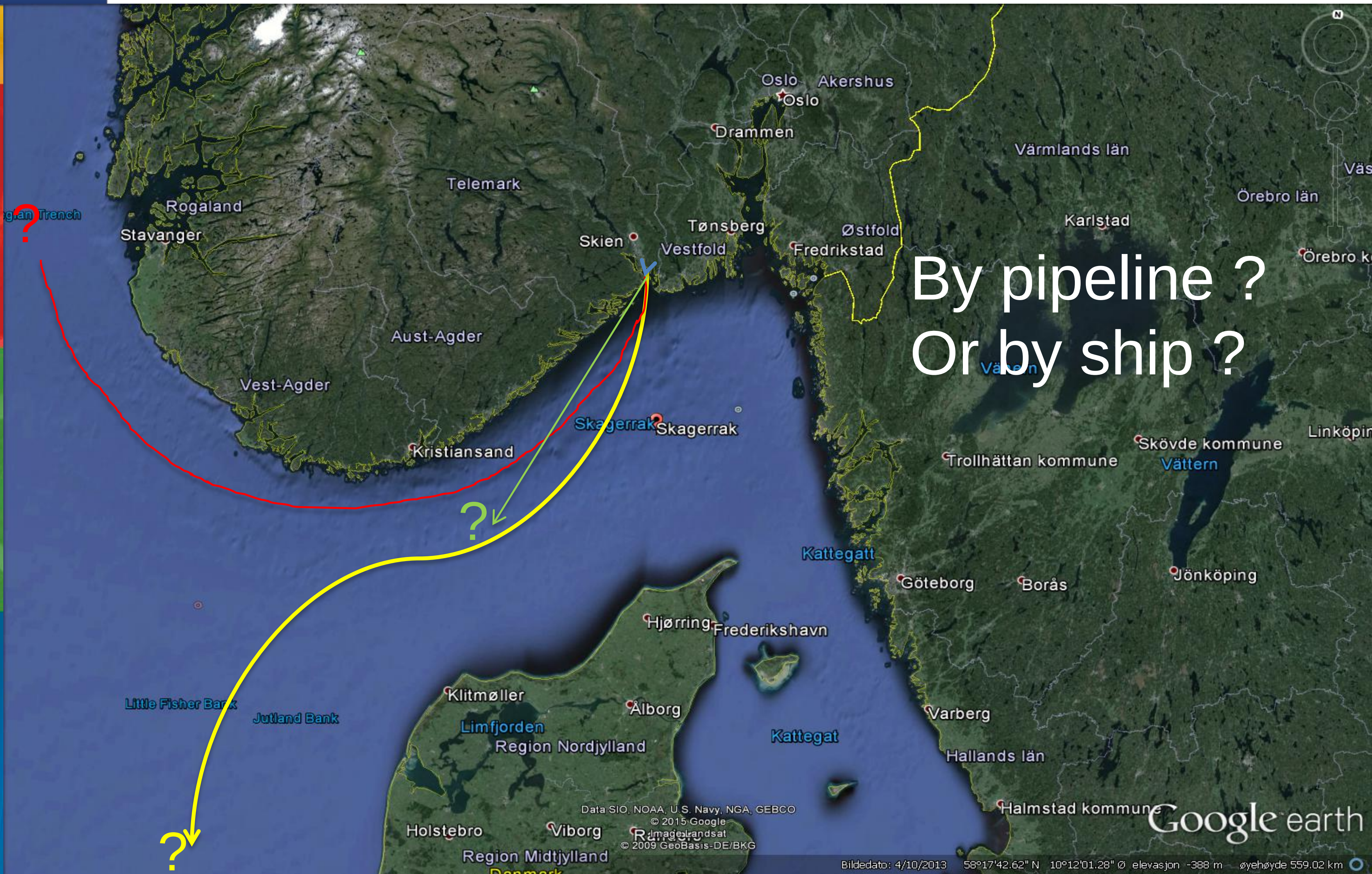
Taking CO_2 from Brevik to where?



By pipeline ?

Or by ship ?

