Nordic CCS Roadmap

Update 2015

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Nordic CCS Roadmap: why an update?

- Climate is worsening faster than expected
  - Heat waves already killing thousands in India and globally
  - Extreme rain, flooding, mud slides at home
- More agreement globally that CO_2 must be reduced to limit rise in average global temperature to 2°C
  - The Conference of Parties will meet in Paris in Nov 2015 to implement solutions
- CCS projects now advancing rapidly worldwide
  - Norway: 2 operational (Sleipner, Snøhvit), Yara (CO_2 production)
  - US: 7 operational, 6 in planning
  - Canada: 3 operational (Boundary Dam started 2014), 3 in planning
  - China: 9 projects starting 2017-2020

Extreme rain causing flooding in Alfta, Sweden, (Photo: Leif Larsson/TT/ NTB scanpix)

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Recap: Nordic climate targets cannot be met *without* CCS

- EU goal: 40% reduction in CO_2 emissions by 2030
- Most economical solution: application of CCS to 14% of world's CO_2 emission sources (IEA)
- Nordic Energy Technology Perspectives (NETP) 2050 goals:
  - 85% CO_2 reduction vs. 1990 levels; carbon credits offset remaining 15%
  - **Minimum 20 Mt CO_2/year must be captured and stored in Nordic region – mainly from industrial applications** (aligns with NORDICCS project estimates)

Photo: Shutterstock

CCS is ready for deployment!

- Proven, cost-effective solution
- Will create green industry and jobs
- Nordic Countries must act urgently to meet climate targets

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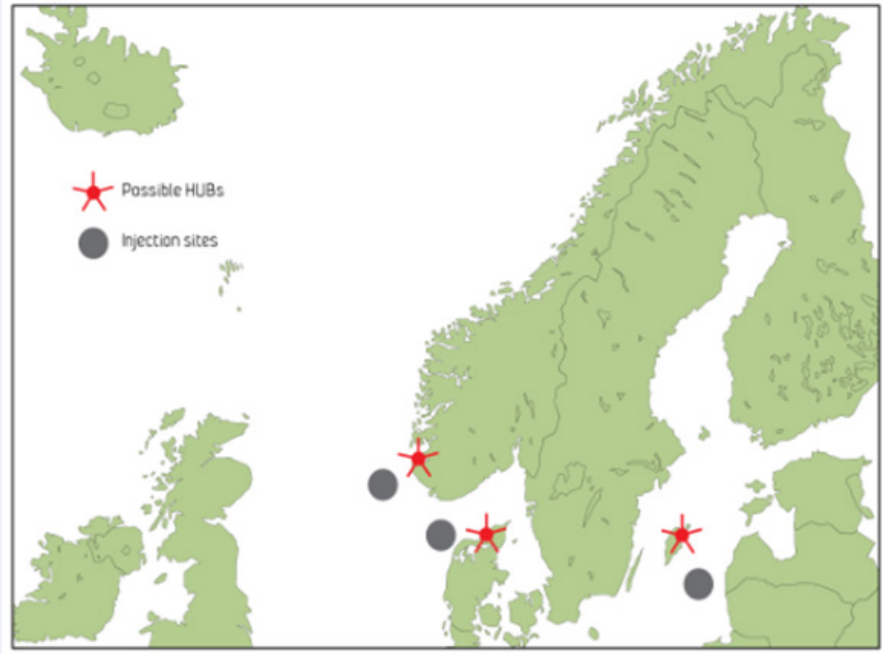
Joint CO_2 transport and storage infrastructure needed to kick-start CCS

- Comprises onshore hub and harbour with unloading equipment + pipeline to Utsira storage site
- Utsira has already been storing CO_2 from Sleipner for nearly 20 years
- Utsira is large enough to receive CO_2 from CCS projects throughout the entire Nordic region *and* Northern Europe – particularly the UK



