MARCO POLO - DK

METHANOL
Availability **R**eadiness **C**ost **O**perationality
Port **Lo**gistics - **D**enmar**k**

Final report

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Investing in your future

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Project Summary

The use of Power-to-X (PtX), to generate liquid fuels from renewable energy, is a pre-requisite for achieving the deep CO2 emission reduction required – both on global scale as well as in Denmark. The MARCO POLO DK project assess how PtX-products can be put into operation through the activation and development of the Danish ports.

The project will assess four archetype ports:

- International ferry port
- Domestic ferry port
- Fishing port
- CO2 import/export port

The first three port types are found globally (more than 5.000 ports), whereas the latter is a port type gaining a lot of interest over the last years. The utilization of PtX in relation to passenger carriers (RoPAX, ferries) as well as small vessels (fishing) will be depending on e-methanol, as ammonia from a safety point-of-view will not be qualified within the next 10-15 years. Hence, Carbon Capture and Utilization - CCUS (for the first three port types) and Carbon Capture and Storage (CCS) (for the fourth type) will be essential for the project. As a natural consequence, the project will be focussing on ports in Northern Jutland, as this will be a natural collaboration with '*Erhversfyrtårne Nordjylland – CCUS*'.

The project is divided into five key activities

- Assessment of two ports to cover the four archetypes
- Safety and regulatory requirements for handling methanol at the ports
- Establishing business cases for utilizing methanol on actual routes (green corridors)
- Description of the further applicability of the insight to Danish and International Ports
- Road map for direct implementation of findings into FEED studies

The project is carried out by a consortium consisting of ports, relevant GTS (Godkendt Teknologisk Service) and Research Institutes as well as NGOs and Project Support Organisations. In addition, the project has a strong Advisory Board comprising key PtX stakeholder and future customers for the PtX products, as well an important trade organizations.

Table of Content

1 Introduction

1.1 Objective

The MARCO POLO DK (**M**ETHANOL **A**vailability **R**eadiness **C**ost **O**perationality for **Po**rt **Lo**gistics – **D**enmar**k**) aims to deliver a Port Readiness Assessment and Safety & Regulation Evaluation for four archetype ports (Figure 1): Domestic Ferry (1), International Ferry (2), Fishing (3), CO2 Import/Export (4).

The project is focused around the ports in Northern Jutland, as this will:

- Focus on ferries requiring liquid fuels (in contrast to electrical)
- Focus in the key area for fishing (6 of the 8 fishing regions in Denmark)
- Support the Nordjyske Erhvervsfyrtårn "CCUS Fyrtårn Nordjylland" (CCUS = PtX → methanol)

These vessel segments are requiring e-methanol (through PtX/Carbon Utilization) as ammonia for passenger vessels and small vessels will not be safety-wise ready for usage in this decade.

In addition to providing the insight for the ports in the Northern Jutland, the MARCO POLO DK project will develop roadmaps for the archetype ports, allowing other Danish ports to utilize the information, but also for Danish enterprises and research institutes/GTS' to export the insight to the Nordic countries as well as globally.

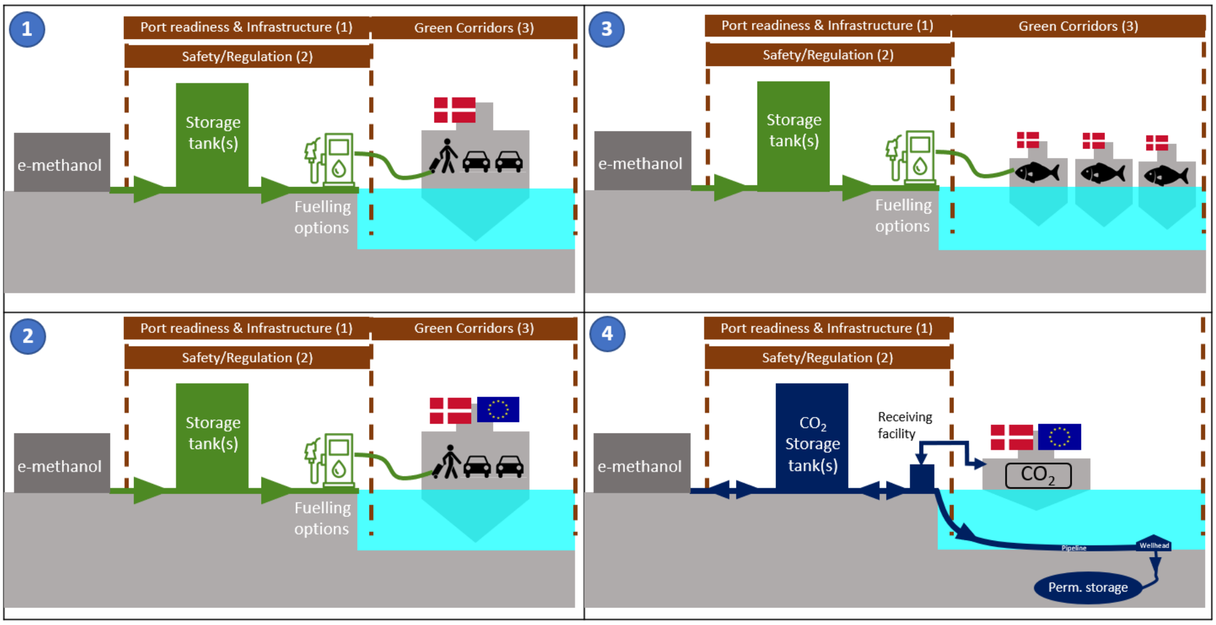


Figure 1: Illustration of the four archetype ports being assessed in the MARCO POLO DK project. Domestic Ferry (1), International Ferry (2), Fishing (3), CO2 Import/Export (4).

The scope of the MARCO POLO DK project is to make the feasibility study as to how ports (both the specific as well as from a more generic point-of-view) can be an integrated part of the green transition, especially with focus on Power-to-X (PtX). The project assesses four (4) archetype ports, who will play a cardinal role in the decarbonization of the Danish Maritime Industry, as well as for any country with similar climate ambition and fleet configuration as Denmark (currently estimated to be ~50 countries and more than 5,000 ports). The project hence plays directly into the targets for the EU maritime and the EU-strategy: "A hydrogen strategy for a climate-neutral Europe".

Furthermore, the project assesses the feasibility of ports being import/export of facility – in cases where the PtX process for one reason or the other has too much/little feedstock, and thus avoids beaning back the methanol production following the hydrogen production.

1.2 Indicators

The following is the indicators set for the project, being monitored throughout the project period and to indicators monitored after. (The table below is in Danish, since it is indicators towards ERST).

Hovedaktiviteter	Målemetode, inklusiv måleenhed	Samlet måltal	Forklaring på måltal	Opdateret 30. September 2023
WP0: Project Administration & Dissemination	Antal organisationer til advisoryboard og slutkonference, der ikke indgår som økonomisk partner i projektet. Det måles ved optælling på baggrund af Energy Cluster Denmarks CRM system.	20	1. Advisory Board møde 2. Advisory Board møde 3. Slutkonference	12 deltagere ved 1. Advisory Board møde 8 deltaqgere ved 2. Advisory Board møde 33 deltagere til afslutningskonference I alt 53 deltagere
WP1: Ports as P2X/Methanol hubs	Antal havne, der indgår i projektet. Opgøres ved antal.	2	Antal havne, der er nødvendig for at beskrive arketypehavne	1. Hanstholm 2. Hirtshals 3. Frederikshavn
WP 2: Safety & Regulatory Aspects	Antal delprojekter, som er nødvendige for at afdække sikkerheds og regulatoriske aspekter. Tælles ved antal.	5	Antallet indikerer den store udfordring og GAP der er i forhold til sikkerhed og regulativer i danske havne og til danske myndigheder.	1. Risk and Safety Assessment 2. Mapping Competencies 3. Approval process 4. Feasibility plan 5. Public perception
WP 3 Green corridors	Antal dialoger og møder med øvrige initiativer inden for PtX området, specifikt på grønne korridorer. Tælles ved antal.	10	Antallet af dialoger og møder indikerer behovet for at udvikle grønne korridorer i Scandinavien	1. Meeting: Meeting with Port of Gothenburg & Port of Rotterdam: 8th of March 2. Conference / Presentation: Net Zero Pathways: 30th of March 3. Conference / Presentation: Bornholms Passagerforening Generalforsamling: 25th of April 4. Conference / Presentation: Gothenburg Port Day: 4th-5th May 5. Conference / Presentation: Rotterdam: World Port Climate Action Programme – 16th May 6. Meeting: Meeting with US/UK Green Corridors - Industry Meeting: 15th of June 7. Meeting: Meeting with Korean Ports: 25th of May 8. Conference / Presentation: MMM Accelerate Summit: 23rd of May 9. Conference / Presentation: Invest in Paldinski Conference- Green Corridors in the Baltic Region: 29th of August 10. Conference / Presentation: Turku University - Maritime @STE on Green Corridors & RoPAX in Northern Europe: 30th of August 11. Conference / Presentation: Åbo University Conference on Green Corridors & RoPAX in Northern Europe: 1st of September

				12. Conference / Presentation: DanFish international - presentation of project findings: 11th of October
WP 4 Applicability to National and International Ports	Antal dialoger og møder med øvrige initiativer inden for PtX området, specifikt på grønne korridorer. Tælles ved antal.	10	Antallet af dialoger og møder indikerer behovet for at udvikle havne national og internationalt	1. Port of Aabenraa, dialog 2. Port of Esbjerg, dialog 3. Port of Frederikshavn, dialog 4. ADP, Fredericia, dialog 5. Port of Aalborg, dialog 6. Greenport North, dialog 7. Om vejen til 100 % grønt maritimt brændstof. Konferencen blev afholdt af Greenport North. 8. Grøn omstilling af tung godstransport på tværs – ENERGI d. 14. september (arrangeret af Aarhus Havn - Port of Aarhus DI - Dansk Industri, Danish Shipbrokers and Port Operators, Klimaalliancen Aarhus, Aarhus Transport Group.) 9. Erhvervsdag i Hanstholm den 13. juni 10. Danske Rederier (okt 2023)
WP 5 Next Phase and Roadmap for Deployment	Produktion af slutrapport. Tælles ved antal.	1	Resultatet af feasibility studiet.	The final report

Indikatorer fra Erhvervsfremmestyrelsen:

	Samlet måltal	Forklaring på måltal	
Antal virksomheder som modtaget støtte	6	Det samlede måltal består af de virksomheder, som indgår som økonomiske partnere i projektet	1. ECD 2. NGS 3. DBI 4. MMM-ZCSC 5. AAU 6. Thisted Kommune/ Hanstholm havn
Output	Målemetode, inklusiv måleenhed	Samlet måltal	Forklaring på måltal
Port Readiness Assessment and Safety & Regulation Evaluation Report	Antal rapporter leveret, tælles ved antal	5	Collected in the final report 1. Description of methanol option for selected ports 2. Summary of major risk factors and recommendations for way forward 3. Draft guidance paper on approval processes for methanol handling 4. Options for ports to import/export in relation to PtX 5. Roadmap for how the results of the MARCO POLO DK will be progressed into subsequent project

Resultat	Målemetode, inklusiv måleenhed	Samlet måltal	Samlet måltal efter projektperioden	Forklaring på måltal	Status

Danish Innovative ports	Number of ports, which have implemented new e-methanol facilities in the harbour area directly using the feasibility report. To be monitored after the project period during interviews.	0	6	Companies, who develope and commercialize new solutions, products and services are pr. definition innovative acording to OECD's definition of Innovation	
Eksport	International ports, who download the feasibility study. To be monitored by counting 0-2 years after the project have finished.	0	50	The Danish Feasibility study will be front runner for how to implement E-methanol in Port's	

Marco Polo

METHANOL **A**vailability **R**eadiness **C**ost **O**perationality for **Po**rt **Lo**gistics – **D**enmar**k**

Chapter 2

Description of methanol option for selected ports

Written by

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMM)

Chapter 2 provides a preliminary assessment of the future methanol demand associated with four archetype ports, with Frederikshavn and Hanstholm serving as proxy ports

The MARCO POLO-DK project

The aim of the MARCO POLO-DK project is to assess how PtX-products can be put into operation through the activation and development of the Danish ports.

Chapter 2 in the MARCO POLO-DK project

In order to do so, Chapter 2 zooms in on four archetype ports, namely 1. Domestic RoPAX, 2. International RoPAX, 3. Fisheries and 4. CO_2 Transportation.

In line with the development of Green Corridors and corresponding MMM methodologies, the project quantifies the future methanol demand associated with each type of port and decarbonized maritime activity. Whilst the project findings are specific to the Ports of Frederikshavn and Hanstholm respectively, the methodology and approach can be applied to all similar ports on a national, regional and/or international level.

CCU and CCS Matrix in scope for MARCO POLO-DK assessment	Proxy Port Port of Frederikshavn	Proxy Port Port of Hanstholm
Carbon Capture Utilization (CCU) Methanol Bunkering to accommodate maritime demand	1 Domestic RoPAX 2 International RoPAX	3 Fisheries 4 CO_2 Transportation to accommodate Import Scenario
Carbon Capture and Storage (CCS) CO_2 Import	Not part of the project objective	4 CO_2 Transportation to accommodate Import Scenario[1]

Table 2.1: Green Corridor assessments in scope for MARCO POLO-DK project

-> Definition of Green Corridors based on MMM Blueprint

Green corridors are shipping routes on which there are commercially operating ships using exclusively alternative fuels.

1. The Port of Hanstholm is the only proxy port for CO_2 transportation. Based on the available data and information, only the CO_2 Import scenario is deemed realistic within the project's timeline.

Chapter 2 utilizes the MMM methodologies and tools in order to guide the Technical Assessment of the four Green Corridors

Chapter Flow of Findings per Corridor

Green Corridor Technical Assessment → **Fuel Demand** → **Business Case**

Applicability of Analysis and Methodologies

Green Corridor Technical Assessment / Fuel Demand:

- **1. Domestic RoPAX Archetype** Frederikshavn <-> Læsø
- **2. International RoPAX Archetype** Frederikshavn <-> Gothenburg
- **3. Fisheries Archetype** Port of Hanstholm
- **4. CO_2 Import Archetype** Port of Hanstholm

Business Case:

- **1. Domestic RoPAX Archetype** Frederikshavn <-> Læsø
- **2. International RoPAX Archetype** Frederikshavn <-> Gothenburg
- **3. Fisheries Archetype** Port of Hanstholm

Deep-Dive: Methodologies for Green Corridor Technical Assessments

The project delivers four Green Corridor technical assessments, providing a quantification of the potential methanol demand associated with each route and archetype port. This is done in line with the MMM Green Corridor Blueprints.

The assessment of the two RoPAX corridors is done leveraging a RoPAX specific methodology, which accounts for the predictability and focus on interconnectivity inherent in this segment. Appendix 2.1 includes a deep-dive on the MMM RoPAX Methodology.

The assessment of the corridors on Fisheries and CO_2 Transportation follow the MMM Green Corridor Blueprints, and include segment specific reflections and adjustments in the analysis. These are covered in the introduction of each sub-analysis in this Chapter.

The project delivers three Business Case calculations into Chapter 2 relating to the roll-out of the Phase 1 domestic RoPAX Corridor (Frederikshavn <-> Læsø), international RoPAX Corridor (Frederikshavn <-> Gothenburg) and lastly the fishing fleet (10-15 vessels in the Port of Hanstholm).

To this purpose, the MMM Cost Model has been utilized to deliver the three Business Cases, with a particular focus on enabling a total cost comparison for each corridor running on LSFO compared to methanol over a 25-year period, as well as quantifying the necessary willingness to pay, in order to close the additional cost gap.

In order to do so, the MMM Cost Model has been run selecting Europe as the bunkering region for the corridors, as well as selecting the model vessel segments most reflective of the segments in scope for the project. This has been based on the vessel size and corresponding CAPEX and OPEX of the vessels in scope in this project, namely 1,000GT RoPAX as equivalent for the domestic RoPAX, 25,000GT Cruise as equivalent for the international RoPAX and lastly tugboats for fisheries.

CCU and CCS Matrix in scope for MARCO POLO–DK assessment	Proxy Port Port of Frederikshavn	Proxy Port Port of Hanstholm
Carbon Capture Utilization (CCU) Methanol Bunkering to accommodate maritime demand	1 Domestic RoPAX 2 International RoPAX	3 Fisheries 4 CO_2 Transportation to accommodate Import Scenario
Carbon Capture and Storage (CCS) CO_2 Import	Not part of the project objective	4 CO_2 Transportation to accommodate Import Scenario[1]

In focus ..

Archetype Port: **1. Domestic RoPAX**

Proxy Port: **Frederikshavn**

Proxy Route: **Frederikshavn <-> Læsø**

Frederikshavn <-> Læsø serves as the proxy route for the domestic RoPAX Corridor, and has been assessed based on the MMM Methodology

Technical Assessment Insights

Methodology

The MMM Methodology for RoPAX Green Corridors combines an assessment of the assets and operators on the Frederikshavn <-> Læsø route, in order to deliver a technical assessment on whether and how the route can transition to alternative fuels.

Scoring – Asset Criteria: POSITIVE ASSESSMENT

Frederikshavn – Læsø is serviced by two assets, where only one has a yearlong deployment (Margrete Laesoe). The roll-out of the Green Corridor is therefore recommended to initially begin only with the asset with yearlong deployment, in order to provide a steady demand signal and incentivize investments across the value chain. In the long-run, both assets are of similar and high age (26;28) and are therefore strong candidates for replacement. Additionally, both assets sail on the Danish flag, and as such will be impacted and can benefit from Danish emission control mechanisms and/or subsidies.

Scoring – Operator Criteria: POSITIVE ASSESSMENT

Frederikshavn – Læsø is covered by one operator, namely the Municipality of Læsø in Denmark, with key focus on this route. Additionally, the operator is involved in an ongoing assessment of different decarbonization pathways for the route, including retrofitting of existing assets.

MMM RoPAX Technical Assessment – Step 1& 2

The table below provides a snapshot of the technical assessment of the domestic RoPAX Corridor based on the MMM Methodology. The Scoring Mechanism follows a Showstopper to Best Case approach (0 to 3), with a scoring scale tailored to each criterion (A1 to B3). An extensive explanation of this can be found in Appendix 2.1.

Step 1: Route Mapping	
Route Type: **Single Stop - 2 ports on Route**	
Number of Operators 1	**Number of Assets 2**
Læsø Kommune	Margrete Laesoe
	Anne Laesoe

Step 2: Scoring						
Asset Criteria (A)			**Operator Criteria (B)**			**Asset Score**
A1. Deployment Type	**A2. Age**	**A3. Flag**	**B1. Operator Route Coverage**	**B2. Operator Regional Presence**	**B3. Operator Decarb. Commitment**	**Max Score: 3**
3	2	3	3	1	2	**2.3**
0						

Table 2.2: Technical assessment of domestic RoPAX Corridor – Step 1&2

The annual methanol demand for the domestic RoPAX Corridor out of Frederikshavn is estimated at 3,444t initially, with the potential to reach 4,028t when all assets are decarbonized[1]

Asset Decarbonization Trajectory

Based on the assessment of individual assets, the **following decarbonization trajectory is assumed** for the route Frederikshavn <-> Læsø.