The transport chain

1. Preparation for transport
   - Compression and drying

2. Transport
   - Pipelines
   - Ships, compressed CO_2
   - Ships, liquefied CO_2
   - Barges

Physical properties of liquid CO_2

- Low viscosity liquid, almost like water, density about 1.1 t/m^3
- Liquid only under pressure
- Triple point @ –56,6 ^oC and 4,17 barg (5,18 bara)
- Dry ice, density 1,6 t/m^3 and -80 ^oC
- Critical point @ 31 ^oC and 73 barg
- Not miscible with water, but somewhat soluble

CO_2 in dense phase

- Dense phase = supercritical CO_2 at pressures near or above 73 baro and near or under 31 ^oC
- Supercritical CO_2 has no definite or visible transitions between liquid, dense and gas
- Dense phase CO_2 has a density of 900 ± 100 kg/m^3 and behaves as a compressible liquid

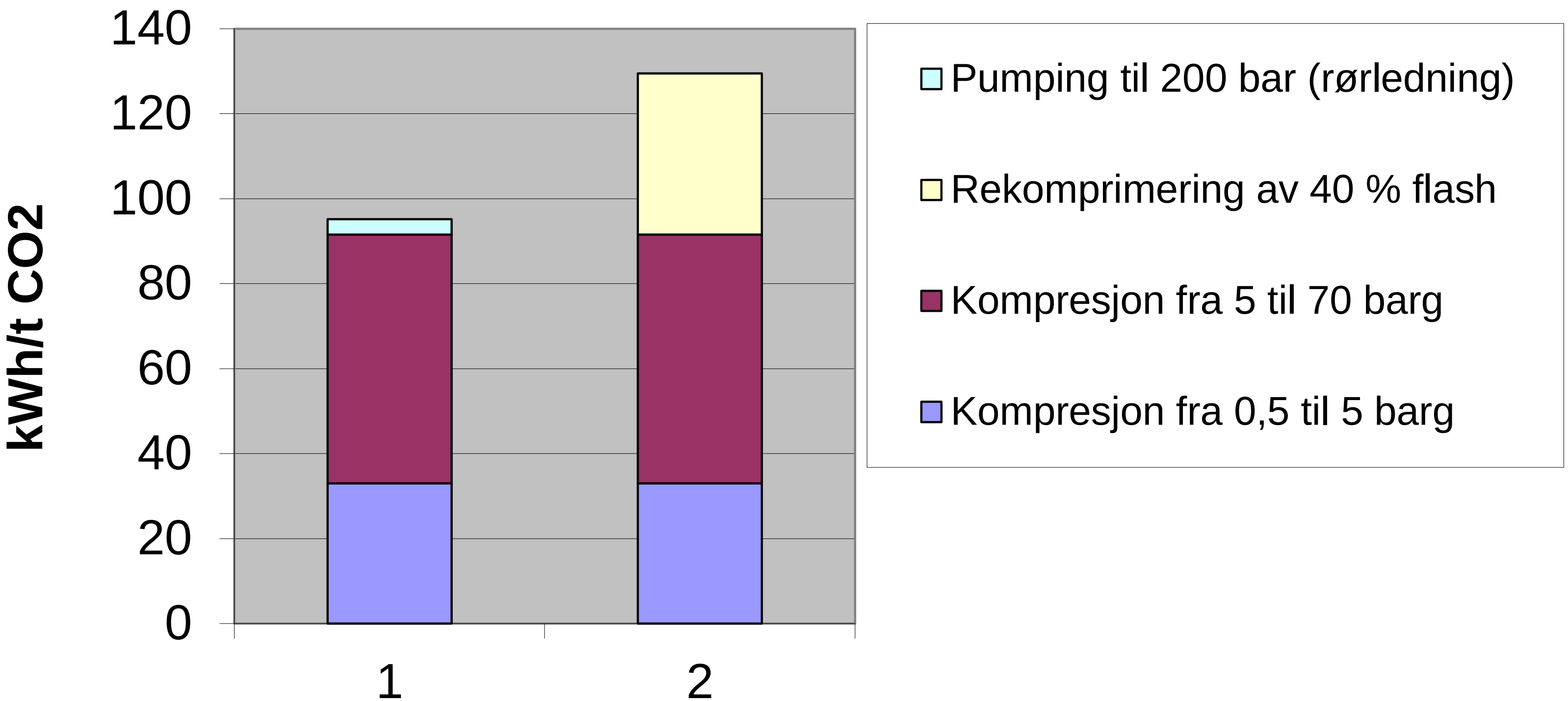
Transport conditions

- Dense phase CO_2 in pipeline:
  - >80 barg, 25 ^oC, <600 ppmv H_2O
- Compressed CO_2 on ship:
  - 40 - 80 barg, 0 - 25 ^oC, <600 ppmv H_2O
- Liquefied CO_2 on ship:
  - 5,8 barg, –50 ^oC <50 ppmv H_2O

