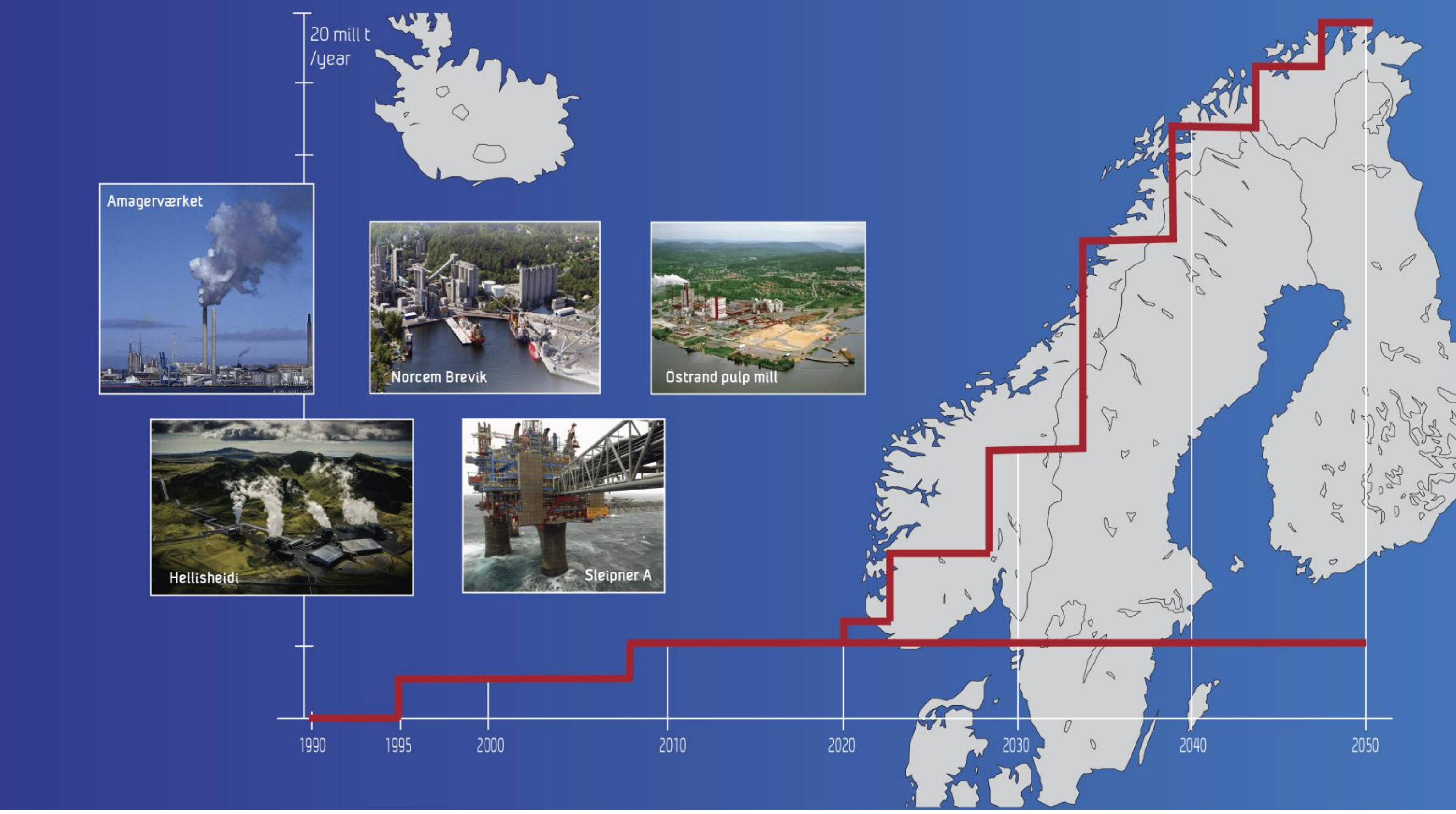


# Mapping and estimating the potential for geological storage of $CO_2$ in the Nordic countries – a new project in NORDICCS


Karen L. Anthonsen


**NORDICCS Conference contribution D 6.1.1205 (1)**


November 2012



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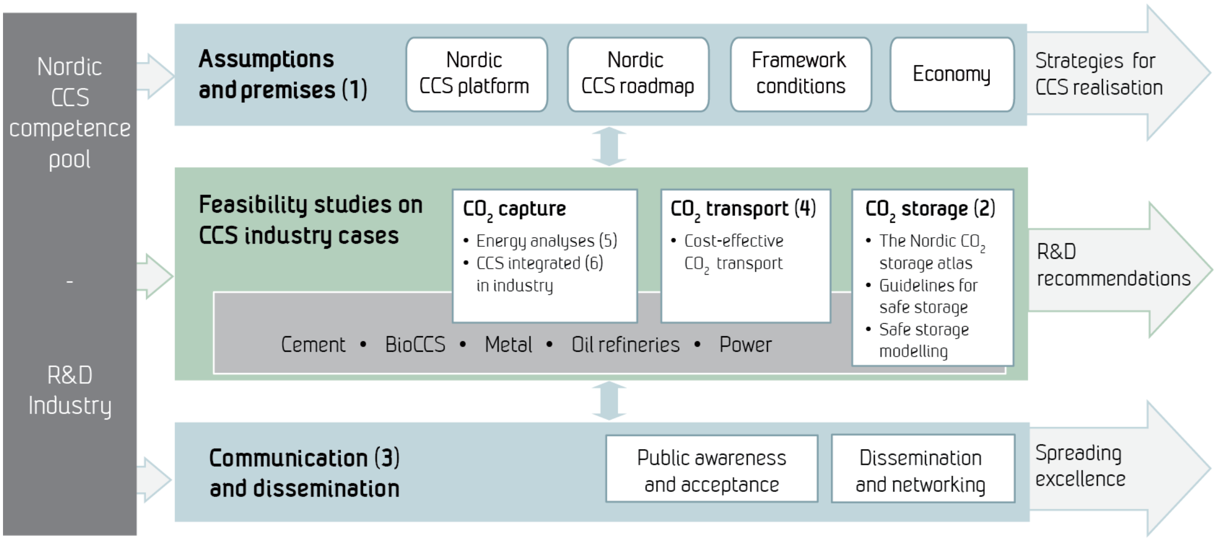
Top-level Research Initiative

nordiccs
Nordic CCS Competence Centre

**NORDICCS concept:**




**Partners:**

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IVL Swedish Environmental Research Institute
SGU Sveriges geologiska undersökning Geological Survey of Sweden
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# Summary

Previous European projects mapped and estimated the potential storage for hydrocarbon fields, not-mineable coal beds and saline aquifers. The European projects only included two Nordic countries (Norway and Denmark) and a unified database covering all of the Nordic countries does not exist.
In November 2011, the Nordic countries research program - the Nordic Top-level Research Initiative (Nordic Innovation Center), launched NORDICCS – Nordic Competence Centre for CCS. One of the Centers major tasks is the creation of a Nordic CO2 storage atlas. NORDICCS will build a database of geological information on potential storage sites, improve methods to quantify storage capacity and defining criteria to characterise a safe storage site. Further the option to store CO2 in basalts will be considered and potential areas mapped.

**Keywords** CCS, Nordic, storage potential, saline aquifers, basalts

**Authors** Karen Lyng Anthonsen, GEUS – Geological Survey of Denmark and Greenland, Denmark, kla@geus.dk

**Date** November 2012

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Top-level Research Initiative

***About NORDICCS***

*Nordic CCS Competence Centre, NORDICCS, is a networking platform for increased CCS deployment in the Nordic countries. NORDICCS has 10 research partners and six industry partners, is led by SINTEF Energy Research, and is supported by Nordic Innovation through the Top-level Research Initiative.*

# ER 2: Mapping and Estimating the Potential for Geological Storage of $CO_2$ in the Nordic countries – a new project in NORDICCS

*Karen Lyng Anthonsen, GEUS – Geological Survey of Denmark and Greenland, Copenhagen, Denmark. kla@geus.dk*

Abstract: To reduce human impact on climate changes in the near future it is considered necessary to reduce $CO_2$ emissions from fossil fuel combustion. This fact has intensified research in methods capable of reducing emissions substantially and one of the methods being looked into is carbon capture and storage (CCS). CCS could relatively fast help to reduce $CO_2$ emissions form large point sources e.g. power stations, because the technology builds on already existing knowledge from oil and gas production. To be prepared for a possible future implementation of CCS it is, however, important to know where and how much $CO_2$ can be stored in the sub-surface.

Several EU co-funded projects has mapped the potential for geological storage of $CO_2$ in Europe, beginning with the Joule II project in 1993, estimating a total storage capacity of 800 giga tonne (Gt), to GeoCapacity estimating a total storage capacity of 360 Gt in 2009. The results from these projects concluded that EU has sufficient storage capacity to store the yearly emission of $CO_2$ of 1.9 Gt from large stationary point sources. The European projects mapped and estimated the potential storage for hydrocarbon fields, not-mineable coal beds and saline aquifers. The GeoCapacity project concluded that the aquifers have by far the largest storage capacities with a total capacity of 325 Gt. The European projects only included two Nordic countries (Norway and Denmark) and a unified database covering all of the Nordic countries does not exist.

It is clear, that the very different geology of the Nordic countries reflects the variation in $CO_2$ storage capacity, from the old basement rocks beneath Finland and most of Sweden, across the Caledonian mountains on-shore Norway, the large sedimentary basins in the sub-surface of Denmark and off-shore Norway to the active rift zone in Iceland. This was recently illustrated in a research study comprising an overview of the potential for applying CCS in the Nordic countries, where Finland and Sweden only had limited storage capacity; Denmark and especially Norway large $CO_2$ storage potential, and on Iceland the basaltic rocks offers the possibility to store $CO_2$ by mineral trapping, a method where the $CO_2$ is chemically attached to minerals in the basalts.

In November 2011, the Nordic countries research program - the Nordic Top-level Research Initiative (Nordic Innovation Center), launched NORDICCS – Nordic Competence Centre for CCS. One of the Centers major tasks is the creation of a Nordic $CO_2$ storage atlas. NORDICCS will build a database of geological information on potential storage sites, improve methods to quantify storage capacity and defining criteria to characterise a safe storage site. Further the option to store $CO_2$ in basalts will be considered and potential areas mapped.