Phase 1

Decarbonization of Margrete Laesoe as the main asset servicing the route. Given that the route is serviced only by one asset yearlong, there is no need to distinguish between a Phase 1a and 1b in the decarbonization trajectory of the route and its assets.

Phase 2

In the long-run, the transition of the entire route to alternative fuels will include the subsequent decarbonization of Anne Laesoe, as the second and last asset servicing the route.

Potential Methanol Demand

Based on the decarbonization trajectory described, the table below provides **a preliminary quantification of the potential methanol demand associated with each asset, as well as an aggregated demand for each Phase of the route's decarbonization.**

The volumes are derived based on an analysis of the individual asset's deployment and operational profile, and represent **a scenario where deployment will be exclusively on methanol[2].** Potential methanol demand is quoted as annual demand, as well as maximum and minimum monthly demand, to leverage the predictability in the RoPAX segment, provide visible demand signals, and support fuel sourcing and storage considerations.

Potential Methanol Demand associated with Frederikshavn <-> Læsø (t)

Asset(s)	Phase 1a			Phase 1b			Phase 2		
	Annual Demand	Maximum Monthly Demand	Minimum Monthly Demand	Annual Demand	Maximum Monthly Demand	Minimum Monthly Demand	Annual Demand	Maximum Monthly Demand	Minimum Monthly Demand
Margrete Laesoe	3,444	344	199				3,444	334	199
Anne Laesoe							584	157	0
Phase Total	**3,444**	**344**	**199**				**4,028**	**491**	**199**

Table 2.3: Potential methanol demand associated with domestic RoPAX Corridor

1. The potential methanol demand assessment is derived based on the existing assets on the route and does not account for material changes in the type and number of assets deployed on this route in the future.
2. Deployment on alternative fuels requires a carbon-based pilot fuel.

The Phase 1 roll-out of the domestic RoPAX Corridor out of Frederikshavn entails a significant incremental cost, delivering emission reduction in the range of 89-93% compared to LSFO

Cost Model Methodology

The MMM Methodology for the Green Corridor Cost Model demonstrates the incremental cost of the route transitioning to alternative fuels in Phase 1. The assessment is based on input on energy and fuel(s), port(s) and vessel(s).

In the case of RoPAX, only methanol is reviewed, allowing for comparisons between the E-methanol (PS), E-methanol (DAC) and Bio-methanol options.

MMM Cost Model Assessment

MMM Cost Model assumptions and input

Bunker region	Europe
Year in operation	2030
Vessel segment	RoPAX
Vessel size	1,000 GT
Number of vessels on Corridor	1
Lifetime of corridor (Years)	25
Average vessel speed (knots)	14
Cargo per vessel (PAX)	500
Cargo value (USD/PAX)	19.5
Distance per one leg (NM)	17
Days at sea	132
Number of legs per year	2,609
Cargo utilization	45%

Table 2.4: Cost Model assumptions for domestic RoPAX Corridor

Margrete Laesoe has been identified as the only vessel suitable to be replaced by a methanol fuelled vessel in Phase 1 and serves therefore as the proxy vessel for the Cost Model.

MMM Cost Model output w. carbon cost at $100 USD/t$CO_2$ (~90 EUR)[1]

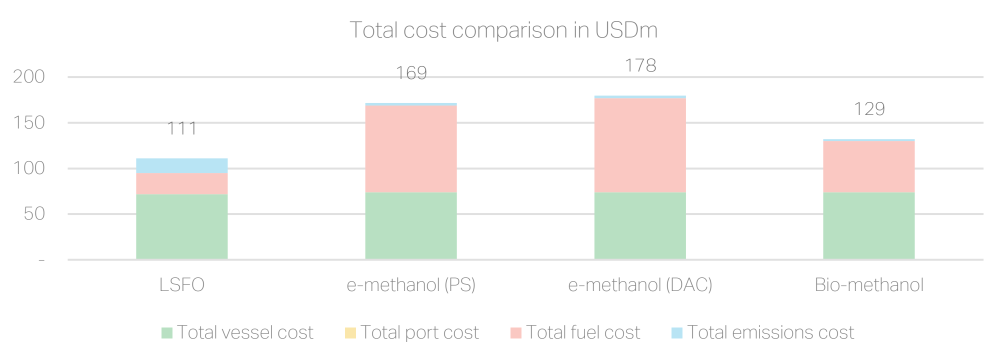


Table 2.5: Cost Model output for domestic RoPAX Corridor – Total Cost Comparison

As can be seen in the graph above, the increased fuel cost associated with methanol (any sub-type) significantly drives the higher total cost associated with the methanol corridor(s). In comparison, cost associated with port infrastructure has been kept the same across all scenarios (at 0 USDm), whereas total vessel cost (CAPEX for newbuilding) has been adjusted upwards for the assets in the methanol corridor(s). The model also takes into account the cost of carbon emissions, which in this case may come in the form of the EU ETS. A cost of $100 USD/t$CO_2$ (~90 EUR) is applied, reducing the incremental cost for E-Methanol (DAC) from 85% to 60%, and for Bio-Methanol from 35% to 16% over the lifetime of the vessel.

1. Under current guidelines a vessel under 5000GT, or a vessel connecting islands with populations less than 200,000 to the mainland are not subject to EU ETS. The carbon cost has been included in the domestic RoPAX assessment to account for any potential changes to EU ETS in 2030, or any carbon taxes imposed on a national level.

The incremental cost associated with the domestic RoPAX Corridor in Phase 1 can be absorbed through a 1.3 to 4.6USD increase in the ticket price per leg

Cost Model Methodology

For the purpose of estimating the incremental cost of transitioning the service to a methanol fuelled vessel, the key components are, "Number of Legs per Year" and "Cargo Utilization". This is due to the fact that these inputs provide the number of passengers per year, which enables the cost model to calculate incremental cost per ticket price per leg.

MMM Cost Model Assessment

MMM Cost Model assumptions and input	
Bunker region	Europe
Year in operation	2030
Vessel segment	RoPAX
Vessel size	1,000 GT
Number of vessels on Corridor	1
Lifetime of corridor (Years)	25
Average vessel speed (knots)	14
Cargo per vessel (PAX)	500
Cargo value (USD/PAX)	19.5
Distance per one leg (NM)	17
Days at sea	132
Number of legs per year	**2,609**
Cargo utilization	**45%**

Table 2.6: Cost Model assumptions for domestic RoPAX Corridor - with key input highlighted

MMM Cost Model output w. carbon cost at \$100 USD/tCO_2 (~90 EUR)

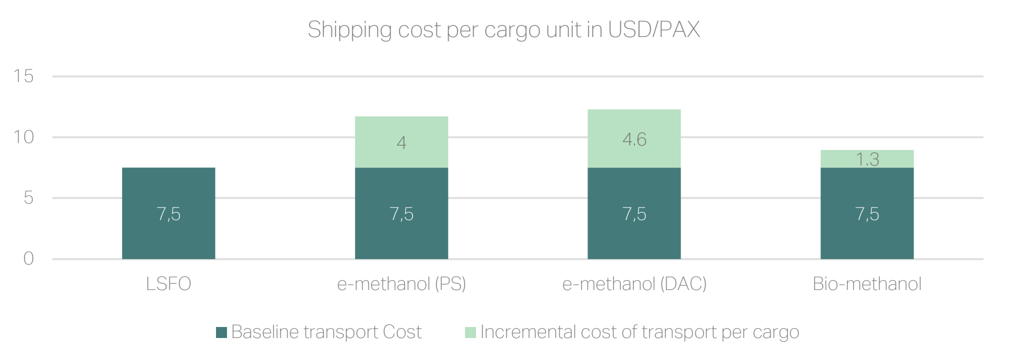


Table 2.7: Cost Model output for domestic RoPAX Corridor – Shipping Cost per Cargo

The table above demonstrates the incremental cost (per PAX) that would be seen if the route would be serviced by a vessel running on a variation of methanol, ranging between 1.3 and 4.6 USD/PAX. The "Baseline transport Cost" shown here is comprised of the cost of LSFO fuel and carbon price, coupled with the other associated OPEX cost built into the Cost Model. The OPEX costs (omitting cost of fuel) remain constant for all scenarios, meaning that the incremental cost of transport per PAX is the added cost associated with higher prices of methanol only. Given that the current cost of a one way ticket is around \$19.5USD equivalent, passengers would need to be willing to pay between \$20.8USD for Bio-Methanol and \$24.1USD for E-Methanol (DAC).

CCU and CCS Matrix in scope for MARCO POLO–DK assessment	Proxy Port Port of Frederikshavn	Proxy Port Port of Hanstholm
Carbon Capture Utilization (CCU) Methanol Bunkering to accommodate maritime demand	1 Domestic RoPAX 2 International RoPAX	3 Fisheries 4 CO_2 Transportation to accommodate Import Scenario
Carbon Capture and Storage (CCS) CO_2 Import	Not part of the project objective	4 CO_2 Transportation to accommodate Import Scenario[1]

In focus ..

Archetype Port: **2. International RoPAX**

Proxy Port: **Frederikshavn**

Proxy Route: **Frederikshavn <-> Gothenburg**

Frederikshavn <-> Gothenburg serves as the proxy route for the internat. RoPAX Corridor, and has been assessed based on the MMM Methodology

Technical Assessment Insights

Methodology

The MMM Methodology for RoPAX Green Corridors combines an assessment of the assets and operators on the Frederikshavn <-> Gothenburg route, in order to deliver a technical assessment on whether and how the route can transition to alternative fuels.

Scoring – Asset Criteria: POSITIVE ASSESSMENT

Frederikshavn – Gothenburg is serviced all year round by two assets, with one additional asset servicing on an ad-hoc / seasonal basis. The roll-out of the Green Corridor is therefore recommended to initially begin only with the two assets with yearlong deployment – Phase 1a entailing the oldest of the two vessels (Stena Danica) and Phase 1b entailing the second oldest (Stena Jutlandica). In line with its current age (18), the seasonal asset (Stena Vinga) can be decarbonized in the long run. All three assets sail on the Swedish flag, and as such can be partially impacted by Danish emission control mechanisms and/ or regional subsidies.

Scoring – Operator Criteria: POSITIVE ASSESSMENT

Frederikshavn – Gothenburg is covered by one Swedish operator, namely Stena Line. Additionally, the operator has a strong decarbonization track-record, having recently completed the first ship-to-ship bunkering of a RoPAX vessel (Stena Germanica) out of Gothenburg, as well as being involved in ongoing assessments of different decarbonization pathways both for the route assessed, as well as for multiple other assets and routes in the region.

MMM RoPAX Technical Assessment – Step 1 & 2

The table below provides a snapshot of the technical assessment of the international RoPAX Corridor based on the MMM Methodology. The Scoring Mechanism follows a Showstopper to Best Case approach (0 to 3), with a scoring scale tailored to each criterion (A1 to B3). An extensive explanation of this can be found in Appendix 2.1.

Step 1: Route Mapping	
Route Type: **Single Stop - 2 ports on Route**	
Number of Operators 1	**Number of Assets 3**
Stena Line	Stena Danica
	Stena Jutlandica
	Stena Vinga

Step 2: Scoring						
Asset Criteria (A)			**Operator Criteria (B)**			**Asset Score**
A1. Deployment Type	**A2. Age**	**A3. Flag**	**B1. Operator Route Coverage**	**B2. Operator Regional Presence**	**B3. Operator Decarb. Commitment**	**Max Score: 3**
3	3	3	3	3	3	**3**
3	2	3	3	3	3	**2.83**
0						

Table 2.8: Technical assessment of international RoPAX Corridor – Step 1&2

The annual methanol demand for the internat. RoPAX Corridor out of Frederikshavn is estimated at 20,534t initially, with the potential to reach 47,300t when all assets are decarbonized[1]

Asset Decarbonization Trajectory

Based on the assessment of individual assets, the **following decarbonization trajectory is assumed** for the route Frederikshavn <-> Gothenburg.

Phase 1a

Decarbonization of Stena Danica as the oldest (all other criteria are equal) of the two vessels servicing the route all year round.

Phase 1b

Decarbonization of Stena Jutlandica as the second vessel servicing yearlong the route.

Phase 2

In the long-run, the transition of the entire route will include Stena Vinga or equivalent vessels, covering additional demand / deployment on the route on a seasonal basis.

Potential Methanol Demand

Based on the decarbonization trajectory described, the table below provides **a preliminary quantification of the potential methanol demand associated with each asset, as well as an aggregated demand for each Phase of the route's decarbonization.**

The volumes are derived based on an analysis of the individual asset's deployment and operational profile, and represent **a scenario where deployment will be exclusively on methanol[2].** Potential methanol demand is quoted as annual demand, as well as maximum and minimum monthly demand, to leverage the predictability in the RoPAX segment, provide visible demand signals, and support fuel sourcing and storage considerations.

Potential Methanol Demand associated with Frederikshavn <-> Gothenburg (t)

Asset(s)	Phase 1a			Phase 1b			Phase 2		
	Annual Demand	Maximum Monthly Demand	Minimum Monthly Demand	Annual Demand	Maximum Monthly Demand	Minimum Monthly Demand	Annual Demand	Maximum Monthly Demand	Minimum Monthly Demand
Stena Danica	20,534	1,987	1,577	20,534	1,987	1,577	20,534	1,987	1,577
Stena Jutlandica				23,086	2,825	1,580	23,086	2,825	1,580
Stena Vinga							3,679	1,512	0
Phase Total	**20,534**	**1,987**	**1,577**	**43,620**	**4,812**	**3,157**	**47,300**	**6,324**	**3,157**

Table 2.9: Potential methanol demand associated with international RoPAX Corridor

1. The potential methanol demand assessment is derived based on the existing assets on the route and does not account for material changes in the type and number of assets deployed on the route in the future.
2. Deployment on alternative fuels requires a carbon-based pilot fuel.

The Phase 1 roll-out of the internat. RoPAX Corridor out of Frederikshavn entails a significant incremental cost, delivering emission reduction in the range of 92-97% compared to LSFO

Cost Model Methodology

The MMM Methodology for the Cost Model Green Corridors demonstrates the incremental cost of the route transitioning to alternative fuels in Phase 1. The assessment is based on input on energy and fuel(s), port(s) and vessel(s).

In the case of RoPAX, only methanol is reviewed, allowing for comparisons between the E-methanol (PS), E-methanol (DAC) and Bio-methanol options.

MMM Cost Model Assessment

MMM Cost Model assumptions and input	
Bunker region	Europe
Year in operation	2030
Vessel segment	Cruise
Vessel size	25,000 GT
Number of vessels on Corridor	2
Lifetime of corridor (Years)	25
Average vessel speed (knots)	17
Cargo per vessel (PAX)	1,858
Cargo value (USD/PAX)	22.5
Distance per one leg (NM)	50
Days at sea	173
Number of legs per year	1,411
Cargo utilization	45%

Table 2.10: Cost Model assumptions for internat. RoPAX Corridor

Stena Danica and Stena Jutlandica are the two vessels in Phase 1. The model assumes that all new vessels operating on the route are sister vessels. Aggregate annual PAX capacity and Number of legs remain constant, thus ensuring current deployment patterns could be fulfilled by new vessels.

MMM Cost Model output w. carbon cost at $100 USD/tCO_2$ (~90 EUR)

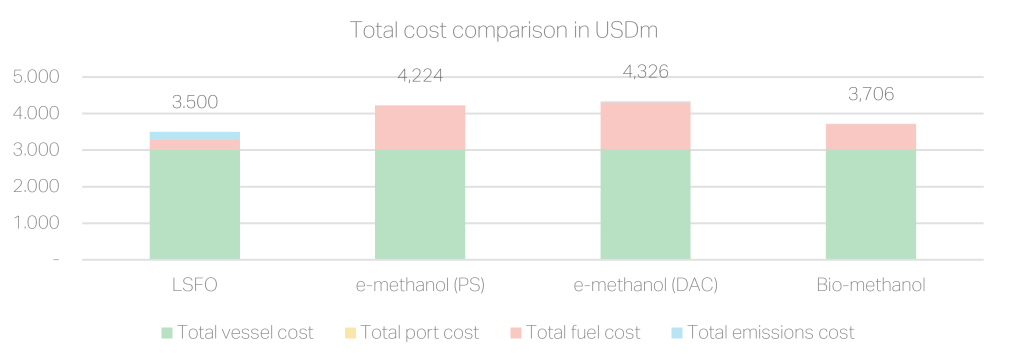


Table 2.11: Cost Model output for international RoPAX Corridor – Total Cost Comparison

As can be seen in the graph above, the increased fuel cost associated with methanol (any sub-type) significantly drives the higher total cost associated with the methanol corridor(s). In comparison, cost associated with port infrastructure has been kept the same across all scenarios (at 0 USDm), whereas total vessel cost (CAPEX for newbuilding) has been adjusted upwards for the assets in the methanol corridor(s).

A carbon cost of $100 USD/tCO_2$ has been assumed, which would be enforced by EU ETS imposed on existing vessels on this route in 2024. Here, an additional $826m USD would be required to fund the transition when using E-Methanol(DAC), compared to an additional cost of $206m USD for Bio-methanol over the same period.

The incremental cost associated with the internat. RoPAX Corridor in Phase 1 can be absorbed through a 3.5 to 14USD increase in ticket price per leg

Cost Model Methodology

For the purpose of estimating the incremental cost of transitioning the service to a methanol fuelled vessel, the key components are, "Number of Legs per Year" and "Cargo Utilization". This is because these inputs provide the number of passengers per year, which enables the cost model to calculate incremental cost per ticket price per leg.