Preparation for transport: Energy need

1. Compressed CO_2 for transport in pipeline or ship

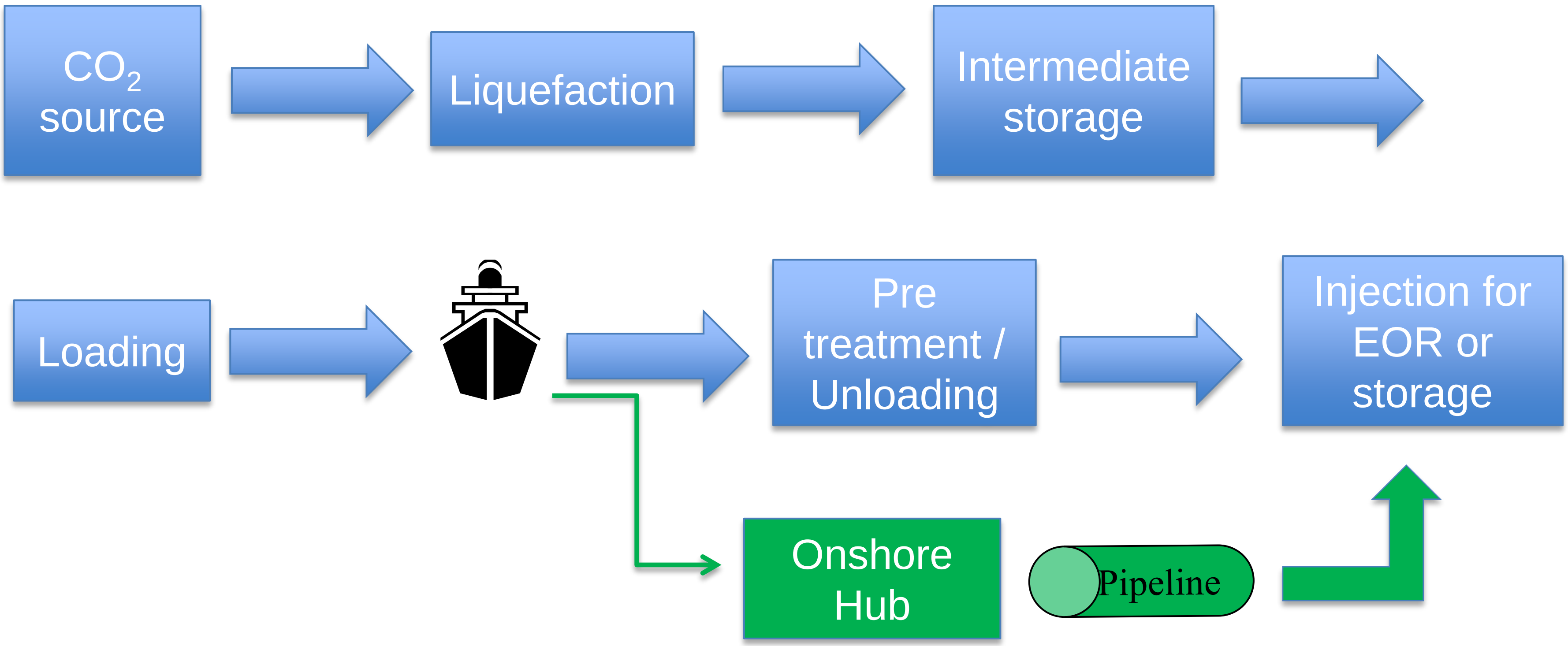
2. Liquefied CO_2 at -50 ^oC



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

Ship based CCS chain



Existing CO_2 ship

Food grade CO_2 transport

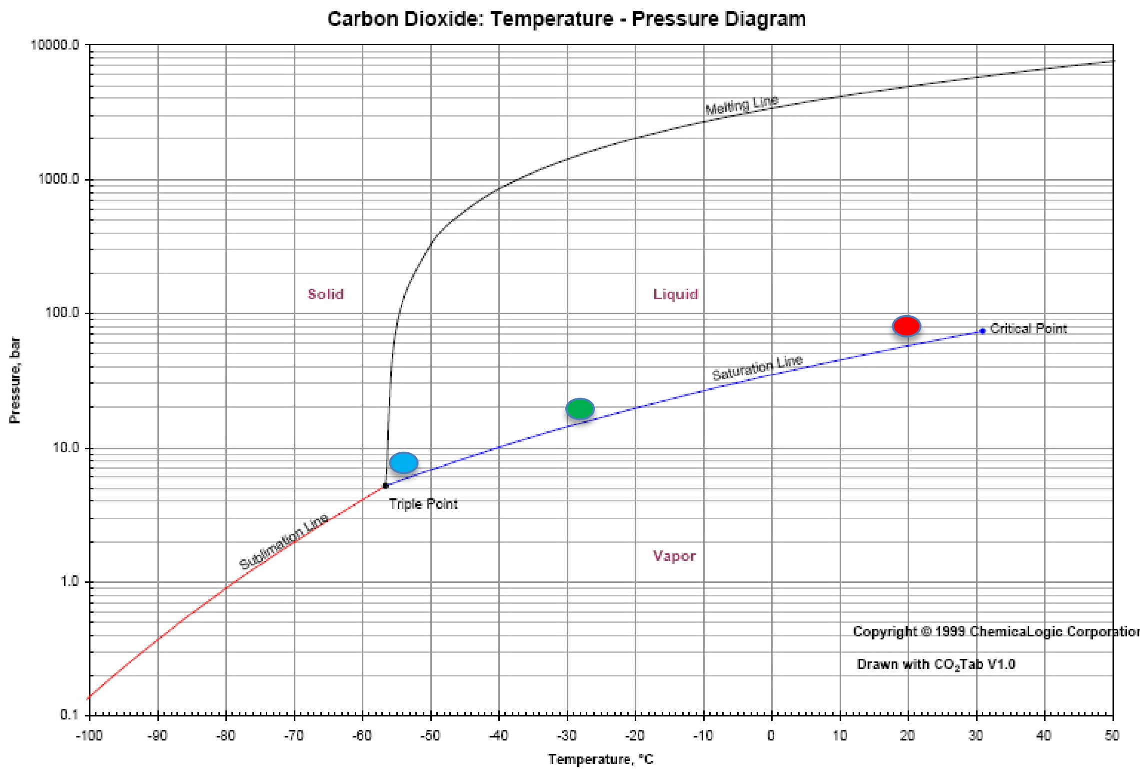