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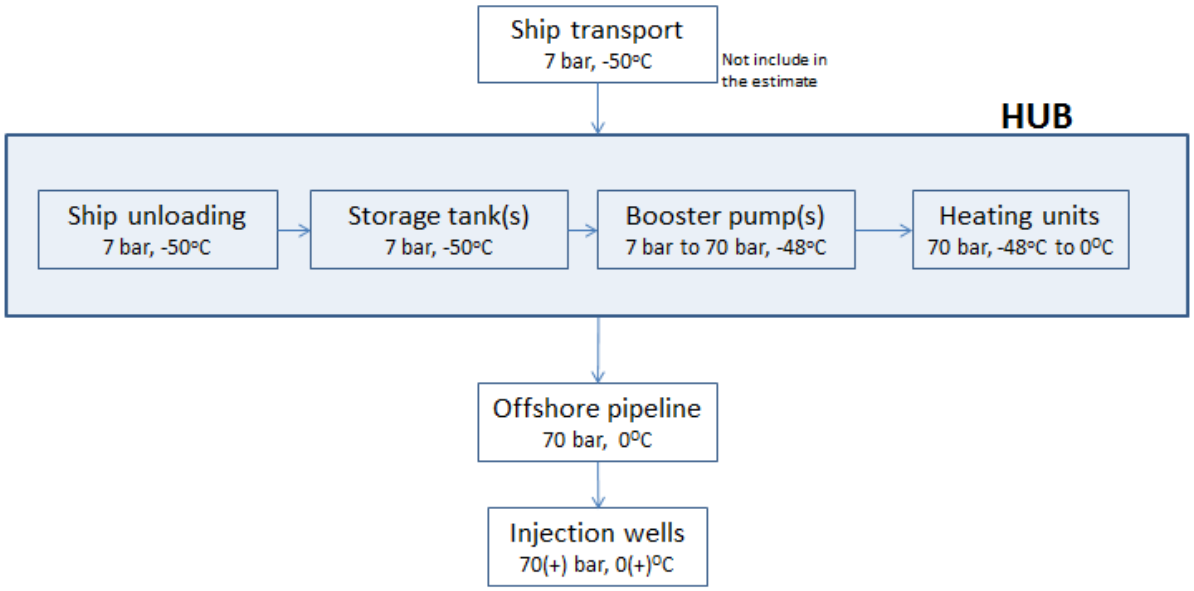
How CO_2 transport and storage works

- Relatively inexpensive 22k tonne ships transport liquid CO_2 to hub where it is unloaded, heated and re-pressurised
- Each well can inject 3 Mt CO_2/year
- Pipeline will be built to a capacity of 12 Mt (serving 4 wells)



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Ship transport most cost-effective option in 85% of Nordic CCS cases

- Transporting CO_2 by ship is most cost-effective option in 85% of 50+ Nordic CCS cases analysed
- Norway already has extensive experience: Yara ships 200,000 tCO_2/year for sale to European food and beverage industry
- Cost increases only moderately with increasing distance

Jetty with (un)loading arms (Photo: Shutterstock)

Site	Ship transport cost (€/tonne)	Breaking point with pipeline (Mtpa)
Brevik	13	4.0
Lysekil	12	5.0
Hvidovre	13	9.0

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Key benefits of an onshore hub

- Fewer weather problems for ships unloading at the dock
- As jetty has unloading arms, ships are much cheaper than those designed for offshore unloading
- A long pipeline will be built out to storage site when profitable
- A steady, secure supply of CO_2 from multiple sources can also be delivered from the hub to nearby oil fields for EOR

CO_2 hub for shipment of liquid CO_2 at Yara's harbour, Porsgrunn, Norway – visit by NORDICCS CCS Summer School students (Photo: SINTEF)

CCS can start as soon as infrastructure is ready to receive the CO_2!