MMM Cost Model Assessment

MMM Cost Model assumptions and input	
Bunker region	Europe
Year in operation	2030
Vessel segment	Cruise
Vessel size	25,000 GT
Number of vessels on Corridor	2
Lifetime of corridor (Years)	25
Average vessel speed (knots)	17
Cargo per vessel (PAX)	1,858
Cargo value (USD/PAX)	22.5
Distance per one leg (NM)	50
Days at sea	173
Number of legs per year	**1,411**
Cargo utilization	**45%**

Table 2.12: Cost Model assumptions for international RoPAX Corridor - with key input highlighted

MMM Cost Model output w. carbon cost at $100 USD (~90 EUR)

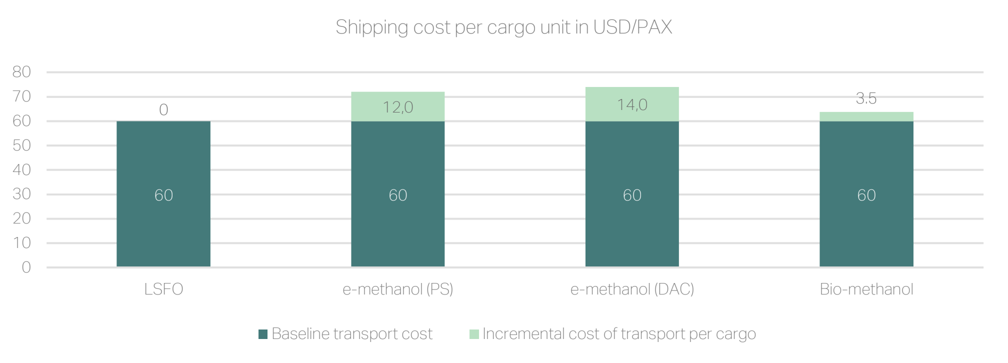


Table 2.13: Cost Model output for domestic RoPAX Corridor – Shipping Cost per Cargo

The table above demonstrates the incremental cost (per PAX) that would be seen if the route would be serviced by a vessel running on a variation of Methanol, ranging between 3.5 and 14 USD/PAX. The "Baseline transport Cost" shown here is comprised of the cost of LSFO fuel and carbon price, coupled with the other associated OPEX costs built into the Cost Model. The OPEX costs (omitting cost of fuel) remain constant for all scenarios, meaning that the incremental cost of transport per PAX is the added cost associated with higher prices of methanol only. Given that the current average cost of a one way ticket is $22.5 USD equivalent, passengers would need to be willing to pay between $26USD for Bio-Methanol and $36.5USD for E-Methanol (DAC).

Frederikshavn is the common denominator between the domestic and intern. RoPAX Corridors and can take some or all the future bunkering[1]

Methodology

The MMM Methodology for RoPAX Green Corridors includes a mapping of homeport and ports of call, and potential bunkering ports for each route. The subsequent scoring of the port relations in each route generates a visualization of the port interplay and potential for bunkering on the route.

Port Interplay Assessment for Port of Frederikshavn

The Port of Frederikshavn forms part of both the domestic and international RoPAX Corridors and is therefore a natural part of the Green Corridor Technical Assessment. The Port Interplay assessment indicates that Frederikshavn can become a methanol bunkering hub for either or both Corridors. For vessels operating via Gothenburg, this would require operational adjustments to be made to provide sufficient time to bunker in Frederikshavn. As a result, the port can benefit from the steady demand associated with the RoPAX Corridors and aggregate volumes to reduce uncertainty and risk in terms of the CAPEX investments. The actual methanol demand will additionally depend on whether other ports on the different routes make methanol available for bunkering, as well as the associated fuel price offered. Chapter 5 in the report deep-dives into future methanol availability in Northern Jutland.

The table below provides a snapshot of the technical assessment of the port interplay of the domestic and international RoPAX Corridors based on the MMM Methodology. The Scoring is explained below, and an extensive explanation of the Methodology can be found in Appendix 2.1.

Scoring Mechanism	
1	Multi-stop and insufficient time to bunker
2	Single-stop (but not homeport) or multi-stop with sufficient time to bunker
3	Homeport

Step 5: Port Interplay					
Archetype Route	**Assets**	**Port 1: Frederikshavn**	**Port 2: Læsø**	**Port 3**	**Port 4**
Domestic RoPAX	Margrete Laesoe	2	3		
	Anne Laesoe	2	3		
Archetype Route	**Assets**	**Port 1: Frederikshavn**	**Port 2: Gothenburg**	**Port 3**	**Port 4**
International RoPAX	Stena Danica	2	3		
	Stena Jutlandica	2	3		
	Stena Vinga	2	2		

Table 2.14: Technical assessment of RoPAX Corridors – Joint Step 5

1. The potential methanol demand assessment is derived based on the existing assets on the route and does not account for material changes in the type and number of assets deployed on the route in the future.

Future methanol demand could range annually from 23,978t in Phase 1a to 51,328t in Phase 2, if both corridors bunker fully at Frederikshavn

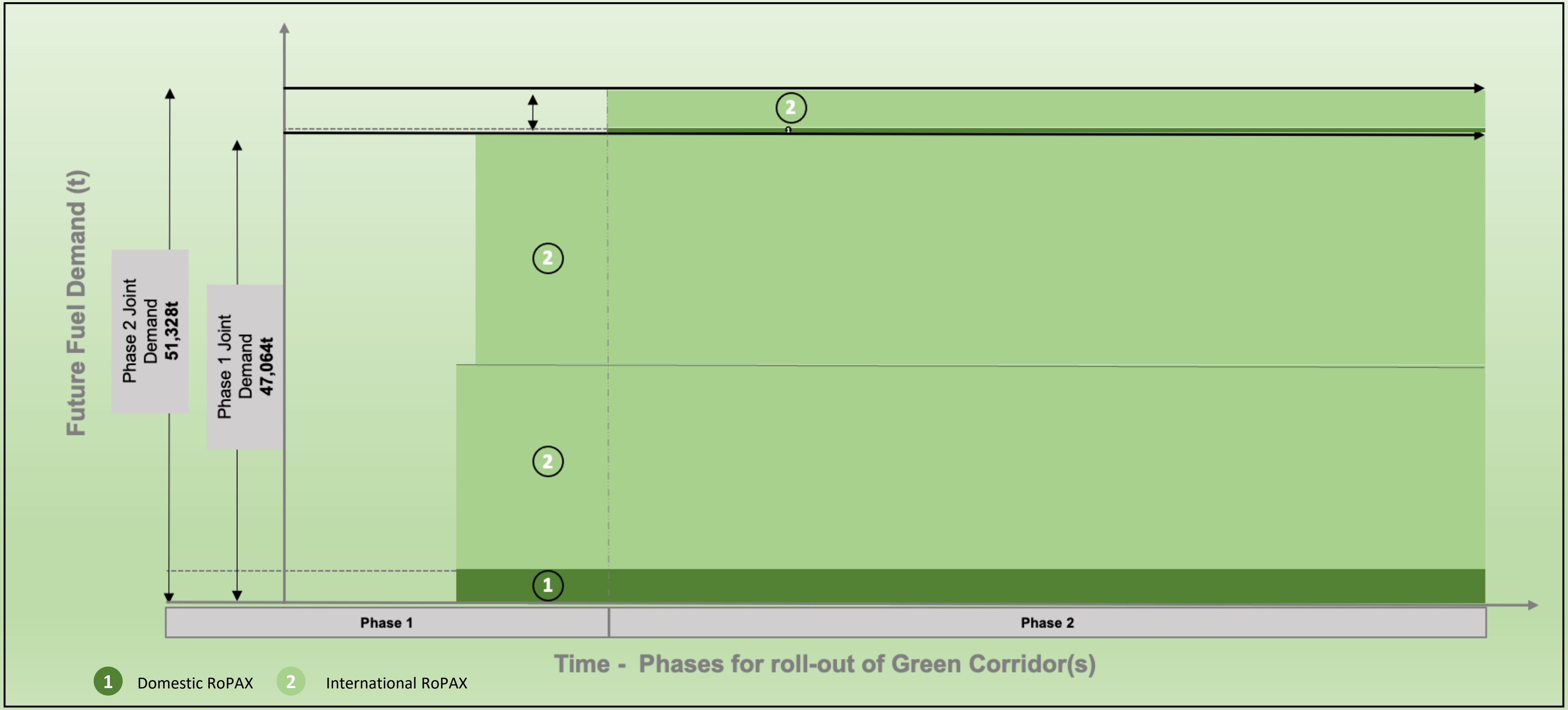


Table 2.15: Phased future methanol demand from domestic and international RoPAX Corridor(s)

CCU and CCS Matrix in scope for MARCO POLO–DK assessment	Proxy Port Port of Frederikshavn	Proxy Port Port of Hanstholm
Carbon Capture Utilization (CCU) Methanol Bunkering to accommodate maritime demand	1 Domestic RoPAX 2 International RoPAX	3 Fisheries 4 CO_2 Transportation to accommodate Import Scenario
Carbon Capture and Storage (CCS) CO_2 Import	Not part of the project objective	4 CO_2 Transportation to accommodate Import Scenario[1]

In focus ..

Archetype Port: **3. Fisheries**

Proxy Port: **Hanstholm**

The Port of Hanstholm serves as the proxy for the Fisheries Corridor and has been assessed based on the MMM Green Corridor Blueprints

Methodology

The MMM Green Corridor Blueprints call for an assessment of the size and configuration of the fleet calling the Port of Hanstholm, as well as for a strategic preliminary sequencing of the decarbonization order / trajectory for all relevant assets in scope.

Size and configuration of fleet calling Hanstholm

The Port of Hanstholm is part of the significant hub of fisheries concentrated in Northern Denmark – both in terms of fleet size and value of catch, as well as in terms of employment. This is confirmed by the review of port call data for the past 7 years, which indicates that Fishing Vessels are the top visiting vessel segment in the Port of Hanstholm, followed by Sailing and Recreational Vessels, and thereafter Cargo Vessels.

Within the realm of Green Corridors, non-commercial vessels are not in scope for the assessments. Similarly, the low density of cargo vessel port calls at the Port of Hanstholm, coupled with many "one-time" visiting cargo vessels do not point to a sufficiently strong demand basis to support the initial roll-out of a Green Corridor centered around cargo vessels.

Size and configuration of fleet calling the Port of Hanstholm (2022)				
Order	**Vessel segment**	**Number of Assets (2022)**	**Number of Arrivals (2022)**	**Number of Flags (2022)**
1st	Fishing Vessels	250	5,237	9
2nd	Sailing & recreation	Out of scope		
3rd	Cargo Vessels	51	72	12

Table 2.16: Size and configuration of fleet calling the Port of Hanstholm (2022)

Fishing fleet at Hanstholm

Based on deployment data for the Port of Hanstholm, the analysis under the Technical Assessment assumes the following size and configuration for the fishing fleet calling Hanstholm:

Size and configuration of fishing fleet (2022)		
Number of asset (s)	250	
Number of flag(s)	9	
Flag Asset distribution	**Number of Asset(s)**	**Number of Call(s)**
Denmark	160	4,351
Norway	44	357
Sweden	12	91
Netherlands	12	87
Germany	10	188
France	5	125
United Kingdom	5	7
Belgium	1	3
Other	1	28

Table 2.17: Size and configuration of fishing fleet (2022)

The annual fuel demand for the Fisheries Corridor is dependent on the volume and density of port calls, estimated initially at the equivalent of 1,331,000 litres of diesel

Asset Decarbonization Trajectory

Based on the volume of annual port calls per asset (most frequently visiting asset made 119 visits in 2022), as well as the distribution of the assets under the different flags, it is recommended to pursue a 3-phased approach to decarbonize the fishing fleet calling the Port of Hanstholm.

Here, each phase includes vessels that meet a specific threshold of number of annual port calls, which has been developed based on the deployment pattern out of the Port of Hanstholm. This is done, in order to ensure a sufficiently steady fuel demand to incentivize the necessary initial investments.

Phase 1

All assets with 85 annual port calls or above

Phase 2

All assets with annual port calls in the range 50-84

Phase 3

All assets calling the Port of Hanstholm

Potential Methanol Demand

Based on the decarbonization trajectory described, the table below provides **a preliminary quantification of the potential fuel demand associated with each Phase of the route's decarbonization[1].**

The volumes for each Phase are derived based on the reference annual fuel consumption of the fishing fleet in Denmark, tailored to account for the sub-type of fishing vessels and their respective size in the Port of Hanstholm. The volumes represent **a scenario where deployment will be exclusively on methanol.**

Potential Fuel Demand associated with Fishing Fleet in Hanstholm (diesel litres)

Phase	Number of Assets		Flag		Total Fuel Consumption
	New	Total	Number	Flag (+threshold of calls)	
1	12	12	1	Denmark (+85)	1,331,000
2	31	43	3	Denmark ,Norway , Germany; (50-84)	11,005,000
3	207	250	9	Denmark, Norway, Germany, Sweden, Netherlands, France, United Kingdom, Belgium, Other	111,531,000

Table 2.18: Potential fuel demand associated with Fisheries Corridor

1. Many of the assets in Phase 3 have low annual port calls in Hanstholm and are deployed in multiple locations per year. The value here reflects the assets' maximum contribution to the fuel demand, if they were to always bunker at Hanstholm. The actual value is subject to their deployment and alternative options for bunkering in the region.

The Phase 1 roll-out of the Fisheries Corridor out of Hanstholm entails a significant incremental cost, delivering emission reduction in the range of 90-95% compared to LSFO

Cost Model Methodology

The MMM Methodology for the Green Corridor Cost Model demonstrates the incremental cost of the route transitioning to alternative fuels in Phase 1. The assessment is based on input on energy and fuel(s), port(s) and vessel(s).

In the case of Fisheries in MARCO POLO-DK, only methanol is reviewed, allowing for comparisons between the E-methanol (PS), E-methanol (DAC) and Bio-methanol options.

MMM Cost Model Assessment

MMM Cost Model assumptions and input	
Bunker region	Europe
Year in operation	2030
Vessel segment	Tug
Vessel size	100 DWT
Number of vessels on Corridor	12
Lifetime of corridor (Years)	25
Average vessel speed (knots)	11
Cargo per vessel (Ton)	35
Cargo value (USD/Ton)	919
Distance per one leg (NM)	211
Days at sea	80
Number of legs per year	100
Cargo utilization	75%

Table 2.19: Cost Model assumptions for Fisheries Corridor

Twelve vessels have been identified as suitable to be replaced by methanol fuelled vessels in Phase 1.

MMM Cost Model output w. carbon cost at $100 USD/tCO_2$ (~90 EUR)

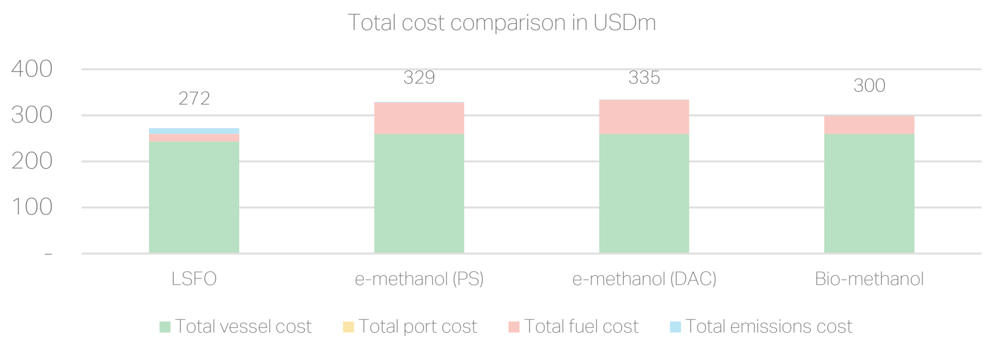


Table 2.20: Cost Model output for Fisheries Corridor – Total Cost Comparison

As can be seen in the graph above, the increased fuel cost associated with methanol (any sub-type) significantly drives the higher total cost associated with the methanol corridor(s). In the comparison, cost associated with port infrastructure been kept the same across all scenarios (at 0 USDm).

The model also takes into account the cost of carbon emissions, which in this case may come in the form on the EU ETS[1]. A cost of $100 USD/tCO_2$ (~90 EUR) is used meaning the cost increase for E-Methanol (DAC) falls from 28% to 23%, and from 15% to 10% for Bio-Methanol over the lifetime of the vessels.

1. Under current guidelines a vessel under 5000GT, or a vessel connecting islands with populations less than 200,000 to the mainland are not subject to EU ETS. The carbon cost has been included in the Fisheries assessment to account for any potential changes to EU ETS in 2030, or any carbon taxes imposed on a national level.

The incremental cost associated with the methanol Fisheries Corridor in Phase 1 can be absorbed through a 41 to 87USD per ton increase in price

Cost Model Methodology

For the purpose of estimating the incremental cost of transitioning the route to a methanol fuelled vessel, the key components are, “Number of Legs per Year” and “Cargo Utilization”. This is because these inputs derive the total tons of cargo (fish) landed per year, which enables the cost model to calculate incremental cost per ton of fish landed.

MMM Cost Model Assessment

MMM Cost Model assumptions and input	
Bunker region	Europe
Year in operation	2030
Vessel segment	Tug
Vessel size	100 DWT
Number of vessels on Corridor	12
Lifetime of corridor (Years)	25
Average vessel speed (knots)	11
Cargo per vessel (Ton)	35
Cargo value (USD/Ton)	919
Distance per one leg (NM)	211
Days at sea	80
Number of legs per year	**100**
Cargo utilization	**75%**

Table 2.21: Cost Model assumptions for Fisheries Corridor - with key input highlighted

MMM Cost Model output w. carbon cost at $100 USD/t$CO_2$ (~90 EUR)

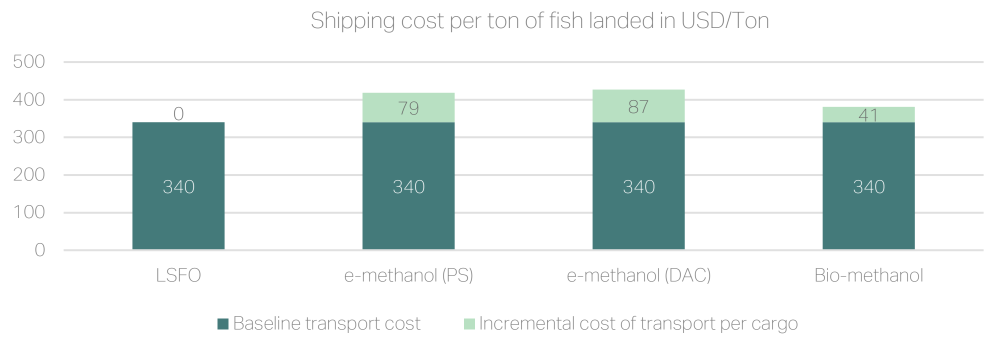
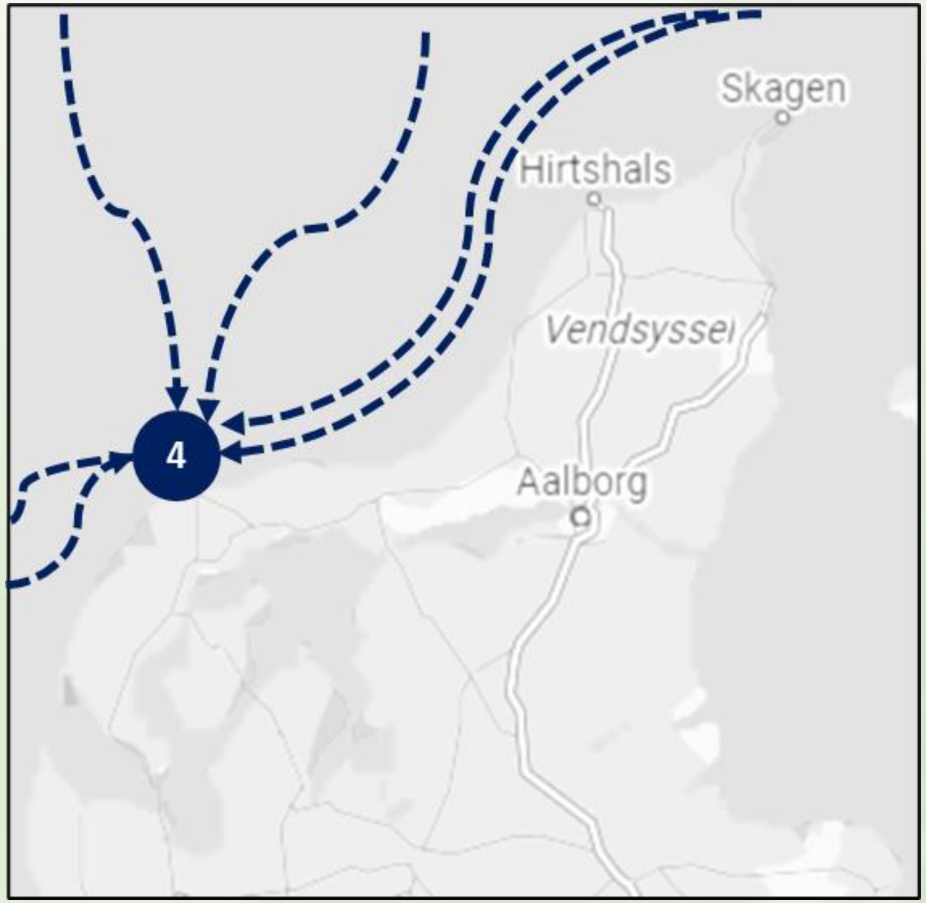


Table 2.22: Cost Model output for Fisheries Corridor – Shipping Cost per ton of fish landed

The table above demonstrates the incremental cost (per ton) that would be seen if the route would be serviced by 12 vessels running on a variation of methanol, this ranges between 41 and 87 USD/ton. The “Baseline transport Cost” shown here is comprised of the cost of LSFO fuel and carbon price, coupled with the other associated OPEX costs built into the Cost Model. The OPEX Costs (omitting cost of fuel) remain constant for all scenarios, meaning that the incremental cost of transport per ton of fish landed is the added cost associated with higher prices of methanol only.