M/T Yara Gas III alongside the quay near Yara's ammonia plant in Porsgrunn,
Capacity: 1200 t of liquefied CO_2 in 2 tanks of 600 tons capacity each
Ship type: Converted container vessel

Photo: Larvik Shipping

Ship 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;

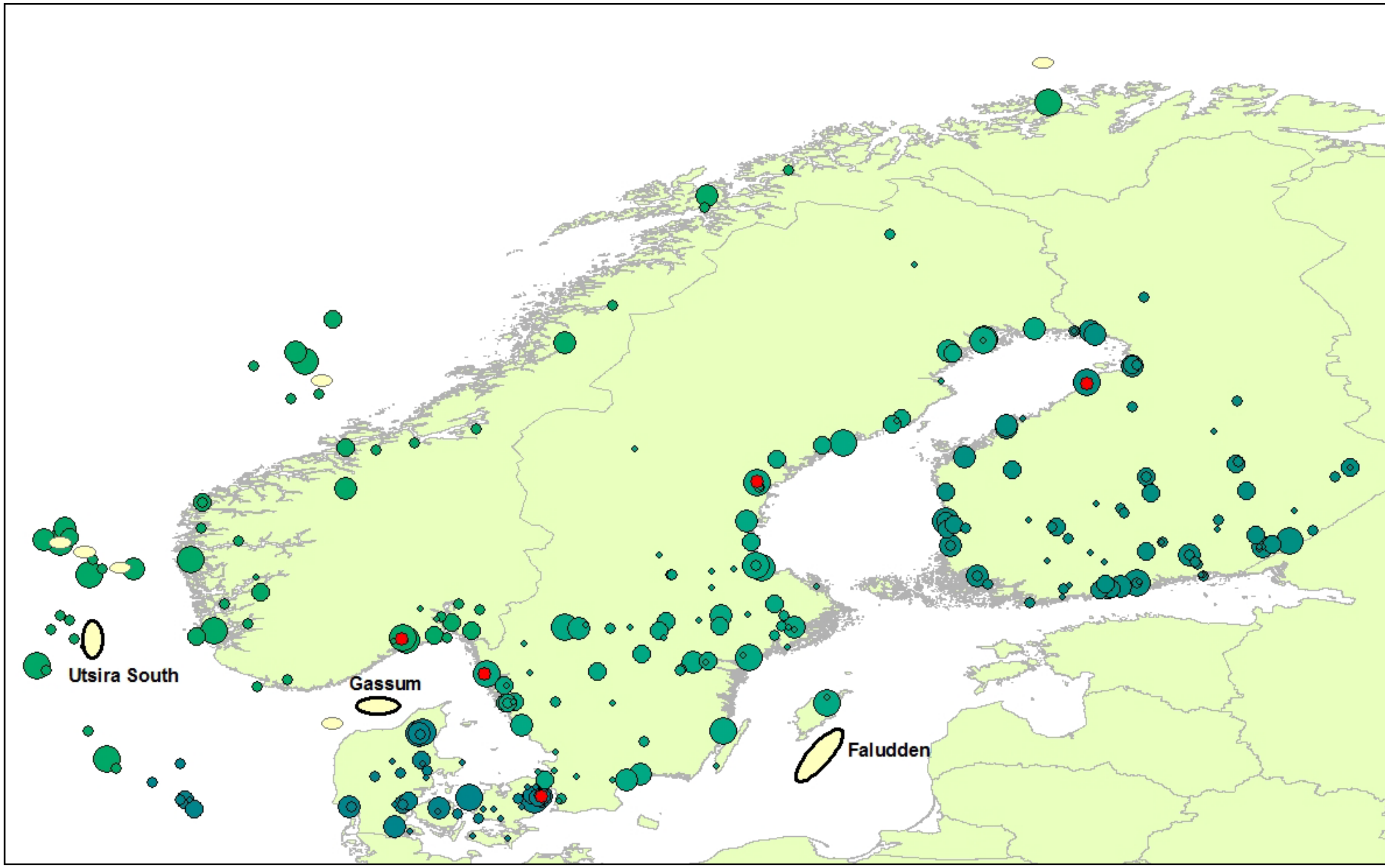
    15 – 18 bar, -22 to -28ºC (liquefied)

