COURSE: ASPECTS OF CCUS IN THE BSR

Alla Shogenova (alla.shogenova@taltech.ee)
Department of Geology, Tallinn University of Technology
SHOGenergy (SHOGenergy.eu)
Board Member of BASRECCS bcforum.net

Part 1. The role of CCUS clusters and hubs in reaching carbon neutrality

- 1.1 The concept of CCUS clusters and hubs, its advantages (cost savings, synergy with renewables, sharing infrastructure and technologies), and possible challenges (political, regulatory, technical and financial).
- 1.2 The best known CCUS clusters in the world (operated and ready to start soon).
- 1.3 Possible onshore and offshore cross-border scenarios in the Baltic Sea Region (regulatory basis, reusing infrastructure, examples and cost estimates)
- 1.4 Conclusions and lessons learned from the recent developments.

1.1 The concept of CCUS clusters and hubs

- According to IEA (2015) the concept of CCS cluster includes any development which has been proposed or implemented in which multiple sources of captured CO2 share infrastructure, usually the transport system, but also capture and storage facilities.
- Many emissions-intensive facilities (both power and industrial) tend to be concentrated in the same areas and they could be included in CCUS clusters and hubs.
- After the implementation of the EU CCS Directive in 2011, which regulated also the need for CO2 storage monitoring (before, during storage and post-closure), sharing of monitoring infrastructure and costs is also one of the common parts of the value chain to be shared by clusters.
- About 10 years ago it was decided worldwide to move from CCS to CCUS. Including CO2 utilization (or CO2 use) should intensify and support the implementation of CCS technologies by adding revenues and decreasing the high costs of new technology.
- By allowing captured CO2 to be used, CCUS gives an additional market and business case for companies to pursue the environmental benefits of CCS.
- Now, the concept of CCUS cluster and hubs includes CO2 capture, utilization, transport and storage and relevant socio-political, economical and legal aspects on regional and local levels (the concept described in the new Horizon Europe CCUS-ZEN project –will be shown at the end).

1.1 The concept of CCUS clusters and hubs

- Currently, the primary revenue source for capturing CO2 in USA and Canada is the restoring of depleted oil and gas reservoirs for re-use.
- Secondarily, the IRS 45Q law in USA provides a tax credit for 12 years after a carbon capture project.
- In Europe EU ETS system provides intensities to apply CCUS through EEAP (CO2 tax).
- Potential other CO2 use applications are shown at the scheme (right hand).
- CO2 use can be divided into Non-Conversion methods (Desalination and subsurface CO2 use) and Conversion methods.
- Conversion methods include

➢ CO2 use for Mineral Carbonation

➢ Biological (acceleration for the growth of algae) and

➢ Chemical CO2 use:

✓ liquid fuels,

✓ polymers and plastics,

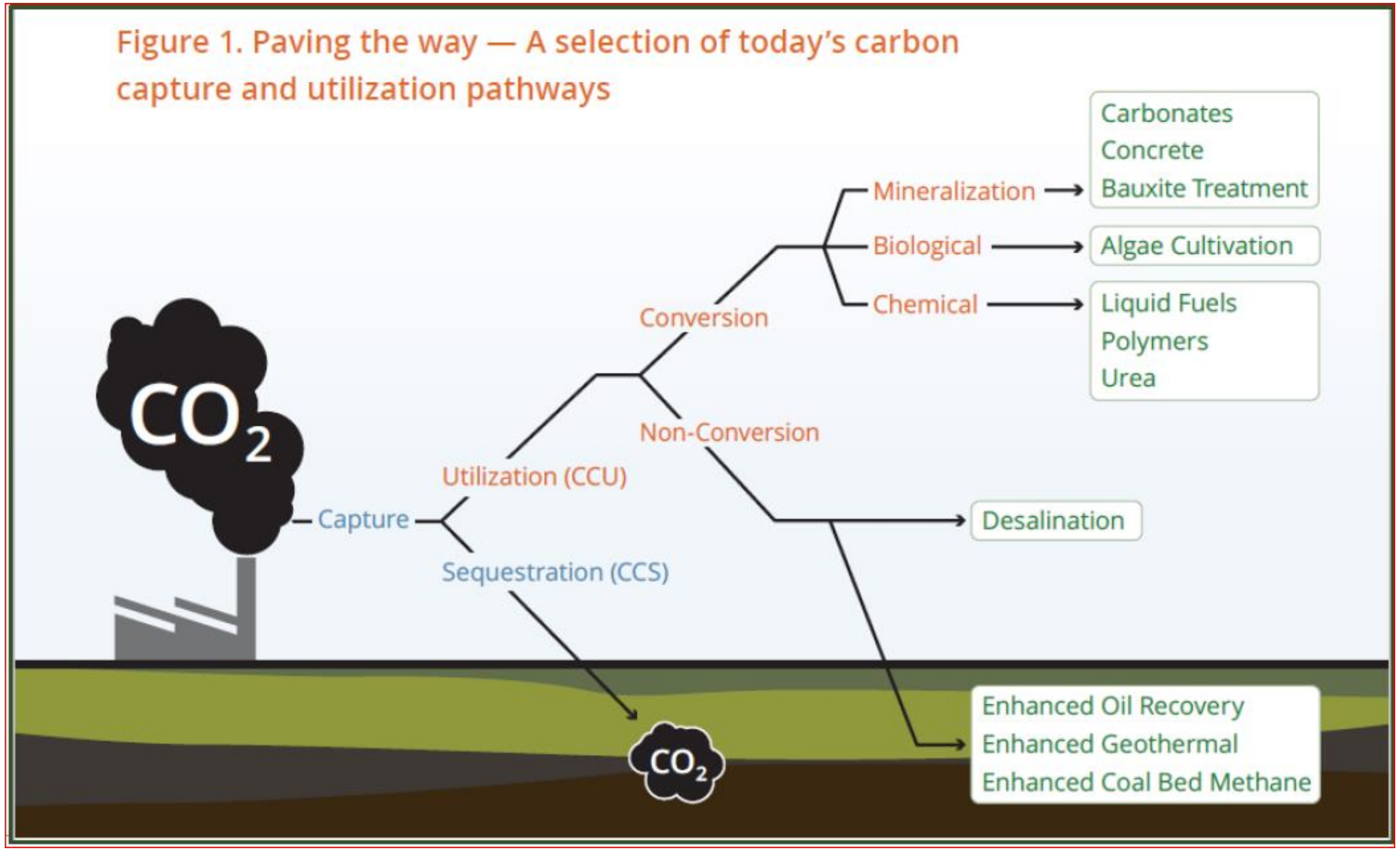
✓ urea,

✓ novel materials (carbon composites, carbon fiber, graphene),

✓ soda carbonization,

✓ refrigeration and more.

Possible pathways for capturing and utilizing CO2 (source: Pembina and ICO2N)



1.1 The concept of CCUS clusters and hubs:
Why we need hubs?

- Today, CCUS projects around the world store about 40 million tons of CO2/per year.
- To reach climate neutrality **we need to increase CO2 storage from millions into billion tons/year.**
- CCUS hubs is one of the options to accelerate this needed scale-up.
- The IEA recently developed a scenario to show what technologies must be deployed to reach net zero emissions from the energy sector.
- It sees carbon capture reaching **1.6 billion tons (Gt) per year by 2030 and 7.6 Gt/year by 2050.**
- Stand-alone CCUS facilities can capture around **1-2 million tons** CO2/year.
- CCUS hubs will be able to store **5-10 million tons** of CO2/year by 2030,
- So around **two hubs/month** would need to be built every year until **2030** to meet the IEA scenario.

Source: CCUS Hub, GCCSI, 2022

In total, CCUS contributes nearly 15% of the cumulative reduction in CO_2 emissions worldwide compared with the Stated Policies Scenario, which takes into account current national energy- and climate-related policy commitments.

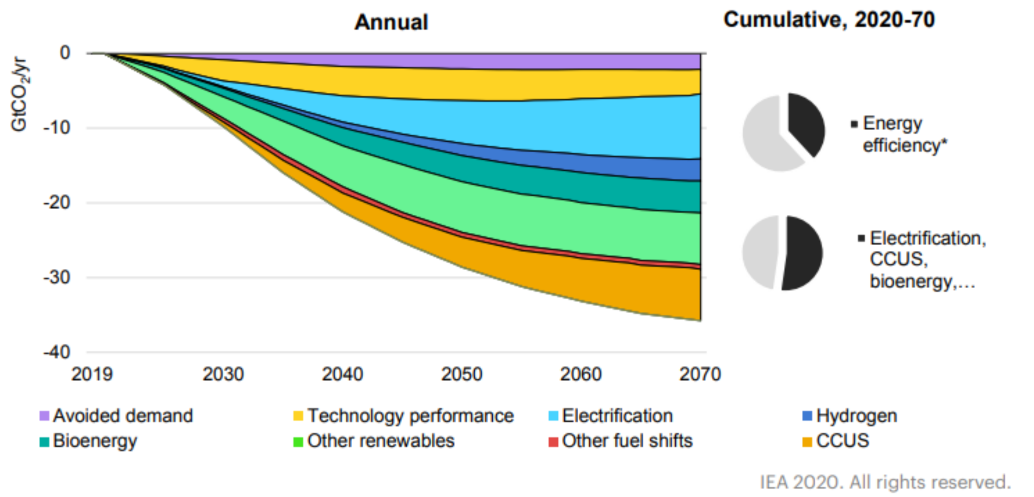


Figure 2.1 Global energy sector CO_2 emissions reductions by measure in the Sustainable Development Scenario relative to the Stated Policies Scenario, 2019-70

IEA 2020. All rights reserved.

- The contribution of CCUS to the transition to net-zero emissions grows over time, accounting for nearly one-sixth of cumulative emissions reductions to 2070.

Energy Technology Perspectives 2020, Special Report on Carbon Capture, Utilisation and Storage, IEA 2020, https://www.iea.org/reports/ccus-in-clean-energy-transitions

1.1 The concept of CCUS clusters and hubs:
Why we need hubs?

Getting to gigatons: priorities to scale up CCUS

- Three priorities can help to scale the contribution of CCUS from tens of millions of tons to gigatonnes of CO2 capture within the next decade:

➢ **1. Establish policies that create sustainable and viable markets for CCUS investment.**

➢ **2. Target industrial clusters with shared infrastructure**

➢ **3. Identify and develop CO2 storage**

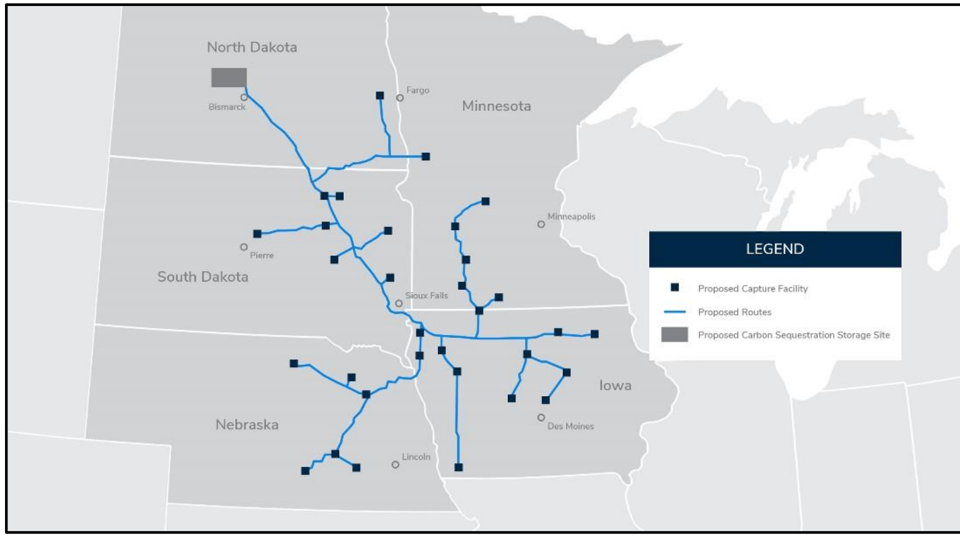
Source: McCulloch S., IEA, 2022

Advantages of CCUS clusters and hubs

1. Faster scale up
2. Decrease the unit cost
3. Reduce the risk of investment
4. Reduce cross-chain risk
5. More support
6. New Jobs
7. CO2 use revenues
8. Synergy with renewables
9. Synergy with CO2 negative technologies
10. Increased public awareness and improved perception

Advantages of CCUS clusters and hubs: 1. Faster scale up

- CCUS must expand rapidly to play a role in reaching climate goals.
- At present, the average large-scale CCUS project captures and stores around 1 Mt of carbon dioxide per year.
- Early CCUS hubs are aiming to capture around 5-10 Mt a year or more by 2030 and expect exponential growth.
- Future hubs are likely to be even larger.
- The smaller emitters (0.1-0.2 Mt CO2) can join CCUS clusters and hubs, otherwise infrastructure is too expensive for them.
- The availability of excess capacity can substantially reduce lead times for future CCUS facilities and be a major factor in new facilities adopting CO2 capture. (The Alberta Carbon Trunk Line in Canada received significant government support (around $430 million), enabling it to be built with more than 90 per cent of its 14.6 MtCO2 capacity free to accommodate future projects) (Next slide).



The US Summit Carbon Solutions bioethanol CO2 network project will transport CO2 from 31 individual bioethanol plants, offering economical shared transport and storage. With a capacity of just under 8 Mtpa, it will be the world’s single largest BECCS network.
https://summitcarbonsolutions.com/project-footprint/

ACTL cluster projects in Canada

- Alberta Carbon Trunk Line (ACTL) project in Canada has the world's largest capacity pipeline for CO_2 from human activity.
- Agrium Fertilizer Facility and North West Redwater Refinery, producing in 2018 about **0.3 and 1.3 Mt CO_2** correspondingly will transport captured CO_2 emissions using **240 km of 16 inches** pipeline to CO_2-EOR and storage site in Clive field in Alberta, which includes Leduc Formation and Nisku reservoirs at the depth of 1900 m.
- The CO_2 pipeline with annual capacity of 14.6 Mt CO_2 will be open access to all CO_2 producers in Alberta's Industrial Heartland and central Alberta.
- HCG's North American subsidiary Lehigh Cement in November 2019 announced a feasibility study of a full-scale CCS project. The pilot capture Lehigh Hanson CP in Edmonton could capture 0.6 Mt CO_2 per year. The plant located at 170 km to the Clive storage site. Integration of the Lehigh Hanson CP in Edmonton into the ACTL project will increase its ongoing annual capacity from 1.6 to 2.2 Mt CO_2.
- The availability of excess capacity can substantially reduce lead times for future CCUS facilities and be a major factor in new facilities adopting CO2 capture. The Alberta Carbon Trunk Line received significant government support (around $430 million), enabling it to be built with more than 90% of its 14.6 MtCO2 capacity free to accommodate future projects

