Outlook of CO_2 logistics in Finland for CCUS

Project results webinar, 4.10.2024, online

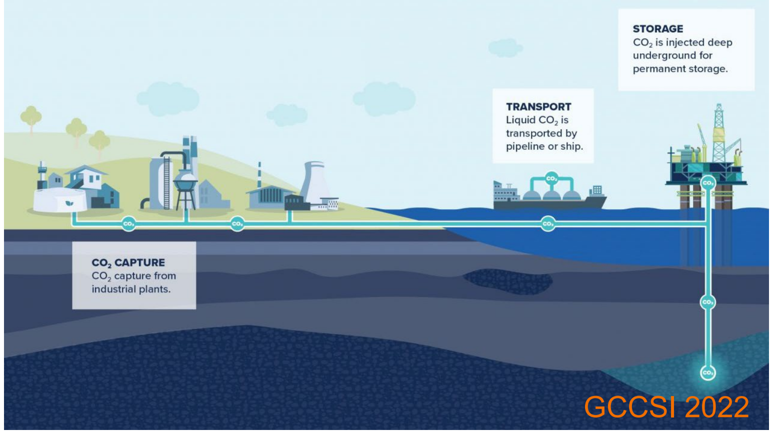
Lauri Kujanpää, Onni Linjala

Logistics is crucial for CCUS realization

- If CO_2 cannot be stored or utilized at site of capture, it must be transported to a suitable location via pipelines, ships, trains, or trucks.

- Shared logistics infrastructure can reduce costs due to economies of scale benefits, while also encouraging to CCUS participation due to easier access and reduced investment risks.

- Development of CO_2 transport infrastructure is at key role in EU's industrial carbon management strategy, which aims to develop needed regulatory frameworks, market design and infrastructure planning, set accounting rules, establish standards, and assess the use of existing infrastructure for CO_2 transport.



GCCSI 2022


Northern Lights 2023

Ships are needed to reach geological CO_2 storage sites from Finland

- Finland's bedrock is not suitable for geological storage of CO_2
- 19 transport and storage projects are in preparation in Europe (ZEP 2023)
- The most promising storage potential lies currently in the North Sea region
- EU's Net-Zero Industry Act (2024/1735):
  - Annual CO_2 injection capacity target of 50 $MtCO_2$ in the EU by 2030
  - Member States must map storage areas
  - Obligations for oil and gas companies to develop storage infrastructure