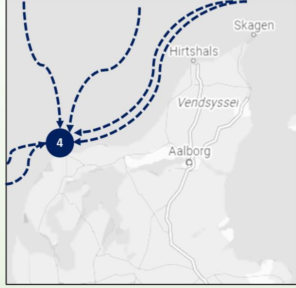
CCU and CCS Matrix in scope for MARCO POLO–DK assessment	Proxy Port Port of Frederikshavn	Proxy Port Port of Hanstholm
Carbon Capture Utilization (CCU) Methanol Bunkering to accommodate maritime demand	1 Domestic RoPAX 2 International RoPAX	3 Fisheries 4
Carbon Capture and Storage (CCS) CO_2 Import	Not part of the project objective	CO_2 Transportation to accommodate Import Scenario[1] 4

In focus ..



Archetype Port: **4. CO_2 Transportation (Import)**

Proxy Port: **Hanstholm**



The Port of Hanstholm serves as the proxy for the CO_2 Import Corridor and the potential fuel demand for this new trade has been assessed

Technical Assessment – Context Setting

CO_2 Transportation as a new trade

CO_2 Transportation is an emerging trade in Northern Europe and Denmark, linked closely with the uptake of Carbon Capture Utilization (CCU) and Carbon Capture and Storage (CCS).

Modelling CO_2 Transportation

Within the MARCO POLO-DK project, Northern Jutland has been a key focus area as a result of the significant regulatory and commercial investments to accelerate the uptake of CCUS in the region.

In line with the timeline in scope for the project, the MMM model for CO_2 transportation has been utilized to quantify the type and size of vessels necessary to enable the import of CO_2 into Denmark.

Technical Assessment – Scenarios and Findings

Quantifying the potential methanol demand to accommodate CO_2 import to Denmark

Based on the realization timeline for the MARCO POLO-DK project and input from Chapter 5 on the import sources and volumes for CO_2 import into Denmark, the MMM model for CO_2 transportation has been deployed to quantify the potential methanol demand to fuel import vessels at the Port of Hanstholm.

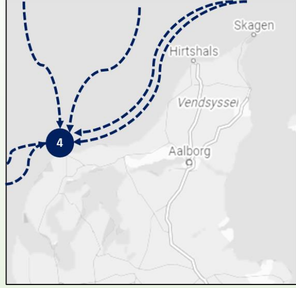
<u>Asset deployment and operational assumptions</u>

CO_2 transportation is an emerging trade on the backdrop of CCUS, and we therefore expect a growing number of dedicated vessels to be built for this purpose. The model is built as a “pipeline” simulation, where assets are deployed dedicatedly between a unique export port and unique import [here Port of Hanstholm], transporting CO_2 into Denmark at a pre-determined vessel utilization and returning in ballast.

For the MARCO POLO-DK project the model utilizes two vessel sizes, one of 10,000 ton carrying capacity and another of 25,000 ton carrying capacity. The 10,000 ton carrying capacity vessel is slightly larger than the vessels currently built to accommodate Northern Lights, whereas the 25,000 ton carrying capacity vessel's size has been picked to accommodate current CO_2 carriers ordered for deployment on longer distances. In doing so, the model builds-in flexibility on its findings, at the same time as the market for CO_2 transportation in Northern Europe grows.

<u>Volume assumptions</u>

Based on the import volumes identified in Chapter 5, the MMM model has run three scenarios for the percentage of the import volume shipped to the Port of Hanstholm vs. other Danish ports. The three scenarios account for; 33% of the lowest given import volume, 50% of the standard import volume, and 100% of the highest given import volume, being shipped to the Port of Hanstholm.



The annual methanol demand for the CO_2 Import into Hanstholm is estimated to range between 50,500t to approx. 341,000t[1] between 2030 and 2040

Import Assumptions: Vessel Size, Volume, Year				Import Operational Implications			Methanol Demand associated with Import
Scenario	**Vessel Size**	**Year**	**CO_2 Imported (Mt)**	**No. Vessels Required**	**No. Hanstholm Port Visits**	**ETA/DAY**	**Total Methanol Demand (t)**
33% Lowest Import	10K	2030	3	8	538	1.5	52,447.54
		2035	5	13	782	2.1	90,526.33
		2040	8	19	1130	3.1	133,033.55
	25K	2030	3	6	397	1.1	50,588.52
		2035	5	8	485	1.3	71,249.75
		2040	8	10	626	1.7	87,347.37
50% Standard Import	10K	2030	8	18	1137	3.1	122,161.29
		2035	14	31	1930	5.3	212,033.04
		2040	19	40	2456	6.7	275,570.60
	25K	2030	8	10	626	1.7	87,347.37
		2035	14	14	855	2.3	124,106.22
		2040	19	17	1042	2.9	150,459.87
Highest	10K	2030	21	45	2679	7.3	314,134.83
		2035	36	71	4362	12.0	488,732.65
		2040	46	90	5579	15.3	617,032.53
	25K	2030	21	21	1290	3.5	185,249.11
		2035	36	31	1920	5.3	272,447.31
		2040	46	39	2435	6.7	341,252.23

Table 2.23 Assumptions and findings for CO_2 Transportation (Import) scenarios

1. Although the table indicates scenarios higher than 341,000t of methanol being required, said scenarios are deemed unfeasible due to the high amount of traffic (12 and 15 ETAs/Day) they entail.

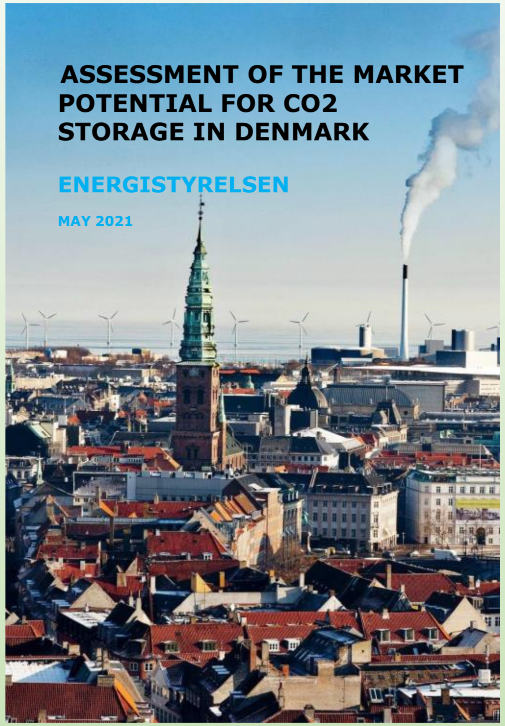
Marco Polo

METHANOL **A**vailability **R**eadiness **C**ost **O**perationality for **Po**rt **Lo**gistics – **D**enmar**k**

Chapter 3- Projected CO_2 imports to Denmark & e-Methanol Production in the Northern Denmark Region- Nordic and regional CCUS perspectives

Nordic Green Solutions

Relevant countries for CO_2 import (1)



The study, carried out by the Danish Energy Agency (DEA) and Ramboll, assessed the potential of various countries to export carbon dioxide (CO2) to Denmark for carbon capture and storage (CCS). The countries under review included Finland, Sweden, Norway, Germany, the Netherlands, Poland, the UK, and the Baltic states. The research scrutinized CO2 sources from the industrial and energy sectors in these countries, estimating their capturability and potential export volumes to Denmark.

In Germany, where approximately 20% of all emissions originate from clusters in Northern Germany, it was projected that up to 50% of the estimated CO2 volumes could potentially be transported to Denmark. This equates to roughly 21 MtCO2 per year.

Finland, with a significant portion of capturable emissions from the pulp & paper industry, often located near coastlines or rivers, was also considered. The study suggested that up to half of the 75% of CO2 intended for CCS could be exported to Denmark, approximately 5 MtCO2 per year.

Sweden could also contribute to Denmark's carbon capture efforts, with an estimated potential export of about 6 MtCO2 per year.

However, the study provided conservative estimates by excluding several countries from the potential CO2 import volumes. The Netherlands, Poland, the UK, and the Baltic states had lower estimated import potentials due to a combination of their own storage capacities, competition from other countries, and logistical constraints. Excluding these countries from the calculations helps to yield a conservative estimate.

With these conservative measures in place, the study estimated that Denmark could potentially import about 32 MtCO2 annually from the evaluated countries for carbon capture and storage. An additional 3 MtCO2 annually from Copenhagen and 2 MtCO2 annually from Aalborg is estimated to be capturable. Hence, the estimated maximum annual CO2 Amounts for CCUS in Denmark was yielded to be 37 Mt annually.

The principle according to which the various emission sources' relevance for Carbon Capture is shown in the table below.

Sector	Significance of CCS	CCS Application Potential
Power and heat generation	LOW for fossil-fired plants, MEDIUM/HIGH for biomass plants	Up to ~90% technical capture potential
Energy-intensive industry	MEDIUM; CCS and hydrogen can be applied	Up to ~60% technical capture potential
Refineries	HIGH	Up to ~50% technical capture potential
Mineral production	HIGH; CCS is key in the cement sector	Up to ~50% technical capture potential
Chemicals	MEDIUM; CCS and CCU can be applied	Up to ~50% technical capture potential
Pulp & paper	HIGH; BECCS is key to compensate for emissions	Up to ~90% technical capture potential

Relevant countries for CO_2 import (2)

Building on the previous analysis, the overall potentials were derived after analyzing each investigated country's domestic policies, funding, domestic storage amounts, and so on.

A summary of the performed analyses can be seen in the table to the right, together with a summary of the reason behind the given country's rating in relation to its potential for DK storage.

It should be noted that the use of CO2 for utilization (CCU) has not been considered for this analysis.

The principle according to which the various emission sources' relevance for Carbon Capture is shown in the table below, for each of the countries.

As can be derived from the table below, each emissions source and its CO2's capturability has been estimated individually, in order to yield a high-quality estimate of the available CO2 amounts.

Whilst the analysis is in-depth, it is still subject to uncertainty, given the high number of variables, and the variability of the given variables of this analysis.

Sector	Significance of CCS	CCS Application Potential
Power and heat generation	LOW for fossil-fired plants, MEDIUM/HIGH for biomass plants	Up to ~90% technical capture potential
Energy-intensive industry	MEDIUM; CCS and hydrogen can be applied	Up to ~60% technical capture potential
Refineries	HIGH	Up to ~50% technical capture potential
Mineral production	HIGH; CCS is key in the cement sector	Up to ~50% technical capture potential
Chemicals	MEDIUM; CCS and CCU can be applied	Up to ~50% technical capture potential
Pulp & paper	HIGH; BECCS is key to compensate for emissions	Up to ~90% technical capture potential

Country	CCS Support	Total CCS Potential 2022-2050 (MtCO2)	Own Storage Capacity (Mt)	Potential for DK Storage
Finland	Moderate	279	N/A	High
Sweden	Moderate	349	6000	High
Norway	Strong	111	103000	Low
Germany	Moderate	871	95000	High
UK	Strong	1,986	78000	Low
Baltics	Low	15	5500	Low
Poland	Low	591	78000	Medium
Netherlands	Strong	274	4000	Medium

Country	Reason for DK Storage Potential
Finland	Finland lacks its own geological formations suitable for CO2 storage, making the export to nearby countries such as Denmark a viable option.
Sweden	Despite having significant storage potential, Sweden is expected to rely on the export of CO2 due to uncertainties about the storage capacity at the national level.
Norway	Norway has a substantial storage capacity and strong domestic policies to support CCS, reducing the likelihood of relying on Denmark for CO2 storage.
Germany	Public opposition and limitations for CO2 storage on national territory make the export of CO2 to other countries such as Denmark a likely option.
UK	The UK already has a significant storage capacity and strong domestic CCS policies, making it unlikely to rely on Denmark for CO2 storage.
Baltics	The capturable amounts are insignificant.
Poland	High domestic storage capacity is expected to cover upcoming CCS activity until 2050.
Netherlands	NL has ongoing developments of domestic storage. Hence, there is significant uncertainty related to importing their CO_2 to Denmark.

Relevant countries for CO_2 import & CO_2 import Scenarios (3)

The standard scenario of 37 MtCO2/yr, determined by DEA and Ramboll's research, will be used to examine cost sensitivity in CO2 import changes.

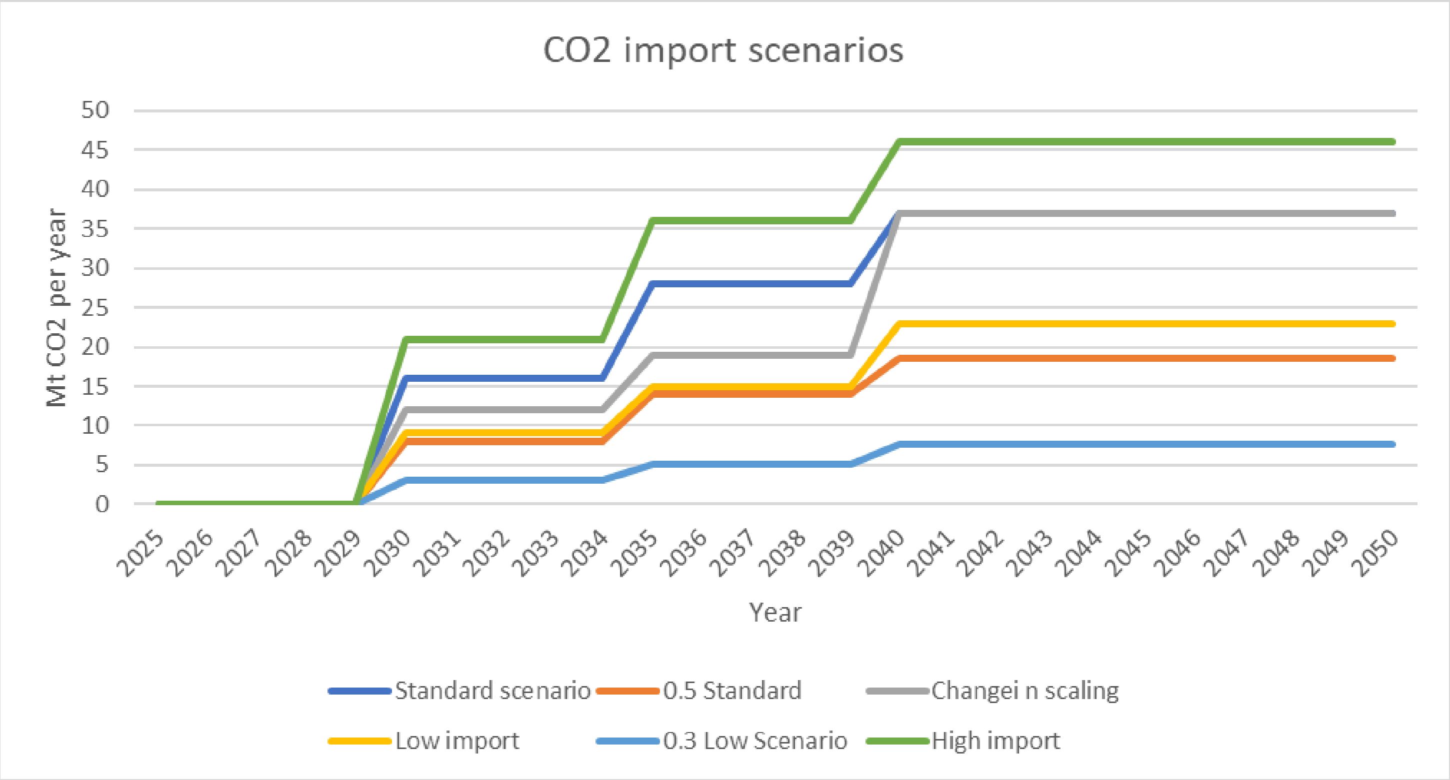
The purpose of investigating the cost sensitivity to various import distributions is to uncover potential business risks and yield effective solutions if required. The scenarios developed for this purpose are presented in the graph below:

The development of the different scenarios serves multiple analytical purposes:
The 0.5 standard scenario and the 0.3 Standard scenario were chosen to investigate the cost impact of decreases in the overall import volume.
The Change in scaling scenario was chosen to evaluate the impact of an alternative distribution of the import amounts across the relevant import countries.

Lastly, the Low import & High import scenarios study cost implications when import amounts are reduced or increased.

Interestingly, we've chosen to investigate more low import scenarios than high import scenarios. The rationale behind this decision is rooted in the inherent risk associated with import projects. Should import amounts turn out lower than expected, the financial risk can escalate since the roll-out of transport and storage capacity carries a high sunk cost. This bias towards low import scenarios ensures that we're prepared for the potential hurdles and challenges that could emerge in less-than-ideal circumstances.

In conclusion, these strategically curated scenarios will offer crucial insights into the cost sensitivity of different import situations. They play a vital role in fortifying Denmark's carbon capture and storage strategies, ensuring that they are economically viable, resilient, and adaptable to a broad spectrum of circumstances.