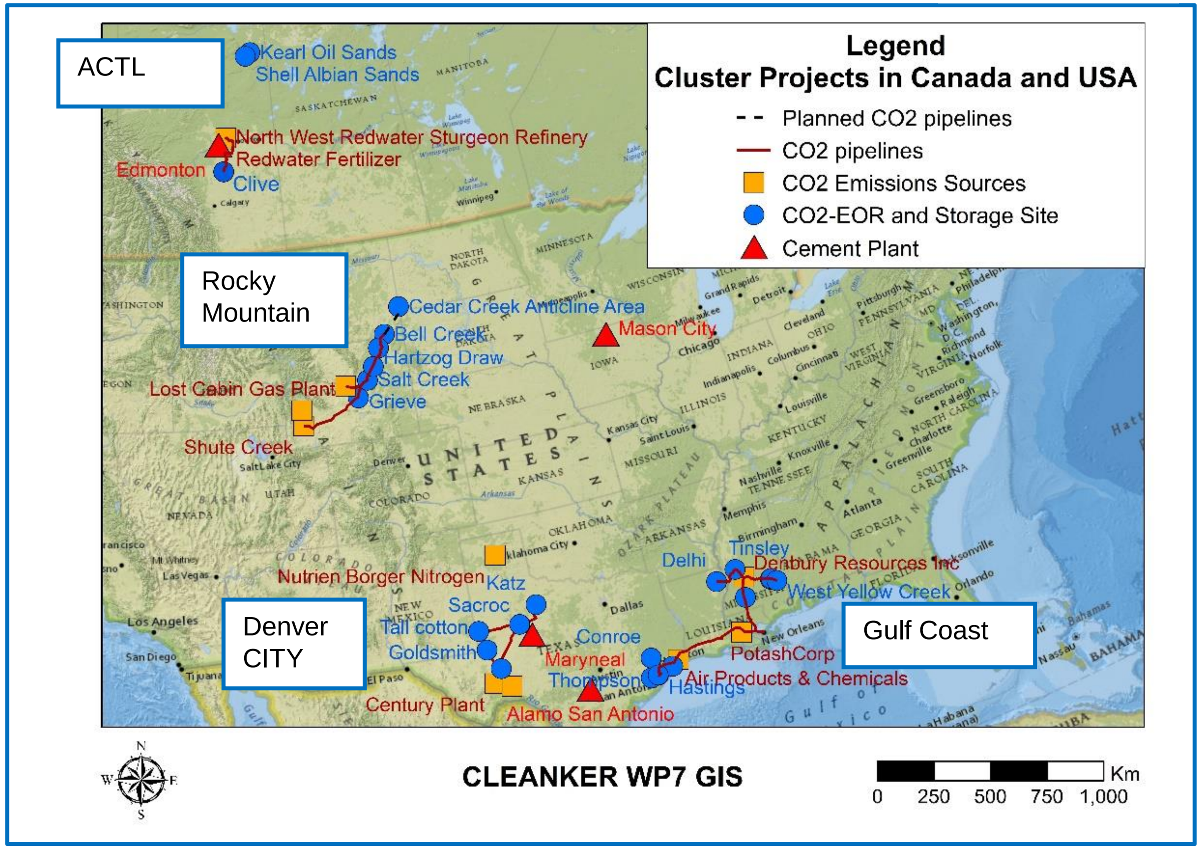
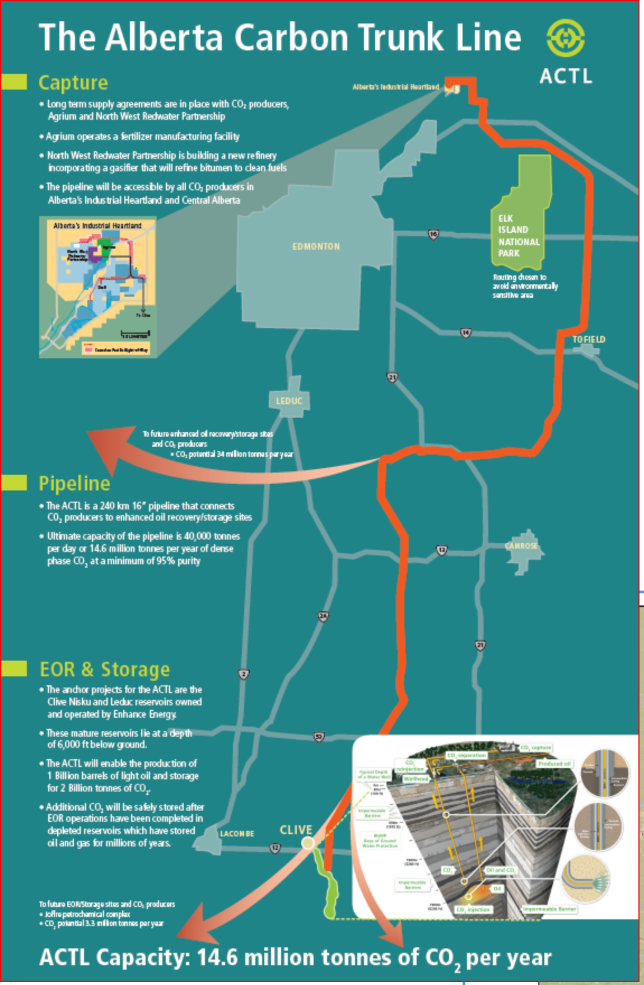


Fig. 1. North American Cluster projects: (1) ACTL project in Canada with HCG Edmonton CP included; 2) Rocky Mountain project with HCG Mason City Lehigh Portland CP proposed; 3) Denver CITY Cluster project in Texas with BU Maryneal CP; 4) The Gulf Coast cluster with BU Alamo San Antonio CP.

ACTL CCUS Cluster and Clive Storage site (ACTL brochure)



The Alberta Carbon Trunk Line

ACTL

Capture

- Long term supply agreements are in place with CO_2 producers, Agrium and North West Redwater Partnership
- Agrium operates a fertilizer manufacturing facility
- North West Redwater Partnership is building a new refinery incorporating a gasifier that will refine bitumen to clean fuels
- The pipeline will be accessible by all CO_2 producers in Alberta's Industrial Heartland and Central Alberta

To future enhanced oil recovery/storage sites and CO_2 producers
- CO_2 potential 34 million tonnes per year

Pipeline

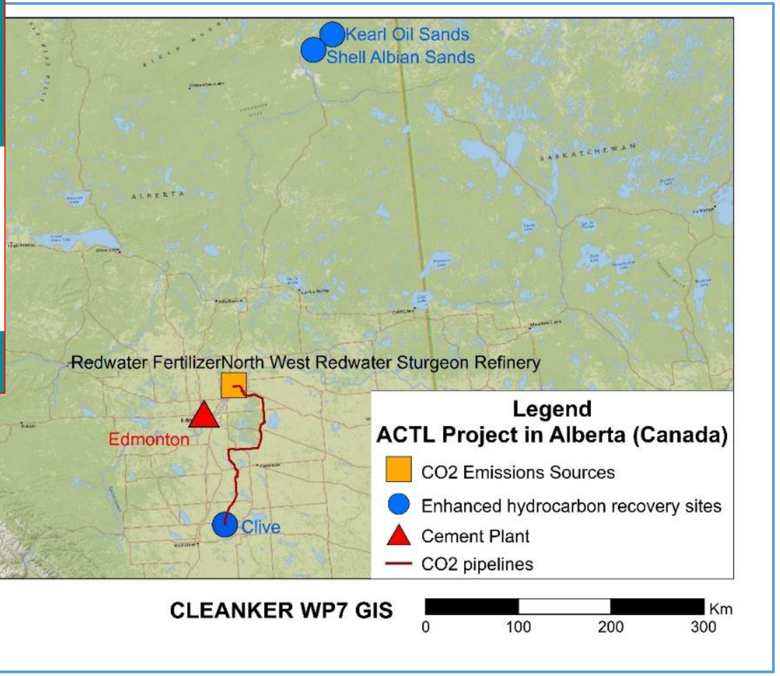
- The ACTL is a 240 km 16" pipeline that connects CO_2 producers to enhanced oil recovery/storage sites
- Ultimate capacity of the pipeline is 40,000 tonnes per day or 14.6 million tonnes per year of dense phase CO_2 at a minimum of 95% purity

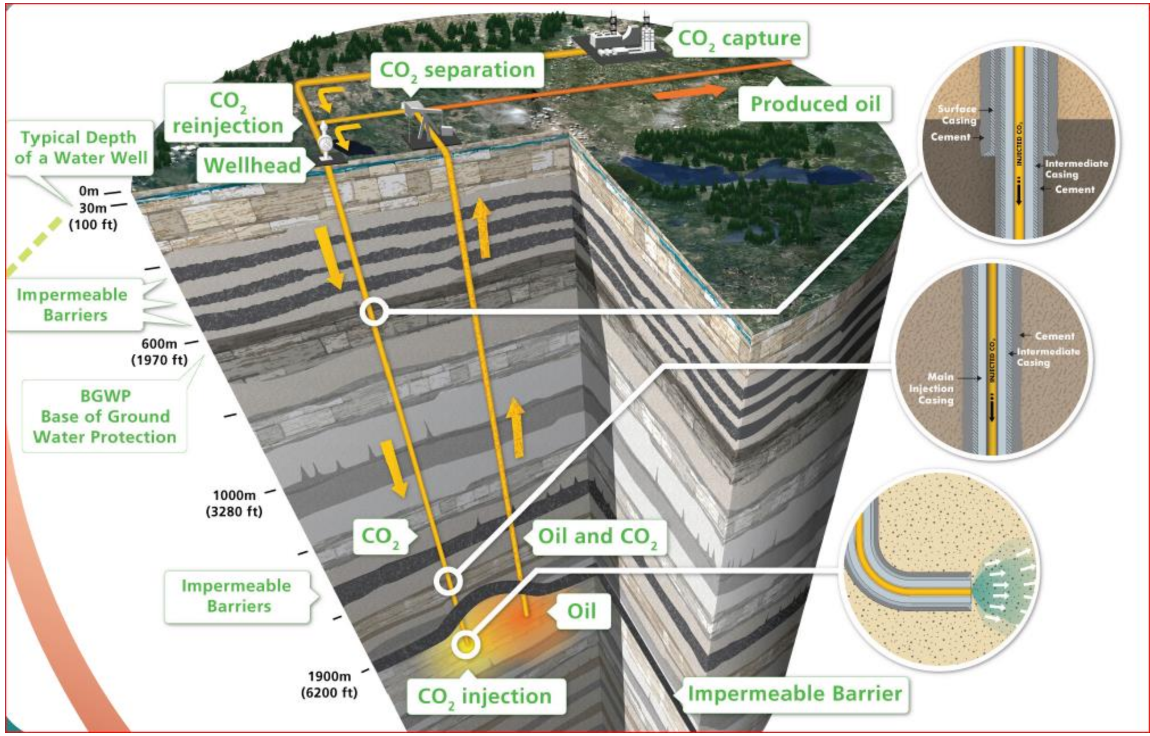
EOR & Storage

- The anchor projects for the ACTL are the Clive Nisku and Leduc reservoirs owned and operated by Enhance Energy.
- These mature reservoirs lie at a depth of 6,000 ft below ground.
- The ACTL will enable the production of 1 Billion barrels of light oil and storage for 2 Billion tonnes of CO_2.
- Additional CO_2 will be safely stored after EOR operations have been completed in depleted reservoirs which have stored oil and gas for millions of years.

To future EOR/Storage sites and CO_2 producers
- Joffre petrochemical complex
- CO_2 potential 3.3 million tonnes per year

ACTL Capacity: 14.6 million tonnes of CO_2 per year

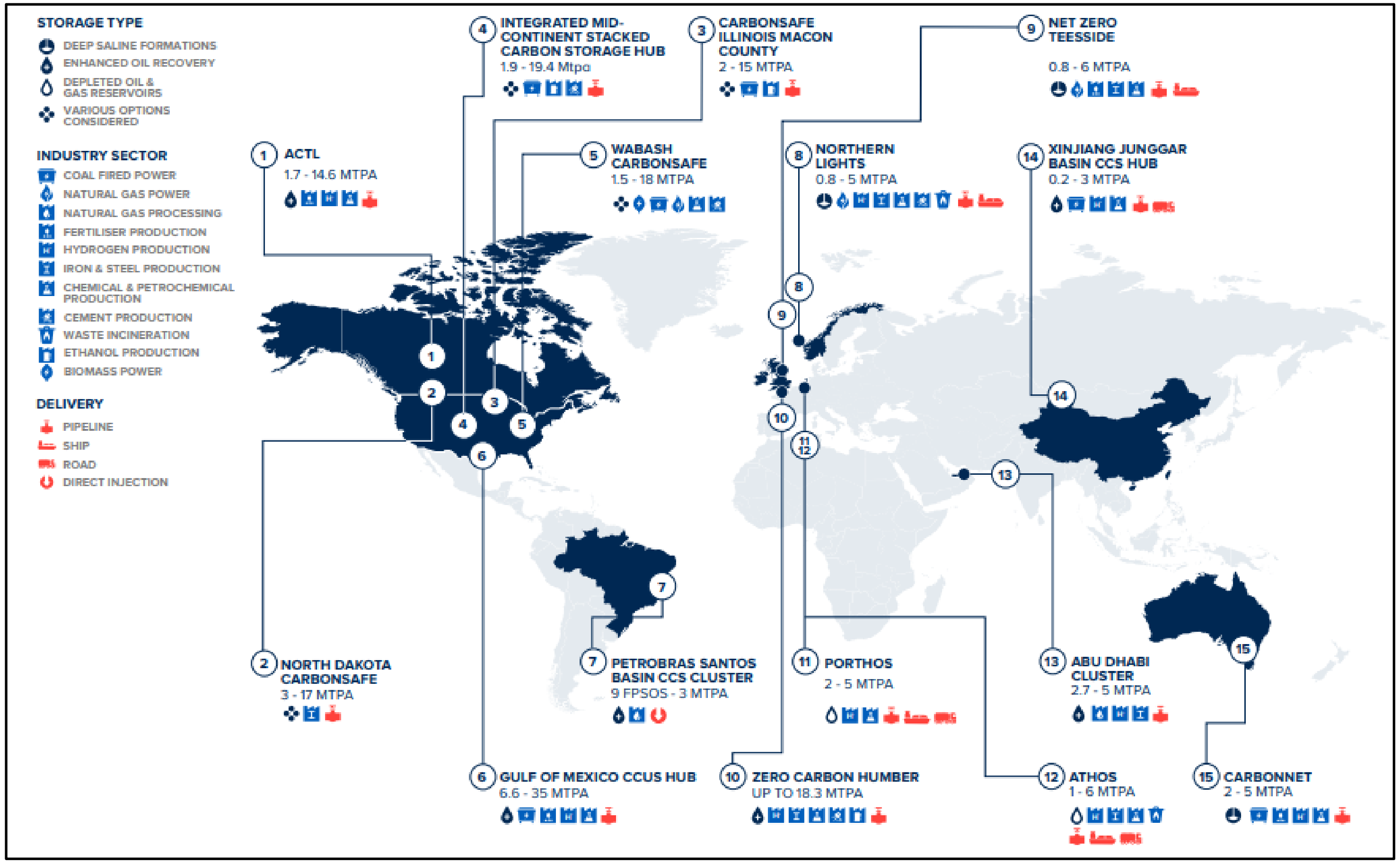




Enhance Energy Inc., the sequestration site operator for the ACTL project, has noted that since entering into operation in 2020, the ACTL project has captured and sequestered over 3.0 million tonnes of CO2 (https://www.alberta.ca/carbon-capture-utilization-and-storage-funded-projects-and-reports.aspx#jumplinks-1).

Advantages: 2-3. CCUS hubs and clusters decrease the unit cost of CO_2 transport and storage and reduce the risk of investment

- CCUS hubs and clusters take advantage of the fact that many emissions intensive facilities (both power and industrial) tend to be concentrated in the same areas.
- **Hubs and clusters significantly reduce the unit cost of CO_2 storage through economies of scale, and offer commercial synergies that reduce the risk of investment**.
- Shared lessons and standardization will bring down the costs of carbon capture and **reduce risk**.
- In the early stages of appraising potential new storage sites for hubs, **sharing costs and risks make it simpler to get started** in areas that have not been developed.



Source: Global Status of CCS 2020, GCCSI, 2021

Source: CCUS HUBS AND CLUSTERS GLOBALLY, WITH SIGNIFICANT DEVELOPMENTS IN 2019, CCUS Playbook, 2022

Advantages: 4. CCUS HUBS AND CLUSTERS REDUCE CROSS-CHAIN RISK

- The CCS value chain requires a broad range of skills and knowledge. In most cases the CO2 capture plant operator will not have the competencies needed for handling and transporting dense phase gases, or appraising and operating geological storage. Similarly, a host plant operator such as a cement manufacturer, will be unlikely to have expertise in CO2 capture, transport or geological storage. In most cases, a maximum efficiency value chain will involve multiple parties, each specializing in one component.
- A CCS project requires coordination of multiple investment decisions, all with long lead times.
- Once a CCS project is operating, interdependency along value chain actors remains. The storage operator relies upon the capture operator to supply CO2 and vice versa.
- If any element of the chain fails, the whole chain fails. **This creates cross-chain risk.** In general, regional colocation of industries and firms creates an industrial ecosystem that benefits all.
- **CCS networks reduce counterparty or cross chain risks by providing capture and storage operators with multiple customers or suppliers.**
- **Cross-border transport networks** enable nations lacking good local CO2 storage resources to undertake CCS projects. For example, industrial regions such as Dunkirk, France; Ghent, Belgium; and Gothenberg, Sweden; are planning to aggregate their industrial CO2, then liquefy and ship it for storage in the North Sea, including via Norway’s Northern Lights project.

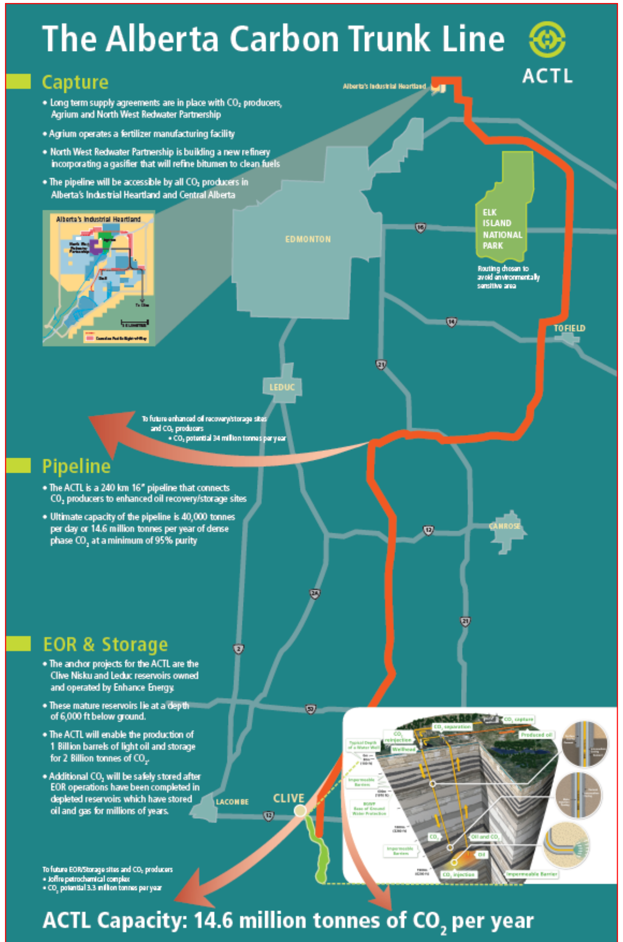
Source: (GCCSI 2021).