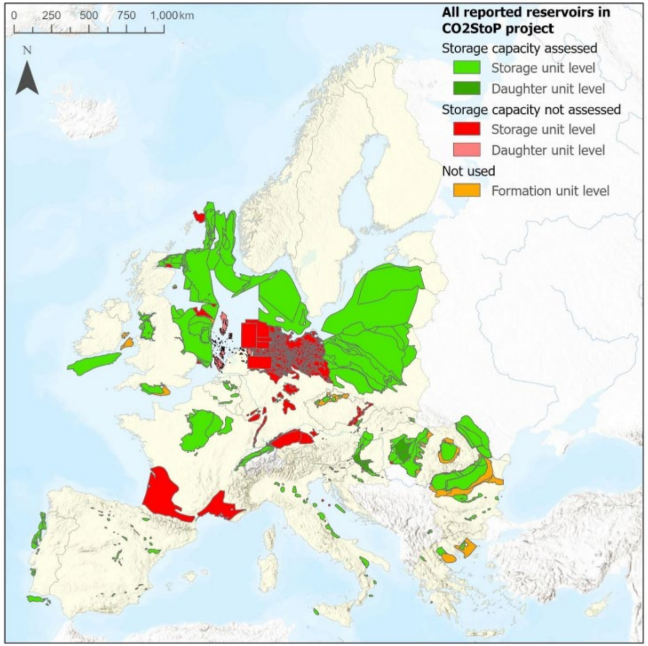


Figure: JRC 2024

Transporting CO_2 to storage sites can involve multiple stages

CO_2 capture and compression

Transport by truck or train to harbour terminal or CO_2 pipeline

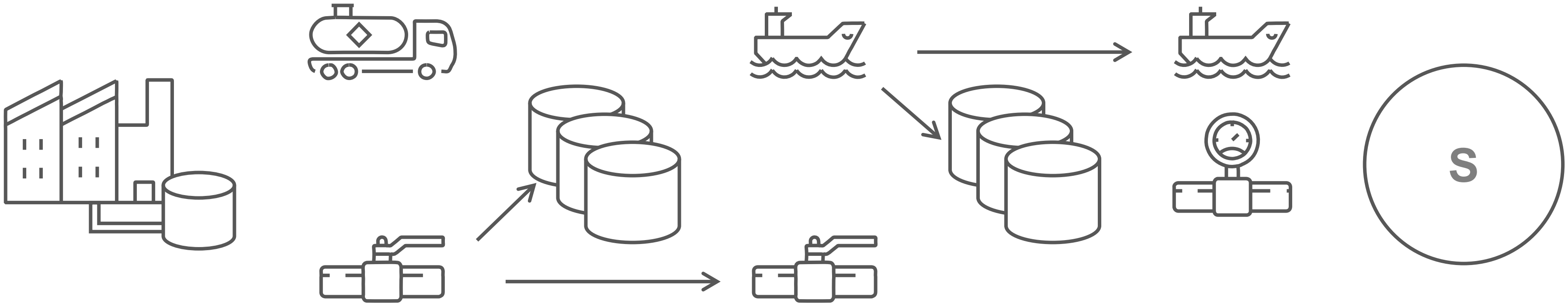
Liquefaction, intermediate storage for transport by ship

CO_2 transport by ship or pipeline

Liquefaction, intermediate storage in final terminal

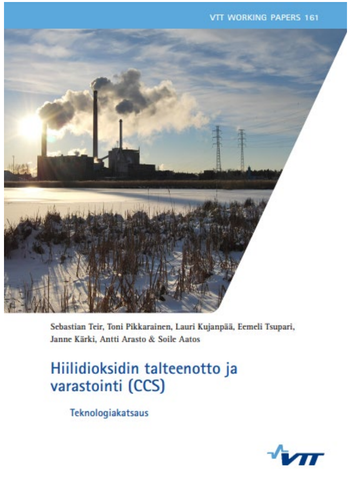
CO_2 transport by pipeline to storage site. Ship can be unloaded at the storage site at sea.

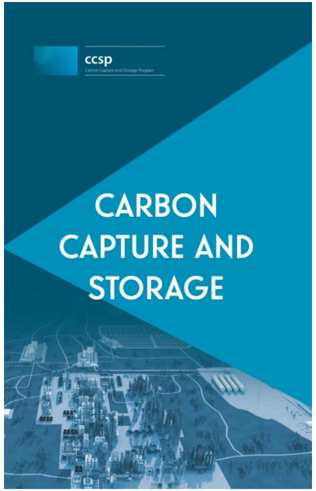
Permanent geological storage (or mineralisation)

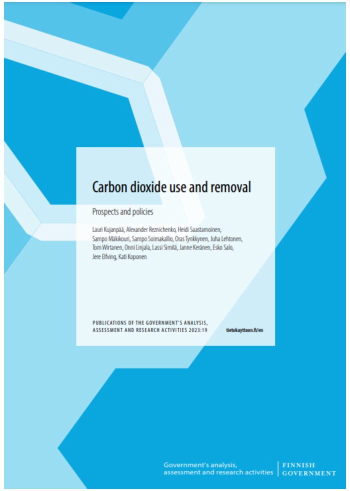


VTT's past public studies on CO_2 logistics in Finland

- CCS Finland (2008-2011)
- CCSP (2012-2016)
- CO_2 use and removal: Prospects and policies (2022-2023)
- Technological carbon sinks in Finland (2023)







Objetive and scope of our present study

- We have assessed potential transport options and network designs for CO_2 logistics in Finland and evaluated investment and unit costs of CO_2 transport.

- **Outlook on industrial CO_2 point sources and potential CO_2 hubs**
  - Data collection on CO_2 point sources and existing transport infrastructure
  - Identification of potential CO_2 hubs
  - Design of CO_2 logistics development scenarios

- **Transport mode options and costs of transport**
  - Definition and application of unit cost estimation method

- **Investment costs of CO_2 logistics infrastructure**
  - Rough level assessment of required investments per mode of transport, type of infrastructure, and the developed transport scenarios.

Industrial CO_2 emissions and design of CO_2 transport scenarios

Industrial CO_2 emissions in Finland

- CO_2 emissions from Finnish industrial facilities with annual emissions of ≥100 kt were studied.*
- The 72 examined industrial facilities accounted for 45.3 Mt of CO_2 emissions of which 30.1 Mt was biogenic.