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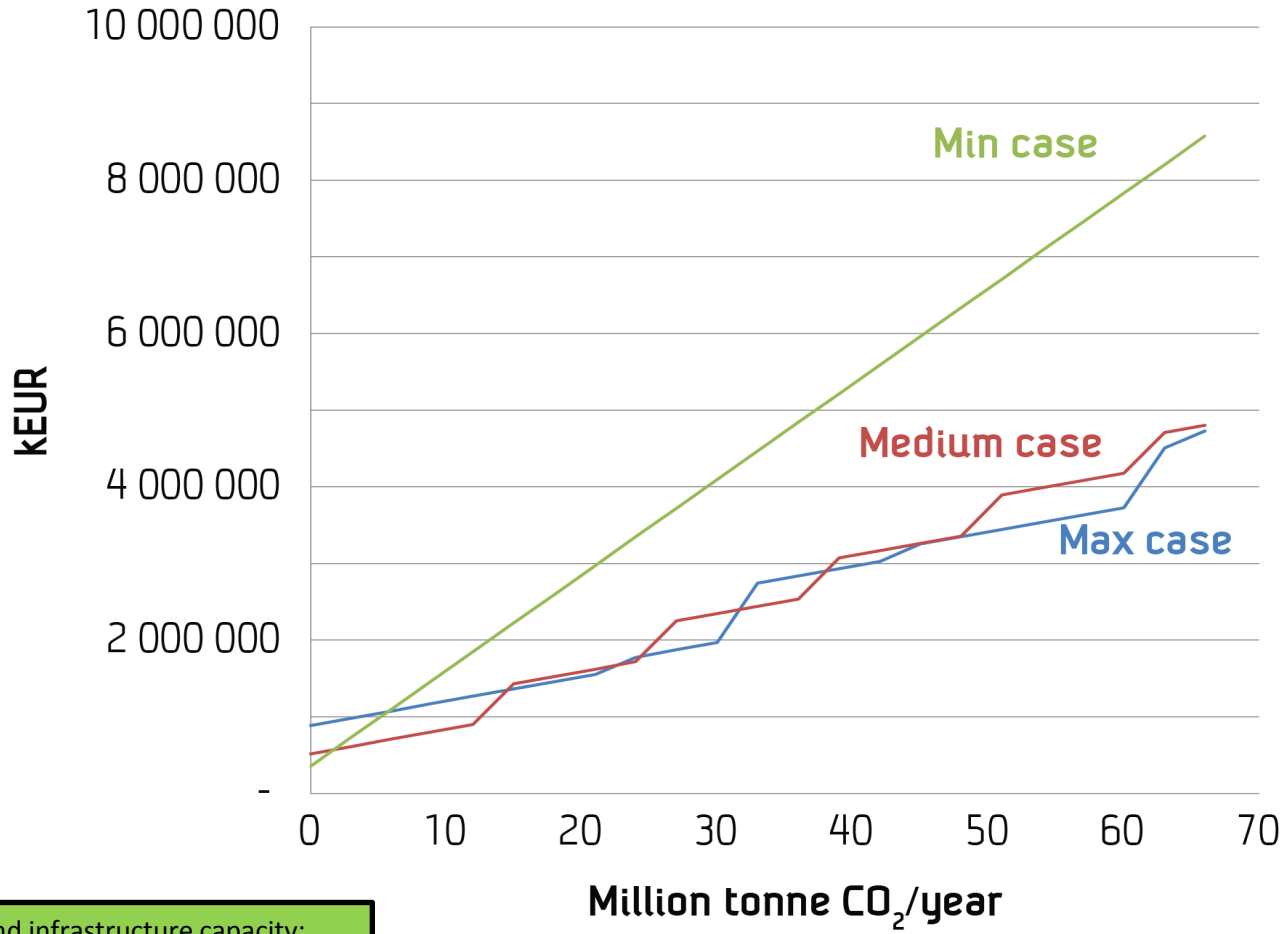
Hub, pipeline & storage: investment costs



Pipeline and infrastructure capacity:
Max : 21.9 Mt/year
Medium : 12 Mt/year
Min: 3 Mt/year