Offshore unloading to buoy, platform

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

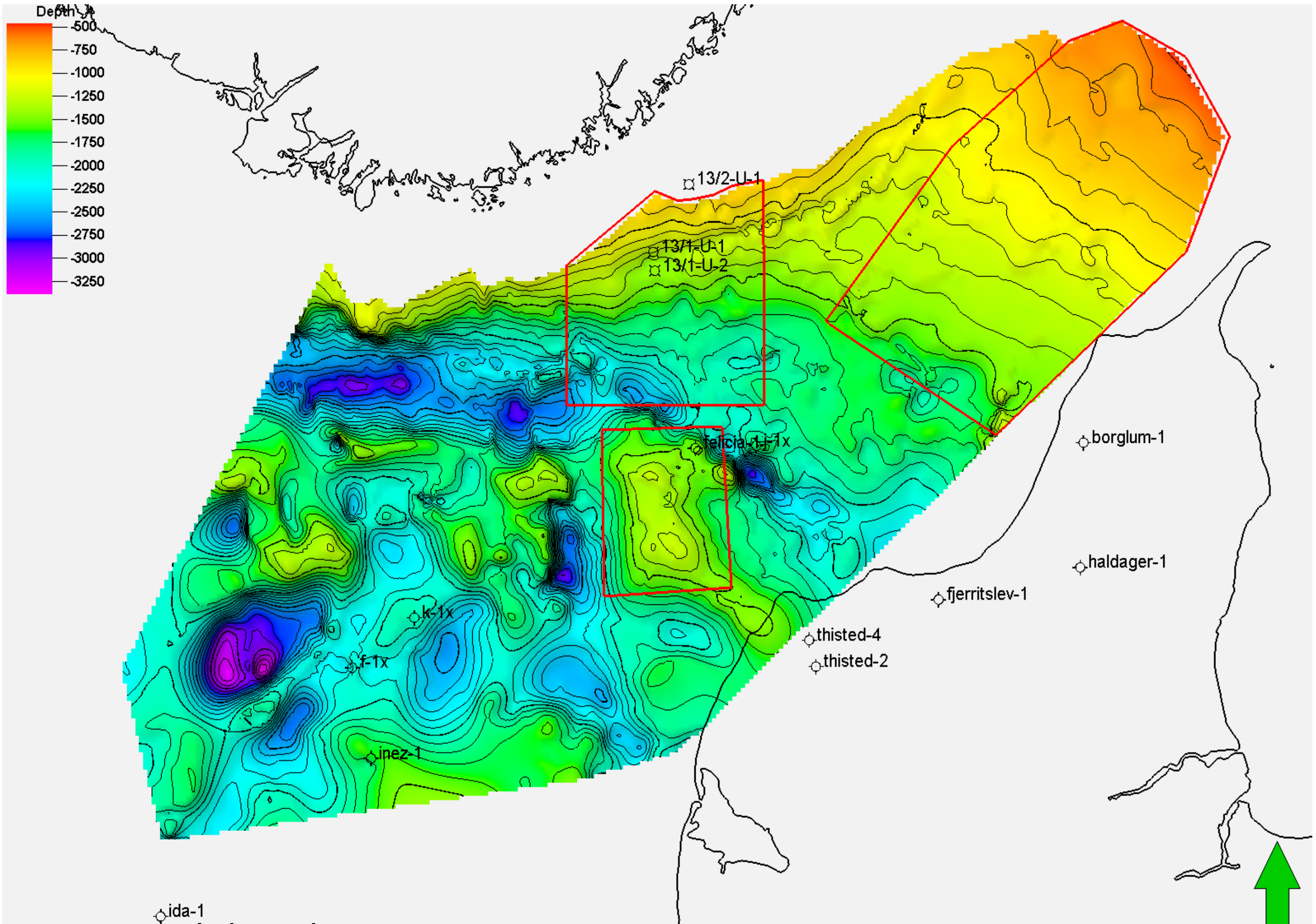
CO_2 sources and possible storage sites in the Nordic region