Industry	No. of facilities	Total $MtCO_2$	Bio $MtCO_2$	Share of bio-CO_2
Forest industry	20	21.7	20.5	94 %
Thermal power stations and other combustion installations	40	15.2	8.7	58 %
Iron and steel	2	2.8	0	0 %
Oil refining	1	2.6	0	0 %
Waste-to-energy	5	1.4	0.8	58 %
Cement	2	0.9	0	0 %
Chemicals	2	0.7	0	0 %
All industries	72	45.3	30.1	66 %

*Data on CO_2 emissions has been collected from the European Pollutant Release and Transfer Register and manually updated regarding missing and expired data.

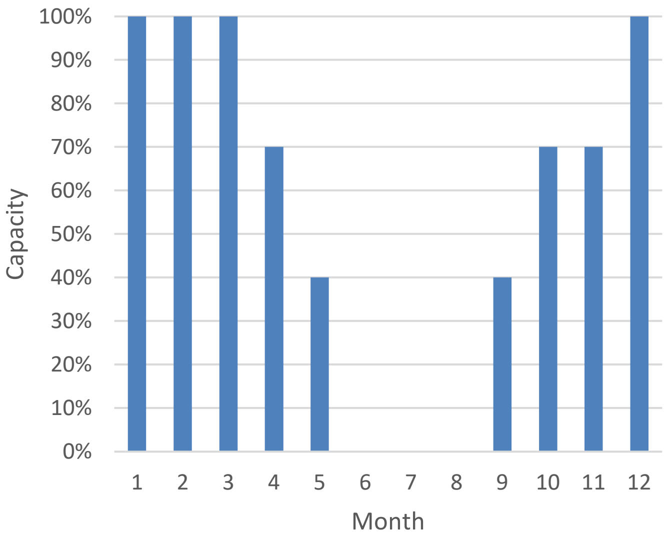
Seasonal variation affects logistics dimensioning

- Seasonal variation of the examined industrial facilities were studied as annual fluctuation of CO_2 emissions affects dimensioning of the logistics infrastrucure.

- 23 district heating CHP plants prone to seasonal load changes were identified.

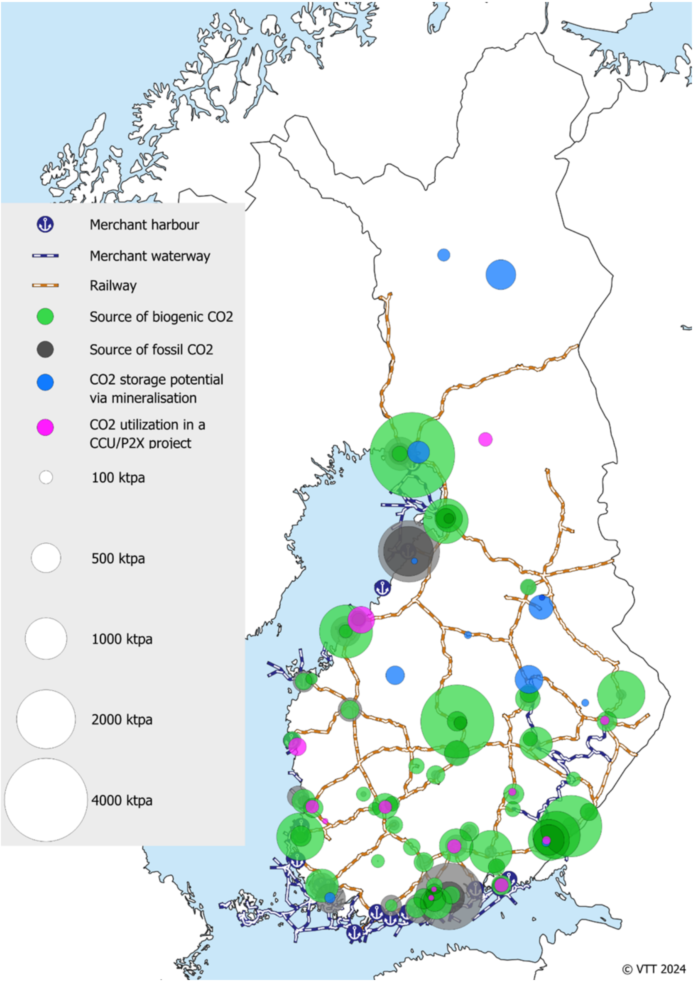
- We assumed monthly operating capacities based on discussions with DH operators, based on which maximum CO_2 outputs were calculated for logistics dimensioning.