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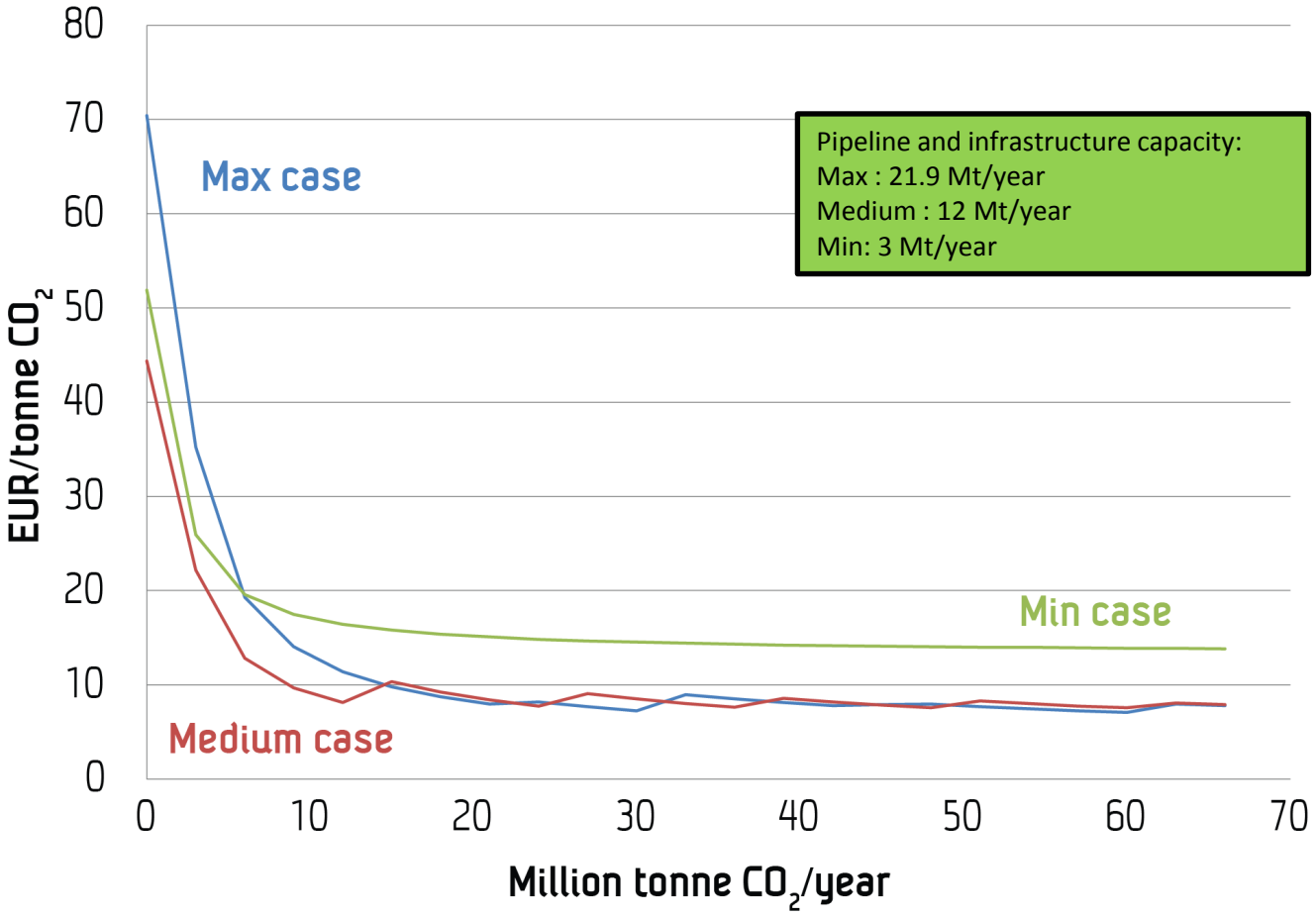
Hub, pipeline and storage: unit costs



Offshore CO_2 storage costs

- Infrastructure costs for a CO_2 hub with offshore storage in the North Sea (12 Mt/year capacity)
  - CAPEX: 517 M€
  - OPEX: 7.75 to 4.50 M€ /year
- Deposit cost is reasonable: 15 €/tonne CO_2 (includes costs for hub, pipeline and storage)
- Upfront public investment required to kick-start CCS
  - Shared by all the Nordic Governments and where all Nordic countries have rights

The first offshore storage site in the North Sea could become the CO_2 Bank of Europe!

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EOR: unique opportunity to kick-start CCS and create a European CO_2 market

Opportunities

- EOR can create a market for CO_2 that will kick-start CCS in land-based industry
- **New oil & gas infrastructure being built NOW – window of opportunity to incorporate EOR is closing**

Challenges

- Previous attempts in Denmark and Norway failed partly due to insufficiently large volumes of CO_2 (2-5 Mt/yr required)

Solution

- Large-scale CO_2 storage will facilitate EOR by providing a large, steady supply of CO_2
- CO_2 will have a value (market value in the US is approx. 35-40/tonne)

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Norway: only country in Europe operating CO_2 capture, transport & storage projects

Sleipner: 1 Mt CO_2/year (Photo: Dag Myrestrand, Statoil)

Snøhvit: 0.9 Mt CO_2/year (Photo: Helge Hansen, Statoil)

Yara, Porsgrunn: captures and sells 200,000 t CO_2/year to European food & beverage industry (Photo: SINTEF)

(NORCEM project in planning Photo: NORCEM)

…and more projects in the planning!