Advantages: 5. More support from government and EU Innovation Fund

- A hub can decarbonize an entire industrial region, saving jobs and attracting clean new industries.
- With such **social and economic benefits**, on top of its contribution to meeting climate goals, a hub is much more likely than an individual project to gain **government support**.
- Efforts to create hubs in the UK, for example, have ensured that the government develops policy incentives for emitters and operators.
- The Norwegian and Dutch governments worked to change European regulations on the cross-border export of carbon dioxide, and both Northern Lights and Porthos attracted large-scale EU funding.
- The Northern Lights has gained support from standard setter Verra and emitting industries to take a new look at carbon accounting for CCUS.
- The four CCUS projects that received support from the EU Innovation Fund in 2021 are all connected to a hub.

Advantages: 6. CCUS Hubs and clusters provides thousands new jobs

- The growing CCS industry provides opportunities for jobs across various industries, including, but not limited to, the fields of raw materials (e.g., MEA, steel), engineering and design (e.g., design of carbon capture, pipelines, injection sites, SCADA), construction (retrofitting, pipeline development, injection sites, trucking), operation, and maintenance (US DOE, 2022).
- It is common to require thousands of workers during peak construction demand for infrastructure projects, as seen with the Boundary Dam CCS facility in Canada (1,700 people) and the Alberta Carbon Trunk Line (2,000 people).
- New jobs will increase public acceptance



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Advantages: 7. CO2 use revenues

- Utilization may also extend to other industrial uses.
- CO2 can be used as a value-added commodity.
- This can result in a portion of the CO2 being permanently stored –for example, in concrete that has been cured using CO2 or in plastic materials derived from biomass that uses CO2 as one of the ingredients.

Bioenergy-BIOLOGICAL UTILIZATION OF CO2 INTO CHEMICALS AND FUELS

- **Description**

Microalgae absorbs CO2 and can then be converted into proteins, fertilizers and biomass for biofuels.

- **Opportunities**

competitive source of biofuel can use flue gas directly can result in permanent storage

- 1 tonne of micro algae can fix 1.8 tonnes of CO2
- **Barriers**
- algae sensitive to impurities, pH
- cost of controlling growth and drying conditions
- large area and sunny climate needed for ponds
- high energy need for photobioreactors

Examples of algal cultivation technologies: closed photobioreactor (Huang et al., 2017).

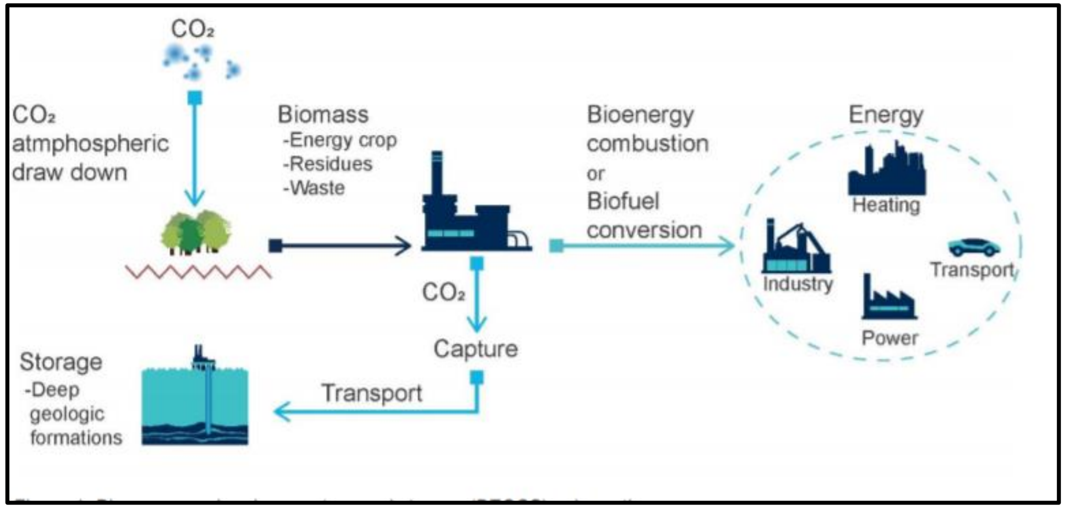
Examples of algal cultivation technologies: an open raceway pond (www.energy.gov/eere/bioenergy/production).

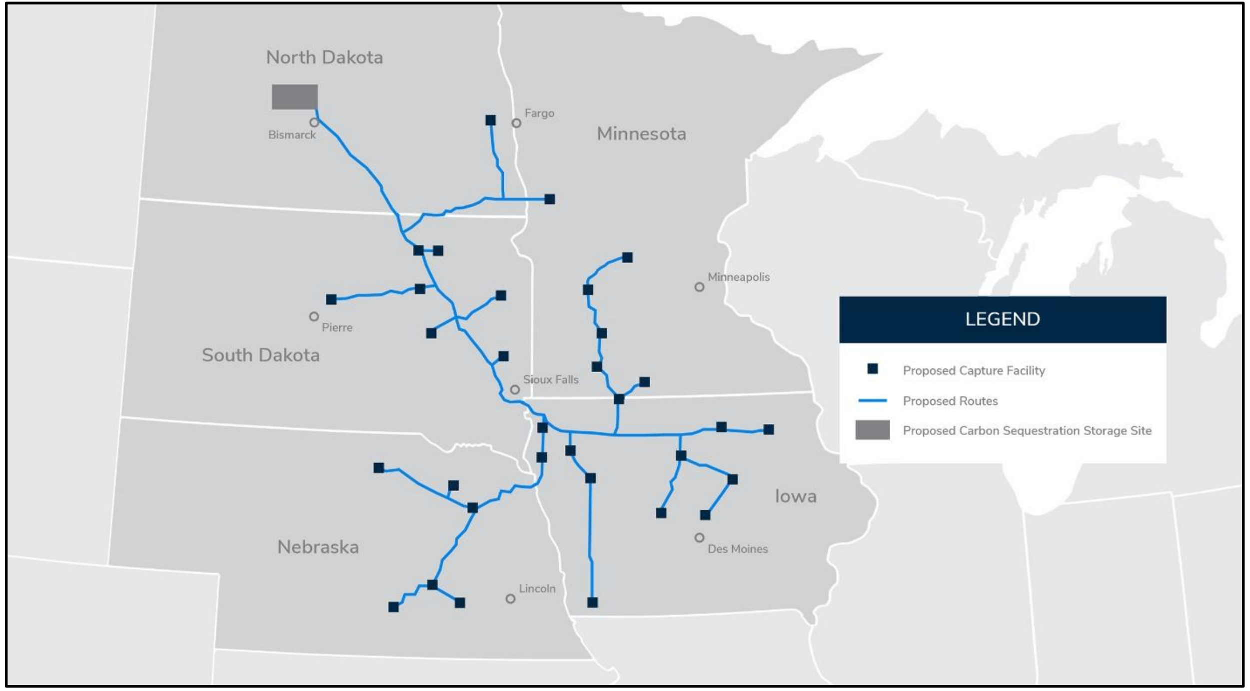
Advantages: 8. Synergy with renewables

- The CO2 can also be converted into biomass. This can be achieved, for example, through algae farming using CO2 as a feedstock. The harvested algae can then be processed into bio-fuels that take the place of non-biological carbon sources.
- Combined CCS and renewable energy schemes are emerging, e.g. with biomass leading to negative emissions (bio-CCS) or with **geothermal energy**, combining heat production and CO2storage.
- Combined with hydrogen produced by water electrolysis, CO2could be transformed **into gaseous or liquid hydrocarbons**, which will substitute in future primary fossil resources.
- Synergy with renewables will bring more revenues and increase public acceptance (improve public perception)

Advantages: 9. Synergy with CO2 negative technologies (BECCS)

- Bioenergy with Carbon Capture and Storage **BECCS**: Combining bioenergy production with carbon capture and sequestration can lead to net negative emissions as carbon stored by photosynthesizing rather than released to the atmosphere (IEA, 2011).
- The concept was first developed by Obersteiner et al. (2001) and by Keith (2001) as a potential mitigation tool.





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https://summitcarbonsolutions.com/project-footprint/

Advantages: 9. CO2 negative technologies
Direct Air Capture

- Direct Air Capture is a technology that captures carbon dioxide directly from the air with an engineered, mechanical system.
- DAC does this by pulling in atmospheric air, then through a series of chemical reactions, extracts the carbon dioxide (CO_2) from it while returning the rest of the air to the environment.
- This is what plants and trees do every day as they photosynthesize
- DAC does it much faster, with a smaller land footprint, and delivers the carbon dioxide in a pure, compressed form that can then be stored underground or reused.

https://carbonengineering.com/our-technology/

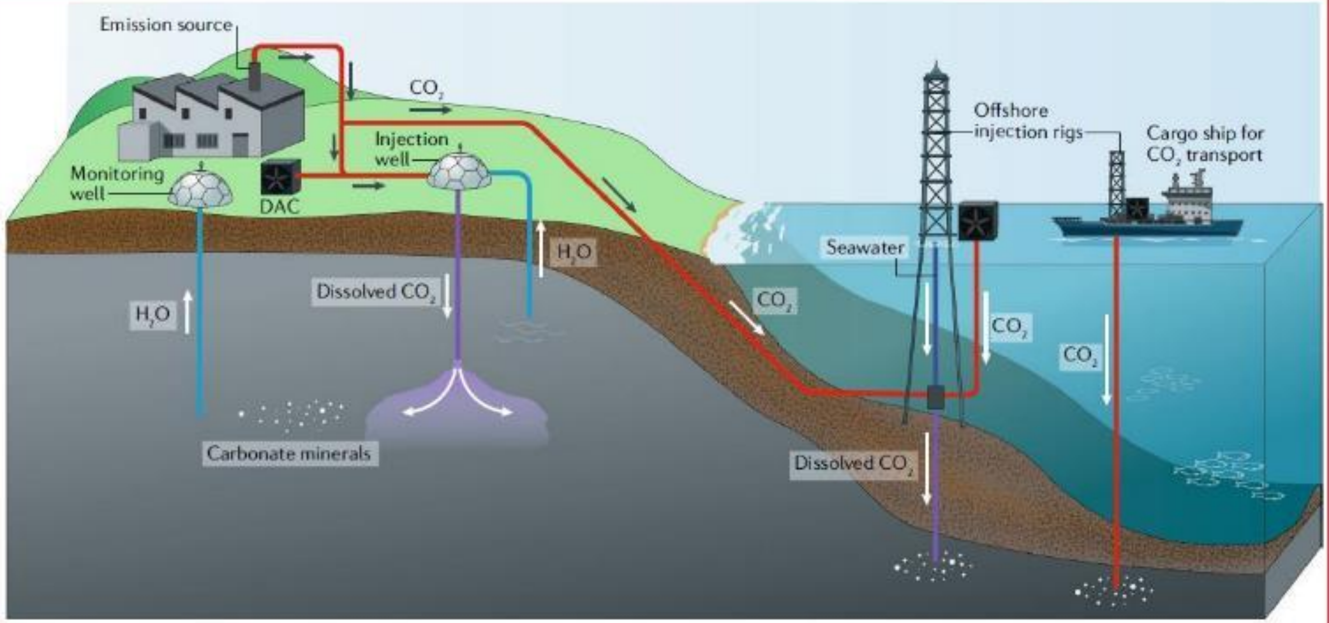


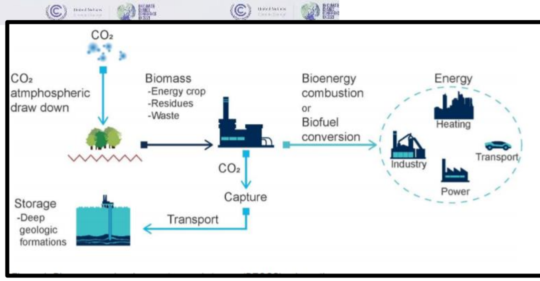
Fig. 6 | **Advanced carbon-mineralization operations.** Schematic illustrating the design of an industrial CarbFix operation, offshore injections and the integration of direct air capture (DAC) installations with carbon-mineralization technology (on land and offshore). For onshore operations, the CO_2 is dissolved in water prior to injection. For offshore injection, the CO_2 is either dissolved in seawater or injected as a separate supercritical phase.

Combining of CO2 storage in basalts with direct air capture
(Snæbjörnsdóttir S. O. et al, 2020, Nature Reviews, Earth & Environment)

Advantages: 10. Increased public awareness and improved perception

Factors increasing public acceptance (improving public perception)

- New jobs
- Governmental support
- Support from Innovation Fund
- Synergy with renewables
- Faster achievement of climate targets and decrease of extreme climate events
- Possibility to include carbon-negative technologies



POSSIBLE CHALLENGES

- 1. Complexity
- 2. Technical
- 3. Political
- 4. Regulatory
- 5. Financial

➢CHALLENGES: Complexity

- A CCUS hub is a multi-stakeholder undertaking, which magnifies the need for careful communication and alignment between partners.
- Decisions on commercial relations, risk management and long-term investments must all be agreed between emitters, operators and government – who are all acting with different drivers and timescales.
- Countries that are pioneering hubs, such as the UK, Norway and the Netherlands, are building on years of frustrating attempts to get large-scale CCUS off the ground.
- They have learned lessons from these failures and are now applying them to make CCUS hubs a reality.

Source: THE CCUS HUB PLAYBOOK / The Role of CCUS Hubs, 2022

CHALLENGES: Political

- For CCUS cluster implementation CCUS technology should be included into the national climate strategy
- In case of transboundary cluster, bilateral and multilateral political agreement between countries are needed
- National governments should take decision about supporting of CCUS cluster development, and later it could be resulted in the national financial support

CHALLENGES: Political challenges in the BSR

- **National climate strategies include CCUS in:**

➢ Norway
➢ Denmark
➢ Sweden

CCUS is not yet included in strategies in the

➢ Baltic States (future prospects in Latvia)
➢ Finland
➢ Poland (future prospects in Poland)
➢ Germany

- Political agreement for transboundary clusters:

Support of national governments resulted in the national financial support available now only in

➢ Norway
➢ Denmark

CHALLENGES: Regulatory

- CO2 storage should be permitted in industrial scale in the countries involved in the CCUS cluster
- For this EU CCS Directive should be implemented and CO2 storage permitted
- EU ETS Directive should be extended to various CO2 transport options (ship, truck, railway). At the present time only CO2 pipelines are included.
- For CO2 export and storage offshore amendment to the article 6 to London Protocol should be implemented
- However, according EU CCS Directive, bilateral agreements between countries could serve instead of LP too (latest message from EC DG Climate).

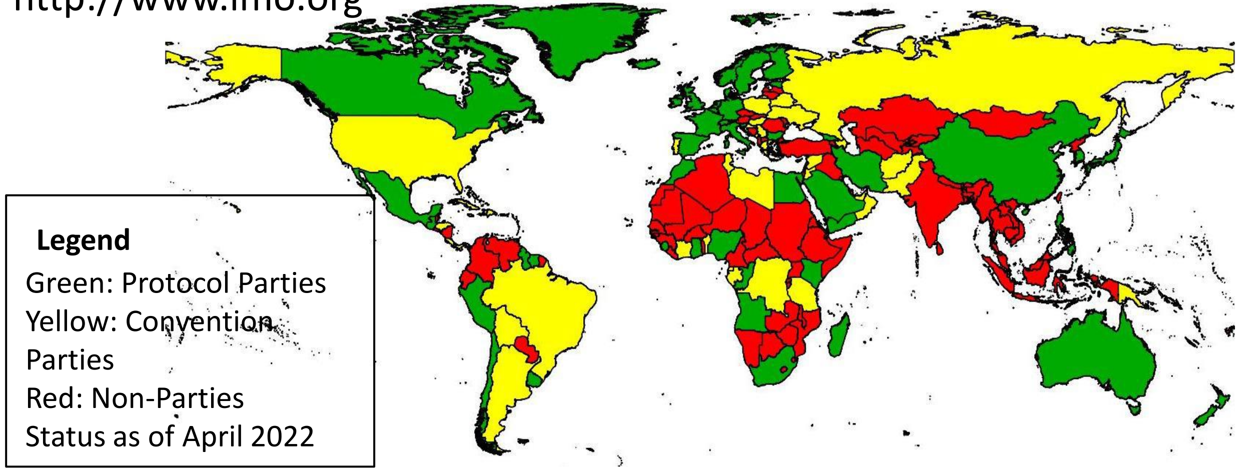
Challenges in national CCS regulations in the BSR

- The most negative latest change in the BSR is banning of CO_2 injection in Lithuania, which came into force in July 2020.
- Before this ban, Lithuania was only one BSR country, where CO_2 storage was permitted both onshore and offshore.
- In Denmark regulations prohibited storage until 2020 (and still now), except for offshore CO_2 -EOR.
- CO_2 storage is prohibited in Poland until 2024 except for demonstration offshore projects. CO_2 use for EOR and EGR and associated CO_2 storage onshore and offshore are allowed. The progress is ongoing (see next slides).
- The mass of CO_2 which can be stored was limited in Germany until 2018 (up to 4 Mt CO_2 can be stored annually and a maximum of 1.3 Mt for any individual project) and CO_2 storage is banned in 5 German Federal States.
- CO_2 storage is prohibited except for research and development in Estonia, Finland and Latvia. Progress could be achieved in Latvia ((see next slides).
- Offshore CO_2 storage is permitted in Sweden and in Norway.