Assumed seasonal variation of district heating CHP plants



CO_2 point sources and existing transport infrastructure

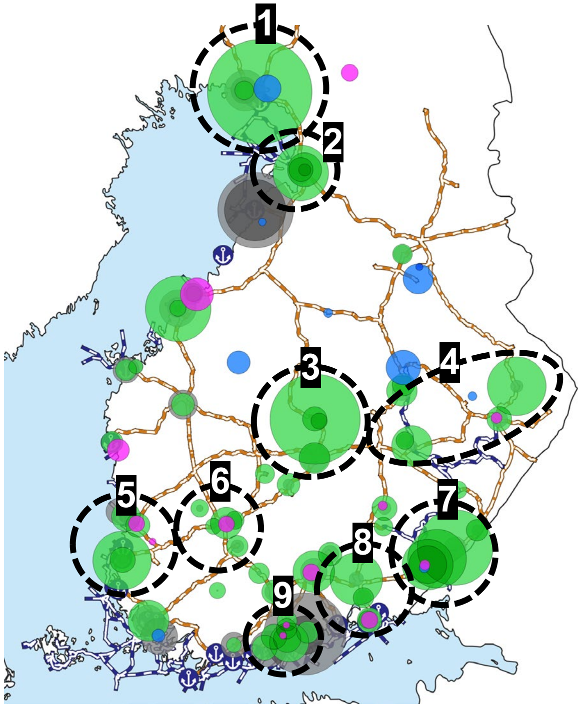
- Large CO_2 point sources are scattered evenly within Finland, excluding the northernmost Lapland region.
- Existing railway network covers nearly all the examined large CO_2 point sources.
- Plans for 13 utilization projects have been announced in Finland, totalling for capacity of only 1.3 $MtCO_2$/year. The projects are largely located near existing CO_2 point sources, from where CO_2 could be supplied to these projects if carbon capture is implemented.
- Potential sites for CO_2 storage via mineralization are mainly located at central and northern parts of Finland, some of which are neither near existing CO_2 point sources nor railways.



Nine potential CO_2 hubs were studied

- CO_2 hubs were created based on regions with significant CO_2 emission point sources within a reasonable distance from each other.

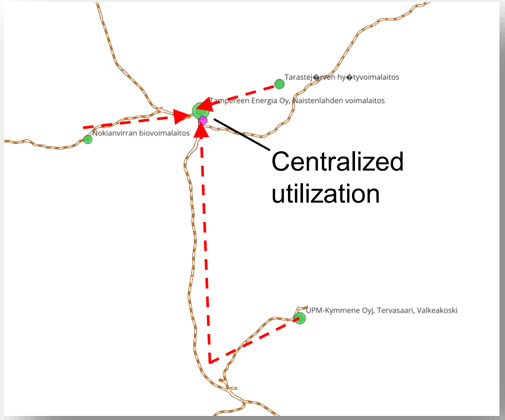
Hub	Total $MtCO_2$	Bio $MtCO_2$
1) Tornio-Kemi	5.2	4.3
2) Oulu	2.3	1.9
3) Keski-Suomi	4.1	3.8
4) Savo-Karjala	2.6	2.3
5) Pori-Rauma	2.3	2.1
6) Pirkanmaa	1.0	0.8
7) Etelä-Karjala	5.8	5.0
8) Kymenlaakso	2.0	1.6
9) Uusimaa	2.8	1.7



Design of logistics development scenarios

- Logistics development scenarios were constructed to study efficient strategies for CO_2 logistics implementation in Finland based on the identified CO_2 hubs.
- In the scenarios, each hub was designated either to storage or utilization in total.
  - In storage hubs all CO_2 is transported to the nearest harbour for shipping to a storage site.
  - In utilization hubs all CO_2 is transported to one key location within the hub for centralized utilization.
- Hubs and transport routes were designed manually. The following guidelines were roughly implemented:
  1. railways are utilized if on route
  2. routing aims to minimize transport distance and transported CO_2 amount
  3. coastal hubs are prioritized for CO_2 storage/ship export to reduce transport demands from inland to shores

Routing in Pirkanmaa utilization hub

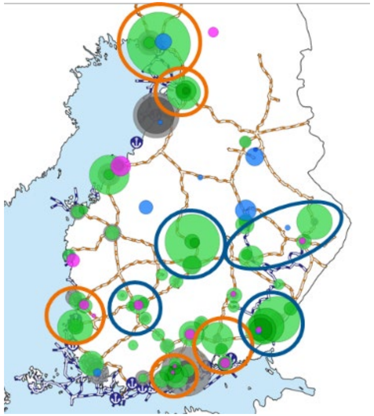


Regional hub scenarios with shared infrastructure

- Scenarios A, B and C consists of regional hubs that have shared infrastructure within the hub, but which are separated from the other hubs.
- The hubs are designated either to storage (ship export) or utilization in full, with the capacities altering between the scenarios.