Biogenic import portion

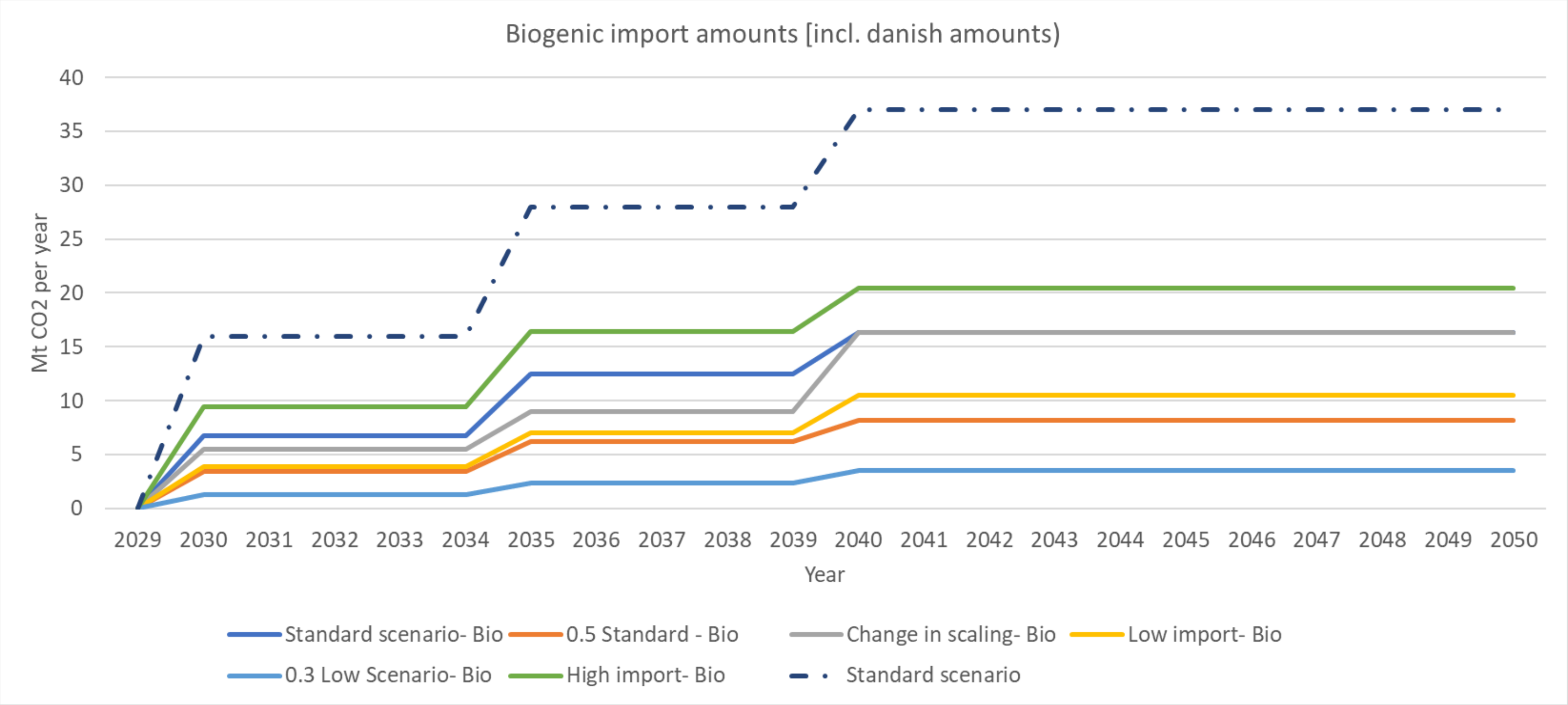
To estimate the portion of imported CO_2 that is biogenically sourced, eurostat data has been used. The biogenic portions are shown by country in the table in the bottom right. Fossil and biogenic amounts are shown the standard scenario, and the lowest & highest import scenarios

The standard scenario of the graph in the previous slide has been shown as a dotted line for comparison.

The purpose of estimating the biogenic portion is that there may be different political use cases for the two sources of CO_2.

For instance, biogenically sourced CO_2 may count as a higher reduction of CO_2 when permanently stored than is the case for fossil CO_2.

The portion of CO_2 captured may hence differ from the overall emitted amounts by country, due to such political decisions.



Biogenic portion by country				
Copenhagen	Aalborg	Germany	Sweden	Finland
53%	53%	13%	67%	53%

Cost and infrastructure cost sensitivity (1)

To assess potential business risks, the cost variability of intermittent storage & transport has been estimated for the investigated scenarios. The calculation will only account for intermittent storage and transport, since these cost elements are the ones expected to vary the most with changes in import amounts.

Additionally, this calculation will establish an outline of the infrastructural requirements, in terms of ship sizing and number, as well as number of port visits to be handled. The cost calculation has been carried out in 2 versions. The first version uses aggreagted data, whilst the second uses disaggregated data. For the purpose of precision and brevity, only the results of the latter version are presented.

It should be noted that all transportation is carried out via shipping. No on-land transport is included in the calculations because short distances are expected. The ports used, distance used is from the largest and nearest emission source cluster to the storage site. Offshore and onshore pipelines are excluded due to their high commitment requirements and the associated organizational demands. Furthermore, shipping is significantly more adaptable to changes to policies, emissions amounts etc.

The input data and assumptions of the cost calculations are shown in the tables of this slide for scenarios using exclusive 25.000 tons carrying capacity or 10.000 tons carrying capacity respectively.

Ship Type	LPG	LPG
Cargo Carrying Capacity (mt)	10.000	25.000
Reference Ship Capacity (Mt)	13.000	22.014
GT	17.585	25.051
DWT	17.841	28.637
DG Fuel Cons (mt/h)	0,118	0,107
Consumption in port (mt/h)	0,18	0,19
Fuel Tank Capacity (mt)	1008	1711
Port unload time	36	36
Port load time	36	36
Operational Speed (knots)	12	12
Cost of build (EUR/tonne carrying capacity)	4.000	4.000
Cost of build (EUR)	40.000.000	100.000.000
Op Ex % (Of cost of build)	0,05	0,05
Opex (EUR)	2000000	5000000
Utilization Factor	0,85	0,85
VLSFO to Methanol factor	2,1457	2,1457

Speed	10k ton ship- Cons. (mt/h)	25k ton ship- Cons. (mt/h)
10	0,31	0,50
11	0,37	0,58
12	0,45	0,66
13	0,53	0,75
14	0,62	0,84
15	0,72	0,93
16	0,82	1,02

Import Location	Distance to Hanstholm (nm)
Copenhagen	231
Aalborg	158
Germany, Rostock	338
Germany, Hamburg	280
Sweden, Stockholm	703
Finland, Turku	793
Average Distance	417,17

Cost and infrastructure cost sensitivity (2)

The yielded methanol demands, number of ships required, OPEX, CAPEX & number of port visits are shown for the investigated years and scenarios, for 10K and 25K carrying capacity ships, respectively. For readability, only the results of 3 import scenarios are shown.

As can be derived from the table, the total methanol demand for the import ships is significantly lower for the scenario using 25K ships. Whilst the smaller ships have a larger number of arrivals to be managed, them being smaller may allow for potential 'stacked arrivals' meaning that multiple ships are in the port at once.

From the point of view of the harbors, the infrastructure requirements for the investigated ship sizes, and their varying degree of stacked arrivals should be investigated. Cost wise, the 25K ships are cheaper in fuel costs, but the significantly higher CAPEX and OPEX result in a higher total cost. Whether the costs related to potential restructuring of the port allows for this cost disrepancy should be investigated.

Scenario	Vessel Size	Year	CO2 Imported (Mt)	No. Vessels Required	No. Hanstholm Port Visits	Total Methanol Demand (mt)	Cap Ex (M-EUR)	Fuel Cost (EUR)	Op Ex (m-EUR)	ETA/DAY
33% Lowest Import	10K	2030	3	8	538	52.447,54	320	51.605.232,33	16	1,5
		2035	5	13	782	90.526,33	200	80.400.962,91	26	2,1
		2040	8	19	1130	133.033,55	240	110.111.868,00	38	3,1
	25K	2030	3	6	397	50.588,52	600	49.776.071,90	30	1,1
		2035	5	8	485	71.249,75	200	63.280.461,28	40	1,3
		2040	8	10	626	87.347,37	200	72.297.418,33	50	1,7
50% Standard Import	10K	2030	8	18	1137	122.161,29	720	120.199.382,49	36	3,1
		2035	14	31	1930	212.033,04	520	188.317.142,46	62	5,3
		2040	19	40	2456	275.570,60	360	228.089.784,94	80	6,7
	25K	2030	8	10	626	87.347,37	1000	85.944.571,46	50	1,7
		2035	14	14	855	124.106,22	400	110.224.936,50	70	2,3
		2040	19	17	1042	150.459,87	300	124.535.631,90	85	2,9
Highest	10K	2030	21	45	2679	314.134,83	1800	309.089.821,72	90	7,3
		2035	36	71	4362	488.732,65	1040	434.067.902,45	142	12,0
		2040	46	90	5579	617.032,53	760	510.717.826,81	180	15,3
	25K	2030	21	21	1290	185.249,11	2100	182.274.007,60	105	3,5
		2035	36	31	1920	272.447,31	1000	241.974.075,87	155	5,3
		2040	46	39	2435	341.252,23	800	282.454.472,73	195	6,7

E-methanol's CO_2 & H_2 demands

To acquire a sense of the amount of CO_2 imported in the various imported scenarios, the CO_2 demand required to cover the methanol demand presented in the previous slide has been estimated.

Though outside the scope of this study, the required hydrogen has been estimated as well.
The purpose of this data is to outline the potential sizes of inflows (CO_2 and H_2), to get a sense of the required infrastructural requirements, for the investigated scenarios.

The CO_2 demand required to cover the methanol for importing CO_2 to Denmark averages 1,79 % of the imported CO_2. This means that the remaining net 98-99% percent (depending on the scenario) is available for CCUS purposes, such as permanent storage.

Whilst this relationship does not come as a surprise, it is an important figure when evaluating the overall business potential of importing CO_2. For distances significantly larger than those used in this scenario, the conclusion would likely be different.

Scenario	Vessel size	Year	CO_2 import [Mt]	Methanol demand [kton]	Req. CO_2 [Mt]	Req. Hydrogen [Mt]
Standard scenario	10k	2030	16	231,6	0,32	0,04
		2035	28	392,3	0,54	0,07
		2040	37	519,3	0,71	0,10
	25k	2030	16	140,2	0,19	0,03
		2035	28	219,8	0,30	0,04
		2040	37	282,9	0,39	0,05
0,3 std. Scenario	10k	2030	3	52,4	0,07	0,01
		2035	5	90,5	0,12	0,02
		2040	7,66	133	0,18	0,03
	25k	2030	3	50,6	0,07	0,01
		2035	5	71,2	0,10	0,01
		2040	7,66	87,3	0,12	0,02
0,5 std. Scenario	10k	2030	8	122,2	0,17	0,02
		2035	14	212	0,29	0,04
		2040	18,5	275,6	0,38	0,05
	25k	2030	8	87,3	0,12	0,02
		2035	14	124,1	0,17	0,02
		2040	18,5	150,5	0,21	0,03
High scenario	10k	2030	21	314,1	0,43	0,06
		2035	36	488,7	0,67	0,09
		2040	46	617,0	0,85	0,12
	25k	2030	21	185,2	0,25	0,03
		2035	36	272,4	0,37	0,05
		2040	46	341,2	0,47	0,06

Discussion points (1)

Dependence on Public Policies in CO2 Import to Denmark:

1. The volume of CO2 imports to Denmark is significantly influenced by the public policies of the countries from which CO2 is sourced. The capability of these countries to co-formulate and enact supportive public policies plays a crucial role.
2. Furthermore, the potential for mutual investment strategies etween these countries and Denmark could further impact the amount of CO2 imported. Collaboration at the policy-making level, as well as a willingness to co-invest, is essential for maximizing import potentials.

Analysis of Biogenic CO2:

1. For the scope of this study, the biogenic portion of the sequestered and imported CO2, categorized by country, has been kept consistent across all years.
2. As a result, it is reasonable to anticipate a larger fraction of biogenic CO2 in future assessments. This study's primary objective was to establish a preliminary understanding of the expected proportion. Decision-makers are urged to conduct a more in-depth analysis before making any policy or investment decisions based on this initial data.

Decision Against Investigating Pipe-based International Transport:

1. The choice was made to exclude the investigation of pipeline transport for CO2 international transit. A major factor behind this decision is the inherent challenges tied to pipeline infrastructure. Specifically, pipelines necessitate a higher level of certainty and collaboration between countries for effective utilization.
2. Additionally, pipelines present less adaptability to fluctuations in CO2 import volumes. These fluctuations might arise due to alterations in public policies, sequestrable CO2 sources, or other unpredictable factors.
3. In contrast, maritime transport, specifically using ships, offers several advantages. Ships provide flexibility, as they can be repurposed based on changing needs. Their investment structure is also incremental, allowing for easy scaling by either adding or reducing the number of operational vessels, depending on demand.

- In conclusion, the results and considerations presented in this study serve as a foundational analysis. Further investigations, especially on the biogenic CO2 front, are recommended to ensure well-informed decision-making.

Discussion points (2)

Evaluation of Technology Cost Data:

1. **Source Concerns**: The technology cost data utilized in this study predominantly stems from the DEA (Energistyrelsen). An immediate observation is the occasional lack of sourcing for some of this data, which poses questions regarding its validity and reliability.
2. **Variability Concerns**: Without consistent sources, the temporal variability of this data remains uncertain. This casts doubt over its relevance in dynamically changing economic and technological landscapes.
3. **Economies of Scale**: Further compounding the issue is the absence of clarity regarding economies of scale. The costs associated with technology often vary significantly based on scale, from small-scale implementations to large-scale operations. Without a clear understanding of this, extrapolations and predictions become challenging.

Variability of CO_2 Source Data:

1. **Geographical Differences**: Data regarding CO_2 emissions from various sources varies significantly across countries. This not only depends on the nature and extent of industrialization but also on local regulations, practices, and technologies in use.
2. **Temporal Dynamics**: As countries evolve in their industrial practices and as new technologies and policies are adopted, the volume and nature of CO_2 emissions are bound to change. This study, while capturing a snapshot, may not always reflect these evolving patterns.
3. **Sequesterability Concerns**: The potential to sequester or capture CO_2 varies based on the source and nature of emissions. Over time, advancements in technology or shifts in emission sources can change this potential. Forecasting these developments is fortunately less important than would have been the case for transport by pipe.

Aggregation of import scenarios:

1. The real development of import amounts will not look as rugged as the graphs presented in this presentation. Developing scenarios with CO_2 amounts specific to each year investigated will smooth out the required investments, and allow for more specific planning of infrastructure

Main sources

- Technology Data for Carbon Capture, Transport and Storage (Energistyrelsen)
  - Used for the cost calculation
- Assessment of the market potential for CO_2 Storage in Denmark (Energistyrelsen, May 2021)
  - E-PRTR 2017
  - EU-ETS 2017 & 2019
    - All three are used in developing the import scenarios
- Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
- eurostat
- Aalborg Universitet
  - Used for estimating the biogenic portions in import amounts by country

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Chapter 4

Projected e-Methanol Production in the Northern Denmark Region –regional CCU(S) perspectives

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THE EUROPEAN UNION
The European Regional Development Fund
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Scoping of the methanol production and export potential

The analysis provides valuable insights for decision-makers, policymakers, and stakeholders in formulating strategies and policies for the future development of the NDR's energy system, particularly in the context of PtX technologies. The analysis consisted of two stages. Firstly, a screening of the planned pipeline projects and their projected methanol production capacities was conducted. This screening was compared to the potential realization of projects under the Open-door scheme and the availability of CO_2 in the region and its proximity to the planned projects. The data for methanol demand was obtained from the ZCSC for the two harbours, demand for ferries in Frederikshavn and CO_2 import vessels demand in Hanstholm. The demand for fisheries was based on other assumptions.

The second stage involved integrating these pathways into the energy system model for the North Denmark Region (NDR), while scaling down the national demands to the regional level. It is important to note that the methanol demands derived from the first analysis are not directly comparable due to the utilization of different methodologies for accounting. However, demands for fisheries and CO_2 vessels are additional demands and export potential can directly be related to these demands from the first analysis.

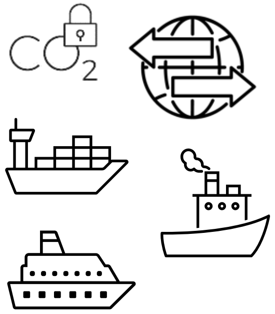
By incorporating 22 different pathways into the energy system model, a comprehensive assessment of the region's energy dynamics and the feasibility of methanol production and export potential was possible.

Screening

- E-methanol projects in the NDR
- Open-door offshore wind projects
- Demand in the 2 ports

Energy system analysis

- 22 scenarios for 2030 and 2045
- System dynamics and export potential



The screening analysis indicates that regional CCU value chains for e-Methanol can be developed within the Northern Denmark Region (NDR).

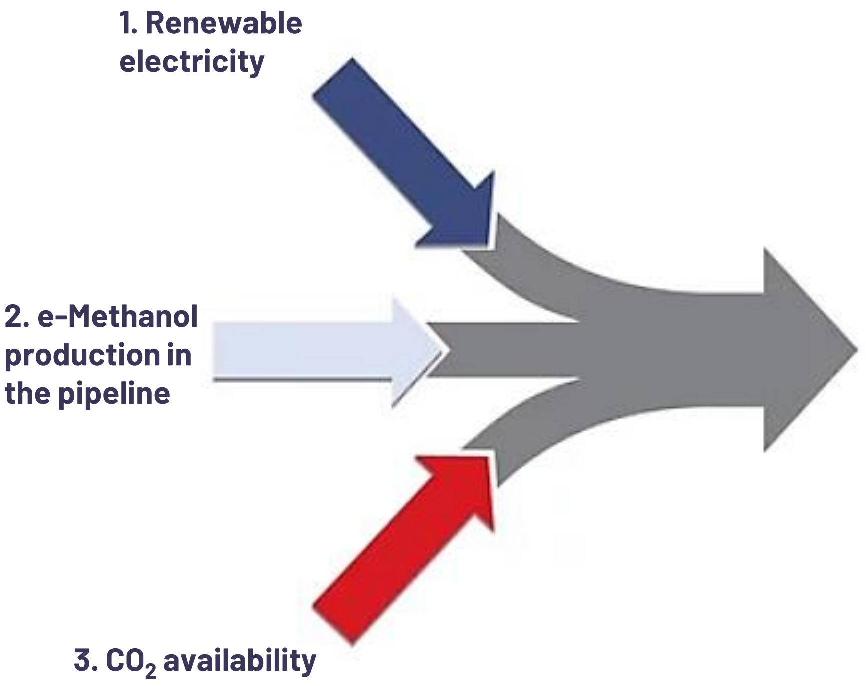
The analysis reveals that the key elements necessary for the successful implementation of e-Methanol projects in the NDR region are expected to converge within the timeframe of the announced projects. The planned offshore projects under the Open-Door Scheme within the NDR have the potential to adequately meet the demand generated by e-methanol production, including the required electrolysis process. However, it is important to note that the government has recently decided to drop a large offshore energy hub project in its current form.