Challenges in International regulations in the BSR

Amendment to article 6 of the London Protocol, 2009 by July 2022

Map of Parties to the London Convention/Protocol (April 2022), IMO, 2022, http://www.imo.org



Legend
Green: Protocol Parties
Yellow: Convention Parties
Red: Non-Parties
Status as of April 2022

BSR Country	London Convention 1972	London Protocol 1996	Amendment to LP 2006	Amendment to LP, 2009 Article 6
Denmark	X	X	X	X
Estonia	–	X	X	X
Finland	X	X	X	X
Germany	X	X	X	–
Latvia	–	–	–	–
Lithuania	–	–	–	–
Poland	X	–	–	–
Sweden	X	X	X	X
Norway	X	X	X	X

- The amendment to Article 6 of the London Protocol, enabling trans-boundary offshore CO_2 storage by July 2022 has been implemented by **Norway, Finland, Estonia, Sweden and Denmark in the BSR.**
- The failure to ratify these amendments means that transboundary transportation of CO_2 for the purpose of geological storage still remains proscribed under the Protocol.
- **However, in October 2019 Parties to the London Protocol adopted a resolution to allow provisional application of an amendment to article 6 of the Protocol**

CHALLENGES: Technical

Technical challenges could be met at different parts of the value chain:

- Capture
- Transport
- Use
- Storage

- One of the common challenges is interdependency of the value chains and their readiness in the planned timeframe

CHALLENGES: Technical

Technical challenges could be met at different parts of the value chain:

- ➢Capture: technology is not yet demonstrated for this industry, or different fuel and material used needs technical modification, which is not yet demonstrated
- ➢Transport: landscape problems for some transport ways (mountains, rivers, lakes), combination of different transport options is needed, problems in switching from one transport option to another. Old infrastructure is not corresponding to new requirements (ISO standards, etc).
- ➢Use: Not enough, or too much waste or waste rock material for CO2 mineralization, new technology (not yet demonstrated), etc
- ➢Storage: CO2 storage atlas is not available. Not enough storage capacity, seal rocks (caprock) is absent, low porosity, or low injectivity, etc. Market of the storage sites is not available.

- One of the common challenges is interdependency of the value chains and their readiness in the planned timeframe

CHALLENGES: Technical in the BSR

Technical challenges could be met at different parts of the value chain:

- Capture: technology is not yet demonstrated for some industries and energy producers (example – Estonian energy production from oil shale, Schwenk Cement is working now in Germany on piloting CO2 capture, which later will be applied in Latvia and Lithuania, etc)
- Transport: Combination of pipelines and ship transport will be needed. No PCI project available yet for infrastructure in the BSR. Natural gas pipelines are still used and will be used for LNG from other countries than Russia.
- Use: CO2 use and synergy with renewables are not yet demonstrated, some funded by innovation fund projects will work in Sweden and Finland.
- Storage: Not available common and public storage storage atlas of the BSR (either not in Europe). Not Available capacity in Finland and Estonia, low porosity in depleted oil fields in Lithuania at depth 2 km and more, or low injectivity, etc. Market of the storage sites is not available in the BSR.
- The first captured CO2 in Finland and Sweden will be transported and stored by the Northern Lights (Longship) project.
- One of the common challenges is interdependency of the value chains and their readiness in the planned timeframe.
- The first captured CO2 cant find storage sites at the nearest location, because they geologically available, but not yet ready for the market.

CHALLENGES: Financial

Decision about financial support of the CCUS cluster should be or could be taken by

- National Government
- Industrial Partners
- European Regional Funds
- National and Regional Development Funds
- European Innovation Fund
- Other possible private Investments (actions emission, etc)
- Regional and European Investment Banks

The lack of funding by some of the partners could cause collapse of the cluster project, because of interdependences between partners

National Carbon Tax (NCT) in the BSR

- The first carbon tax ever introduced was in **Finland**, in **1990**.
- **Norway, Sweden** (both in **1991**) and **Denmark** (**1994**) followed.
- These four countries also introduced the first taxes and fees on other air pollutants, particularly on emissions of sulphur dioxide and nitrogen oxides.
- **A carbon tax introduced in Norway in 1991** has been successful in **incentivising** the development of the Sleipner and SnØhvit CCS projects.
- At **US$17/tCO2**, the cost of injecting and storing CO2 for the Sleipner project was much less than the **US$50/tCO2** tax penalty at the time for CO2 vented to the atmosphere
- This was complemented by a commercial need to separate the CO2 from natural gas to meet market requirements and provided a clear business case to invest in CCS.
- The current level of the tax is higher than the level when it was introduced, making the business case for CCS at Sleipner even stronger
- In 2018 NCT:
- in Finland – 77 US$=65 Euro/Tonne CO2
- Norway – 56 US$=50 Euro/Tonne CO2
- Sweden – 139 US$=120 Euro/Tonne CO2
- Denmark - 29 US$=25 Euro/Tonne CO2

NCT In 2021:

Source: IMF POLICY PAPER, 2019 FISCAL POLICIES FOR PARIS CLIMATE STRATEGIES—FROM PRINCIPLE TO PRACTICE

BSR Country	NCT in USD, 2020	Revenues generated, M USD	Revenues generated, %
Denmark	23.6 - 28.1	575	35
Estonia	2.3	2	6
Finland	**62.3-72.8**	1,525	36
Germany	-	-	-
Latvia	14.1	5	3
Lithuania	-	-	-
Poland	0.1	6	4
Sweden	**137.2**	2,284	40
Norway	**3.9-69.3**	1,758	66

Data: The World Bank. 2021. "State and Trends of Carbon Pricing 2021" (May), World Bank, Washington, DC. Doi: 10.1596/978-1-4648- 1728-1. License: Creative Commons Attribution CC BY 3.0 IGO

https://www.c2es.org/content/carbon-tax-basics/
Green- ETS, Red lines –NCT implemented or planned

Germany: From 1 January 2021, the rate of NCT is €25 per tonne of CO2 emissions.
This amount will rise to €55 in 2025 and €65 in 2026.

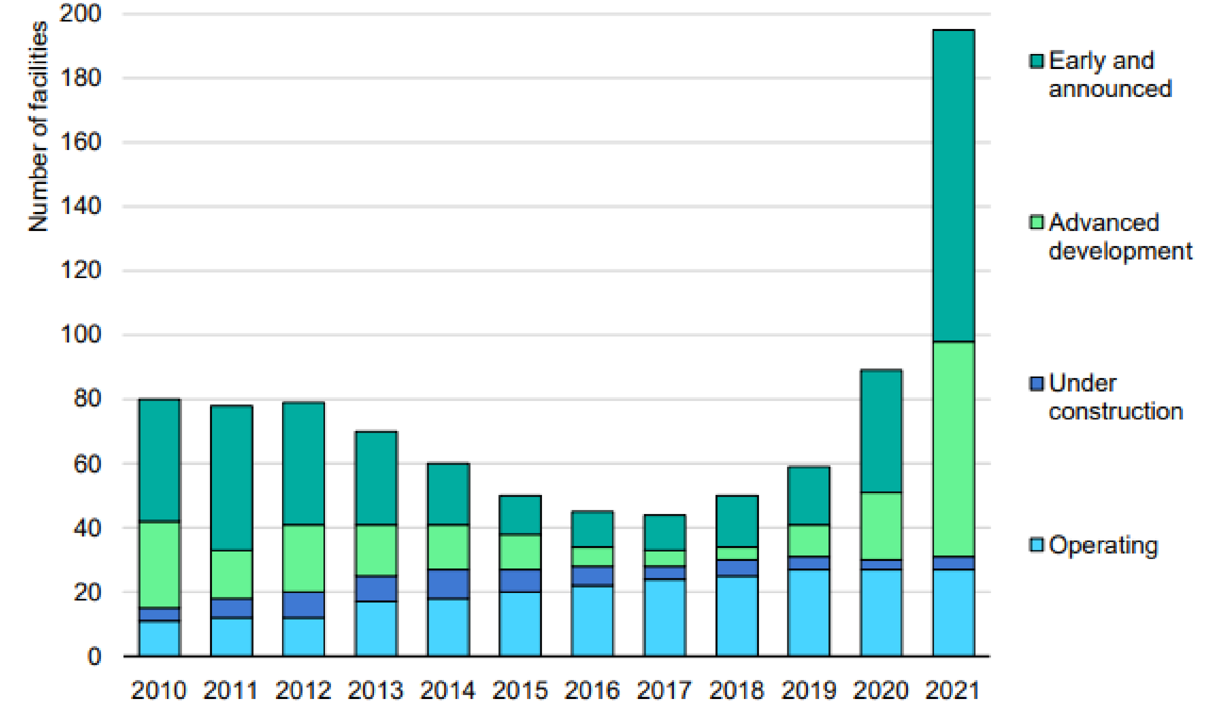
CHALLENGES: Financial (BSR)

- National Governments: Decision about financial support of the CCUS cluster is taken only in Norway and Denmark
- Industrial Partners: Decision about financial support of their possible CCUS pilot is taken in
- Norway, Denmark, Sweden, Finland, Poland …
- European Regional Funds: Not known yet
- National Development Fund: Not known yet
- European Innovation Fund supported CCUS projects in Norway, Sweden, Finland, Poland
- Private Investments: Not Known yet

1.2 The best-known CCUS clusters in the world: INTRODUCTION

- Today, close to **30 commercial CCUS facilities are operating** around the world, with capacity to capture over **40 million** tons (Mt) of CO2 a year.
- Some of these facilities have been operating for decades and progress has been relatively slow, with an average of around **3 Mt CO2** of new capacity added each year since 2010.
- In 2021, plans for more than **100 new CCUS projects were announced**.
- CCUS projects are now operating or under development in **25 countries** around the world and if all projects were to go ahead, the global CO2 capture capacity would quadruple by **2030.**

Global pipeline of commercial CCUS facilities operating and in development

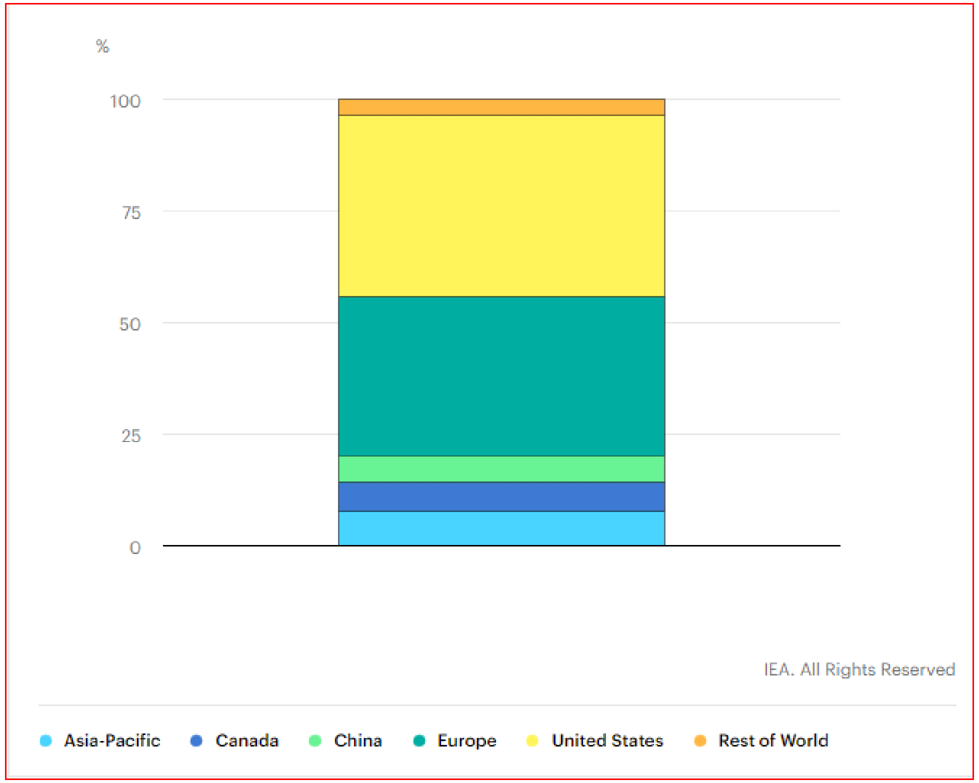


IEA. All rights reserved.

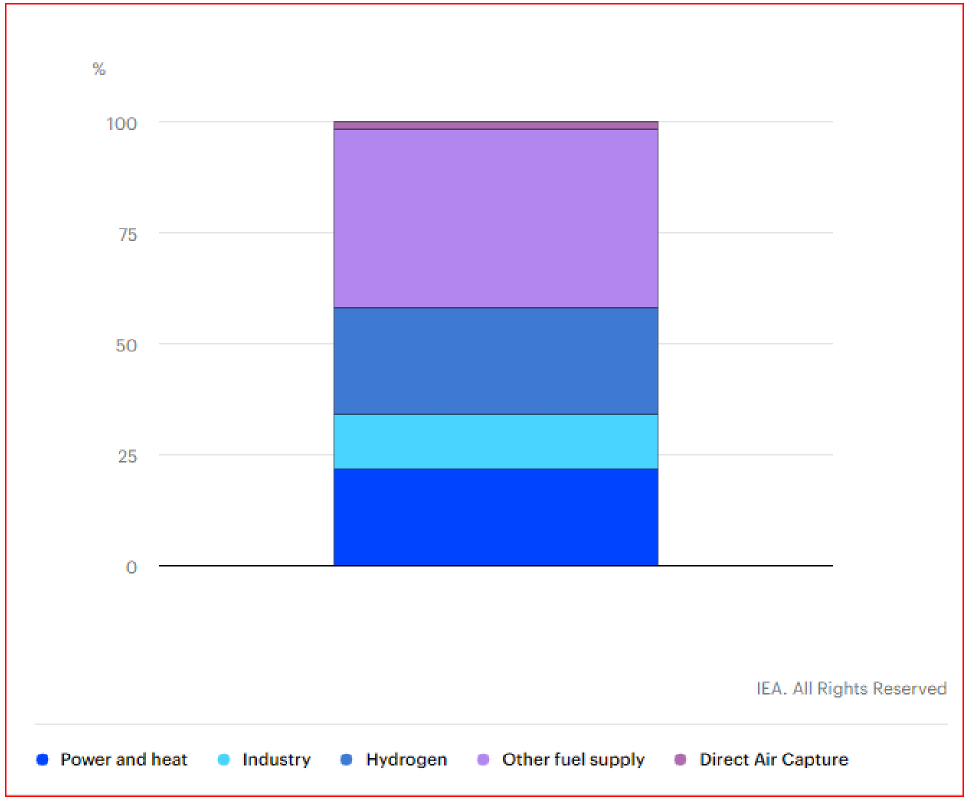
Source: IEA analysis and tracking; Global CCS Institute CCS Facilities Database https://co2re.co/

IEA, *Global pipeline of commercial CCUS facilities operating and in development, 2010-2021*, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-pipeline-of-commercial-ccus-facilities-operating-and-in-development-2010-2021, McCulloch S., 2021

CCUS projects are now operating or under development in 25 countries around the world, with the United States and Europe accounting for three-quarters of the projects in development



IEA, Global CCUS projects in development by region or country, 2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-ccus-projects-in-development-by-region-or-country-2021



IEA, Global CCUS projects in development by application, 2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-ccus-projects-in-development-by-application-2021

1.2 The best-known CCUS clusters in the world

CLEAN clinKER by calcium looping for low-CO_2 cement

CLEANKER

Integration of Buzzi and Heidelberg cement plants into the first operating and planned CCUS cluster projects worldwide, using CLEANKER project GIS database

Background

Technical and geological parameters of 12 CCUS cluster projects of different maturity were collected into the CLEANKER ArcGIS database and integrated with 12 Buzzi Unicem (BU) and HeidelbergCement Group (HCG) cement plants (CP) prospective for CO_2 capture.