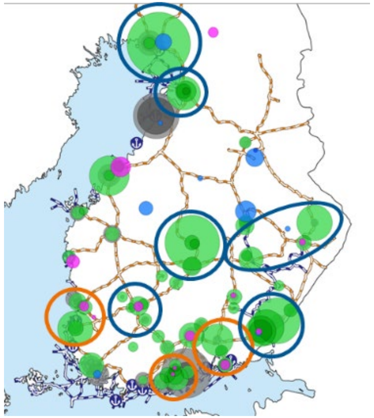
Scenario A – balanced

- Storage: 13.1 Mt (10.4 Mt bio)
- Utilization: 12.2 Mt (10.7 Mt bio)



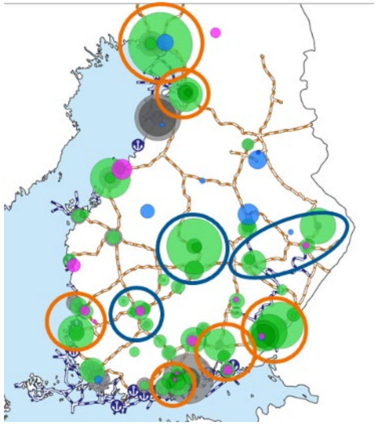
Scenario B – utilization emphasis

- Storage: 6.4 Mt (4.8 Mt bio)
- Utilization: 18.9 Mt (16.3 Mt bio)



Scenario C – storage emphasis

- Storage: 18.3 (14.9 Mt bio)
- Utilization: 7.0 Mt (6.2 Mt bio)

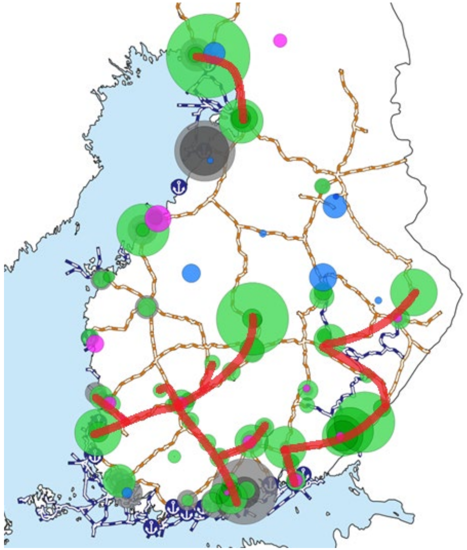


◯ = storage hub ◯ = utilization hub

Trunkline scenarios

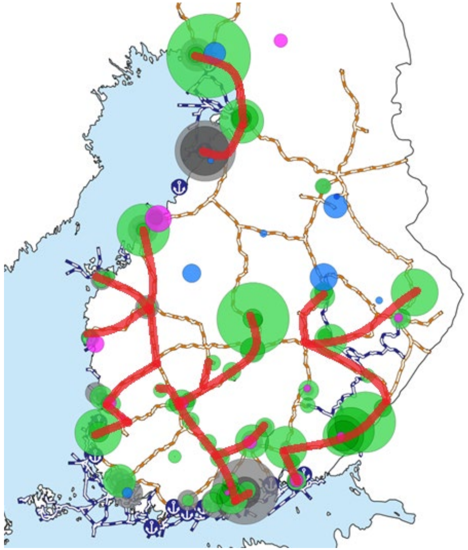
- Two trunkline scenarios were examined to study extended transport network coverage and CO_2 transport between the hubs.
- These scenarios give additional indication of costs and comparison between transport modes (pipeline vs. train).

Trunkline 1 scenario



Trunkline	Total $MtCO_2$	Bio $MtCO_2$
Tornio-Kemi-Oulu	6.7	5.6
KeskiSuomi-Pirkanmaa-Häme-Uusimaa	9.2	7.1
KeskiSuomi-Pirkanmaa-Satakunta	6.9	6.2
Joensuu-Varkaus-EteläKarjala-Kymenlaakso	9.6	8.2

Trunkline 2 scenario



Trunkline	Total $MtCO_2$	Bio $MtCO_2$
Tornio-Kemi-Oulu-Raahe	10.0	5.6
KeskiSuomi-Pirkanmaa-Häme-Uusimaa-Porvoo	12.4	7.3
Pohjanmaa-Satakunta	5.5	4.2
SavoKarjala-EteläKarjala-Kymenlaakso	10.3	8.7