# Mapping and Estimating the Potential for Geological Storage of $CO_2$ in the Nordic countries – a new project in NORDICCS

Karen Lyng Anthonsen

Geological Survey of Denmark and Greenland
Danish Ministry of Climate, Energy and Building

Nordic Geological Winter Meeting, Januar 9th 2012, Reykjavik

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## Outline of talk

- What is CCS?
- Key geological indicators for $CO_2$ storage sustainability
- Mapping of potential $CO_2$ storage options in Europe
- Results of European $CO_2$ storage capacity projects
- Calculation of $CO_2$ storage capacity - aquifers
- Nordic geological $CO_2$ storage projects - NORDICCS

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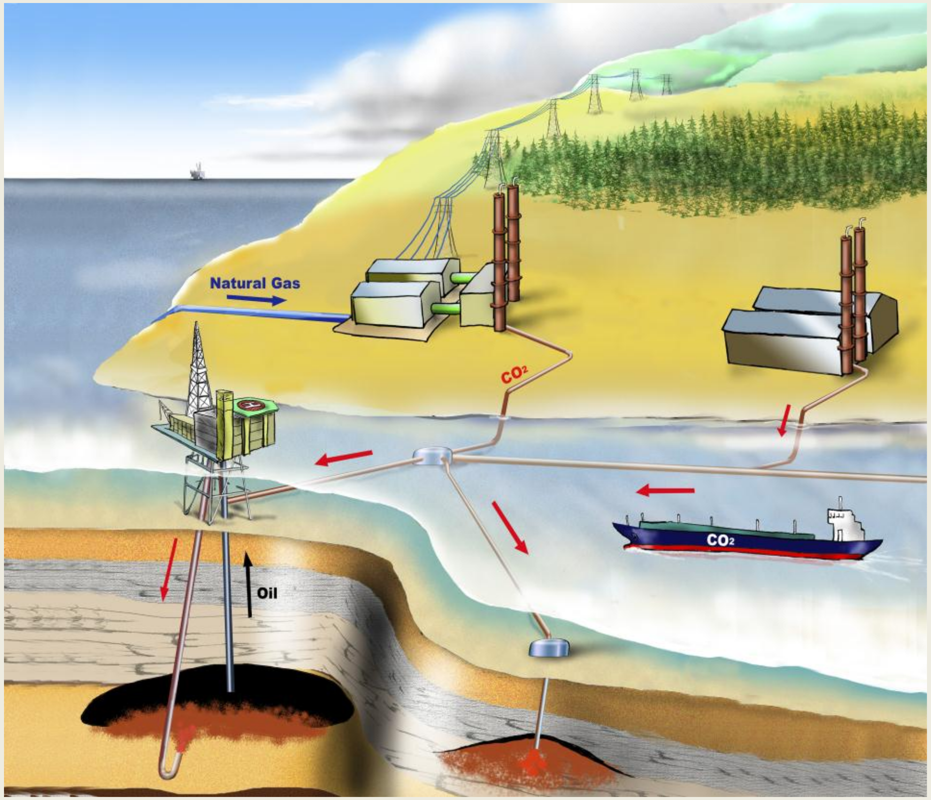
# Carbon, Capture and Storage - CCS

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Emission source
with $CO_2$ capture facilities

Transport
- Pipeline
- Ship

Storage
- Hydrocarbon fields
- Aquifers (saline)
- Coal fields (unmineable)

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## $CO_2$ storage options

- Oil- and gas fields

  Limited storage capacity, but well-known geology and proven capability to retain hydrocarbons

  Possibility to use $CO_2$ for enhanced oil/gas recovery (EOR/EGR)

- Aquifers (saline)

  Large storage volumes, but relatively unknown geology and therefore uncertainties about reservoir integrity and properties

- Coal fields

  Very limited storage capacity and injection rates, but possible to use $CO_2$ for production of methane

- Mineral trapping

  Research area with large perspectives

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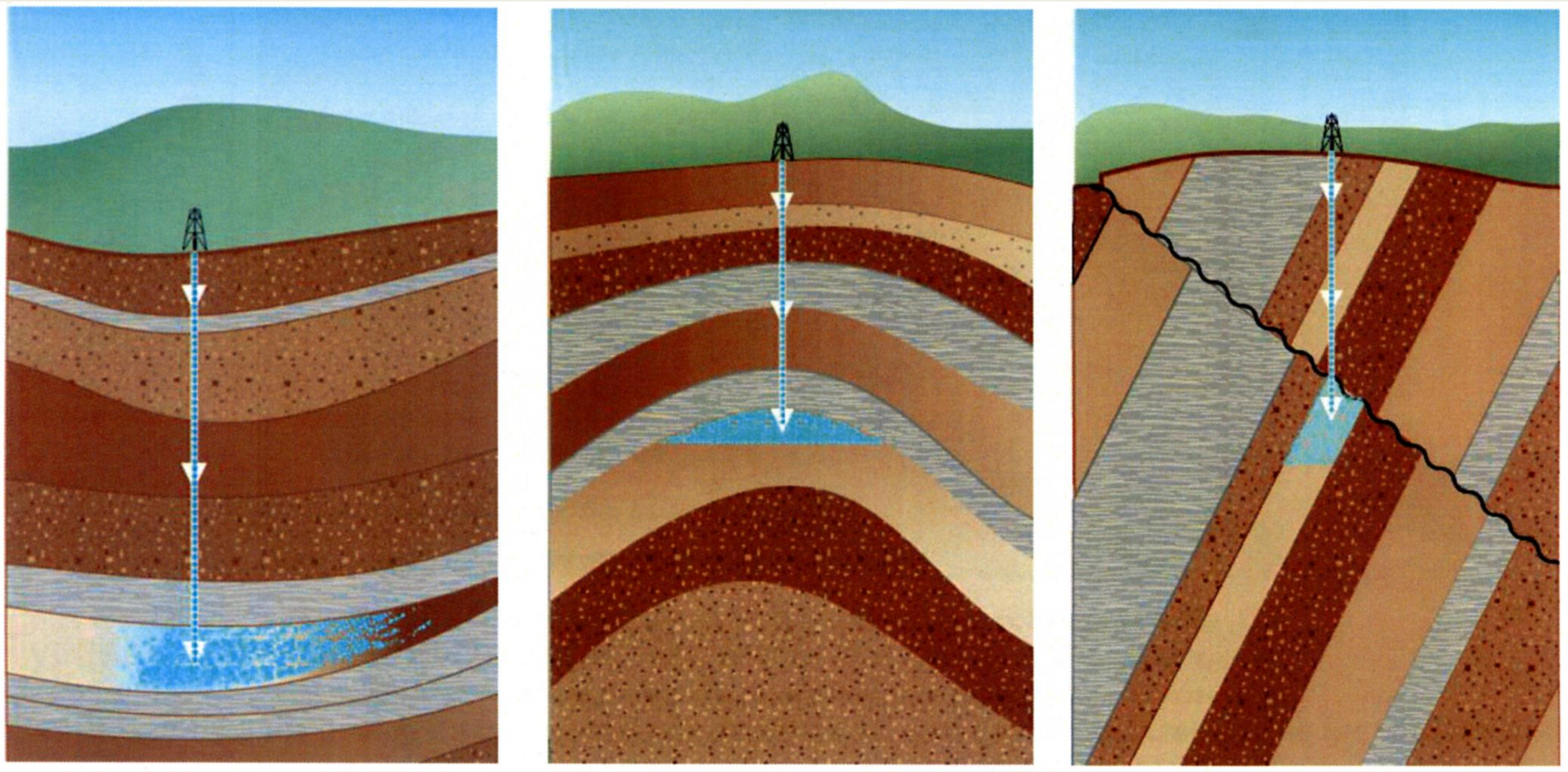
## Trapping mechanisms



Stratigraphical trapping
Porous layer bounded by tight seal

Structural trapping
Porous layer topped by tight seal

Structural trapping
Porous layer in fault contact with seal

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# Key geological indicators for storage site suitability

| Reservoir Properties | Positive Indicators | Cautionary Indicators |
|---|---|---|
| Depth | >800 m, <2500 m | <800 m, >2500 m |
| Reservoir thickness | >50 m | <20 m |
| Porosity | >20% | <10% |
| Permeability | >500 mD | <200 mD |
| Salinity | >100 $gl^{-1}$ | <30 $gl^{-1}$ |
| Stratigraphy | Uniform | Complex lateral variation and complex connectivity of reservoir facies |
| Capacity | Estimated effective capacity much larger than total amount of $CO_2$ to be injected | Estimated effective capacity similar to total amount of $CO_2$ to be injected |
| **Caprock Properties** | | |
| Lateral continuity | Stratigraphically uniform, small or no faults | Lateral variations, medium to large faults |
| Thickness | >100 m | <20 m |