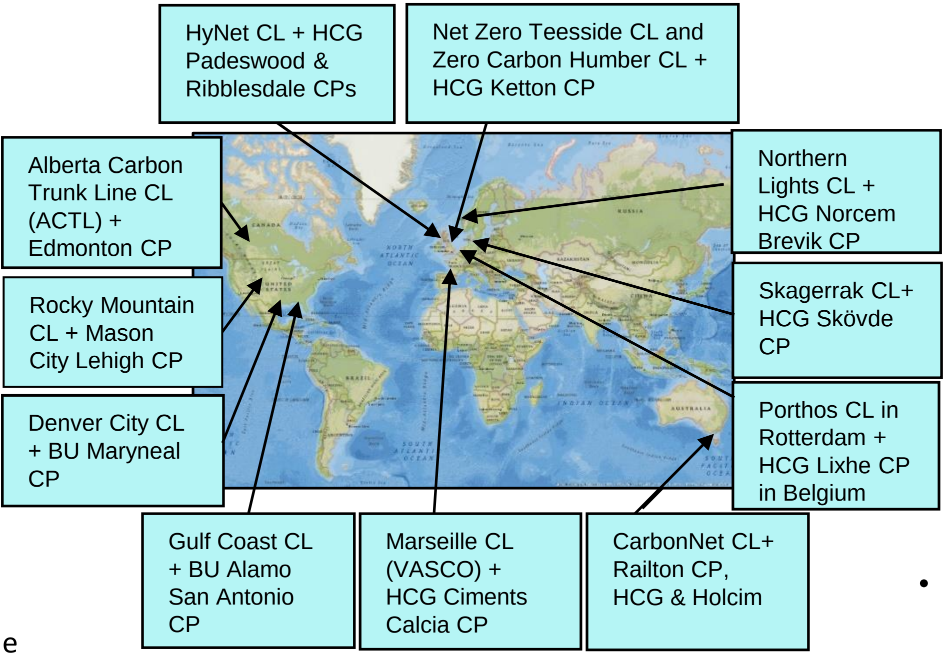
Objective

The main objective was to define suitable BU and HCG CP worldwide for CO_2 capture and CLEANKER project exploitation study, based on transport and storage opportunities of CCS clusters already well documented in the literature.

Methodology

Datasets were developed to collect parameters of the cluster projects and CPs . Data were integrated into ArcGIS. CO2 transport distance were determined from CPs to possible storage sites onshore and offshore. Possible amount of CO2 captured by CPs were determined, based on their annual CO2 production.

CO2 Cluster Projects (CL) with Cement Plants (CP) proposed



HyNet CL + HCG Padeswood & Ribblesdale CPs

Net Zero Teesside CL and Zero Carbon Humber CL + HCG Ketton CP

Alberta Carbon Trunk Line CL (ACTL) + Edmonton CP

Northern Lights CL + HCG Norcem Brevik CP

Rocky Mountain CL + Mason City Lehigh CP

Skagerrak CL+ HCG Skövde CP

Denver City CL + BU Maryneal CP

Porthos CL in Rotterdam + HCG Lixhe CP in Belgium

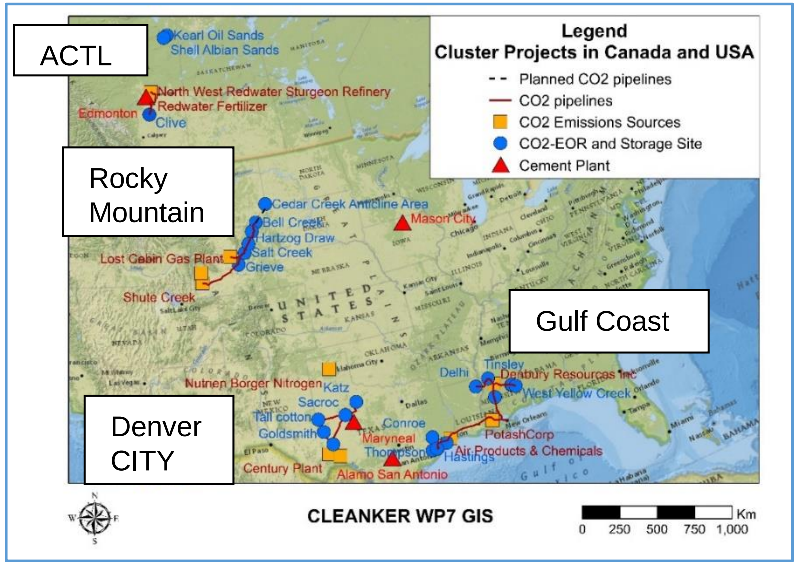
Gulf Coast CL + BU Alamo San Antonio CP

Marseille CL (VASCO) + HCG Ciments Calcia CP

CarbonNet CL+ Railton CP, HCG & Holcim

- Map updated after [1].
- Northern Lights project in Norway with Norcem Brevik is the 1st CP in the world included in the cluster project [3]

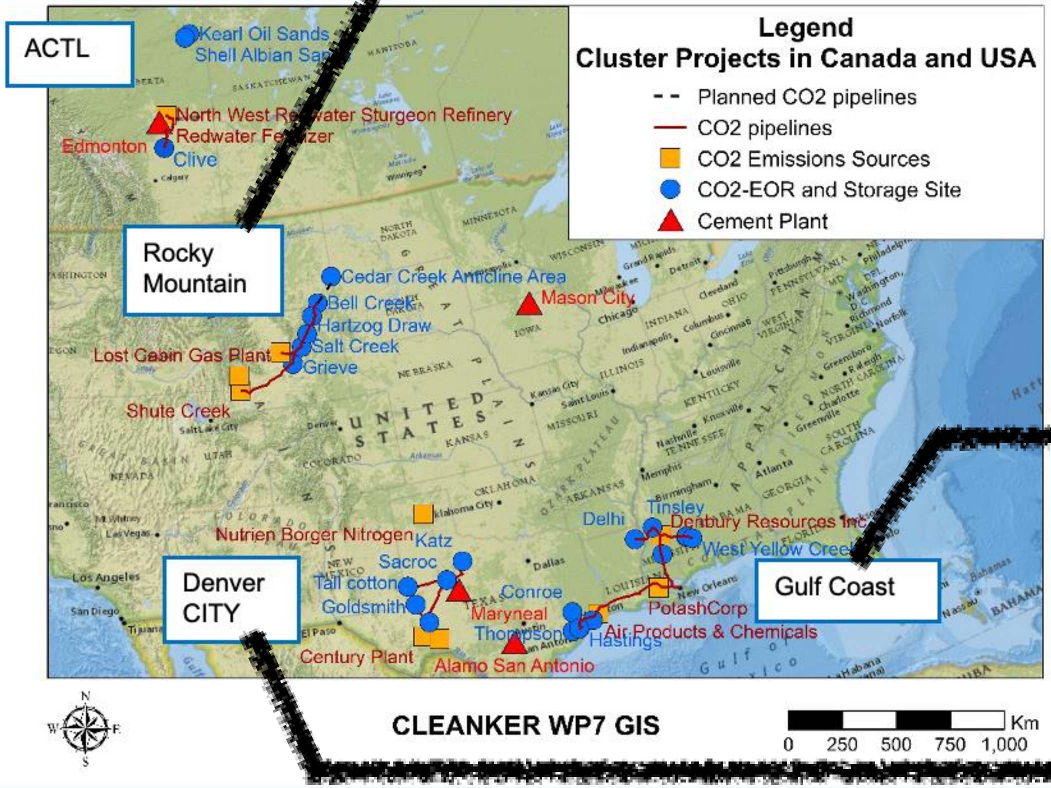
CO2-EOR projects in Canada and USA



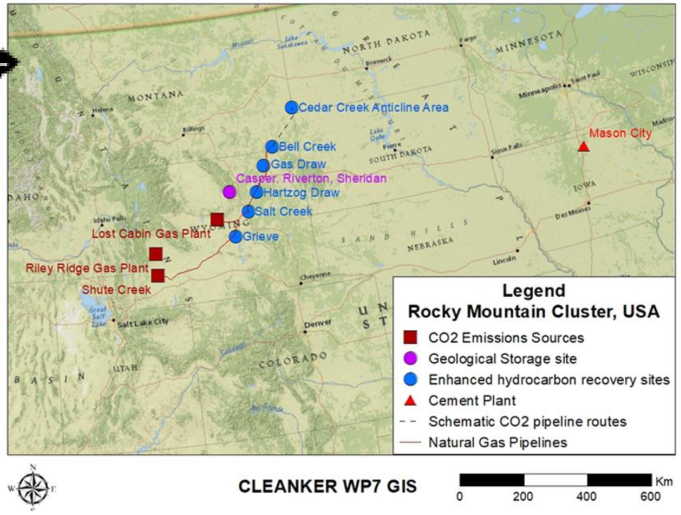
- ACTL project in Canada with **HCG Edmonton CP (**170 km from the Clive DOF) [5]
- Rocky Mountain project with **HCG Mason City Lehigh Portland CP**; [1, 6]
- Denver CITY project in Texas with BU **Maryneal CP (**81 km from Sacroc DOF) [1, 6]
- The Gulf oast project with BU **Alamo San Antonio CP** [1, 6]

1.2 The best-known CCUS clusters in the world

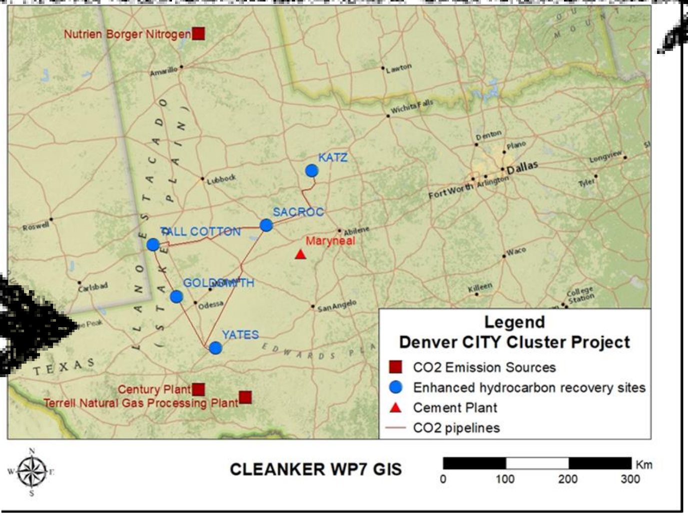
North-America cluster projects: Three studied cluster projects from USA are using **CO_2 for EOR.**



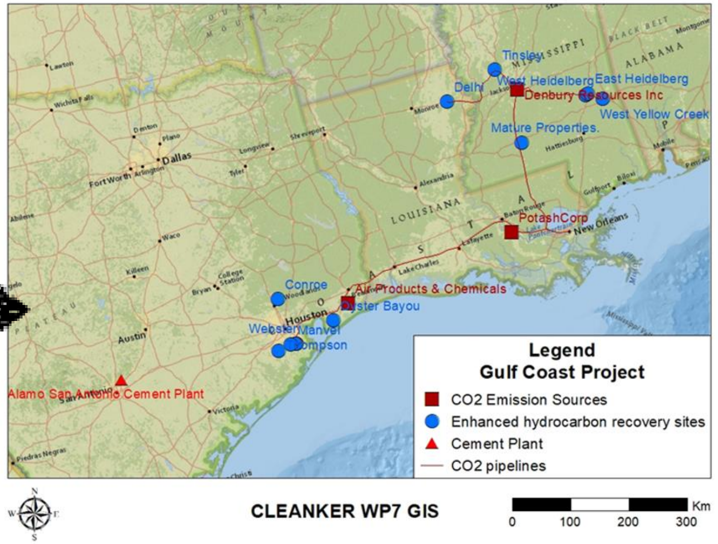
North American Cluster projects: (1) ACTL project in Canada with HCG Edmonton CP included; 2) Rocky Mountain project with HCG Mason City Lehigh Portland CP proposed; 3) Denver CITY Cluster project in Texas with BU Maryneal CP; 4) The Gulf Coast cluster with BU Alamo San Antonio CP



Rocky Mountain project with Mason City (Heidelberg) Lehigh Portland Cement Company Plant



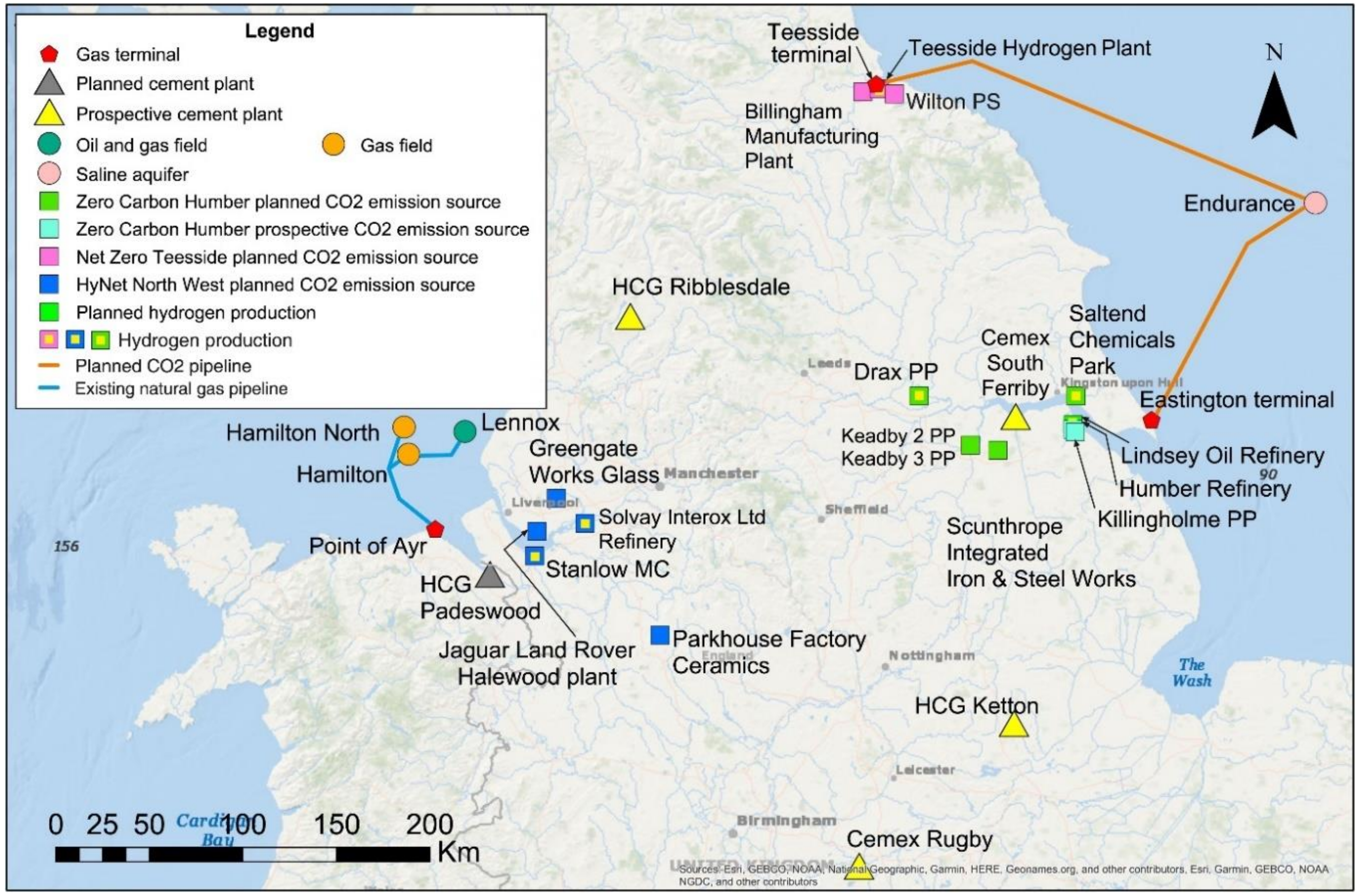
Denver CITY Cluster project in Texas with Maryneal Buzzi Unicem Cement Plant included