Transport costs

The scope of transport cost assessment

Capture facility	Hub	Trunkline	Shipping
Compression & Liquefaction	Transport to hub & buffer storage	Transport to harbour & buffer storage	Loading, ship transport & unloading
• Only compression in case of pipeline transport • **CO_2 capture not included.**	• Pipeline, rail or truck considered. • Intermediate storage not needed if CO_2 is forwarded to trunk pipeline. • Conditioning needed if mode changes from truck/rail to pipeline. • **Buffer storage (1 week) in case of utilization.**	• Pipeline or rail considered for trunklines. • CO_2 liquefaction to low pressure after pipeline. • Onshore buffer storage capacity 1.5 times single ship capacity.	• **Buffer storage and conditioning to pipeline transport pressure are included.**

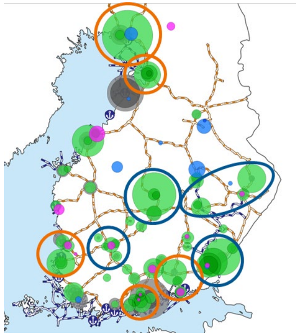
Common scenario assumptions

- In-land transport distance equals a straight line multiplied by a factor of 1.2.
- Lengths of ship routes based on destination port in Norwegian coast near Bergen.
- An intermediate storage assumed in each utilization hub, equal to 7 days of total average capture capacity.
- Economic life 20 years, interest rate 5%.
- Price of electricity 70 €/MWh

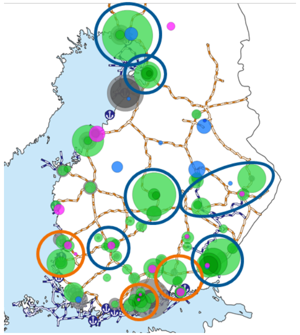
Scenario results: summary

- The more CO_2 is geologically stored, the more investments are needed to infrastructure.
- Costs across clusters, let alone CO_2 sources, vary significantly. Scenario average cost to storage is 45-52 €/tCO_2.
- Cost to transport CO_2 for centralized utilization site within clusters is less expensive, 24-28 €/tCO_2 on average within scenarios.