Chadwick et al., 2008

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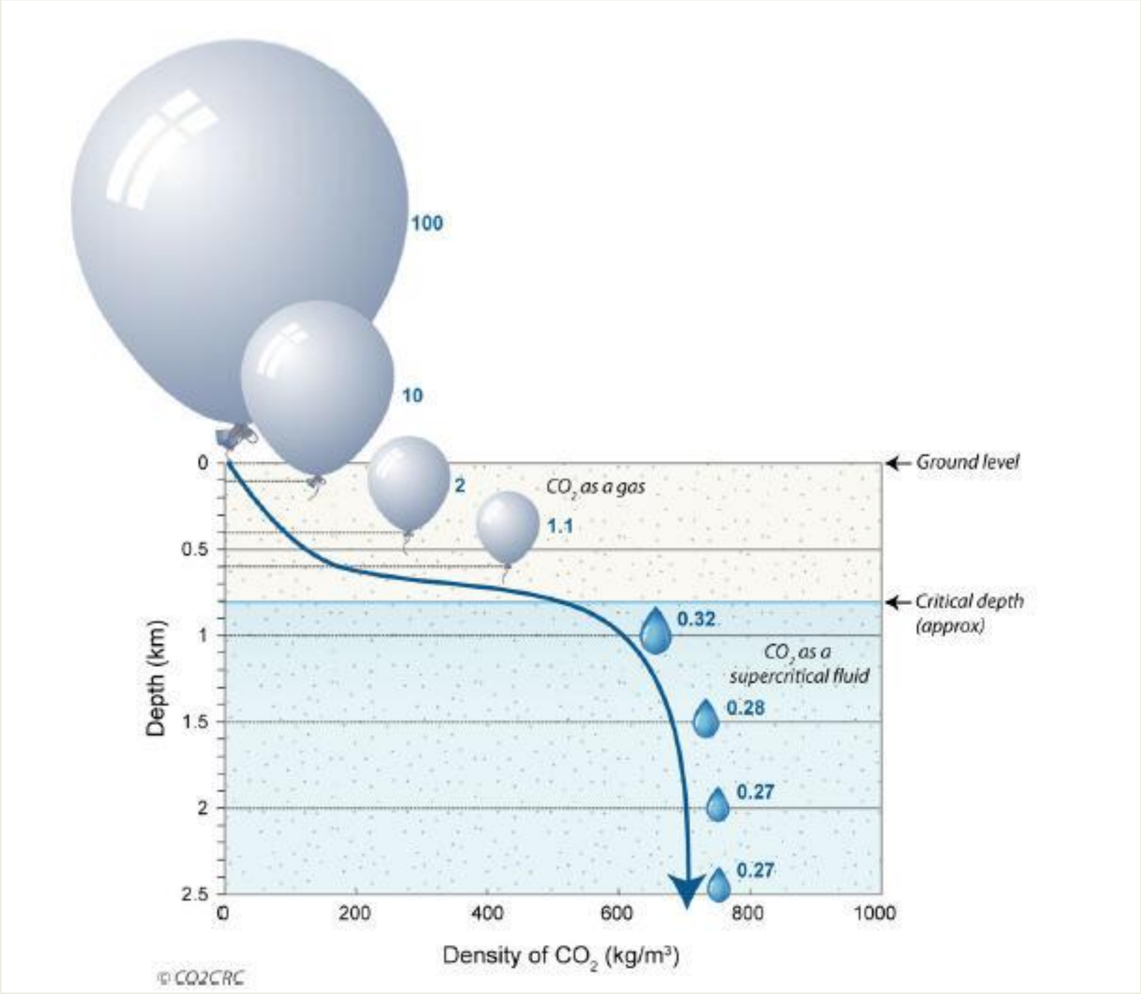
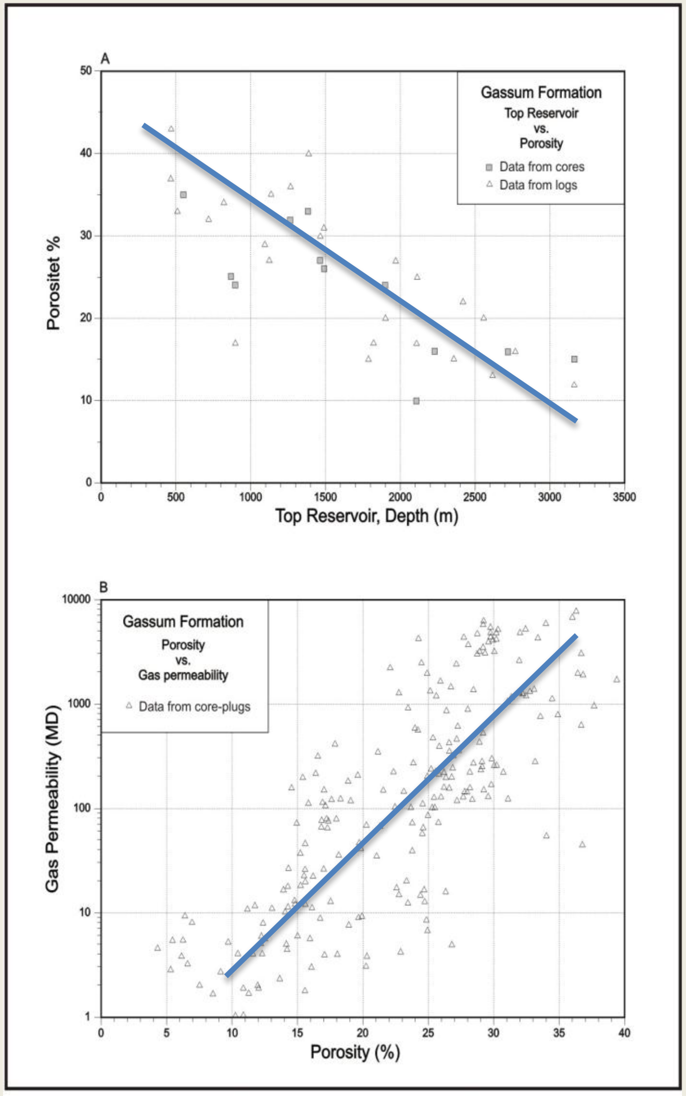
# $CO_2$ density changes with increasing depth






The relationship between porosity and permeability with depth, exemplified by a Danish reservoir sandstone

Porosity decreases with depth

Permeability decreases with decreasing porosity

The optimal depth window for $CO_2$ storage is 800 – 2500 meter

## CO2 storage capacity projects

- **Joule II** finalised 1993
  The joule II project: The underground disposal of carbon dioxide
  All Europe

- **GESTCO** finalised 2003
  Geological Storage of CO2 from Combustion of Fossil Fuel
  Belgium, Denmark, France, Germany, Greece, Netherlands, Norway, UK

- **Castor (WP 1.2)** finalised 2006
  Bulgaria, Croatia, Czech Rep., Hungary, Poland, Romania, Slovakia, Slovenia

- **GeoCapacity** finalised 2008
  Assessing European Capacity for Geological Storage of Carbon Dioxide
  Bulgaria, Croatia, Czech Rep., Denmark, Estonia, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, UK (Albania, FYROM, Bosnia-Herzegovina, Luxembourg)

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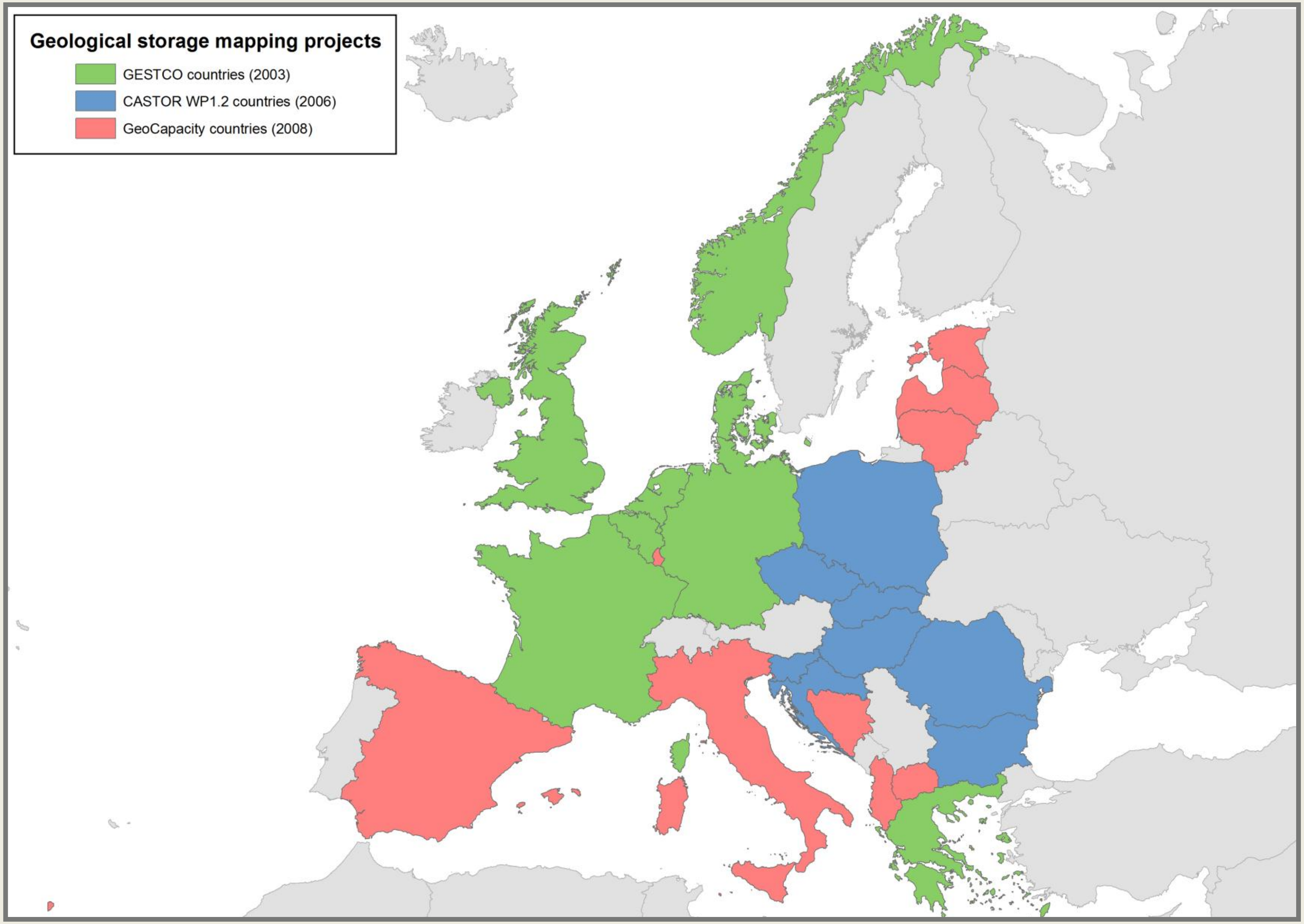
# Mapping of $CO_2$ storage capacity in Europe



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## Mapping of emission sources and infrastructure

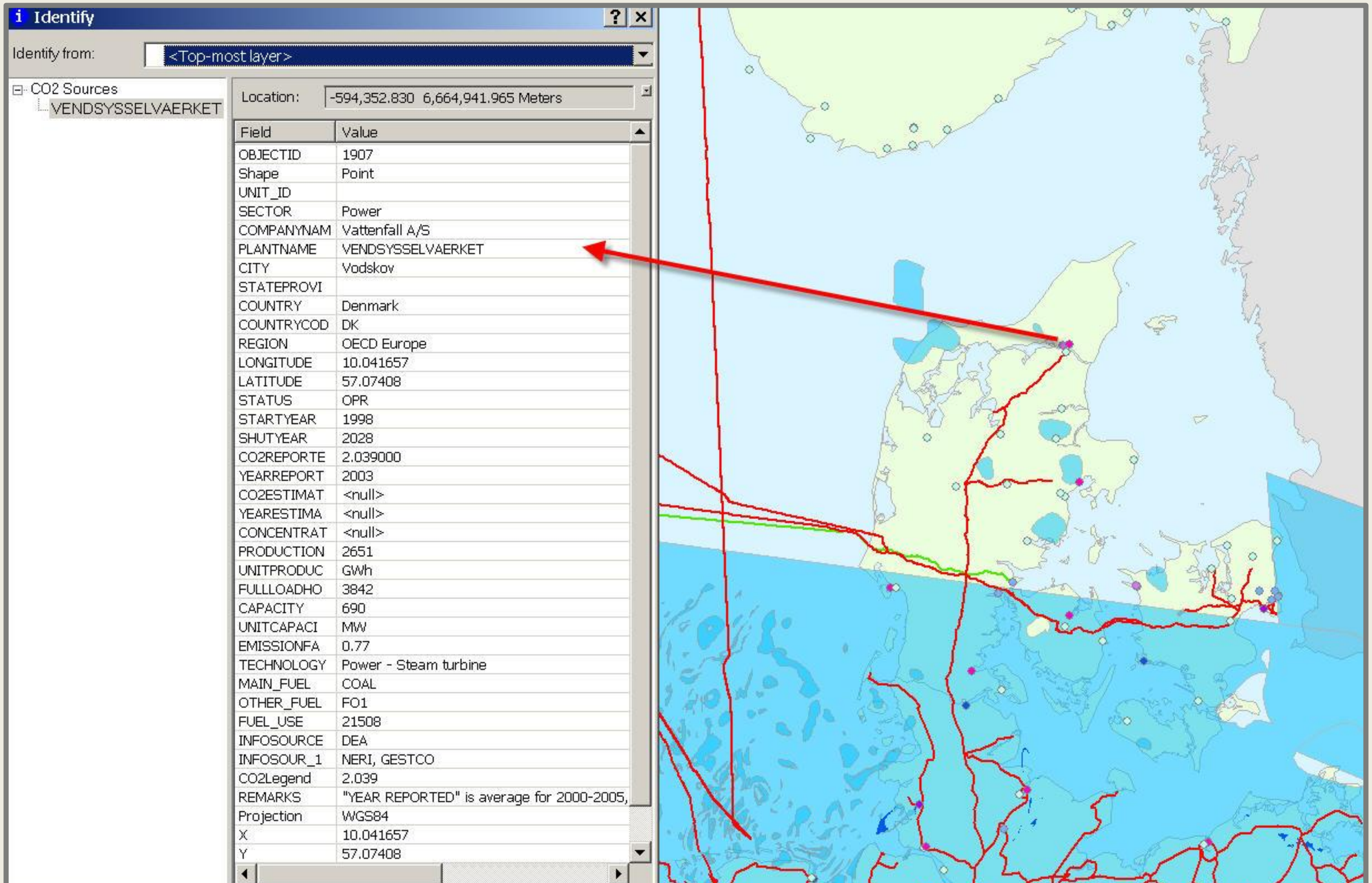
Stationary $CO_2$ emission sources exceeding 100 kt $CO_2$ / year