The estimated total e-Methanol production from the planned projects in the NDR amounts to 466,000 tonnes, with a projected completion date of 2030. The realization of all the planned projects within the specified timeframes is subject to uncertainty, but if they are realized, methanol provided is possible to cover the demands for fisheries, ferries and CO_2 vessels in the 3 ports analysed.

Furthermore, the availability of CO_2 surpasses the demand for the e-methanol projects, particularly through the utilization of Carbon Capture and Utilization (CCU) technologies. The analysis indicates that the NDR will develop a sufficient supply of biogenic CO_2 within the region to support the methanol production in the pipeline.

These findings highlight the favorable conditions for the successful realization of e-methanol projects in the NDR region. The convergence of factors such as wind farm capacity, e-methanol production, and CO2 availability bodes well for the implementation of PtX projects, positioning the NDR as a potential hub for methanol production and associated activities.

However, a broader system analysis is relevant to analyse the developments across sectors.



The energy system analysis verifies that the region has significant potential for exporting methanol, contingent upon the availability of resources.

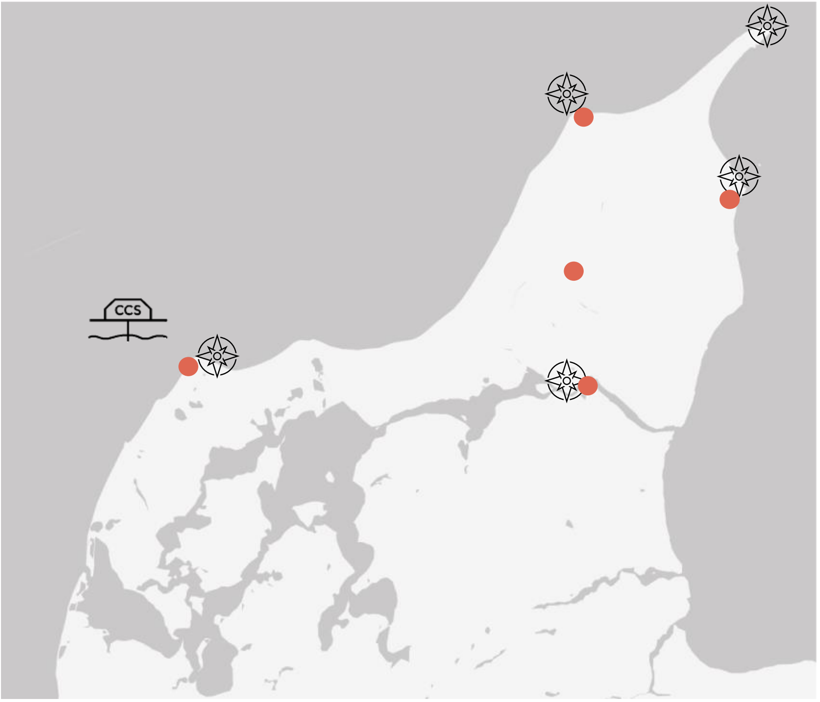
The analysis reveals the interdependence between electrolysis and offshore wind, highlighting the need for sufficient offshore wind installations to provide local electricity supply for methanol projects. If the projects are to be realized, it is necessary to have 10 times more offshore wind than currently approved. The energy system scenario for 2030 and 2045 requires only 122 MW and 480 MW of electrolysis to meet the methanol and other e-fuel demands, while the 20 other scenarios considered up to 3 GW of electrolysis in NDR. These scenarios are only possible if the significant investments in the offshore projects are to become reality.

The analysis also addresses the potential demand for methanol in various sectors, ferries, shipping, long-distance road transport and aviation. The availability of methanol varies across the scenarios, but the main competition occurs in 2045 where the potential of utilizing methanol for jet-fuel production can reduce methanol availability for export by 30-80% depending on the offshore wind capacities. This also reduces the availability for utilization of methanol for fisheries and CO_2 transportation vessels.

The availability of CO_2 resources for methanol production is compared to the demand, with the inclusion of both biogenic and fossil CO_2 sources and CCS demands. It is evident that the NDR has significant CO_2 availability, however not biogenic only. If only biogenic CO_2 is preferred, already in 2030 there is a lack of CO_2 for producing green e-methanol. Utilisation of fossil CO_2 or importing biogenic CO_2 can help meet the demand and open opportunities for different scenarios.

Overall, the findings highlight the potential for methanol production and its integration into the energy system of the NDR. It is possible to integrate large amount of offshore wind in the energy system, if linking it to methanol production, which enables decarbonization of transport sector and positioning NDR and its ports as forerunners.

Location of pipeline projects, harbours and nearshore CO_2 storage in the NDR



Regional perspectives

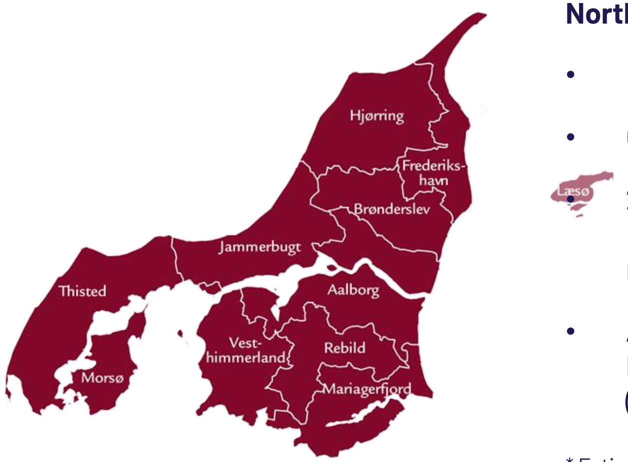
Screening analysis for methanol production

Production vs demand in ports in NDR

The North Denmark Region (NDR) is projected to produce 466 000 tonnes of e-Methanol, based on six new large-scale plants in the pipeline.

Currently, the North Denmark Region (NDR) has a single pilot project called Power2Met, which is being carried out at Aalborg University. However, there are plans for six additional projects in the region, with the majority of them situated near the ports, including those involved in the MarcoPOLO project.

Among these projects, four new large-scale plants have their Commercial Operation Dates (CODs) scheduled before 2030, according to project announcements. These plants are expected to be operational within the specified timeframe. However, two projects do not have publicly announced CODs at this time, and their timelines are not yet confirmed.

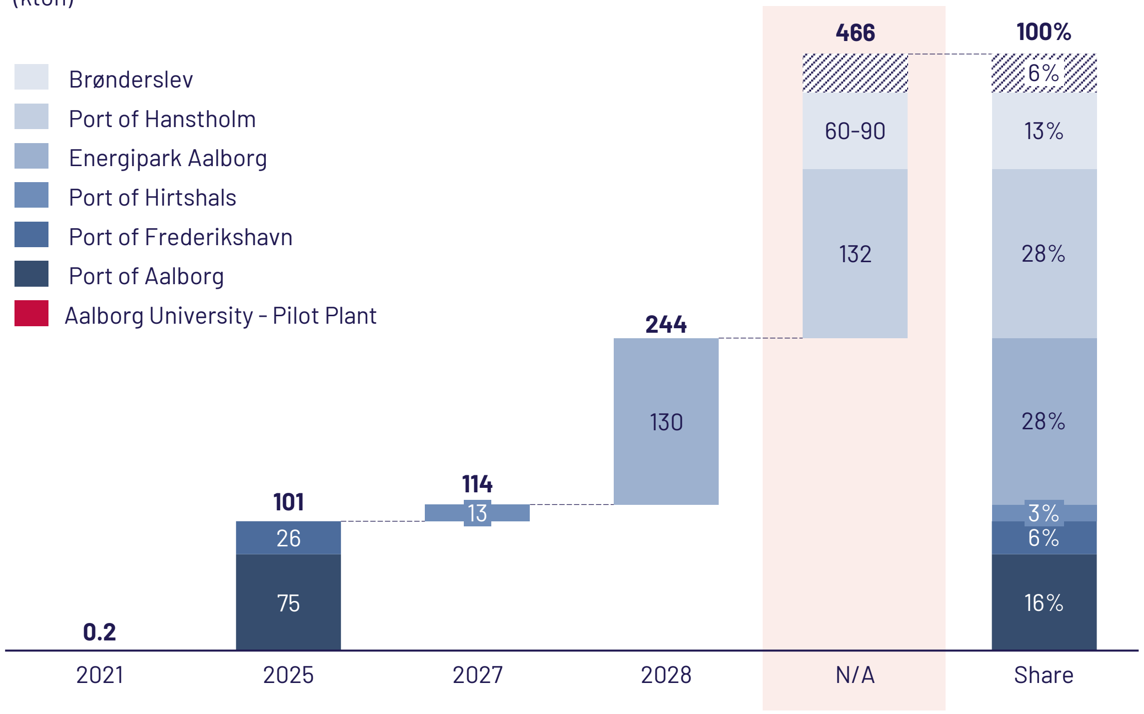


Northern Denmark Region (NDR)

- Population: ~ 590.000 (10% of DK)
- Consists of 11 municipalities
- 2nd highest concentration of CO_2 point sources emissions of DK regions (app. 18% of DK)*
- Aalborg Portland is the single highest point source emitter in DK (app. 11% of DK)*

* Estimations based on *Energiproducenttælling 2021* and *CO2 rapportering 2021* published by the Danish Energy Agency

Estimated methanol production from pipeline projects
(kton)



The figure includes e-Methanol projects in the pipeline, e.g. publicised projects, planned projects etc., and provides a projection of a best case scenario within the region – in which all the projects are commissioned within the announced timeline. Projects without stated COD are accumulated in column N/A. Data is based on public statements from developers, unless otherwise stated.

[1] Based on estimated CO_2 availability from 25-35 mil. m^3 biogas for upgrading, assuming CO2 contents corresponding to standardised CO_2 emission factors from the Danish Energy Agency.

[2] Estimated based on stated electrolyser capacity, assuming ~5000 FLH. The other projects have calculated FLH ranging between 4500-6500 for the electrolyser units.

[3] Possible e-Methanol offtake agreement from the MeSAF project.

Almost 1 GW of planned projects to be implemented in NDR

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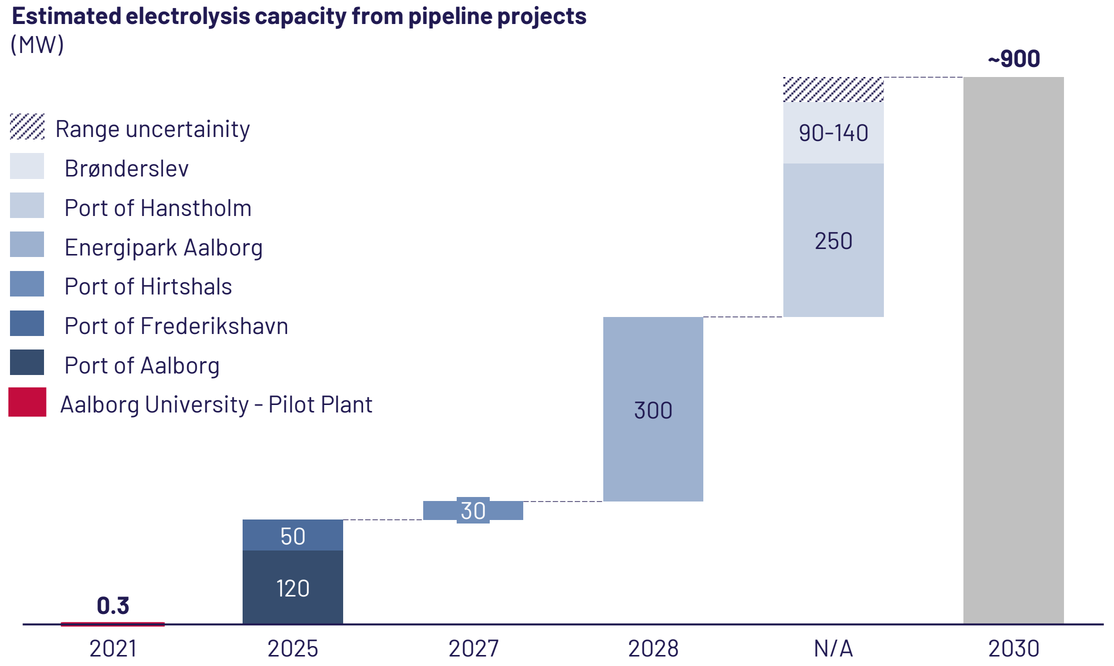
The concentration of these projects near the ports signifies the region's focus on leveraging port infrastructure for the implementation of methanol-related initiatives. This strategic positioning can enhance logistical capabilities and facilitate the efficient transport and export of methanol and related products.

While the Power2Met pilot project currently serves as a notable example of methanol production in the NDR, the planned expansion of six additional projects, especially those located near the ports, indicates the region's commitment to furthering the development and utilization of methanol as an energy resource.

The six planned projects in the North Denmark Region (NDR) collectively have an electrolyser capacity of approximately 900 MW. This capacity represents a significant portion, ranging from 17% to 25%, of the Danish government's target of 4-6 GW for electrolysis installations by 2030. This demonstrates the NDR's substantial contribution towards meeting national goals in renewable energy production.



The figure includes e-Methanol projects in the pipeline, e.g. publicised projects, planned projects etc., and provides a projection of a best case scenario within the region – in which all the projects are commissioned within the announced timeline. Projects without stated COD are accumulated in column N/A. Data is based on public statements from developers, unless otherwise stated.

*2045 scenario includes electrolysis for different fuel pathways, ~50% is for methanol only production. Scenario includes realisation of 12.7 TWh of offshore wind.

2045 scenario: Analysis based on data from CO2 Vision, Aalborg University 2023

[1] Based on estimated NDR MeOH demand + 50% international demand

The projected production requires 670 000 tonnes CO_2 for methanol synthesis. Estimated CO_2 for CCU(S) application in the NDR amounts to ~5 Mtonnes short-term, and ~2.5Mtonnes long-term.

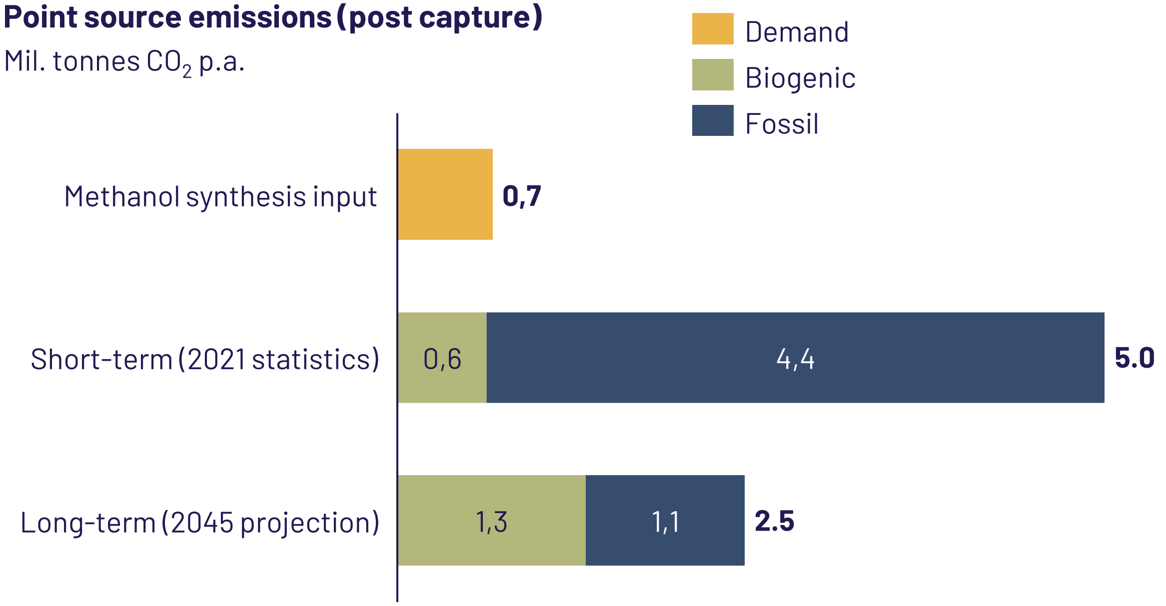
In 2021, CO_2 availability from point sources within the NDR region exceeded 4.5 million tonnes (Mtonnes), ranging from 4.6 to 5.0 Mtonnes, including both biogenic and non-biogenic CO_2 emissions. Approximately 12-15% of the emissions from point sources in 2021 were biogenic in nature, originating from biogas upgrading, biomass-fired combined heat and power plants (CHPs), household and commercial waste incineration, among others. The majority of emissions from Aalborg Portland (45%) and Nordjyllandsværket (25%) stemmed from the combustion of fossil fuels or cement production processes.

Projected developments for reaching climate neutrality in 2045, show a drastic decrease in fossil CO_2 emissions and a doubling in biogenic CO_2 emissions within the NDR.

The available CO_2 resources currently surpass the required CO_2 for methanol synthesis in the identified projects by a factor of 7 in 2021 and a factor of 3.5 in 2045 if both biogenic and non-biogenic resources are used. This excess availability presents opportunities for further Carbon Capture, Utilization, and Storage (CCUS) projects in the region. Alternatively, the additional CO_2 could be stored or exported to areas where it can be utilized effectively.

Point source emissions (post capture)

Mil. tonnes CO_2 p.a.



The figure includes required CO_2 demand for the projected methanol production in the NDR, compared to best case estimates of the current and future CO_2 availability from carbon capture at point sources with emissions exceeding 10 000 tonnes CO_2 per year. The estimated emissions are distributed on biogenic and fossil sources. A capture rate of 90% is assumed for all point sources, with exception for biogas upgrading which has a capture rate of 100%.

Source: Analysis based on data from CO2 Vision, Aalborg University 2023

All e-Methanol project can procure sufficient CO_2 quantities within a 50 km radius of the project site.