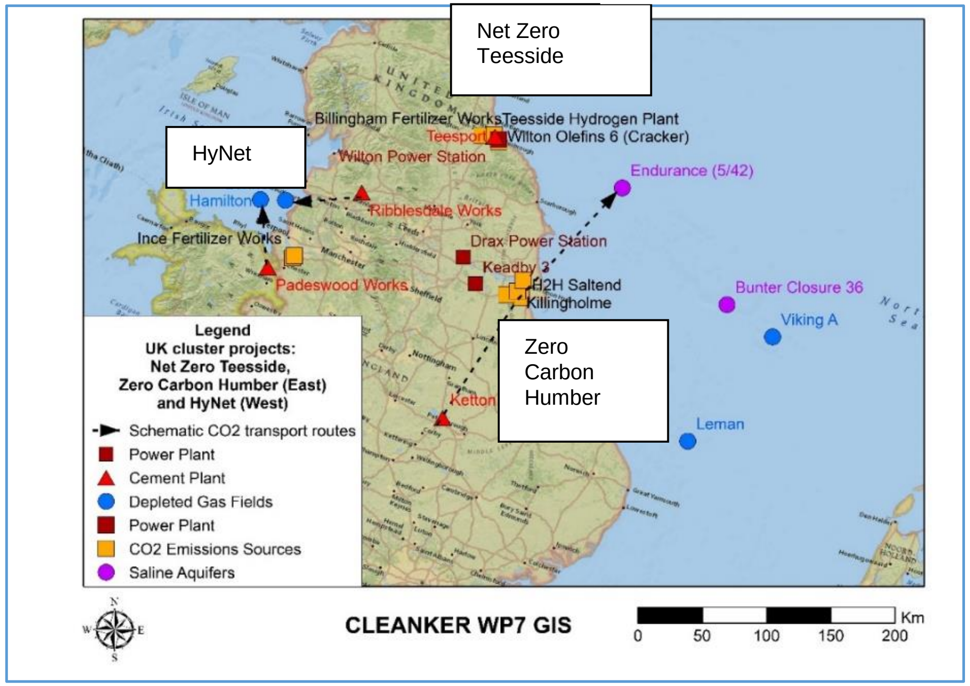


The Gulf Coast cluster in located in Texas, Lousiana and Mississipi states with Alamo San Antonio Buzzi Unicem Cement Plant as a possible candidate for exploitation study

CLEAN clinKER by calcium looping for low-CO_2 cement

1.2 The best-known CCUS clusters in the world: 3 UK clusters studied by the Cleanker project



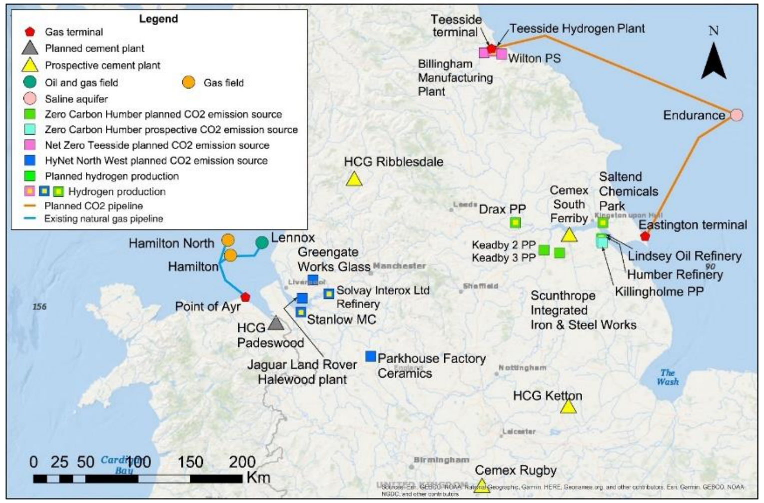


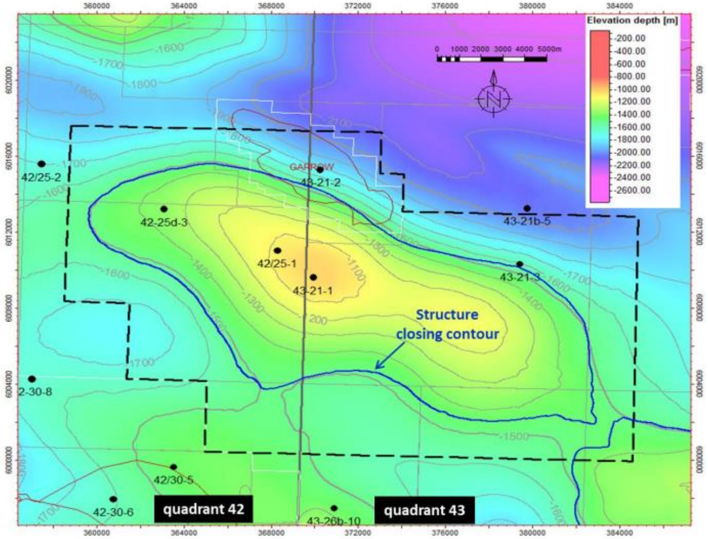
Three CCUS cluster projects in UK.

- HyNet North West cluster can integrate two CPs: Padeswood Works (60 km to Hamilton gas field) and Ribblesdale Works, Hanson UK (~120 km)
- Zero Carbon Humber CL with HCG Ketton Works, Hanson UK CP and storage in Endurance SA (~300 km) (in cooperation with Teesside cluster)

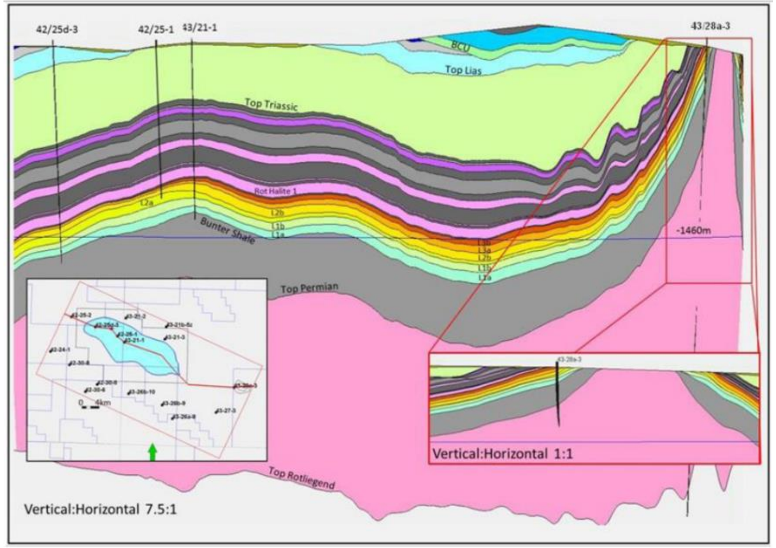
Source: Habicht G., 2021, Master thesis

1.2 The best-known CCUS clusters in the world:
3 UK clusters, Endurance Storage site

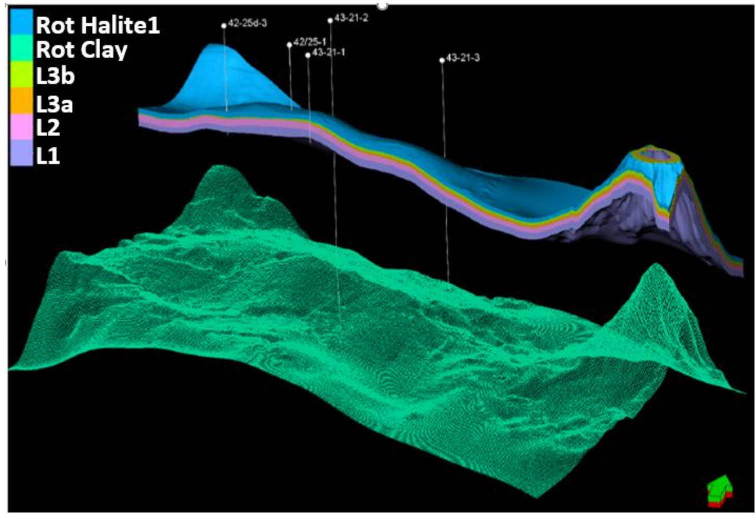




Structure map of the top of the Early Triassic Olenekian Bacton Group Bunter Sandstone Formation in the **Endurance Storage Site** showing licence block boundaries (broken black line) and exploration and appraisal wells. Only wells 42/25d-3, 42/25-1, and 43/21-1 have penetrated the Endurance structure (White Rose, 2016).



WNW-ESE cross-section through Endurance structure and salt diapir to SE (White Rose, 2016).



Static Model of **Endurance Storage Site** .
The Bunter Sandstone and Top Bunter have been divided into units units based on sedimentology, adapted from (White Rose, 2016).

Source: Habicht G., 2021, Master thesis

European Projects – Nordic Region

- The most developed European cluster project in Europe is the Longship project in Norway, with Northern Lights project transport infrastructure and storage site (PCI project) where, represented by HCG Brevik Norcem Cement Plant is already included [11] .
- The HCG Norcem Brevik CP, producing annually 1.2 Mt of cement and about 0.8 Mt of CO_2 is planning to capture annually 0.4 Mt CO_2 starting from 2024.
- It will be the first CP included into the full chain operating CCS project in Europe and in the world.
- The project will also capture 0.4 Mt CO_2 at the waste-to-energy plant **Hafslund Oslo Celsio (earlier Fortum Oslo Varme).**
- Equinor, Shell and Total, included in the main transport and storage consortium of the Northern Lights, are planning to develop an open access infrastructure for CO_2 transport and storage.
- Norway has committed USD 1.7 billion to the Longship project, which includes the Northern Lights offshore storage hub.

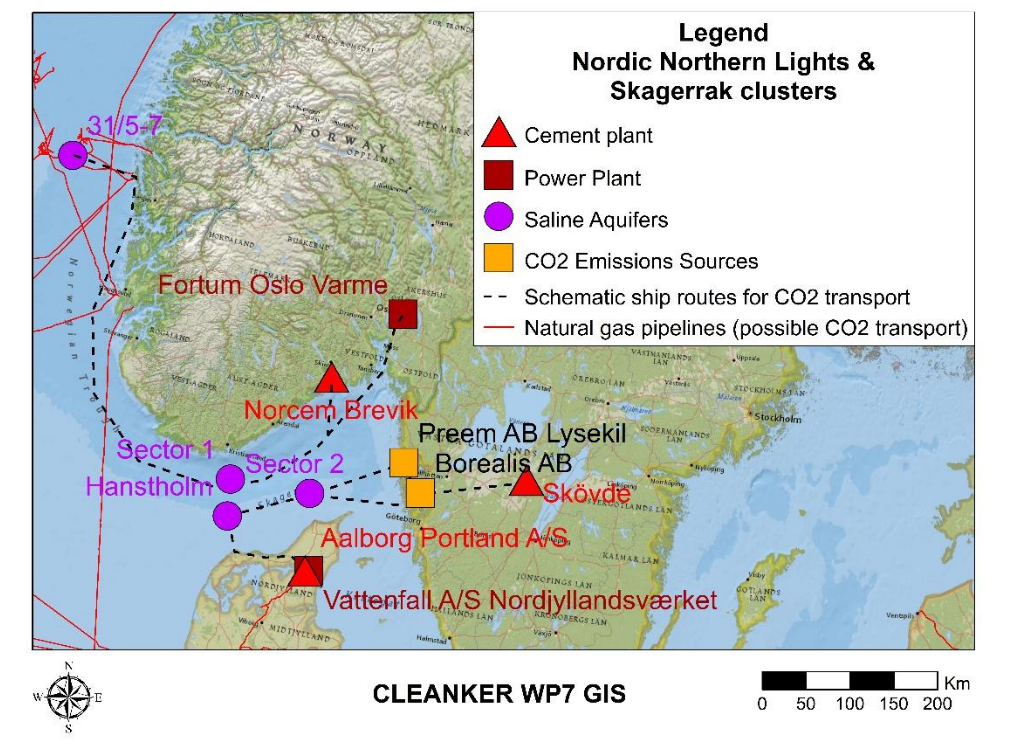


Fig. 6. Northern Lights cluster project in Norway (with already included Norcem Brevik CP) and Skagerrak project offshore Denmark with Aalborg Portland AS (2.2 Mt CO_2 produced in 2018) and possible candidate for exploitation study Skövde Cement Plant (with produced in 2018 504.7 Kt of clinker and 434.5 Kt CO_2).

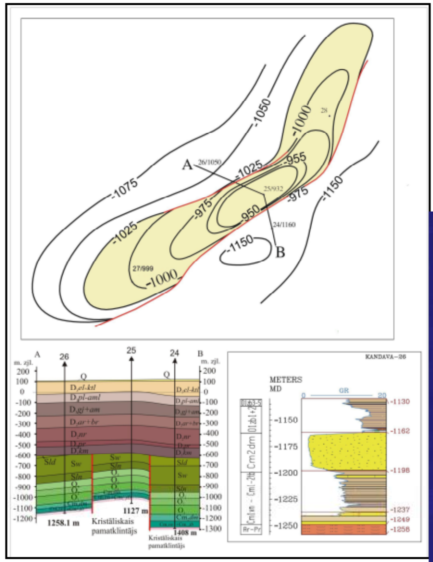
Key lessons Learned from Longship in Norway

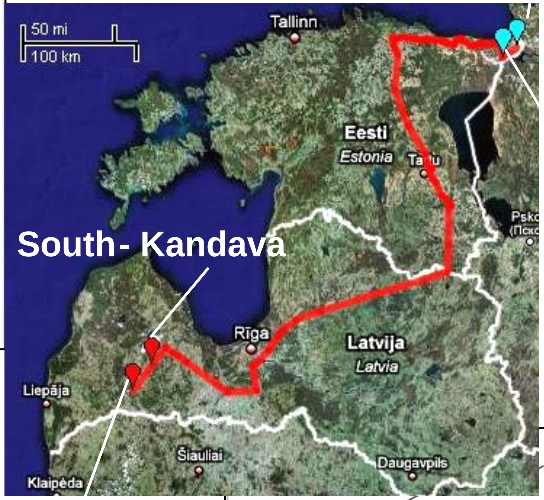
- Developing a CCS chain with CO2 capture, transport by ship and geological storage **is technically feasible and safe**, **but commercially challenging.**
- The London Protocol that has been a barrier for cross-border transport and storage of CO2. However, in 2019 the parties to the London Protocol agreed on a temporary amendment allowing export of CO_2 for the purpose of storage offshore. Aside from this, no regulatory showstoppers have been identified so far.
- It has been possible to develop the **CCS chain with limited use of new technology**, and only for the amine technologies used to capture of CO2 there are no fallback solutions.
- Although there are few comparable CCS chains world-wide, experienced and competent contractors and suppliers can be mobilized and the **technical know-how is readily available**.
- As expected for a first-of-its-kind CCS project, the net cost per tonne for capture, transport and storage is high; for **800,000 tonnes** per year the cost is around **NOK 1,280 (about 55 Euro for storage per one t CO2),** which will decrease with full utilization of the transport and storage facilities.
- The time needed to perform detailed engineering and construct transport and storage facilities based on ships and a greenfield CO2 receiving terminal is approximately **36 months**.
- For a capture plant retrofitted onto an existing industrial plant, this will take up to **42 months**.
- Upon approval by the Parliament, Norcem and Northern Lights will each enter an agreement with the government providing state aid to the construction and first ten years of operation of the CCS-facilities.
- Reflecting the balance between risks and opportunities in these agreements, **the state will bear approximately 84% and 73% of the expected cost of Norcem's and Northern Lights' projects, respectively.**
- The government is ready to cover 40% of Fortum Oslo Varme's cost provided that they are able to secure additional funding from third parties.

Source: Gassnova, 2020

1.3 Possible onshore and offshore cross-border scenarios in the Baltic Sea Region

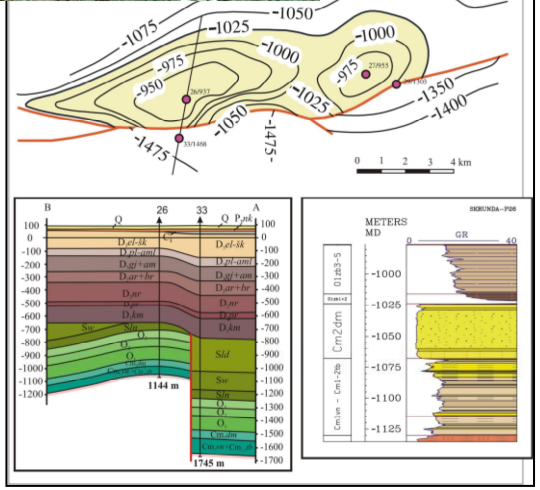
Economic modelling of the capture–transport–sink scenario of industrial CO2 emissions: the Estonian–Latvian cross-border case study, 2011





Luku-Duku

http://www.powerplant.ee/



Summary of the output parameters for Estonian–Latvian cross-border case study

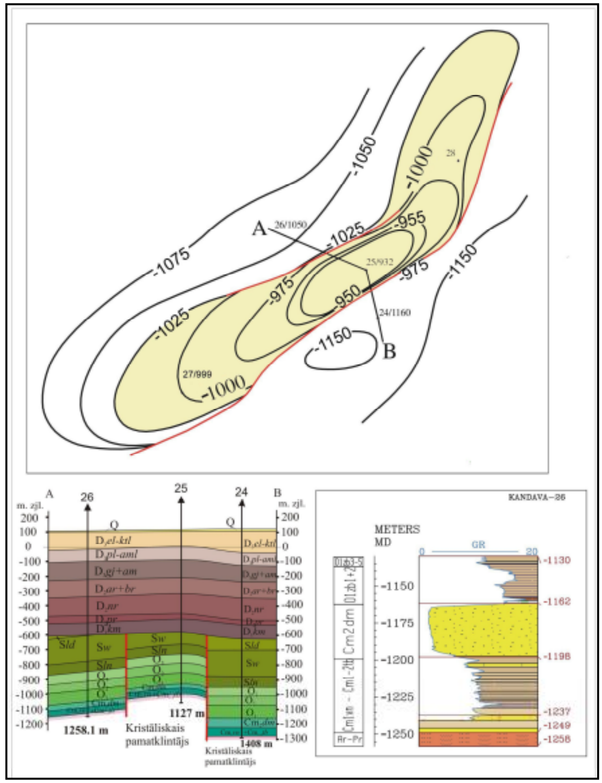
(NPV is a net present value, SRC NPV is a net present value for capture costs).