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

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

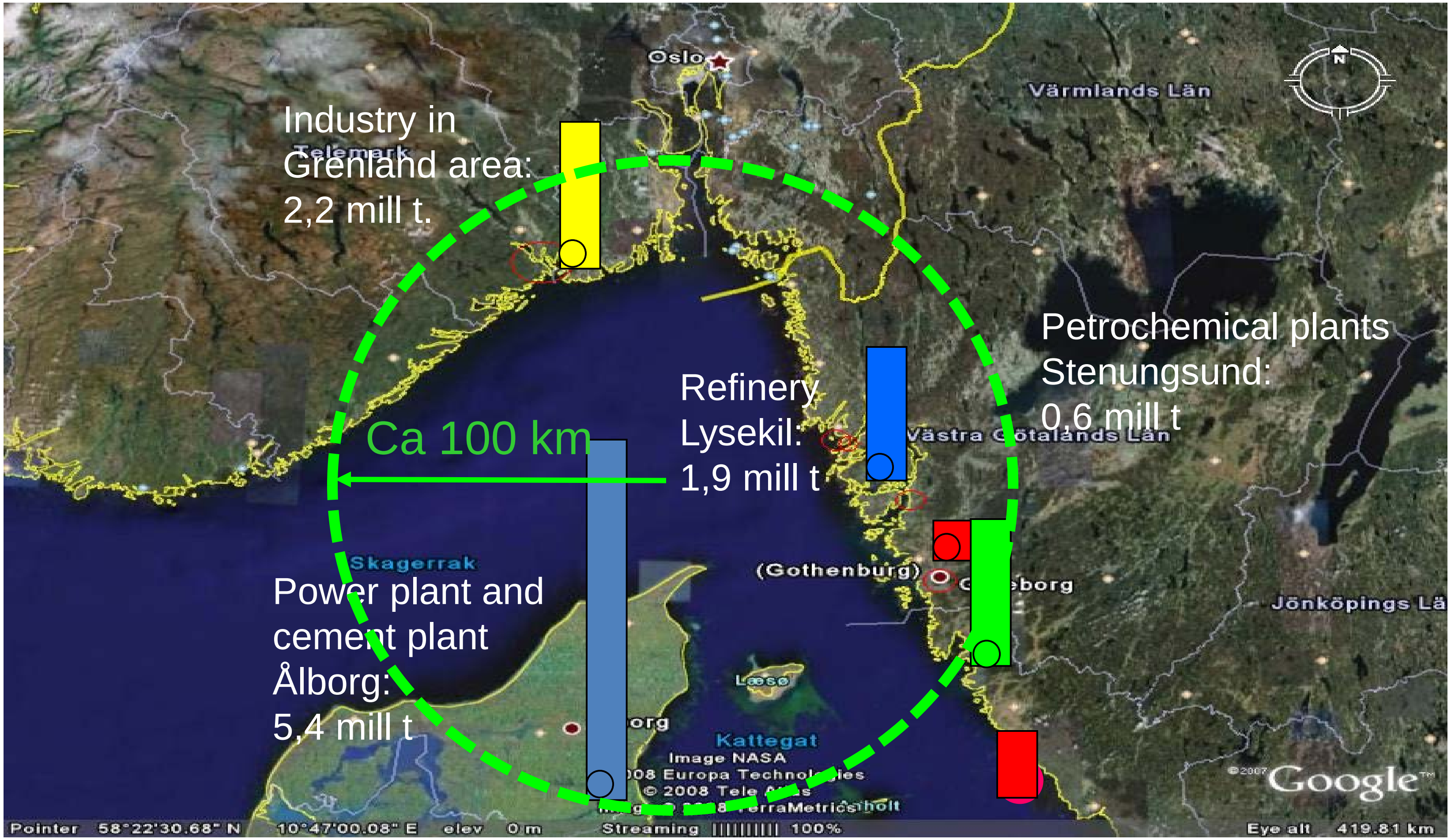
Depth contour map of top Gassum formation and examined storage models