Data sources:

- annual reports for the EU ETS
- national allocation plans
- qualified estimations where data not available

Infrastructure mapping

- pipelines




| Field | Value |
|---|---|
| OBJECTID | 1907 |
| Shape | Point |
| UNIT_ID | |
| SECTOR | Power |
| COMPANYNAM | Vattenfall A/S |
| PLANTNAME | VENDSYSSELVAERKET |
| CITY | Vodskov |
| STATEPROVI | |
| COUNTRY | Denmark |
| COUNTRYCOD | DK |
| REGION | OECD Europe |
| LONGITUDE | 10.041657 |
| LATITUDE | 57.07408 |
| STATUS | OPR |
| STARTYEAR | 1998 |
| SHUTYEAR | 2028 |
| CO2REPORTE | 2.039000 |
| YEARREPORT | 2003 |
| CO2ESTIMAT | <null> |
| YEARESTIMA | <null> |
| CONCENTRAT | <null> |
| PRODUCTION | 2651 |
| UNITPRODUC | GWh |
| FULLLOADHO | 3842 |
| CAPACITY | 690 |
| UNITCAPACI | MW |
| EMISSIONFA | 0.77 |
| TECHNOLOGY | Power - Steam turbine |
| MAIN_FUEL | COAL |
| OTHER_FUEL | FO1 |
| FUEL_USE | 21508 |
| INFOSOURCE | DEA |
| INFOSOUR_1 | NERI, GESTCO |
| CO2Legend | 2.039 |
| REMARKS | "YEAR REPORTED" is average for 2000-2005, |
| Projection | WGS84 |
| X | 10.041657 |
| Y | 57.07408 |

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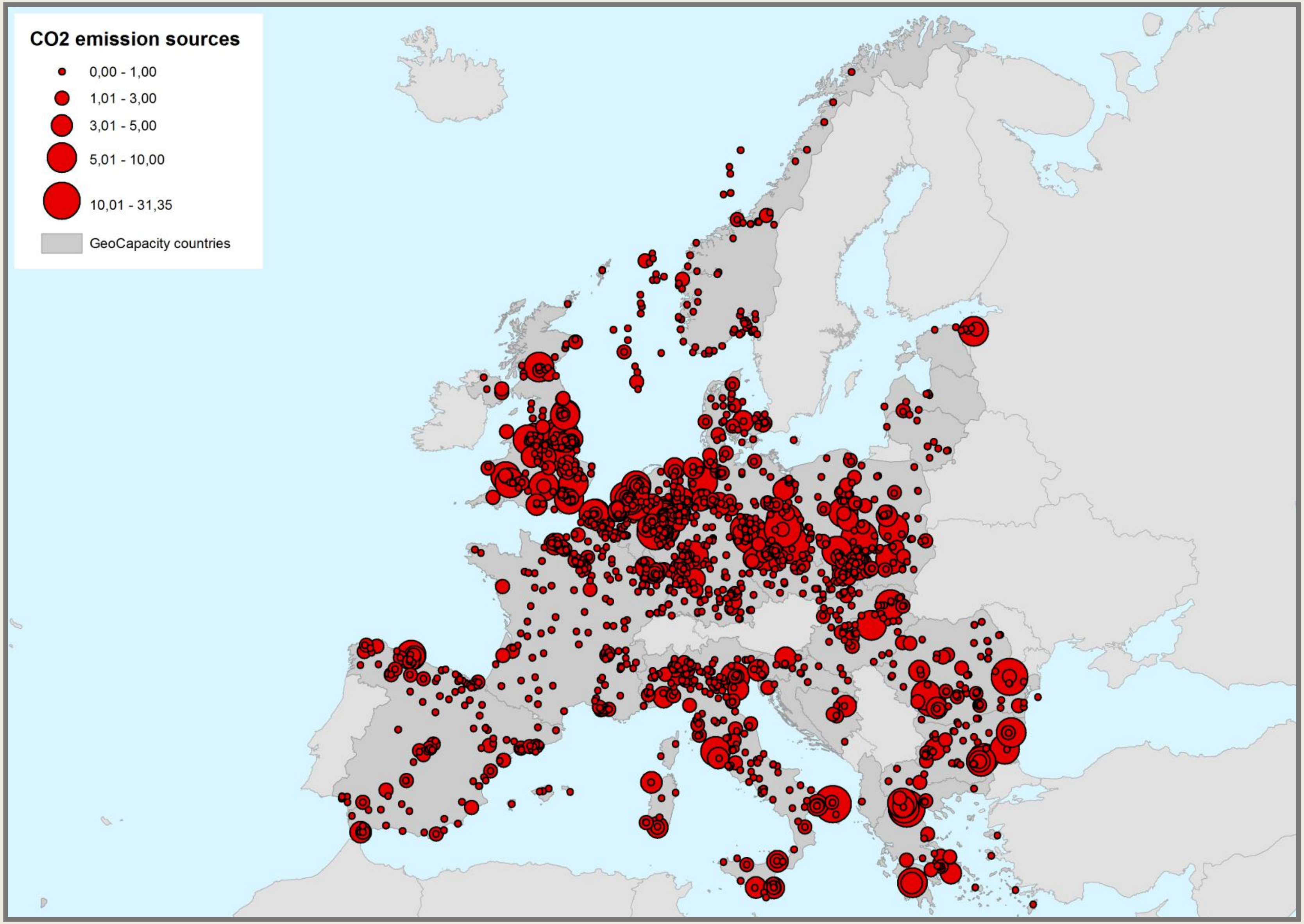
# $CO_2$ emission sources



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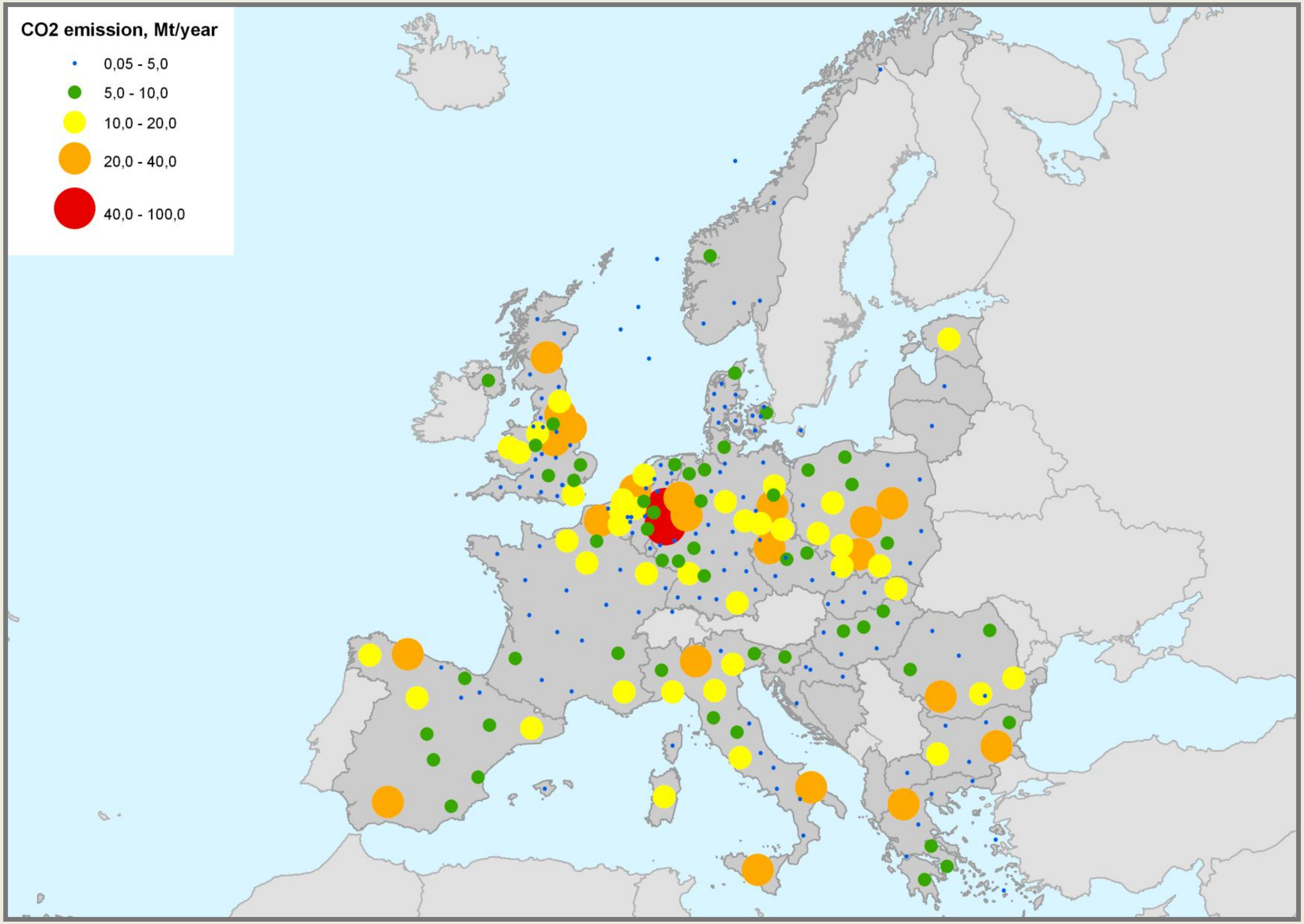
# Clustered $CO_2$ emission sources