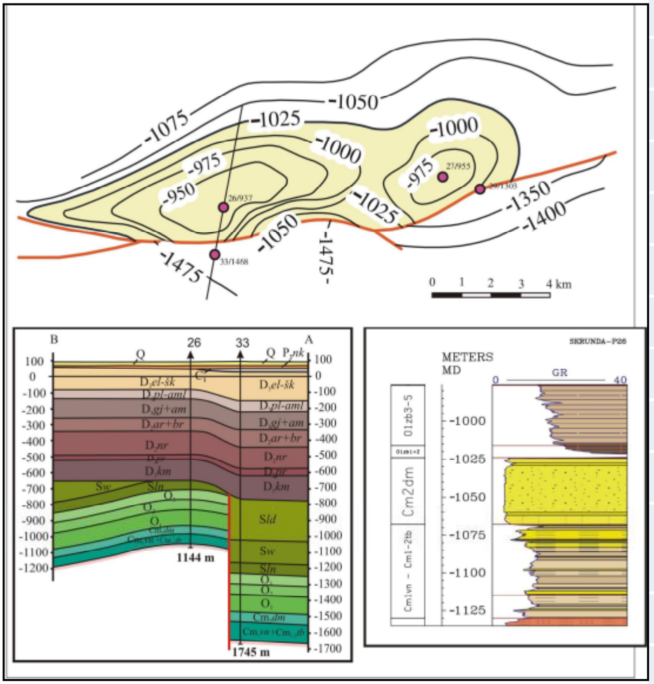
NPV	2835	€ million	NPV storage normalised	3.0	€/tCO$_2$injected
NPV capture	1928	€ million	Unit technical cost	37.4	€/tCO$_2$avoided
NPV compression	210	€ million	Pay out time	30	Yr
NPV transport	447	€ million	SRC NPV capture 0	1103	€ million
NPV storage	250	€ million	SRC NPV compression 0	162	€ million
NPV normalised	37.4	€/tCO$_2$avoided	SRC NPV capture 1	825	€ million
NPV capture normalised	25.5	€/tCO$_2$avoided	SRC NPV compression 1	48	€ million
NPV compression normalised	2.8	€/tCO$_2$avoided	SINK NPV storage 0	129	€ million
NPV transport normalised	5.3	€/tCO$_2$injected	SINK NPV storage 1	121	€ million

Reference

Shogenova, A., Shogenov, K., Pomeranceva, R., Nulle, I., Neele, F. and Hendriks, C. 2011. Economic modelling of the capture–transport–sink scenario of industrial CO2 emissions: the Estonian–Latvian cross-border case study. Elsevier, The Netherlands. *Energy Procedia* **4**, 2385-2392. | DOI |

Summary of the input parameters for storage in the GeoCapacity Model





Sink Name	Luku-Duku	South Kandava
Sink type	aquifer	aquifer
Depth (m) (from the earth surface)	1024	1053
Current reservoir pressure (bar)	93.7	98.3
Maximum reservoir pressure (bar)	107.8	113
Reservoir radius (km)	8	5
Trap radius (km)	8	5
Reservoir thickness (m)	45	28
Porosity (%)	22	20
Connate water fraction	0.25	0.25
Net to gross ratio	0.8	0.8
Reservoir temperature (°C)	19	11
Permeability (mD)	300	300
Well radius (m)	0.15	0.15
Storage capacity (MtCO_2)	40.2	44
Well injection rate (Mt/yr)	2	2
Storage efficiency factor in trap (%)	40	40
Number of wells	3	4
CO_2 concentration	20	20

Source: Shogenova, A., Shogenov, K., Pomeranceva, R., Nulle, I., Neele, F. and Hendriks, C. 2011. Economic modelling of the capture–transport–sink scenario of industrial CO2 emissions: the Estonian–Latvian cross-border case study. Elsevier, The Netherlands. *Energy Procedia* **4**, 2385-2392. | DOI |

Summary of results of 2011 economic modelling

- Two power plants close to the city of Narva, with annual CO_2 emissions of 8.0 and 2.7 Mt were chosen for the economic modelling of the capture–transport–sink scenario using the GeoCapacity Decision Support System (DSS) based on the GeoCapacity GIS database.
- Two anticlinal structures of Latvia, Luku-Duku and South Kandava with the area of 50−70 km^2 were selected for the CO_2 storage. The depth of the top of the Cambrian reservoir is 1020−1050 m, the thickness 28−45 m; permeability of sandstone is more than 300 mD, and the trap storage efficiency factor 40%.
- The conservative storage capacity of these structures 40 and 44 Mt of CO_2 respectively will be enough for 8 years. The estimated pipeline length required for CO_2 transportation is about 800 km.
- The oxyfuel capture technology is applied in this scenario. With a conservative storage capacity for 8 years of emissions, avoidance costs are rated at €37.4 per tonne of CO_2.
- The total cost of the project estimated by the Decision Support System using the GeoCapacity GIS is about €2.8 billion for 30 years of payment period.

Reference

Shogenova, A., Shogenov, K., Pomeranceva, R., Nulle, I., Neele, F. and Hendriks, C. 2011. Economic modelling of the capture–transport–sink scenario of industrial CO2 emissions: the Estonian–Latvian cross-border case study. Elsevier, The Netherlands. *Energy Procedia* 4, 2385-2392. | DOI |

Techno-economic modelling of the Baltic CCUS onshore scenario

- Proposed scenario:
- ✓ 6 CO2 emission sources
- ✓ CO2 use: Mineral Carbonation Plant (CO2+ Oil Shale Ash)
- ✓ Pipeline transport
- ✓ North-Blidene Storage site in Latvia
- ✓ Cambrian saline aquifer: Deimena Formation sandstones
- ✓ CO2 emissions: 2019

Mineral Carbonation Plant

- 110 kg of CO_2 /t OSA
- 250 kg of PCC (precipitated $CaCO_3$) from one t OSA
- 0.42 Mt CO2+3.8 Mt OSA= 0.95 Mt PCC/year

Revenues

- avoided EEAP 40 Euro/t CO_2
- 3 €/t OSA for OSA disposal
- 50 €/t PCC

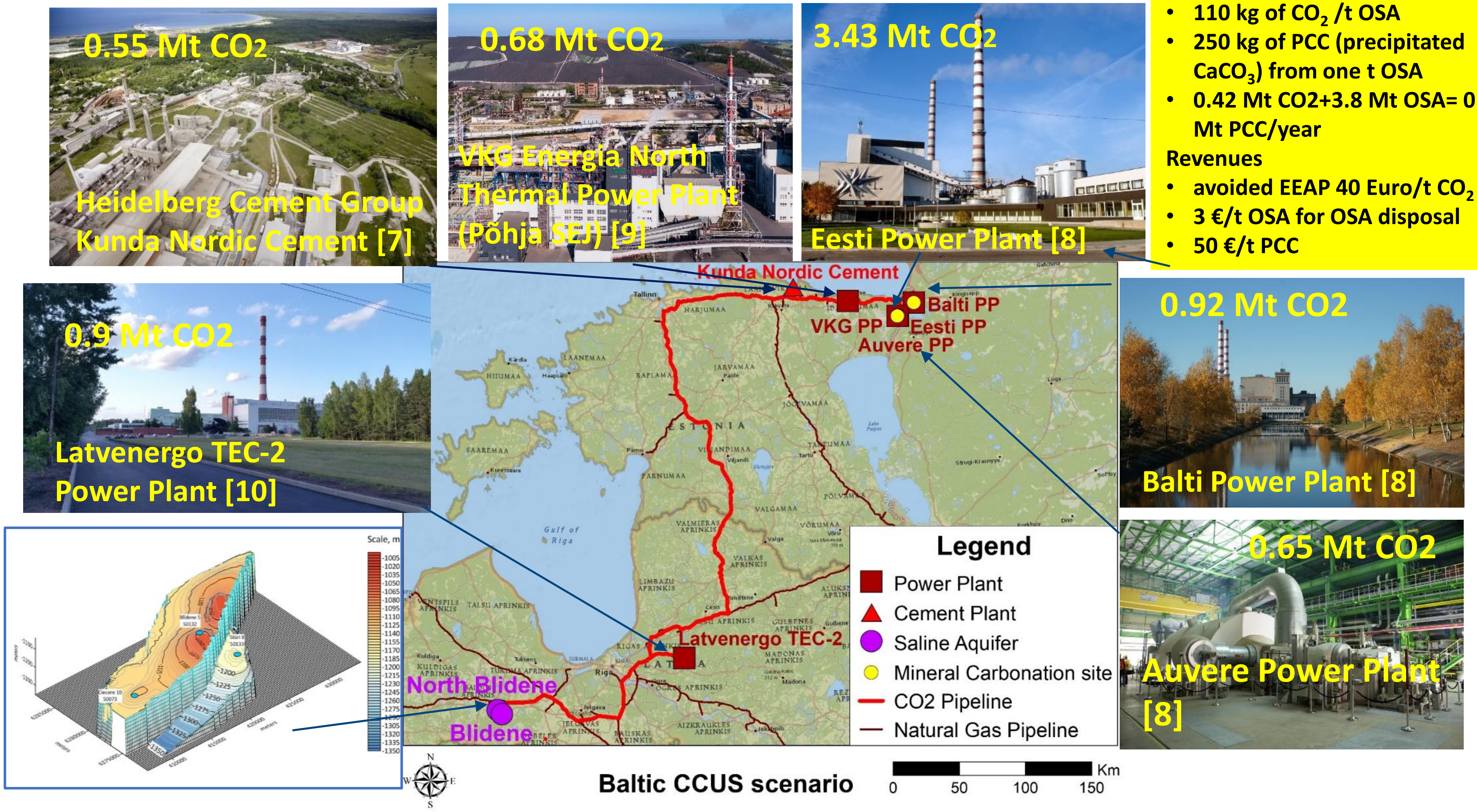


Fig 2. Baltic CCUS scenario.CO2 emissions produced in 2019 are shown in yellow colour

]

Innovative synergy CCUS and renewable energy project offshore Baltic using CO_2 emissions from the cement industry

TAL TECH
DEPARTMENT OF GEOLOGY

Kazbulat Shogenov & Alla Shogenova

- It is proposed **to capture CO_2 from the KNC** and from the **EPP in Estonia**, from the **Lithuanian LACP** and **Latvian TEC-2** (Fig. 2, Table 1).
- After CO_2 will arrive at the offshore platform or drilling rig of the E6 storage site, it will be injected into the CO_2 storage reservoir for **CGS and GCS** and to the oil-bearing reservoir to **enhance oil recovery** (Fig. 3).
- We are planning to drill **6 wells**: **3 wells for injection** (one for CO_2-EOR in the Saldus oil reservoir, two for GCS and CGS in the Deimena Formation), **2 for liquids recovery** (one for oil recovery from the Saldus Formation and one for warm water recovery form the Deimena Formation) and **1 for monitoring**.
- Small **wind offshore floating plant** is planned to be installed around the rig (Fig. 3).
- **Solar panels** will be installed at all available free surfaces of the rig and gained solar energy will be added to the project electricity net for covering energy needs of the project or for selling energy.

Scenario

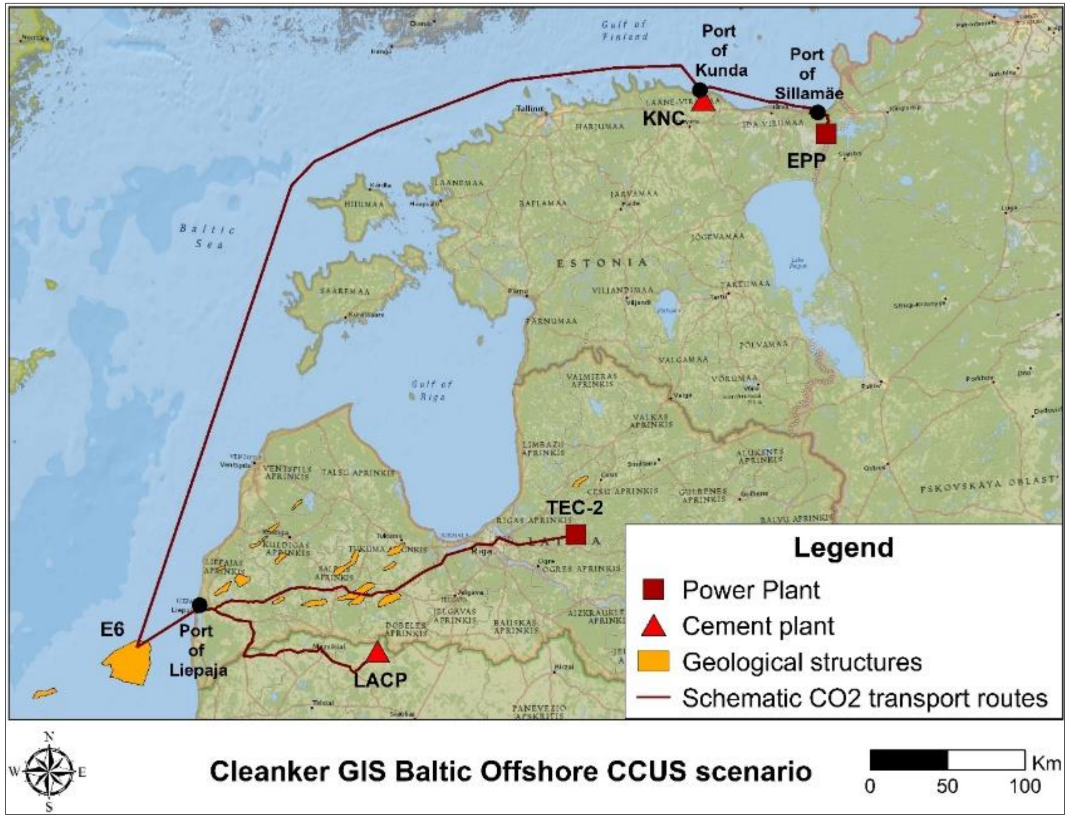


Fig. 2. Transport model of the proposed innovative synergy CCUS and renewable energy project offshore Baltic using CO_2 emissions from the cement industry and energy production from Estonia, Latvia and Lithuania

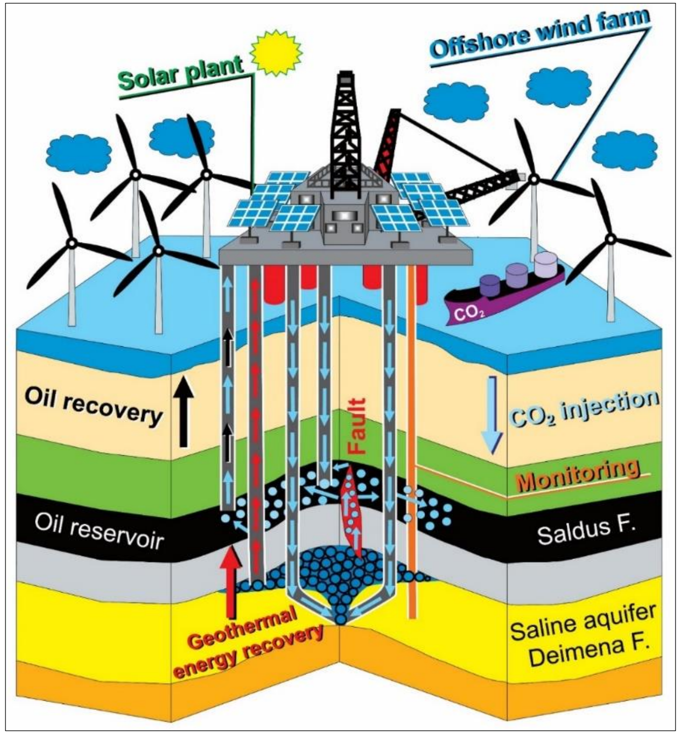
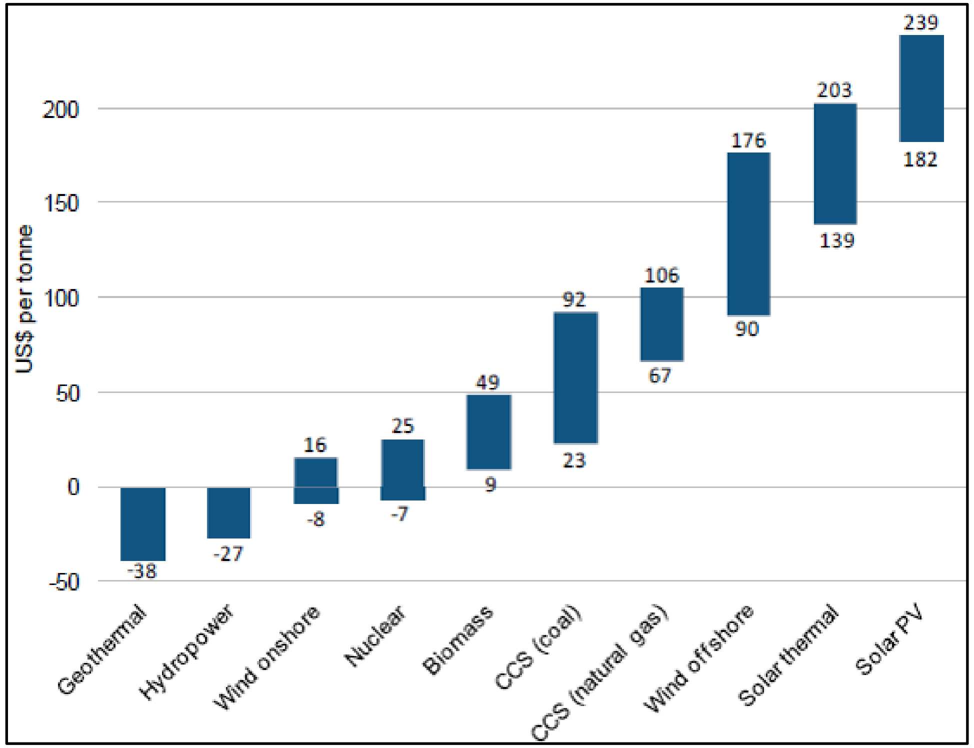