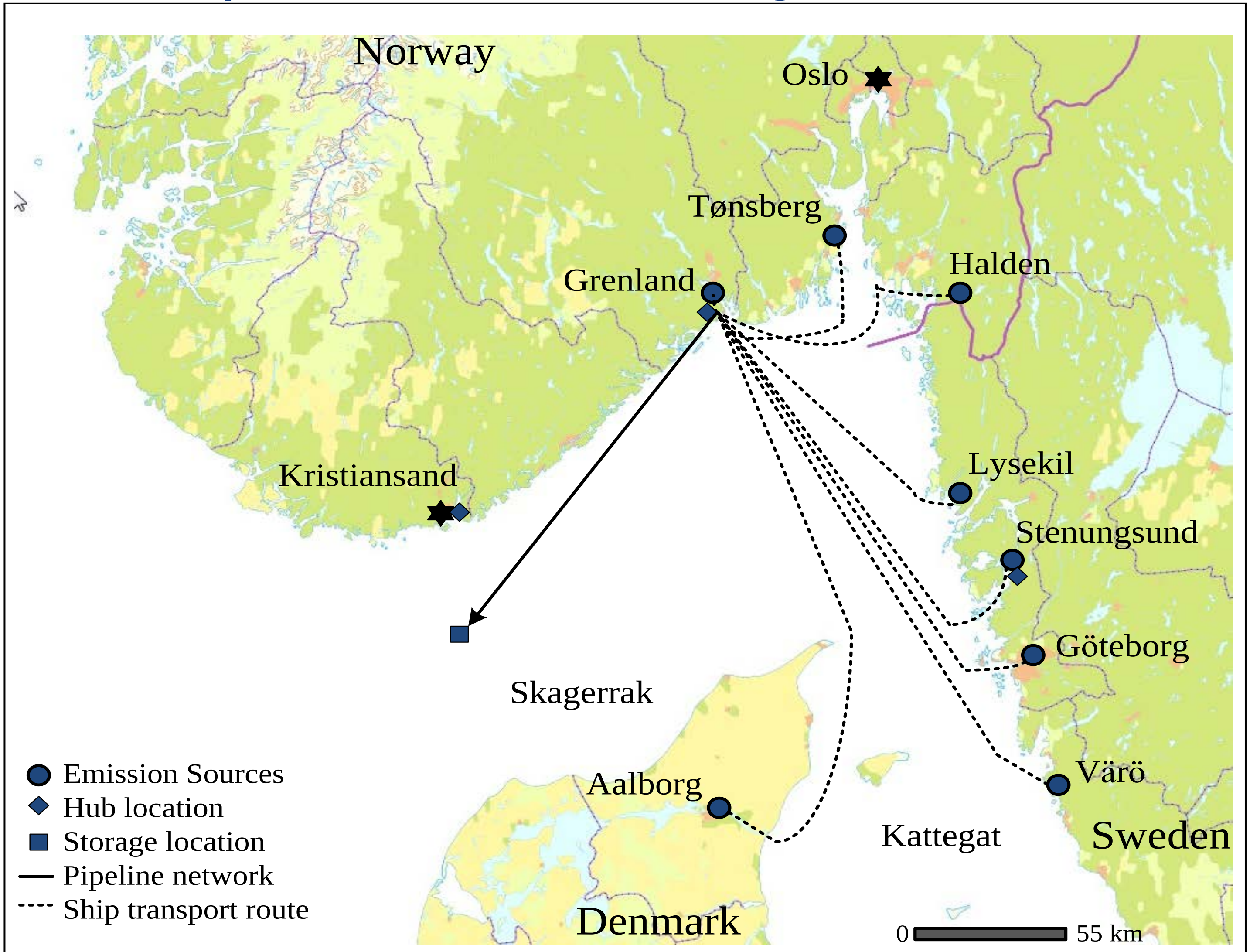
From Bergmo & al. (2012)