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Capture costs for potential projects in the Skagerrak cluster

- Cement is most cost-effective
- Refineries & chemicals have higher construction costs

Source	CO_2 emission, kt/y	CAPEX generic, MEUR	OPEX generic, MEUR	Capture cost generic, EUR/t	Location factor	Capture cost local, EUR/t
Norcem, Brevik Cement	927	143	49	54	1.10	59
Yara Porsgrunn Chemical	815	135	43	60	1.10	66
Preemraff, Lysekil Refinery	1 670	257	86	58	1.48	86
Borealis Krackeranl., Stenungsund Chemical	690	172	48	69	1.13	78
Aalborg Portland, Nordjylland Cement	1 150	204	73	53	1.08	57
Nordjyllandsverket Heat and power	2380	245	108	63	1.08	68

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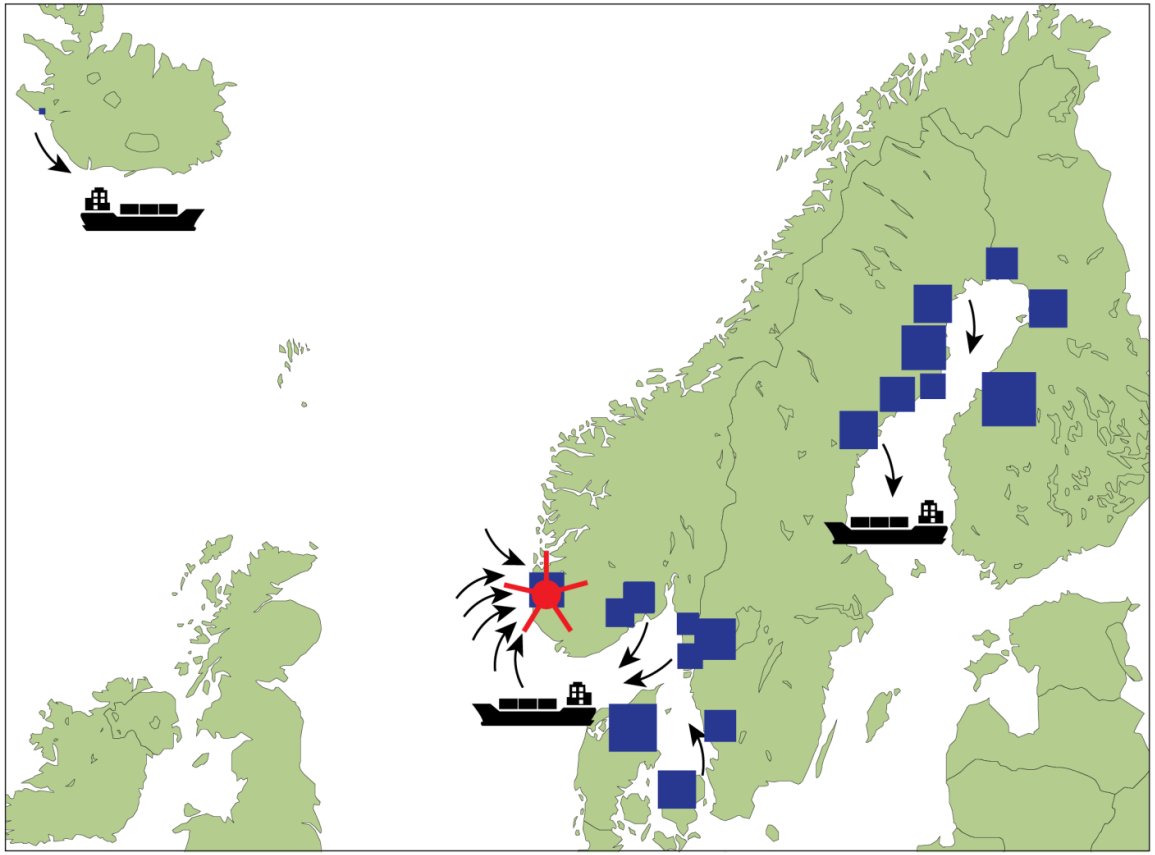
Case studies: determining the most effective solutions for CCS deployment