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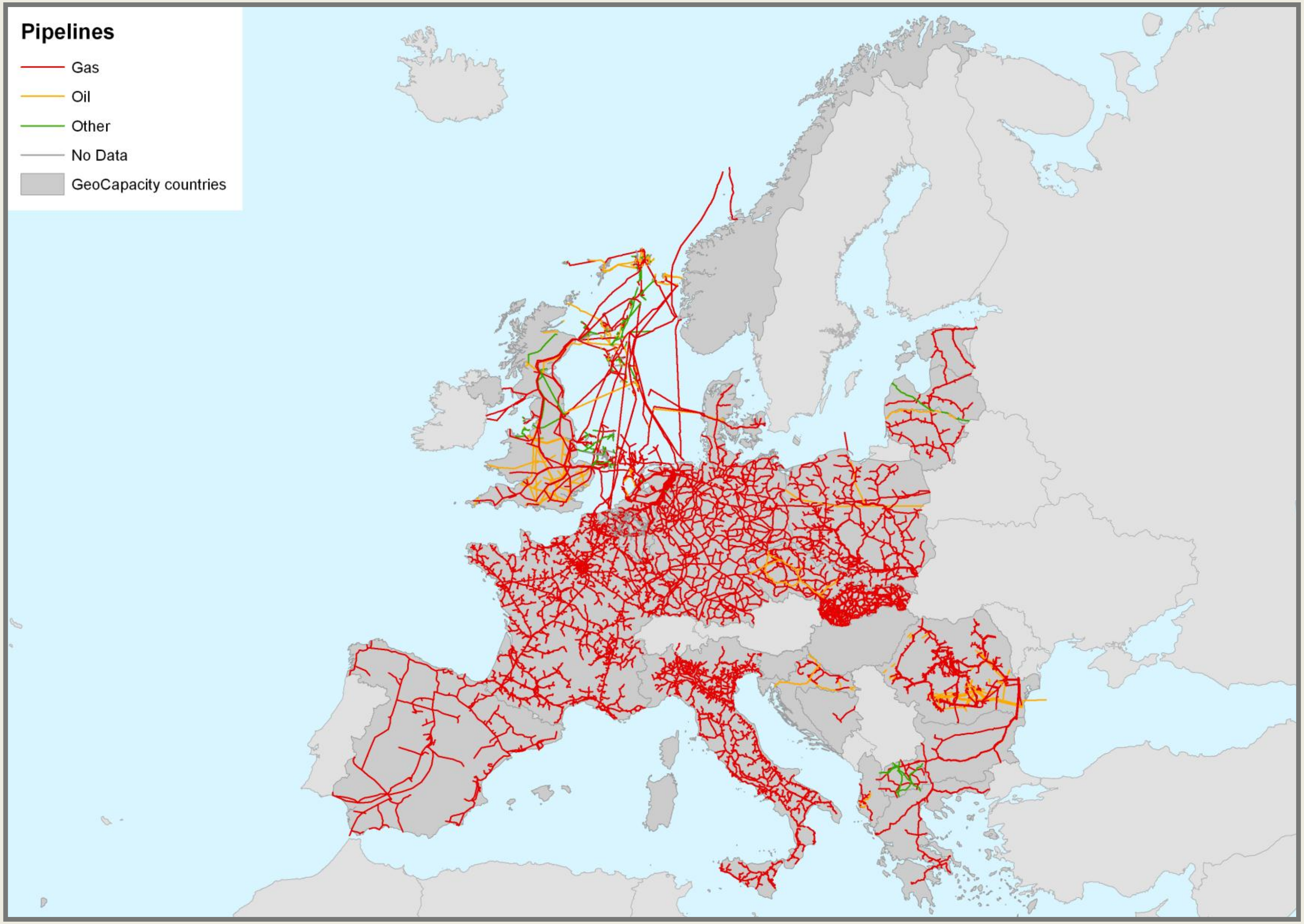
# Pipelines



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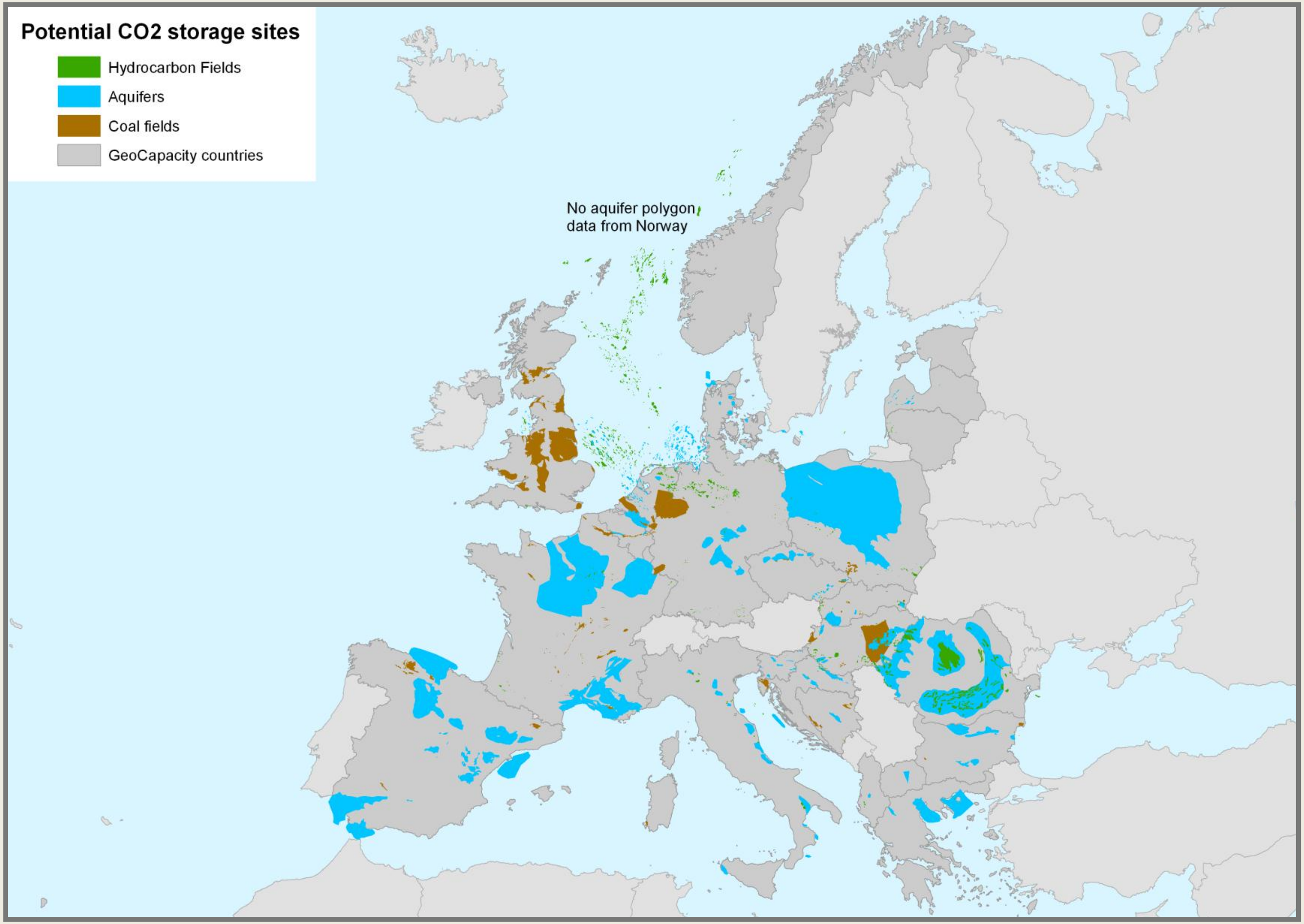
# Potential $CO_2$ storage sites



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## Results from the EU projects

Joule II estimated a total storage capacity for Europe of 800 Gt

GeoCapacity
Emissions from large point sources in the GeoCapacity database is 1.9 Gt $CO_2$/year (1,900,000,000 tones)

Total European storage capacity in GeoCapacity database is 360 Gt $CO_2$
326 Gt in aquifers
32 Gt in hydrocarbon fields
2 Gt in unmineable coal beds

Offshore storage capacity is 244 Gt, onshore capacity is 116 Gt $CO_2$

Almost 200 Gt is located offshore Norway

Total conservative European storage capacity is 117 Gt $CO_2$
96 Gt in aquifers
20 Gt in hydrocarbon fields
1 Gt in unmineable coal beds

www.geocapacity.eu

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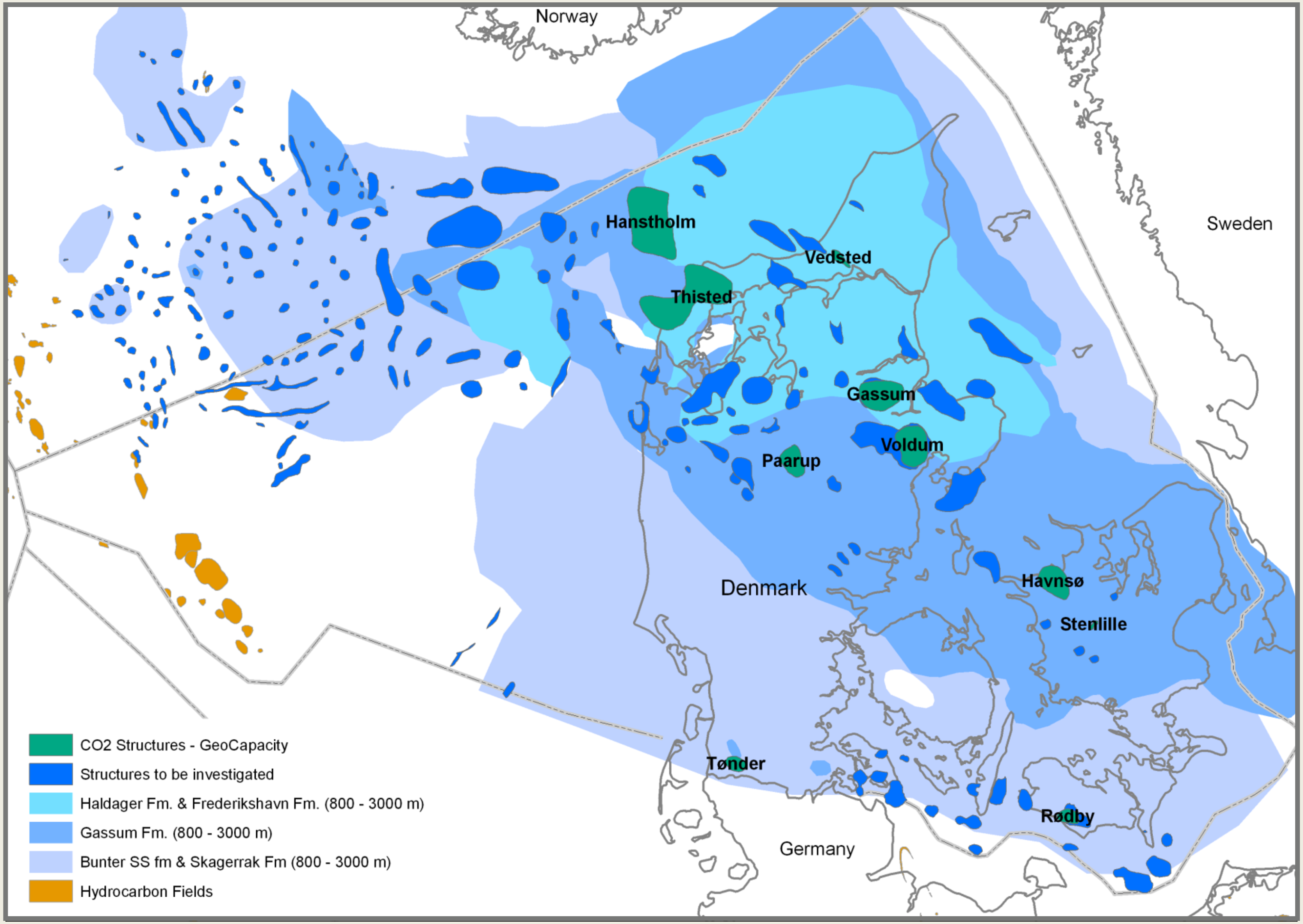
# Calculation of $CO_2$ storage capacity for aquifers