Fig. 3. Conceptual techno–ecological schematic model of CCUS project with different green renewable energy recovery technologies in the structure E6 including synergy of (1) CGS, (2) GCS, (3) CO_2-EOR/EOR+ in different geological formations in the same storage site and (4) solar energy and (5) wind energy recovery

COST ESTIMATION and COMPARISON

CCUS Cluster and hubs will reduce these costs estimated earlier and reported in 2015

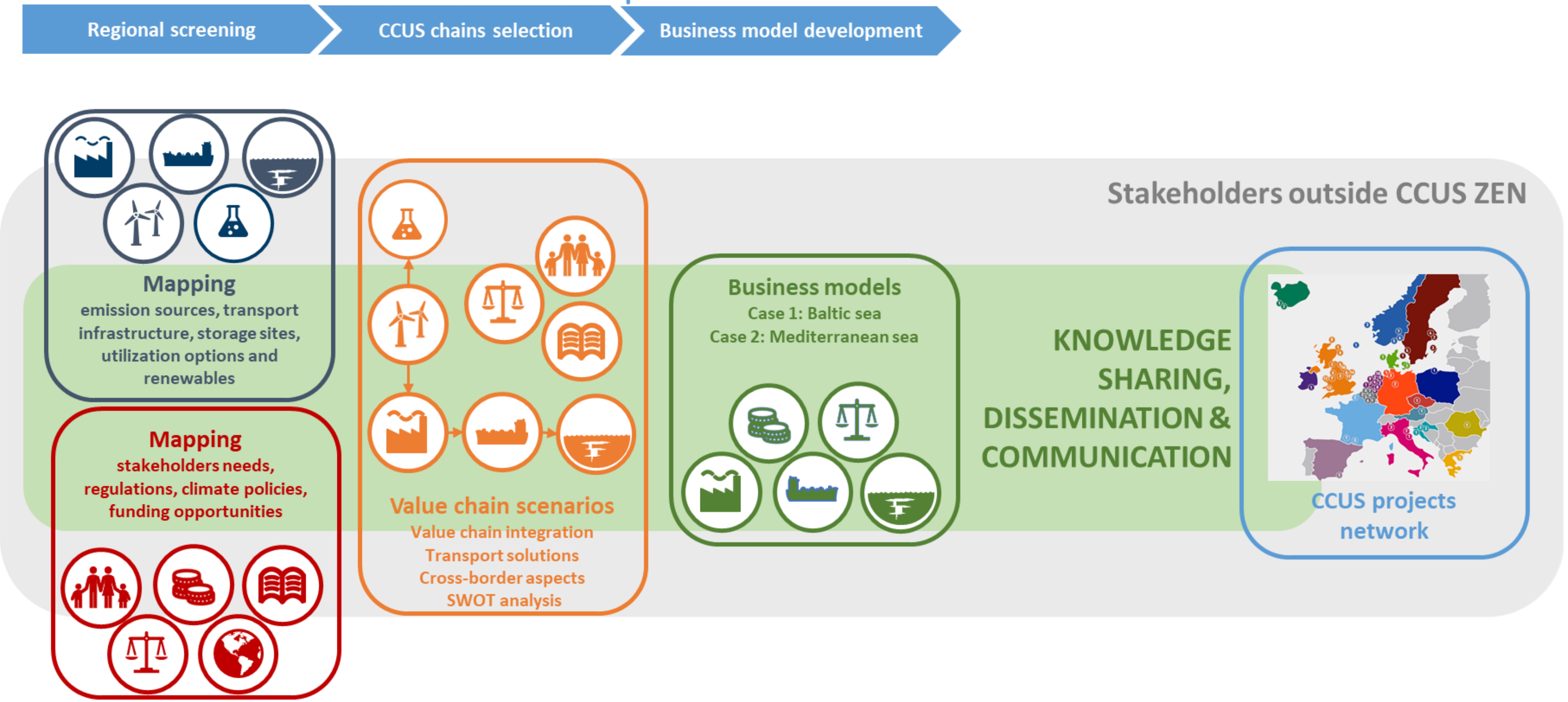


Support to the review of Directive 2009/31/EC on the geological storage of carbon dioxide, 2015

NEW PROJECT:
Zero emission network to facilitate CCUS uptake in industry
CCUS ZEN

This is a Horizon Europe CSA project. It started the 1 Sep 2022 and has a two and a half year duration.

CCUS ZEN framework for CCUS value chain development



Regional screening → CCUS chains selection → Business model development

Mapping
emission sources, transport infrastructure, storage sites, utilization options and renewables

Mapping
stakeholders needs, regulations, climate policies, funding opportunities

Value chain scenarios
Value chain integration
Transport solutions
Cross-border aspects
SWOT analysis

Business models
Case 1: Baltic sea
Case 2: Mediterranean sea

KNOWLEDGE SHARING, DISSEMINATION & COMMUNICATION

CCUS projects network

Stakeholders outside CCUS ZEN

Zero emission network to facilitate CCUS uptake in industry

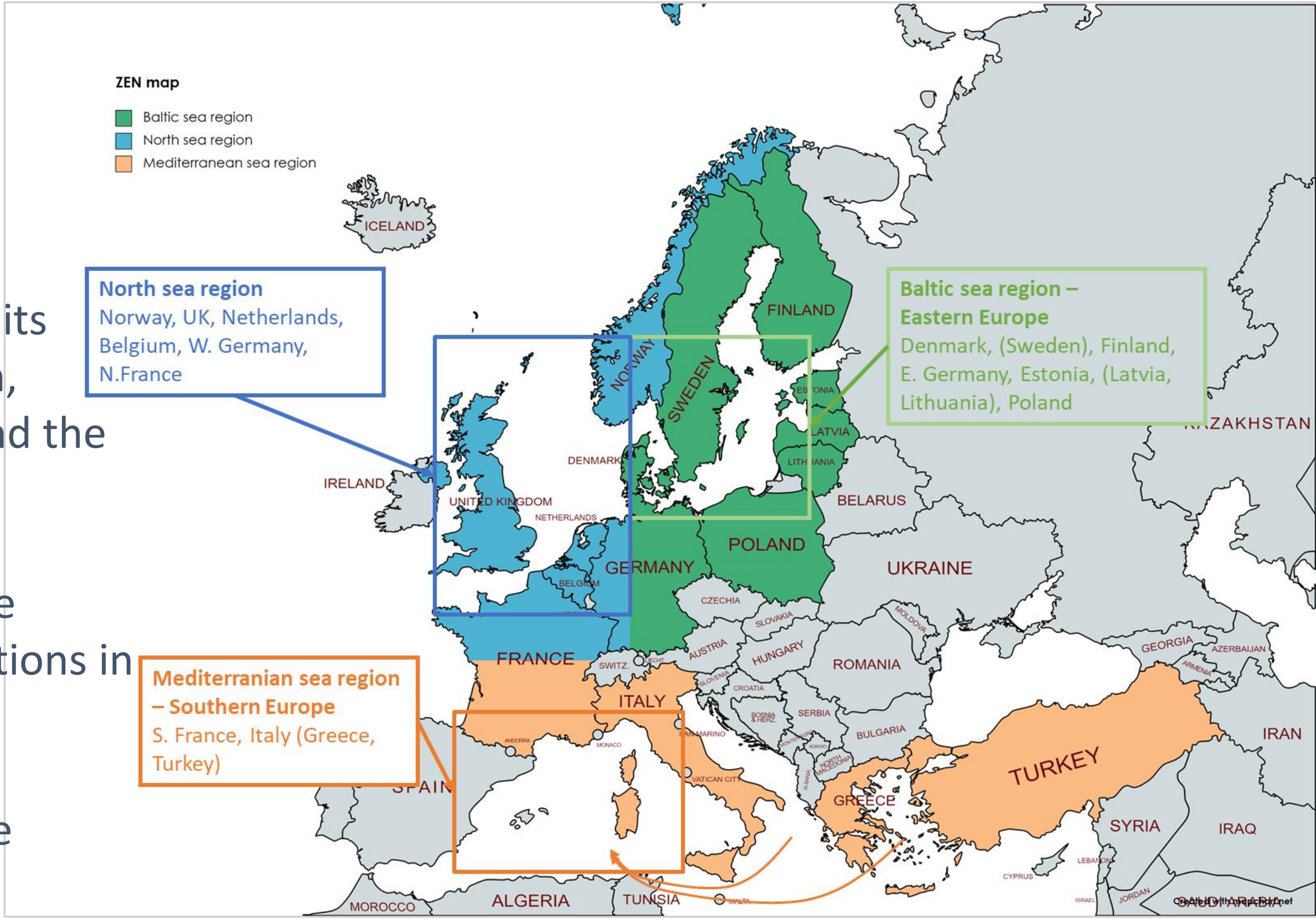
CCUS ZEN map

ZEN REGIONS

Greater Baltic Sea region covering Denmark including its inland waters and the easternmost North Sea, Sweden, Finland, Germany, Estonia, Latvia, Lithuania, Poland and the Baltic Sea.

Mediterranean Sea region covering France, Turkey, the Mediterranean Sea and selected onshore storage locations in Greece and Spain.

***North Sea region** primarily for experience/knowledge sharing



ZEN map

- 🟩 Baltic sea region
- 🟦 North sea region
- 🟧 Mediterranean sea region

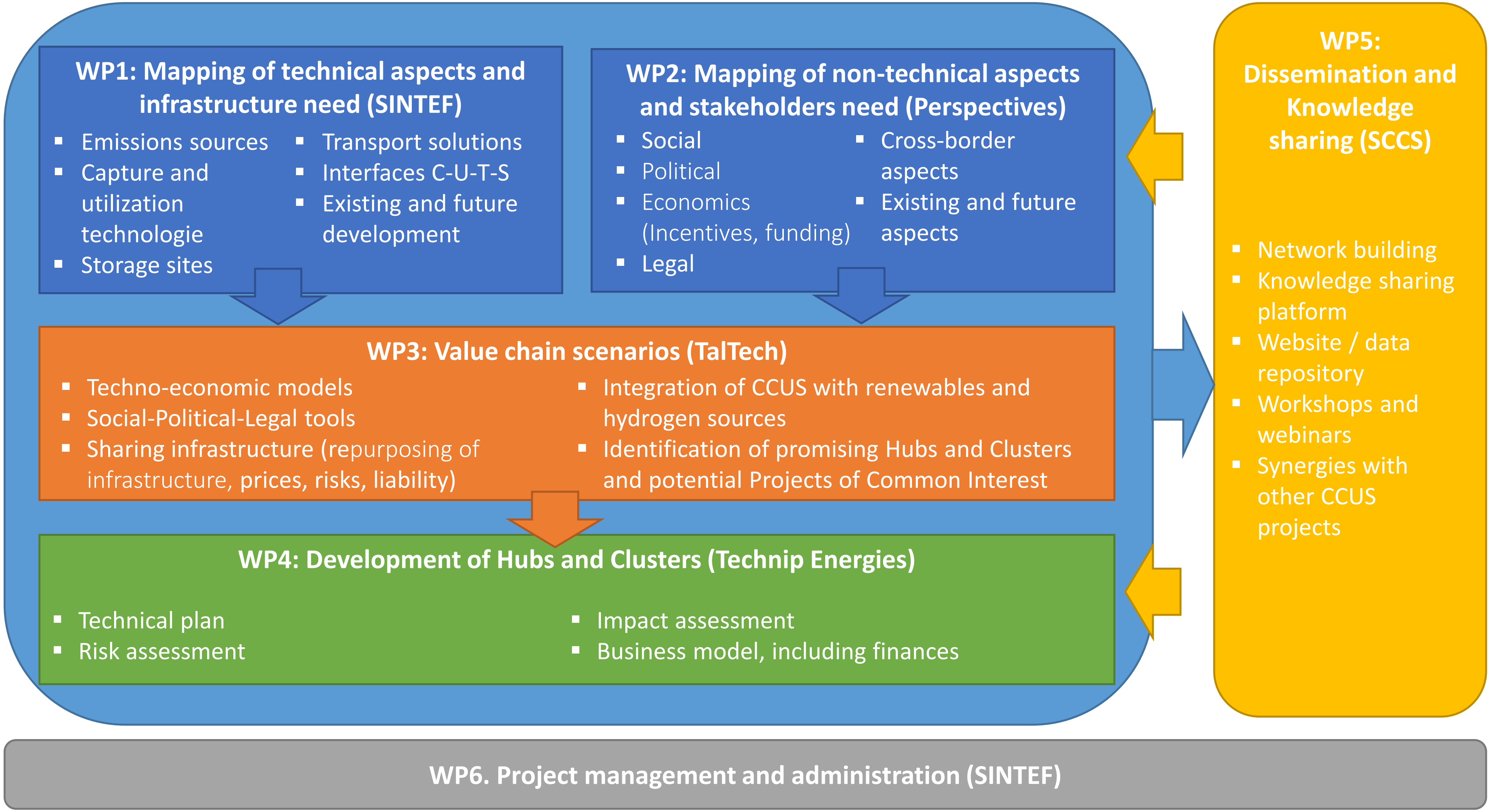
North sea region
Norway, UK, Netherlands, Belgium, W. Germany, N.France

Baltic sea region – Eastern Europe
Denmark, (Sweden), Finland, E. Germany, Estonia, (Latvia, Lithuania), Poland

Mediterranian sea region – Southern Europe
S. France, Italy (Greece, Turkey)

Zero emission network to facilitate CCUS uptake in industry

CCUS ZEN work packages



WP1: Mapping of technical aspects and infrastructure need (SINTEF)

- Emissions sources
- Capture and utilization technologie
- Storage sites
- Transport solutions
- Interfaces C-U-T-S
- Existing and future development

WP2: Mapping of non-technical aspects and stakeholders need (Perspectives)

- Social
- Political
- Economics (Incentives, funding)
- Legal
- Cross-border aspects
- Existing and future aspects

WP3: Value chain scenarios (TalTech)

- Techno-economic models
- Social-Political-Legal tools
- Sharing infrastructure (repurposing of infrastructure, prices, risks, liability)
- Integration of CCUS with renewables and hydrogen sources
- Identification of promising Hubs and Clusters and potential Projects of Common Interest

WP4: Development of Hubs and Clusters (Technip Energies)

- Technical plan
- Risk assessment
- Impact assessment
- Business model, including finances

WP5: Dissemination and Knowledge sharing (SCCS)

- Network building
- Knowledge sharing platform
- Website / data repository
- Workshops and webinars
- Synergies with other CCUS projects

WP6. Project management and administration (SINTEF)

Conclusions

- CCUS clusters and hubs can play a strategically important role in climate change mitigation.
- Cooperation through clustering of CO_2 emitters and CO_2 storage sites and using common infrastructure and adding CO2 use options could decrease costs and will make easier communication with governments and local population, creating new opportunities in the Baltic Sea Region (BSR).
- **CCS NETWORKS REDUCE CROSS-CHAIN RISK.**
- Application of CCUS technology in the BSR can effectively support all other possible measures and technologies and enable reaching CO_2 neutrality by 2050, if implemented in synergy and supported by policy makers (Shogenova et al, 2021 b).

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Nordic Council of Ministers

Nordic Energy Research

BASRECCS

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