- Sources from all 5 Nordic countries
- Ship transport to Utsira hub for storage



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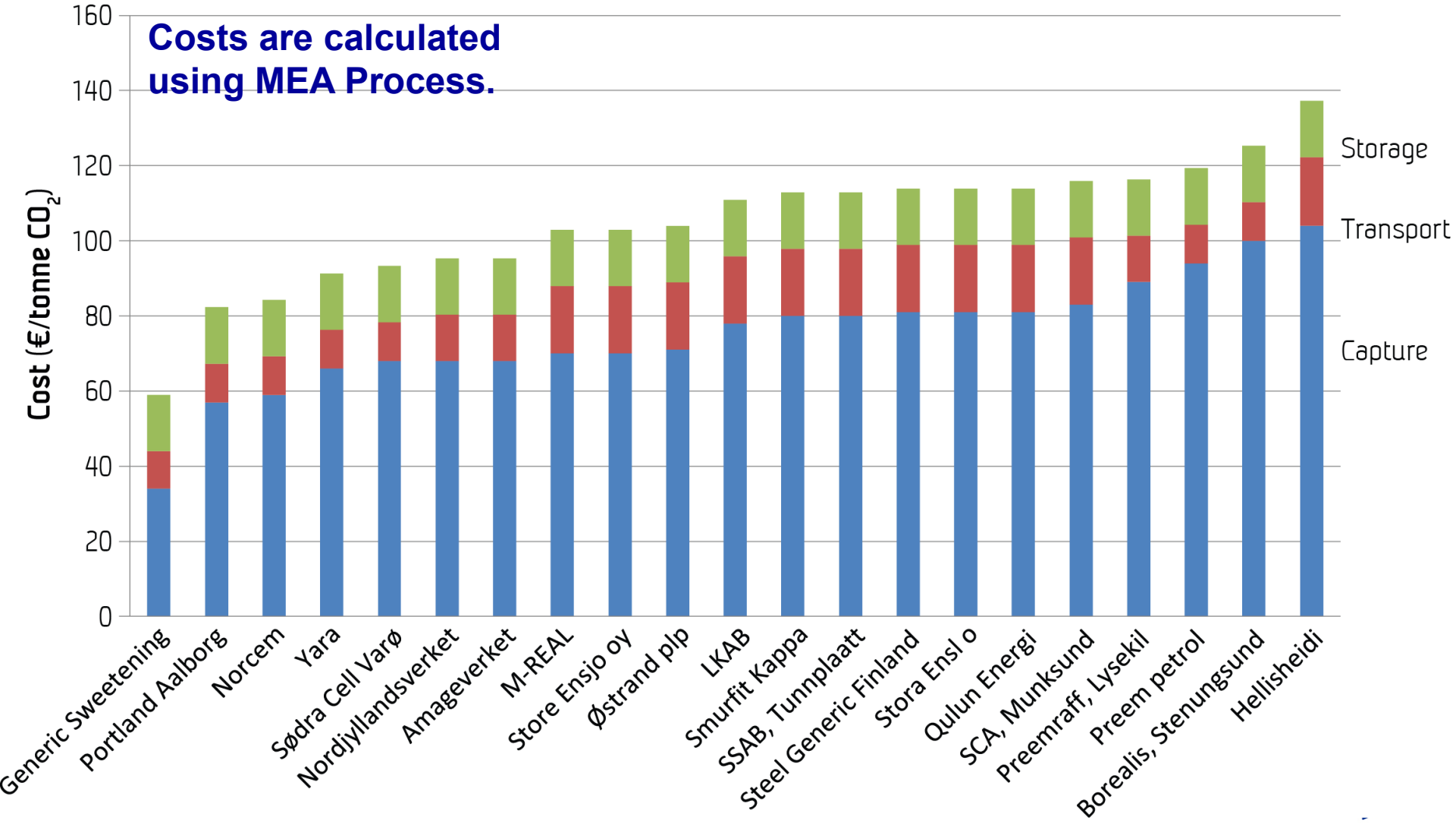
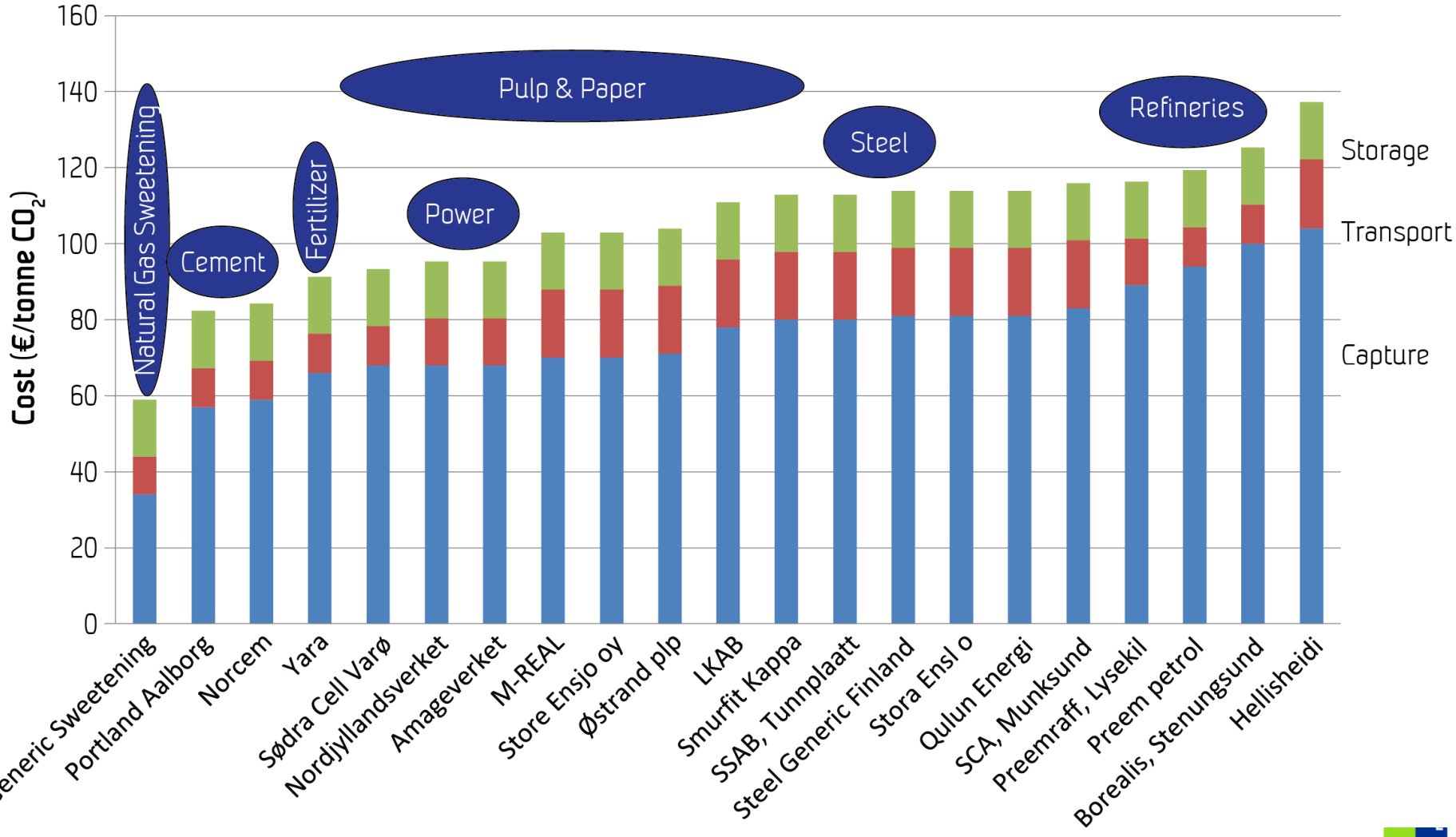
CCS project costs for different industry cases - Nth of a kind Cost