# Theoretical vs. effective capacity

Theoretical capacity: $M_{CO2t} = A \times h \times \phi \times \rho_{CO2r}$

Effective capacity: $M_{CO2e} = A \times h \times \phi \times \rho_{CO2r} \times S_{eff}$

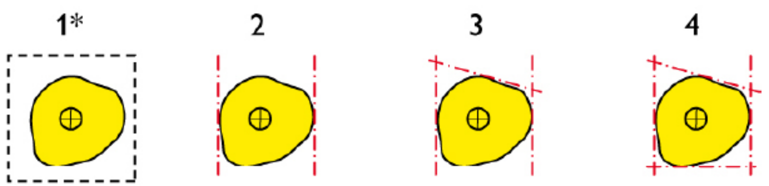
$M_{CO_2}$: Storage capacity
A: Area of aquifer
h: Height $\times$ net to gross ratio
$\phi$: Average reservoir porosity
$\rho_{CO2r}$: $CO_2$ density at reservoir conditions
$S_{eff}$: Storage efficiency factor - depends on connectivity to surrounding aquifer

| Aquifer | Volume ($10^9$ $m^3$) | Net/gross ratio | Porosity | $CO_2$ density (t/ $m^3$) | Theoretical regional $CO_2$ storage capacity (Gt) | Storage efficiency factor | Effective regional $CO_2$ storage capacity (Gt) |
|---|---|---|---|---|---|---|---|
| Bunter and Sk. | 25729 | 0.25 | 0.20 | 0.625 | 804 | 0.02 | 16.1 |
| Gassum | 8557 | 0.25 | 0.20 | 0.625 | 267 | 0.02 | 5.3 |
| Haldager | 1311 | 0.25 | 0.20 | 0.625 | 41 | 0.02 | 0.8 |
| Frederikshavn | 5207 | 0.25 | 0.20 | 0.625 | 163 | 0.02 | 3.3 |
| **Total estimated regional $CO_2$ storage capacity (Gt)** | | | | | **1275** | | **25.5** |

Based US DOE methodology $S_{eff}$ for regional aquifers is 2%

# Open and semi-closed structures

## Storage coefficient (by the rule-of-thumb) $S_{cff}$




| | 1* | 2 | 3 | 4 |
|---|---|---|---|---|
| High quality reservoir | 40 % | 20 % | 10 % | 3–5 % |
| Low quality reservoir | 20 % | 10 % | 5 % | <3 % |

*Volume of bulk reservoir shall be 5-10 times the volume of the reservoir

–·–·– Fault

| Structure | Volume ($10^9$ $m^3$) | Net/gross ratio | Porosity | $CO_2$ density (t/ $m^3$) | Theoretical $CO_2$ storage capacity (Gt) | Storage efficiency factor | Effective $CO_2$ storage capacity (Gt) |
|---|---|---|---|---|---|---|---|
| Hanstholm | 138.8 | 0.40 | 0.20 | 0.620 | 6.9 | 0.4 | 2.8 |
| Gassum | 31.4 | 0.32 | 0.25 | 0.627 | 1.6 | 0.4 | 0.6 |
| Havnsoe | 25.0 | 0.67 | 0.22 | 0.629 | 2.3 | 0.4 | 0.9 |
| Horsens | 29.9 | 0.26 | 0.25 | 0.630 | 1.2 | 0.4 | 0.5 |
| Paarup | 15.8 | 0.23 | 0.10 | 0.625 | 0.2 | 0.4 | 0.1 |
| Roedby | 14.2 | 0.18 | 0.24 | 0.620 | 0.4 | 0.4 | 0.2 |
| Stenlille | 1.1 | 0.76 | 0.25 | 0.631 | 0.1 | 0.4 | 0.1 |
| Thisted | 490.6 | 0.60 | 0.15 | 0.625 | 27.6 | 0.4 | 11.0 |
| Toender | 10.7 | 0.17 | 0.20 | 0.626 | 0.2 | 0.4 | 0.1 |
| Vedsted | 4.3 | 0.74 | 0.20 | 0.633 | 0.4 | 0.4 | 0.2 |
| Voldum | 30.1 | 0.38 | 0.10 | 0.630 | 0.7 | 0.4 | 0.3 |
| **Total estimated regional $CO_2$ storage capacity (Gt)** | | | | | **41.7** | | **16.7** |

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## General considerations for saline aquifers

Distinguish between estimates for bulk volume of regional aquifers and estimates for individual stratigraphic/structural traps

For estimates based on the bulk volume of regional aquifers a storage efficiency factor of 2% based on work by US DOE is suggested

For trap estimates the choice of storage efficiency factor depends on whether the aquifer system is open, semi-closed or closed

For traps in open or semi-closed aquifer systems we suggest a rule-of-thumb approach with values for the storage efficiency factor in the range between 3 - 40%

Storage capacity estimates should always be accompanied with information on assumptions and approach for storage efficiency factor

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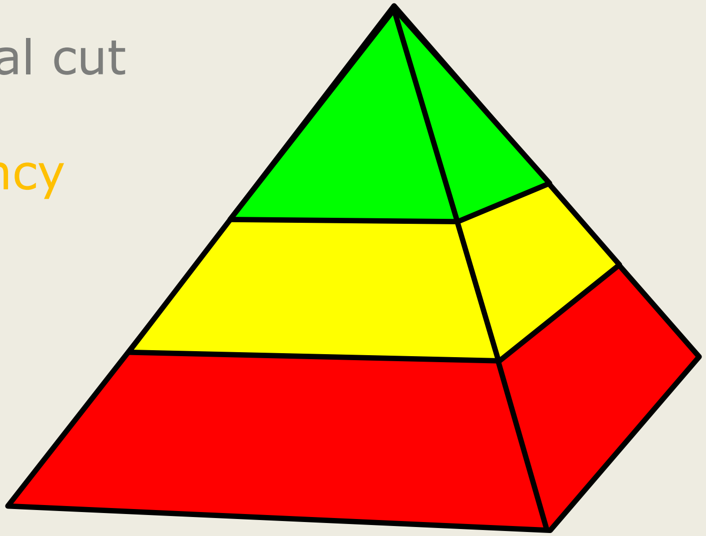
## Techno-Economic Resource-Reserve pyramid

Practical capacity with economic and regulatory barriers applied to effective capacity and with matching of sources and sinks: Site specific efficiency factor from reservoir simulations

Effective capacity with technical/geological cut off limits applied to theoretical capacity: Detailed estimates with evaluated efficiency factor



Theoretical capacity including large uneconomic/unrealistic volumes: Estimates without efficiency factor