Large CO_2 point sources in the Skagerrak / Kattegat region

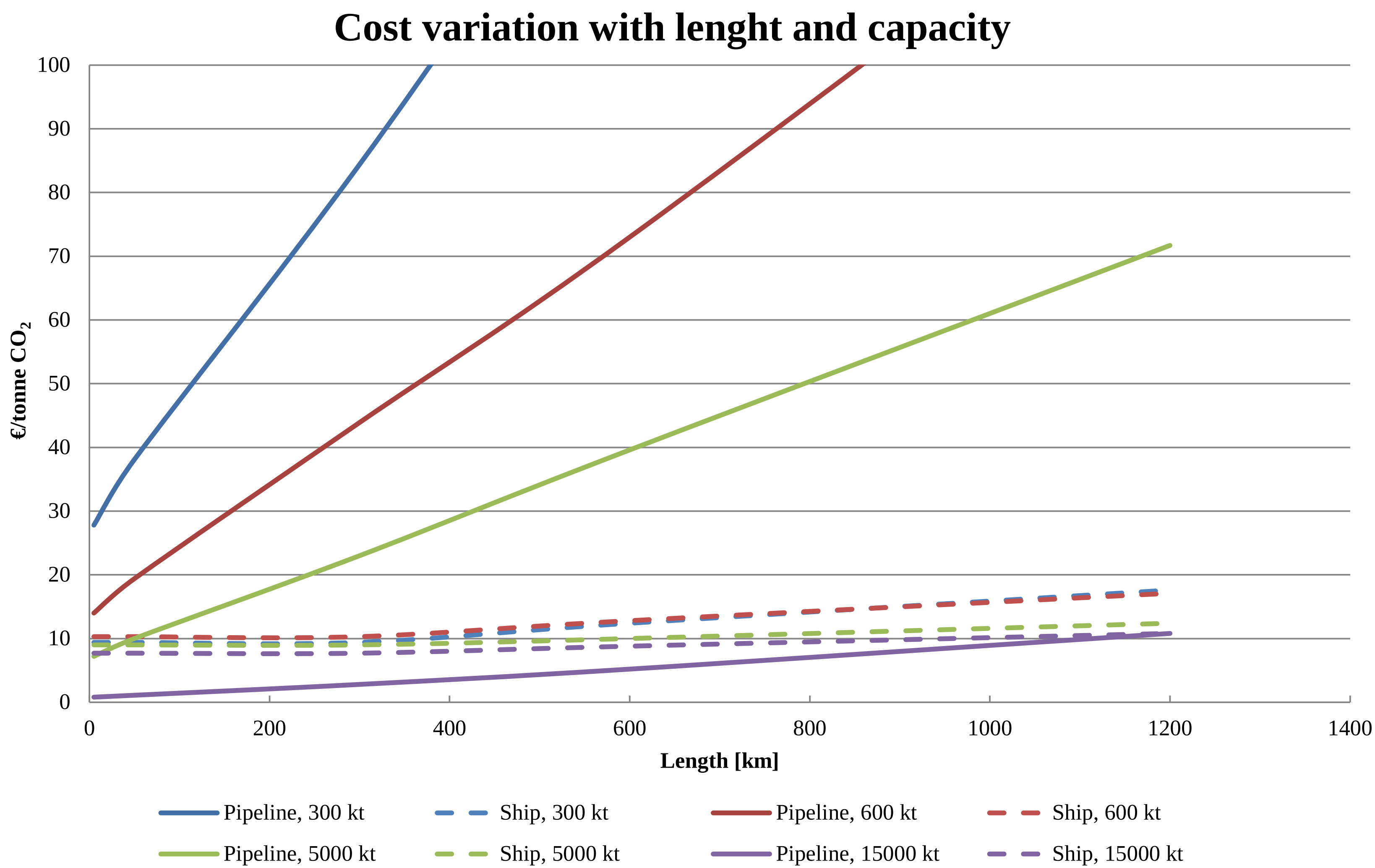
Total emissions from large point sources: Approx 13 mill tonnes CO_2/year



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



Transport cost generic comparison



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

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

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 ?)	

Why are ships crucial in establishing a CO_2 infrastructure?

- Flexible source-to-storage solutions
  - Including combination with pipelines
- 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