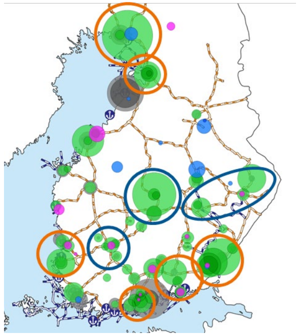
Scenario A



Scenario B



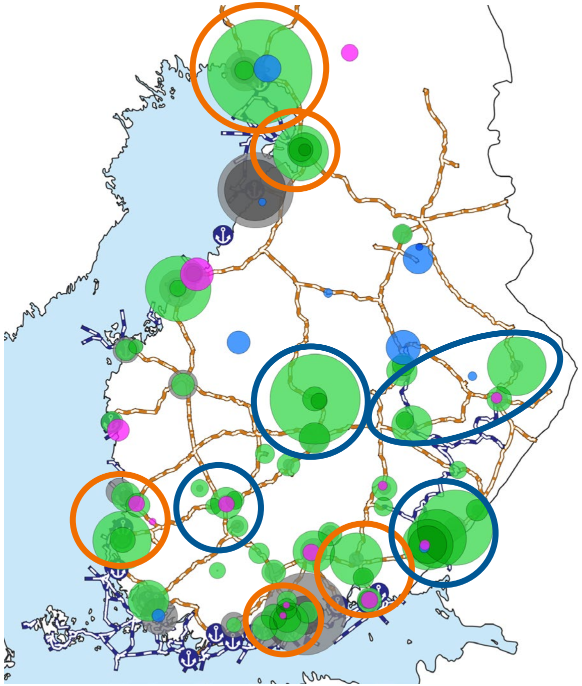
Scenario C



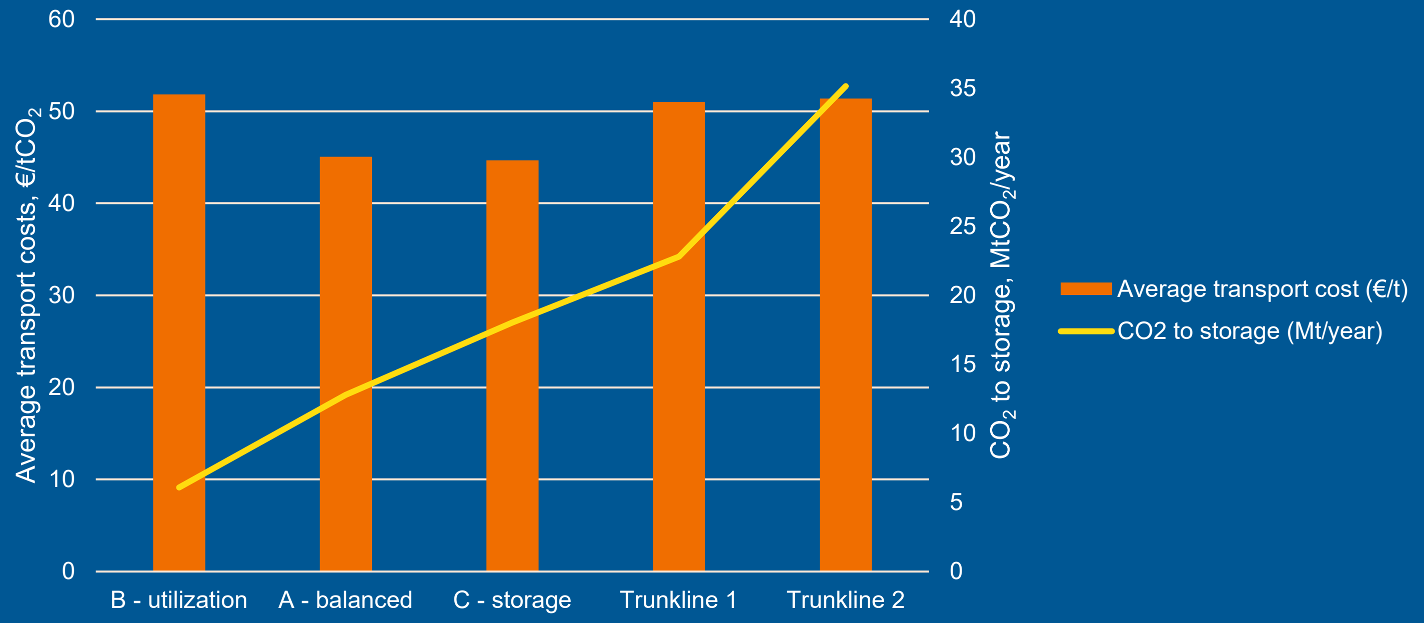
Scenario	Destination		Transport costs			
	Storage (Mt)	Utilization (Mt)	Investments (M€)	Average unit cost to storage(€/t)	Average unit cost to utilization (€/t)	Average unit cost (€/t)
A – balanced	12,8	12,42	4 220	45	26	36
B – utilization	6,1	19,13	3 690	52	24	31
C – storage	18,0	7,27	4 690	45	28	40

CASE A: Baseline results

Hub	Capture amount		Destination		Transport costs	
	Total (Mt)	Bio (Mt)	Storage (Mt)	Utilization (Mt)	Investments (M€)	Average unit cost (€/t)
TORNIO-KEMI	4,7	3,9	4,7		672	35
OULU	2,0	1,7	1,9	0,10	512	49
SATAKUNTA	2,0	1,9	2,0	0,02	435	43
UUSIMAA	2,5	1,5	2,5	0,04	762	56
KYMENLAAKSO	1,8	1,4	1,7	0,11	470	53
Storage hubs total:	**13,1**	**10,4**	**12,8**	**0,27**	**2 850**	
ETELÄ-KARJALA	5,2	4,5		5,2	524	22
SAVO-KARJALA	2,3	2,1		2,3	300	31
KESKI-SUOMI	3,7	3,4		3,7	374	24
TAMPERE	0,9	0,7		0,9	166	37
Utilization hubs total:	**12,2**	**10,7**	**0,0**	**12,2**	**1 360**	