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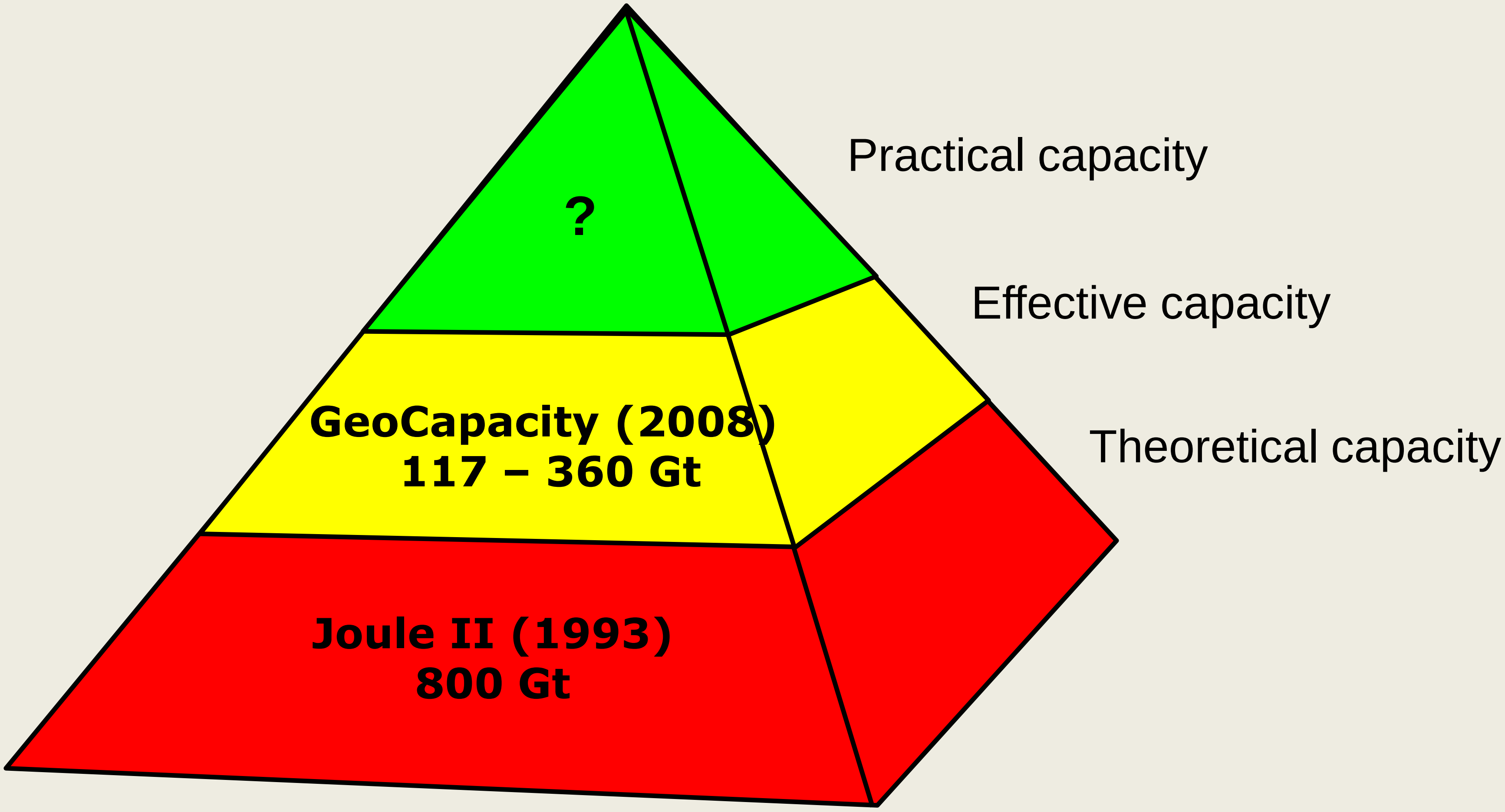
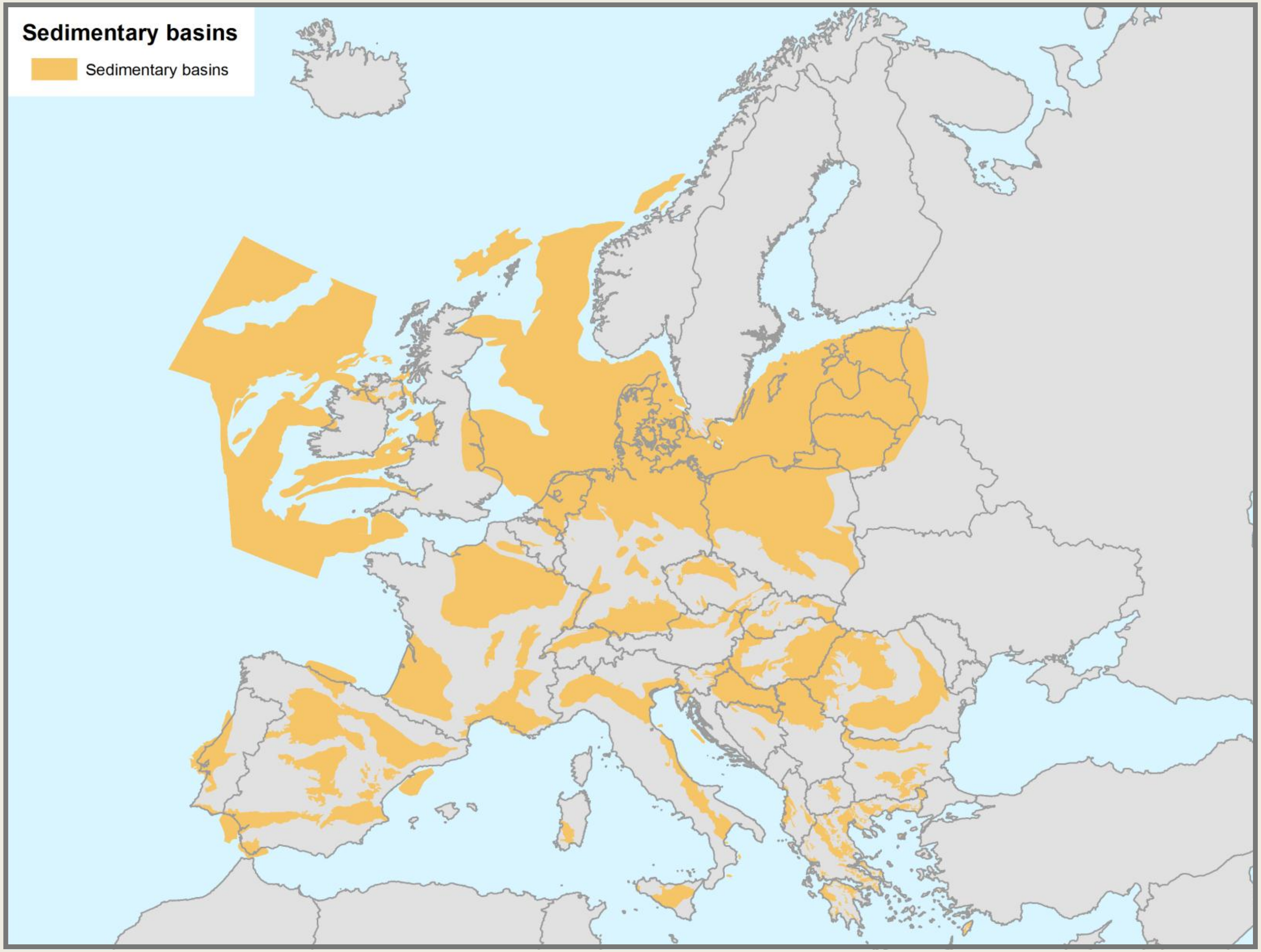
# Techno-Economic Resource-Reserve pyramid



# Sedimentary basins



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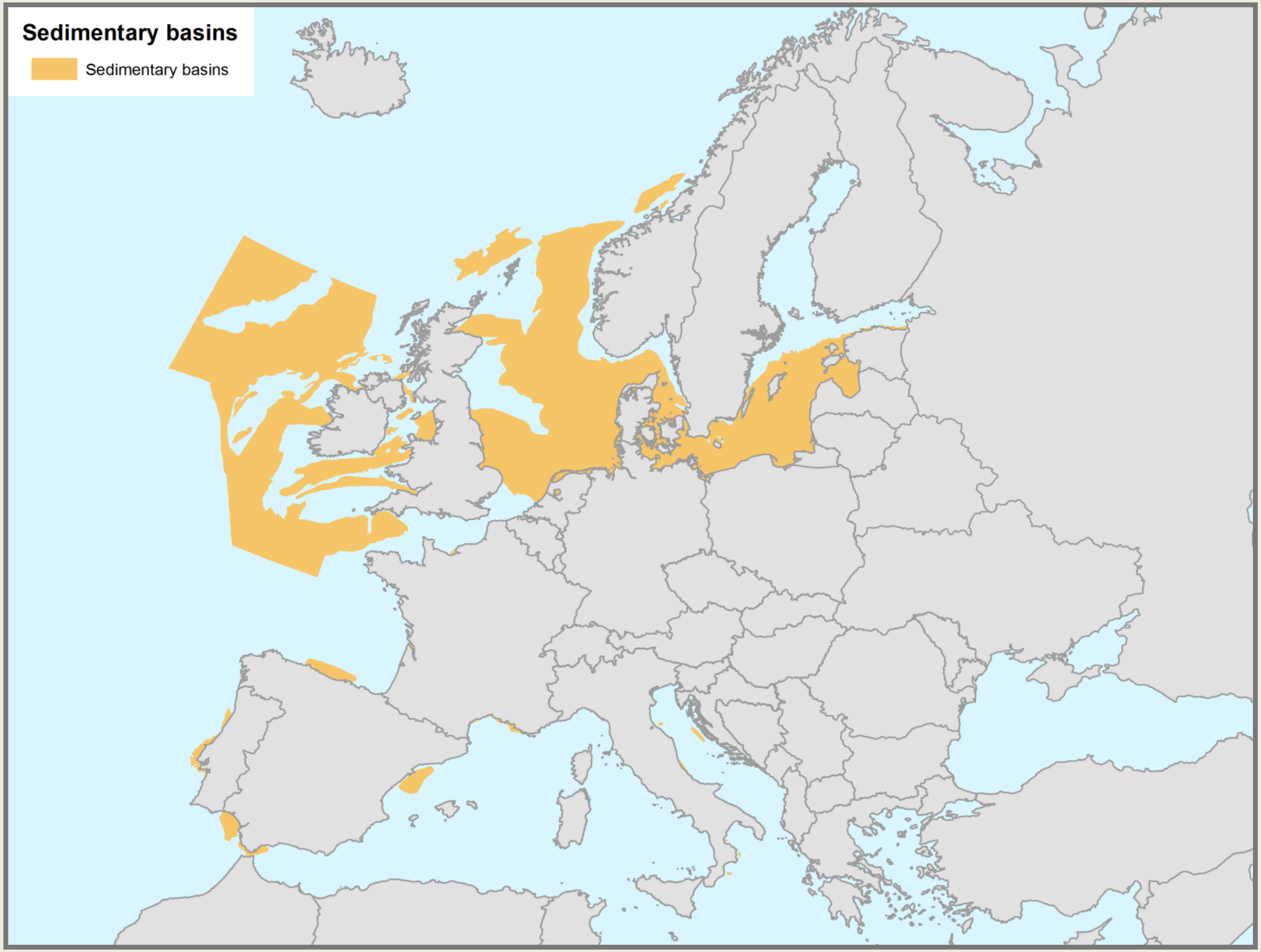
# Sedimentary basins - offshore



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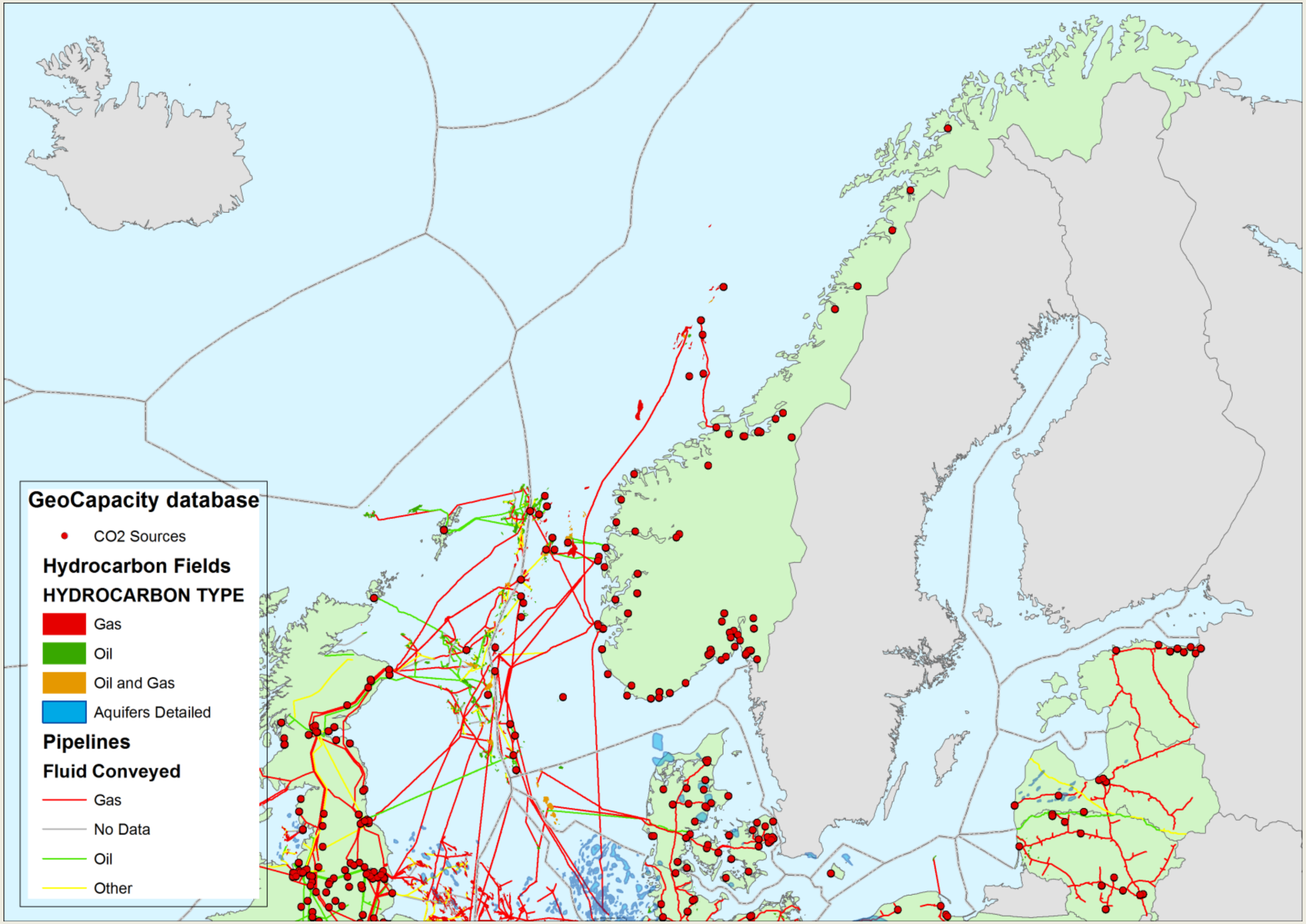
# Why a Nordic CO2 Storage Atlas?