Industrial CCS costs are sector dependent - Nth of a kind Costs



Note: Costs are calculated using an amine process (MEA). Note if Steel CCS case was performed with pressure swing adsorption it would be cheaper!

Prediction of CO_2 safely injected and stored

Mt/year

30
20
10
0

1990 2000 2010 2020 2030 2040 2050

Sleipner
Snøhvit
Cement
Norwegian CCS project
Gas Sweetening
Pulp & Paper
Power Plant
Steel
Refinery


Sleipner A


Melkøya


Norcem Brevik


Ostrand pulp mill


Amagerværket


Hellisheidi

Sleipner A Photo: Harald Pettersen - Statoil

Melkøya - Photo: HELGE HANSEN -Statoil

Urgent action is needed to kick-start CCS

- **Create public investment in 1st transport and storage hub** in the North Sea – shared by all Nordic countries
- **Give priority in Governmental project purchasing to products with low-carbon footprint**, e.g. green cement, steel and aluminium
- **Establish CCS support measures** as early CCS projects require **capital grants** since a "first-of-a-kind" unit will always be more expensive than a nth-of-a –kind unit.
- **Strengthen the ETS** as the long-term driver for CCS and **reward capture and storage of biogenic CO_2** to same extent as fossil CCS
- **Establish Measurement Reporting Guideline which allows CO_2 transport by ship** under the ETS

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