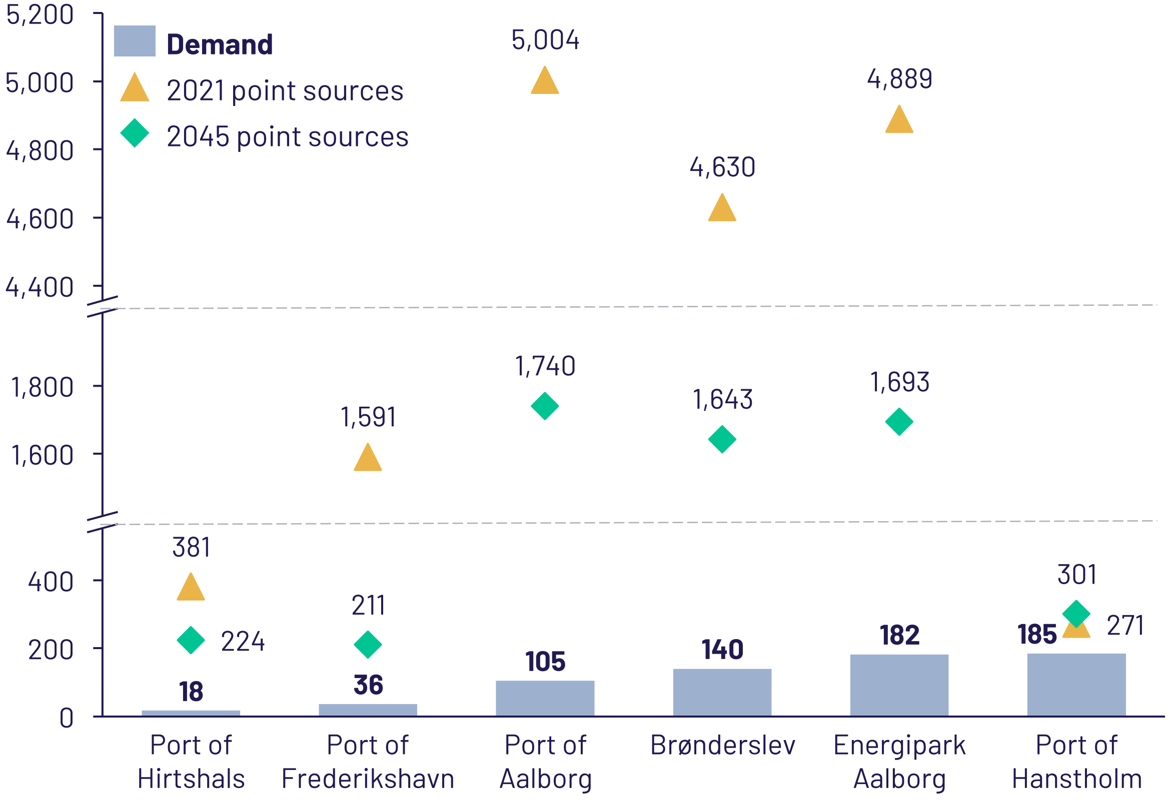
A comparison of CO_2 demand for e-methanol production (CCU) and CO_2 availability within the region show that each methanol project can procure sufficient CO_2 within a 50 km radius of the planned project site, enabling potential cost savings compared to imported CO_2 from other sources.

The comparison is based on a straight-line connection of coordinates for the planned e-methanol project sites and the relevant point sources applicable for CCU(S). The projects in Aalborg and Brønderslev demonstrate ample CO_2 availability, even considering local market cannibalisation. However, Port of Hanstholm has a more limited CO_2 availability from local sources. New biogas projects have been announced in the area which could potentially change the picture for this particular port.

By maximizing the utilization of local CO_2 sources and exploring options for regional CO_2 infrastructure development and import from other European countries, the methanol projects can benefit from a more cost-effective and efficient supply of CO_2.

CO_2 availability within 50 km of project site

1000 tonnes CO_2 p.a. (post capture)



*some sources are not accounted for due to the lack of data

**missing new biogas plants that would increase biogenic CO2 availability

Source: Analysis based on data from CO2 Vision, Aalborg University 2023

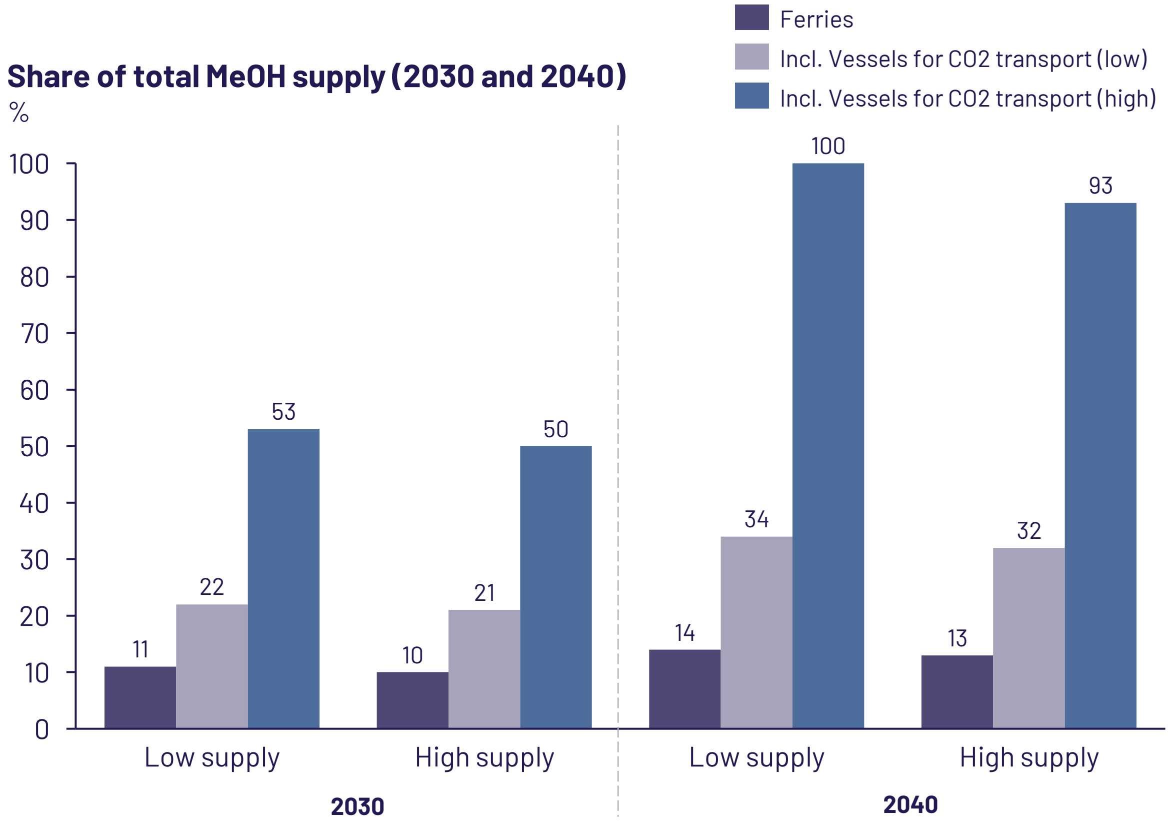
Projected demand for ferries and CO2 transport vessels can be met in most of the scenarios according to the methanol production

In analyzing the demand for ferries, it becomes evident that meeting this demand leaves room for supplying fishing vessels and utilizing methanol in other areas of the transport sector, such as aviation through methanol-to-jet (MeOH-to-jet) processes.

Both low- and high-demand scenarios, which may involve CO_2 transportation vessels, can be adequately met by the current pipeline projects if they are realized, both in 2030 and 2040. However, it is important to note that most of the supply capacities are concentrated in the Aalborg area. This indicates that the current project in Hanstholm havn may not have sufficient capacity to supply the demands for the harbour, even in low-demand scenarios.

The supply capacity in Hanstholm can cover the demand for CO_2 vessels in low-demand scenarios, excluding ferries, representing approximately 39-56% of the local project. However, it is crucial to highlight that the presented overview lacks specific information regarding the demand for fishing vessels. As a result, it is challenging to determine the extent to which the demand for fishing vessels can be supplied.

Share of total MeOH supply (2030 and 2040)



The figure includes e-Methanol projects in the pipeline, e.g. publicised projects, planned projects etc., and provides a projection of a best case scenario within the region – in which all the projects are commissioned within the announced timeline.

*Low supply – 436 kt of MeOH

**High supply - 466 kt of MeOH

***25K vessel carrier

Source: Analysis based on data from ZeroCarbonShippingCenter, WP3

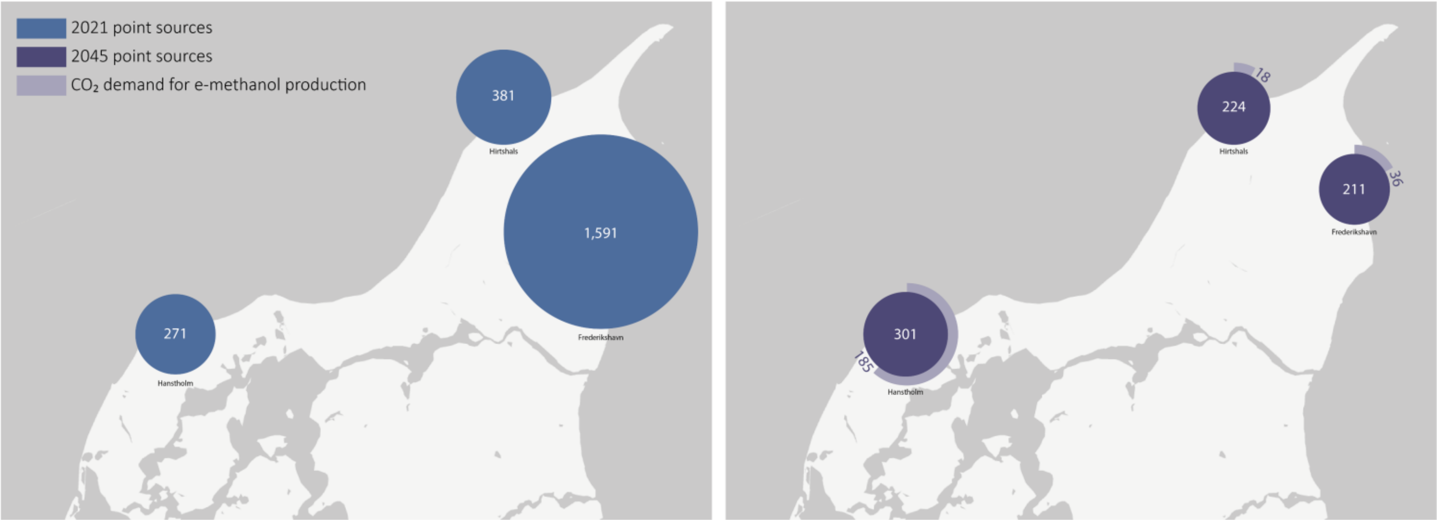
On-site availability versus demand

It is clearly visible from the figures that the onsite availability of CO_2 in relation to the carbon demand for methanol production with the current projects seems reasonable, especially if the fossil resources are used. However, in the case of Hanstholm the availability of the CO_2 is very much depended on the biogas origin and utilization of almost all available resources in the municipality. This could prove to be challenging if the CO_2 is to be used for biogas methanation instead as then there will be obvious mismatch.

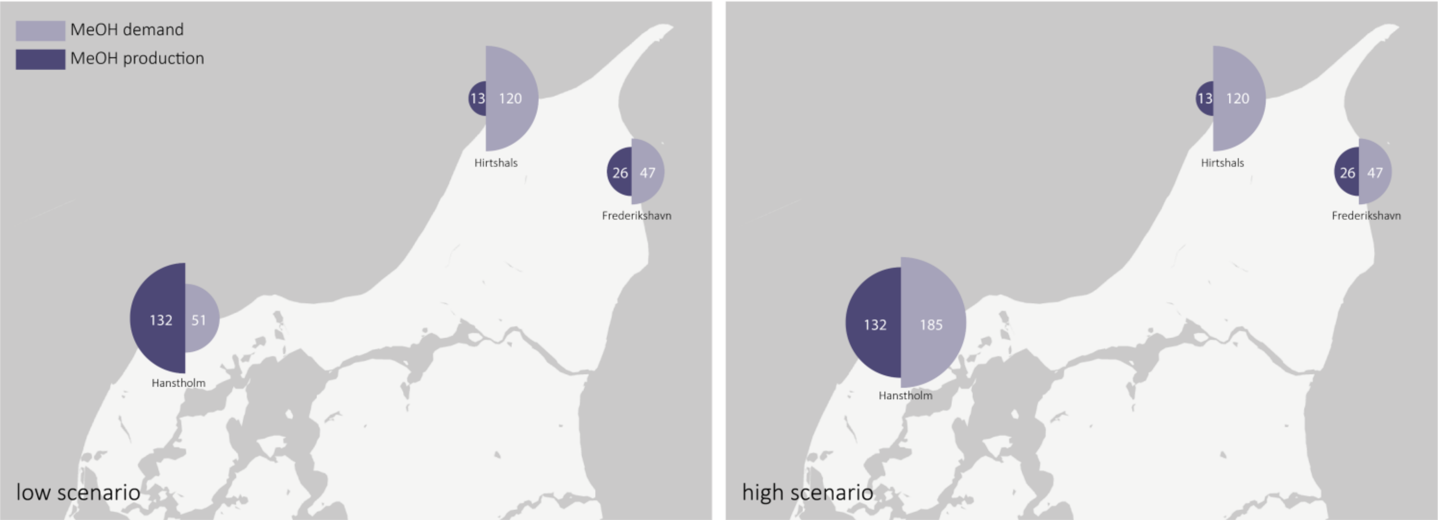
If methanol demand is compared with the production capacity, in most cases the demand higher than the methanol availability. However, due to the relatively proximity of the ports it is possible to distribute the methanol from different projects if the agreements are to be made.

This outcome is based strictly on the planned project within the harbours and some of them already have upscaling plans.

CO_2 availability within 50 km of project site
1000 tonnes CO_2 p.a. (post capture)



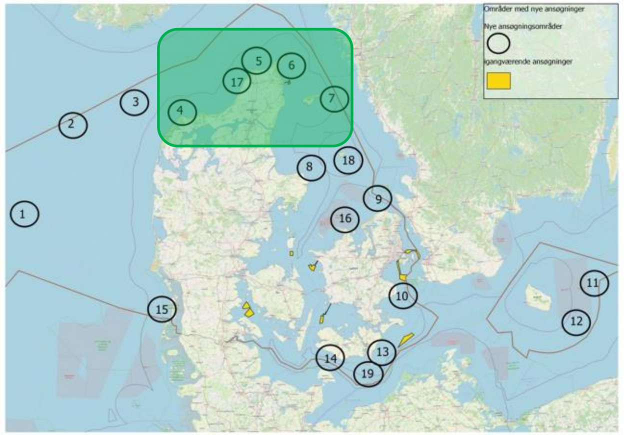
Methanol demand and production at ports (2030)
1000 tonnes MeOH p.a.



Potential for procurement of regional Power Purchase Agreements (PPAs) from Renewable Energy projects in the NDR.

Screening based on the Open Door Scheme within the NDR reveals promising potential for regional Power Purchase Agreements (PPAs) to meet the energy demand. However, it is important to note that this screening only considers one aspect of the equation, as it does not account for land-based wind projects and other energy offtakes.

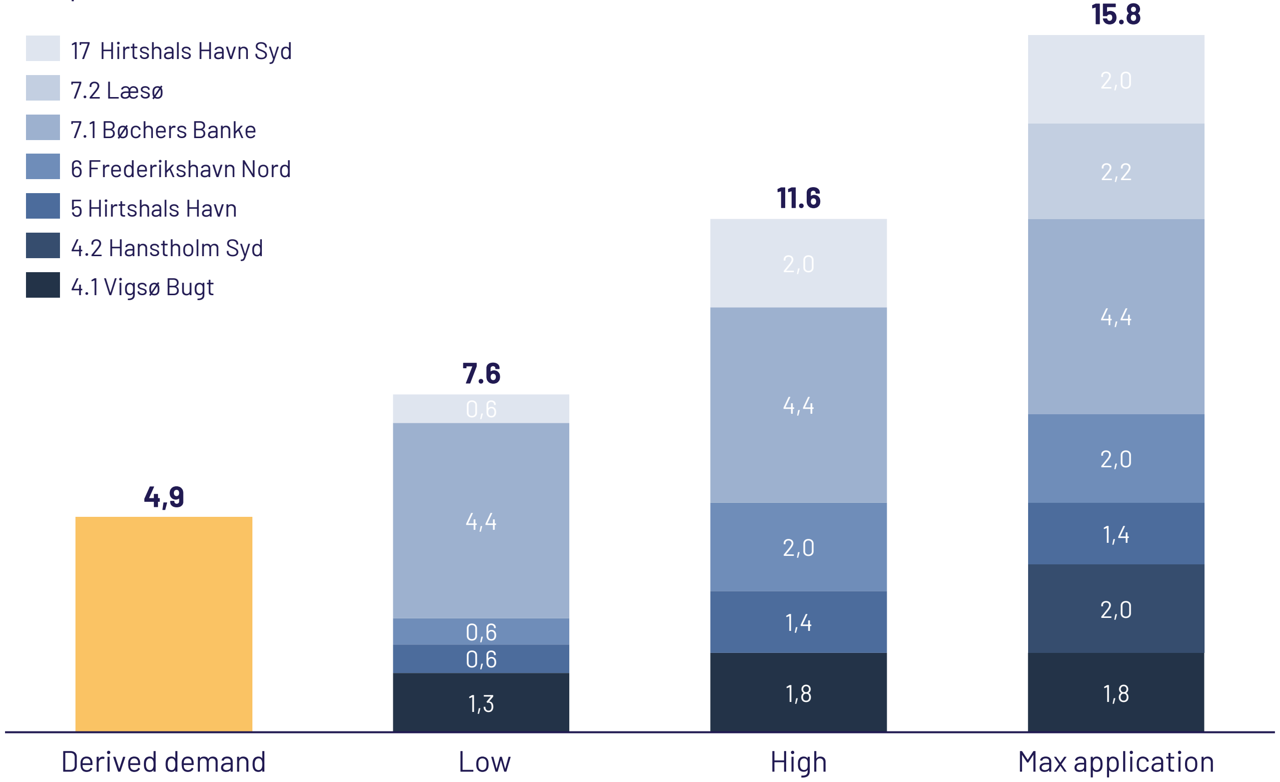
The NDR includes the nearshore regions 4, 5, 6, 7, and 17 (refer to the provided map). However, it is worth mentioning that project timelines for the deployment of these renewable energy sources are uncertain. Nonetheless, based on the timelines of previously completed offshore projects, it is reasonable to anticipate completion within the period of 2027-2030. It is important to note that the government's new marine plan results in the closure of all open-door projects except for three, none of which are located in Northern Jutland.



The map include all areas included in the Open Door Scheme for offshore and nearshore wind farms. NDR projects are within the green square. Source: DEA

Estimated offshore production based on applications in Open Door Scheme in the NDR

TWh p.a.



The figure includes required electricity demand for the projected methanol production (incl. production of green hydrogen) in the NDR, in comparison to estimates on the production from project applications in the Open Door Scheme specifically in the NDR. The estimated demand for electricity is based on an electrolyser efficiency of 66,5%. The nearshore wind farm (WF) production is estimated assuming 4000 FLH. The lower and higher estimate includes the range of capacities included in the first served applications, whereas the max application case assumes completion of overlapping projects.