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# Nordic mapping projects

2010
Oljedirektoratet (Norwegian Petroleum Directorate)
$CO_2$ storage atlas for Norway – published December 2011

2011
The Nordic Top-level Research Initiative announces a call for proposals to support the establishment of a Nordic User Driven Competence Centre for realisation of Carbon Capture and Storage.

2011
NORDICCS is granted 35 mill. NOK for a 4 year period
- One of the major tasks is the creation of a Nordic $CO_2$ Storage Atlas.

# NORDICCS

NORDICCS is the Nordic CCS research and innovation platform involving the major CCS stakeholders in the five Nordic countries.

## Activities

Integrating activities

- Building the Centre
- Defining a common basis

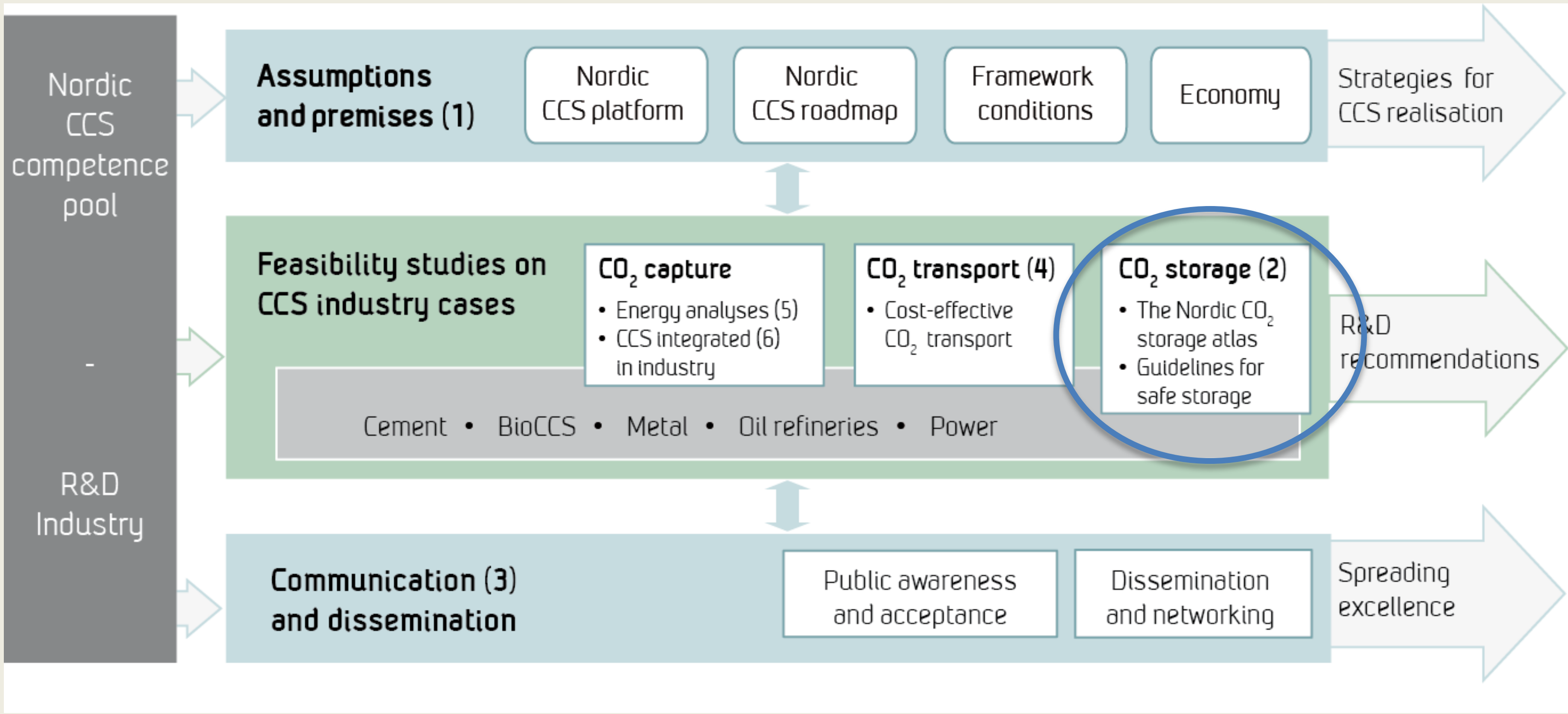
Joint R&D

- Collaborative research and development activities
- Sharing expertise and research infrastructure

Spreading excellence

- Communication to the general public
- Structured information dissemination among partners

# NORDICCS


Nordic CCS competence pool
-
R&D Industry
Assumptions and premises (1)
Nordic CCS platform
Nordic CCS roadmap
Framework conditions
Economy
Strategies for CCS realisation
Feasibility studies on CCS industry cases
$CO_2$ capture
• Energy analyses (5)
• CCS integrated (6) in industry
$CO_2$ transport (4)
• Cost-effective $CO_2$ transport
$CO_2$ storage (2)
• The Nordic $CO_2$ storage atlas
• Guidelines for safe storage
Cement • BioCCS • Metal • Oil refineries • Power
R&D recommendations
Communication (3) and dissemination
Public awareness and acceptance
Dissemination and networking
Spreading excellence

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# NORDICCS

## Partners working with the Nordic storage atlas:

GEUS, SINTEF-PR, University of Oslo, SGU, University of Iceland, Reykjavik Energy

## The Nordic CO2 Storage Atlas

Review and update existing data bases and generate "The Nordic $CO_2$ Storage Atlas"

## Guidelines for Safe Storage in the Nordic area

Define criteria, methods and timeframe for $CO_2$ storage in the Nordic area

## Safe Storage Modelling

Investigate the filling capacity for selected storage site cases and narrow the uncertainty in storage capacity assessment

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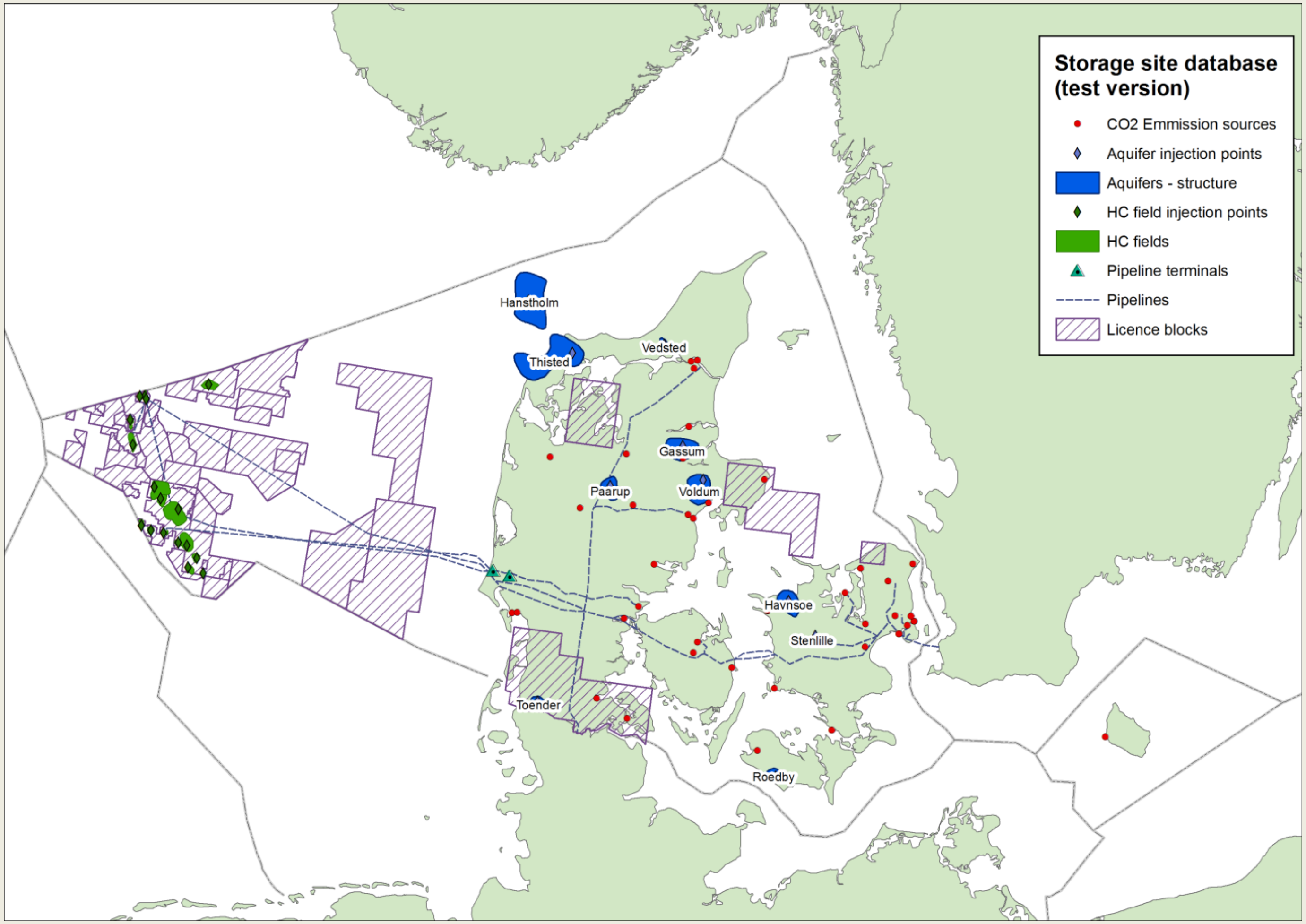
# Expected result in 2015 – a GIS based Nordic $CO_2$ storage atlas



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Orkuveita Reykjavíkur

SIGILLUM UNIVERSITATIS ISLANDIAE
HÁSKÓLI ÍSLANDS

SGU
Sveriges geologiska undersökning

Statoil

NTNU – Trondheim
Norwegian University of Science and Technology

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# Thank you!

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