Average cost of transport to storage vs. export capacity



Key take-aways

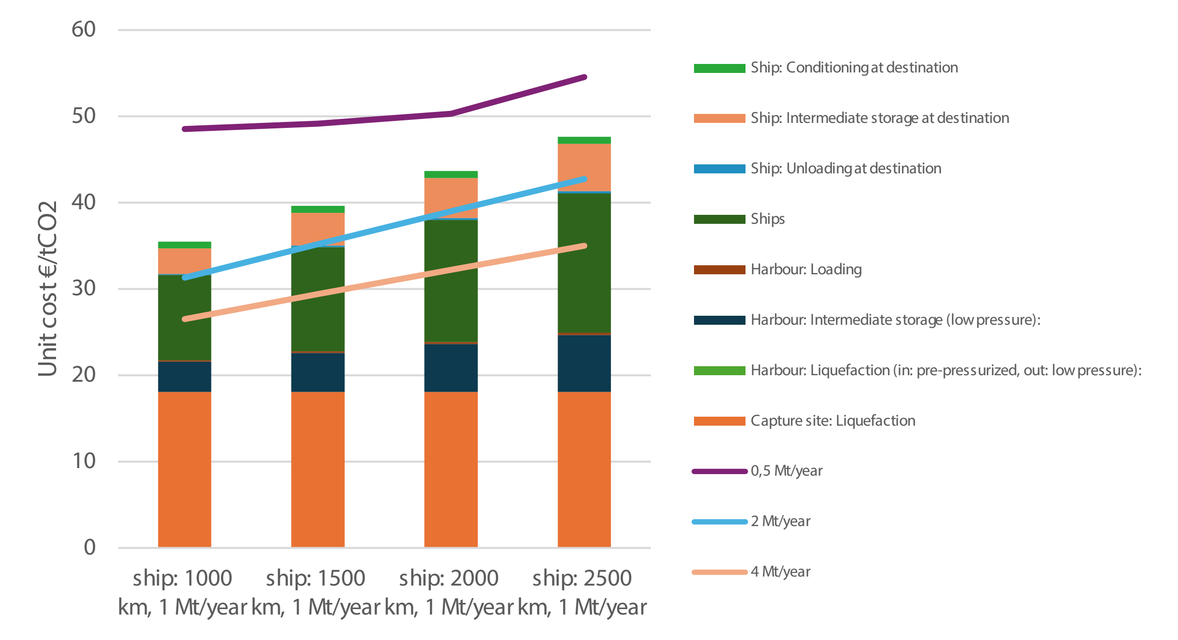
Key emission clusters offer large potential for both utilization and storage of CO_2

- Scenarios A, B and C show how over 25 MtCO_2/year could be collected for utilization or geological storage from the assessed nine emission hubs in Finland. Biogenic share of the captured CO_2 is 21 Mt.
- In all cases the hubs can be created quite locally without the need for long distance cross-country transports.
- Uusimaa (Capital region) has the largest seasonal variation as 6 of the 7 facilities included in the cases are DH CHP plants.
- Assuming rail transport of CO_2 for facilities connected by the rail network, the weighted average transport costs in hubs were between 20-33 (utilization) and 35-59 (storage) €/tCO_2. The cost includes initial compression or liquefaction and buffer storage at the destination.
- Capital costs were between 3,7-4,7 billion in scenarios A, B and C. As can be expected, lowest investment costs are in the utilization-heavy scenario B, and highest in scenario C with storage emphasis.

Nine emission hubs, with capture potential of 25.2 MtCO_2/year (21.0 Mt bio). A balanced option exists to focus (BE)CCS to coastal clusters.

Biogenic CO_2 potential greatly surpasses the currently planned CO_2 utilization capacity and mineralization potential in the country.

Ship and pipeline transport costs depend strongly on capacity



Collecting at least 2-4 $MtCO_2$ to the same harbour would reduce the costs of shipping to a geological storage considerably.

Investment cost of liquefaction and intermediate storages, and indirect fixed costs, are main cost factors and contribute to the uncertainty accordingly.

Shared infrastructure brings cost benefits & railways provide good coverage

- The balanced scenario A was used to compare between road, train and pipeline modes and choice between shared or facility-specific logistics.
- The baseline selection between the modes based on the availability of rails resulted in lowest average costs in hubs, although results were close compared to pipeline network.
- The economic benefits from larger scale in shared transport infrastructure are considerable but facility-specific, ranging from cost reduction of -2% to -73%. An average reduction of transport costs to geological storage for capture facilities in scenario A, due to shared infrastructure, was -30%.
- There are different options how to allocate costs within a transport network. For instance, the extended trunkline scenario would theoretically enable maximum transport amounts if capture sites would pay transport rate based on weighted system average. The facility-specific costs can vary greatly from the average transport system costs.

Use of the existing rail network seems cost-efficient option for CO_2 logistics. This is partly due to the need to liquefy CO_2 in all cases.

Expanding transport networks beyond the nine emission hubs could cover 80% of industrial CO_2 sources, but would set the highest trunkline average costs to up to 60 €/tCO_2.

beyond the obvious

Thank you!

@VTTFinland

vttresearch.com