Electricity demand from PtX projects in ports: Port of Hirtshals: 0.1 TWh, Port of Hanstholm: 1.3 TWh, Port of Frederikshavn: 0.3 TWh

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Short and long-term perspectives

Energy system analysis

Production and potential export of methanol in NDR

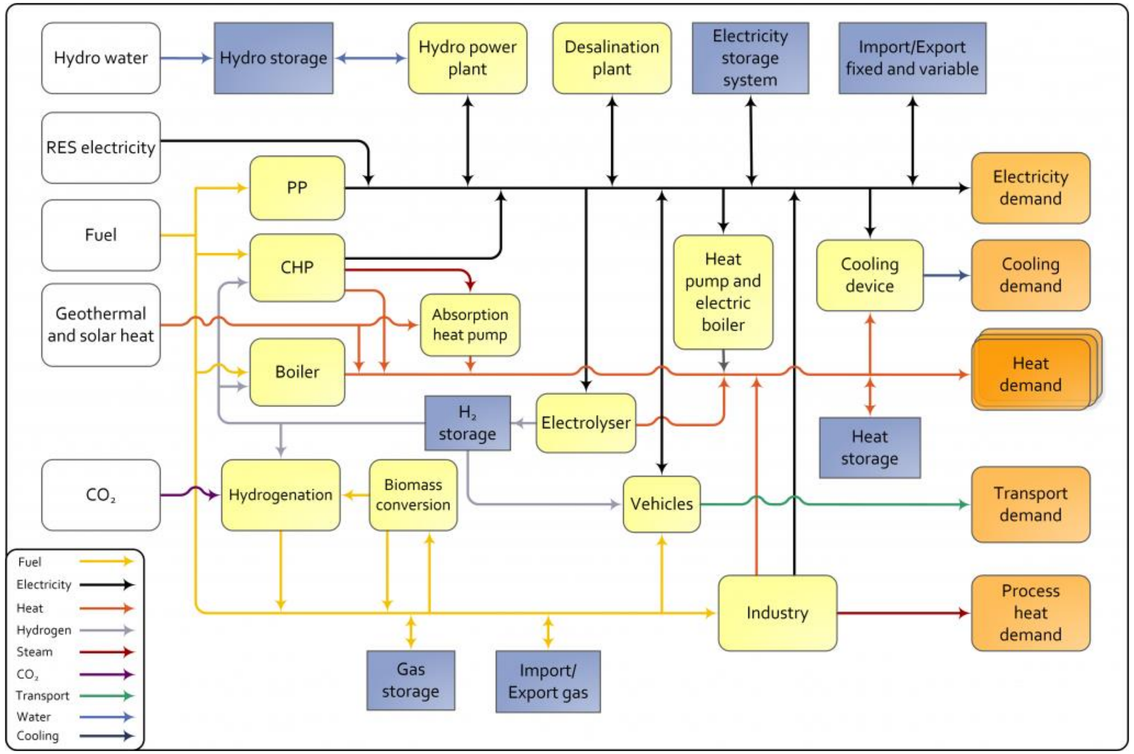
Behind the energy system analysis

While the analysis highlights the potential for regional PPAs and the deployment of onshore wind and solar PV production, it is crucial to consider the broader energy landscape and the integration of other VRES projects and energy offtakes to ensure a comprehensive and sustainable energy system.

This advanced energy system modeling tool EnergyPLAN offers detailed hour-by-hour simulations, enabling a thorough assessment of energy systems at different scales.

By utilizing the EnergyPLAN model, these scenarios can comprehensively capture the intricate interactions and dynamics present within the NDR's energy system. The model considers various factors such as energy production, consumption, storage, and transmission, enabling a comprehensive evaluation of different energy sources and technologies.

Through the employment of the EnergyPLAN model, the complex energy landscape of the NDR can be accurately represented, providing valuable insights into the challenges and opportunities for sustainable and efficient energy planning. The outcomes of these scenario analyses can inform decision-makers, policymakers, and stakeholders in formulating strategies and policies for the future PtX development of the NDR.



Analysis of 22 Scenarios: E-Methanol Production and Potential Export in Northern Denmark Region for 2030 and 2045

The EnergyPLAN model has been utilized to conduct a comprehensive analysis of 22 scenarios specifically developed for the North Denmark Region (NDR). These scenarios cover both the 2030 and 2045 timeframes, providing insights into the energy system implications for the region. The scenarios were constructed based on the IDA Climate action scenarios, which were scaled to accurately reflect the population of the NDR, specifically representing 10% of the population. Furthermore, the models were refined to incorporate the existing energy production facilities within the region, as well as planned expansions. Onshore wind capacity in 2030 is 80 MW which is increased to 500 MW in 2045.

The analyzed scenarios aim to capture the integration of the currently announced methanol projects in the region and the energy system implications of implementing 890 MW of electrolysis, considering the potential for methanol production. Moreover, the analysis examined how the expansion of offshore wind capacities influences the export possibilities for electricity, hydrogen, and methanol. The same scenarios were analyzed in the 2045 model, with the addition of an ambitious offshore wind expansion. In this expansion, open door projects were added to the offshore wind capacity that is needed for supplying electricity in the base scenario.

2030

NDR 2030

Methanol project implementation

Open Door Wind expansion

- LOW deployment
- HIGH deployment

→ Electricity export, H_2 export, Methanol export

2045

NDR 2045

Methanol project implementation

Open Door Wind expansion

- LOW deployment
- HIGH deployment

→ Electricity export, H_2 export, Methanol export

Ambitious offshore wind expansion

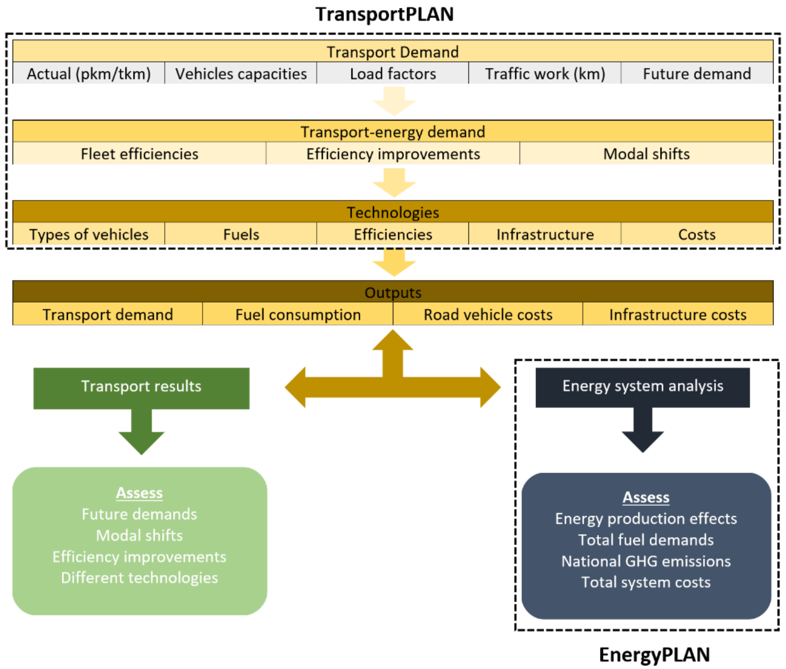
- LOW deployment
- HIGH deployment

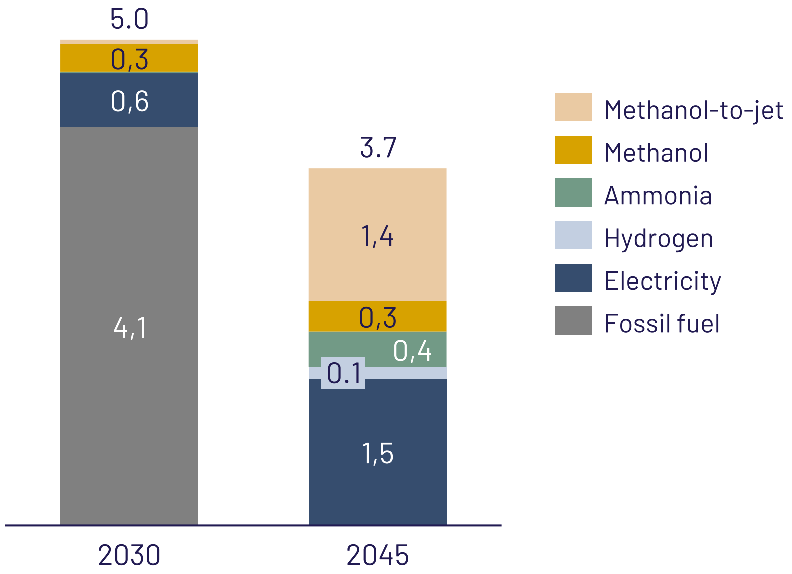
→ Electricity export, H_2 export, Methanol export

Transport demand and methanol use in NDR: 2030 and 2045 scenarios

In assessing the future energy system, the transport demand is projected using the same methodology as in Kany et al[1]. The demand for NDR is determined by scaling down the total transport demand for the whole Denmark. It is important to note that this mapping does not necessarily align directly with the volume of fuel sold within Denmark. Instead, it aims to illustrate the overall Danish transport demand, including the international demand from Danish passengers. While the demand mapping encompasses most marine demand, it excludes fisheries demand. Notably, by 2045, all national ferries are expected to be electrified.

Considering the potential for methanol usage in the future energy system, the demand could be substantial, particularly if the assumed Sustainable Aviation Fuel (SAF) demand is met primarily through methanol-to-jet technology. In an extreme scenario presented below, 82% of the methanol demand is allocated to the aviation sector. The remaining portion of the methanol demand is utilized by international ferries, national and international shipping, as well as certain long-distance road transport segments.





[1]Based on: Kany et al 2022, Energy efficient decarbonisation strategy for the Danish transport sector by 2045, Smart Energy, doi.org/10.1016/j.segy.2022.100063.

Anticipated electrolysis capacities and offshore wind deployments in NDR: 2030 and 2045 scenarios

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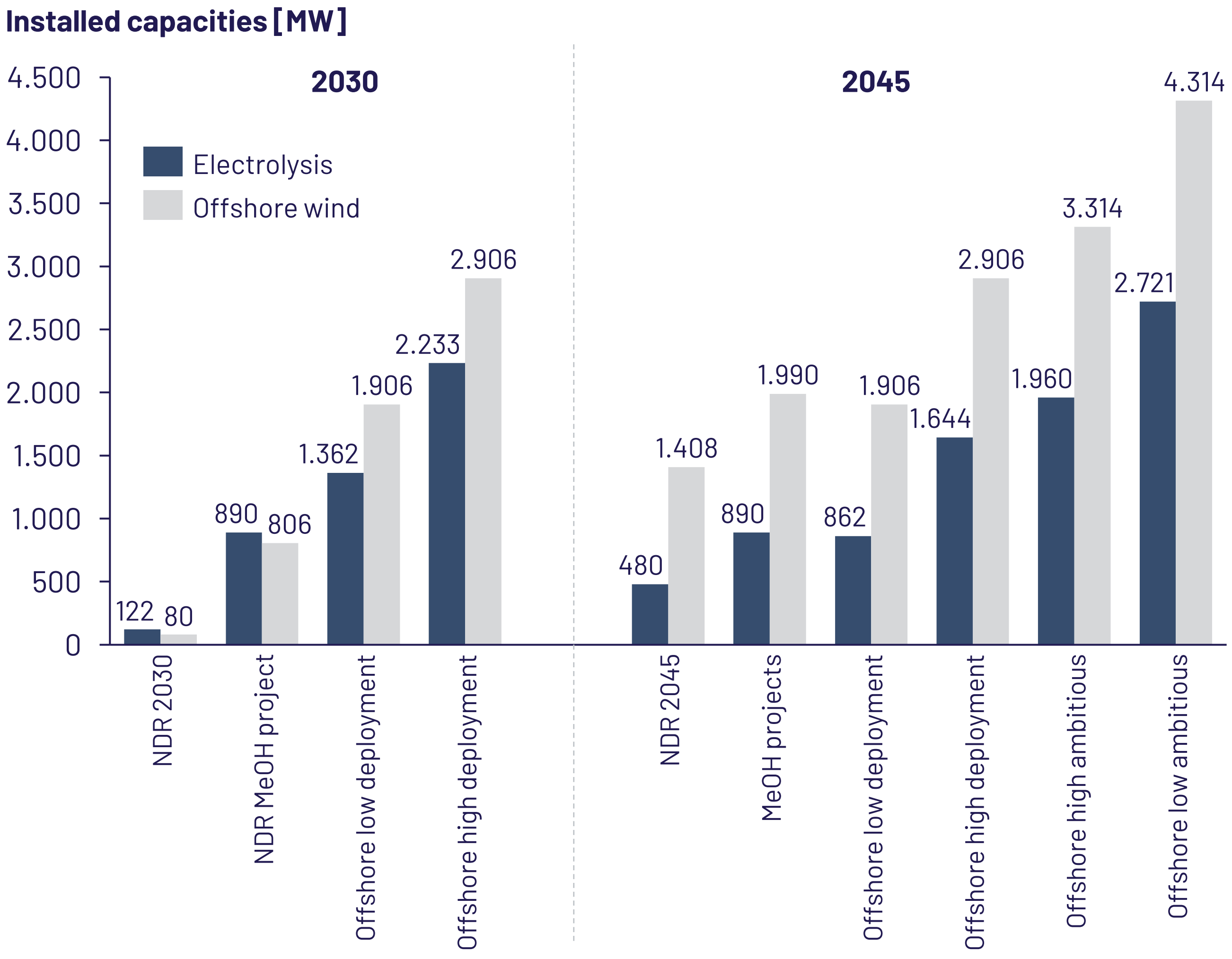
The graph illustrates the anticipated electrolysis capacities and offshore wind deployments in the NDR for the 2030 and 2045 scenarios.

In the 2030 timeframe, the electrolysis capacity ranges from 122.3 MW to 2233 MW, representing the projected capacity for electrolysis installations. The offshore wind capacities in 2030 vary, starting from a planned 80 MW and extending to the realization of open-door projects. As indicated before the open-door projects in Northern Jutland were closed by the government, however it is possible that these will be realized at some point in the future and therefore are included in the scenarios.

The scenario for MeOH projects in 2030 indicates that in order to achieve the targeted 890 MW of electrolysis capacity, it is necessary to have 806 MW of offshore wind installed. This demonstrates the interdependence between electrolysis and offshore wind, highlighting the need for sufficient offshore wind installations to support local electricity supply for all projects.

Looking ahead to the 2045 scenarios, the maximum electrolysis capacity reaches almost 3 GW, contingent on the installations of offshore wind. The offshore wind installations in ambitious scenarios reflect also the scale of the potential share of the large offshore energy hub projects scaled to the population of NDR. However, it is important to note that the government has recently decided to drop this project in its current form.



Enhanced export potential in the NDR through the Open-Door Scheme

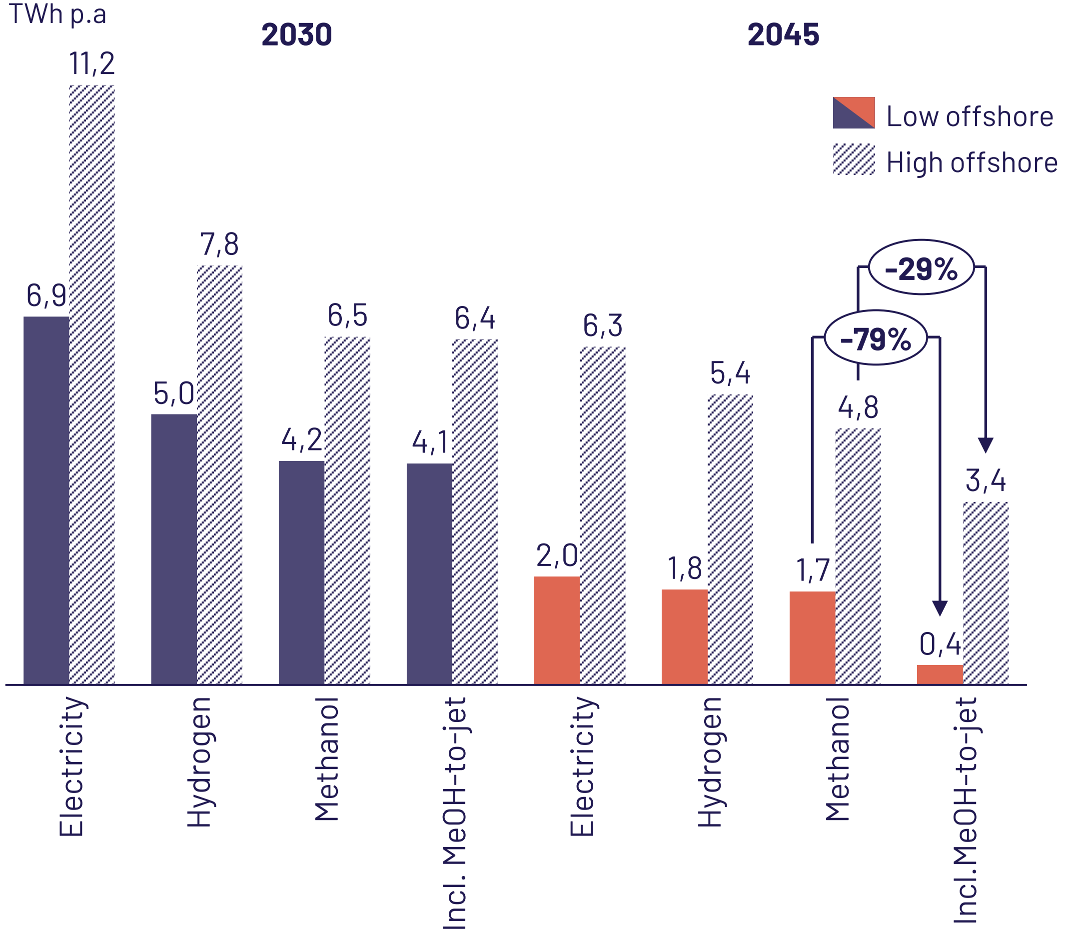
The successful implementation of the open-door scheme in the NDR region presents increased accessibility and opportunities for energy export, including electricity, hydrogen, and methanol. This analysis focuses on the impact of additional offshore wind capacities on the system dynamics and explores the conversion of exported electricity to hydrogen or methanol.

Considering conversion efficiency and system integration mechanisms, the analysis reveals that methanol export is the lowest among the three options. This is primarily due to the existing methanol demand within the system, which does not solely represent fuelling demands at the ports but also includes the overall demand for methanol in transportation across the region, as previously indicated.

The system dynamics in the 2045 model of the NDR demonstrate some differences compared to the 2030 model, reflecting a system with greater flexibility and higher electricity demands. Demands for methanol are similar in 2030 and 2045 model (0.282 or 0.312 TWh), however demand for SAF grows towards 2045, leaving less methanol for export.

If methanol is also used for SAF production the availability for its application in fisheries or for export purposes is reduced by almost 80% in the low offshore wind implementation and to almost 30% in the high implementation scenario in 2045. The differences in 2030 are minimal, due to very low demand for SAF in the scenario.

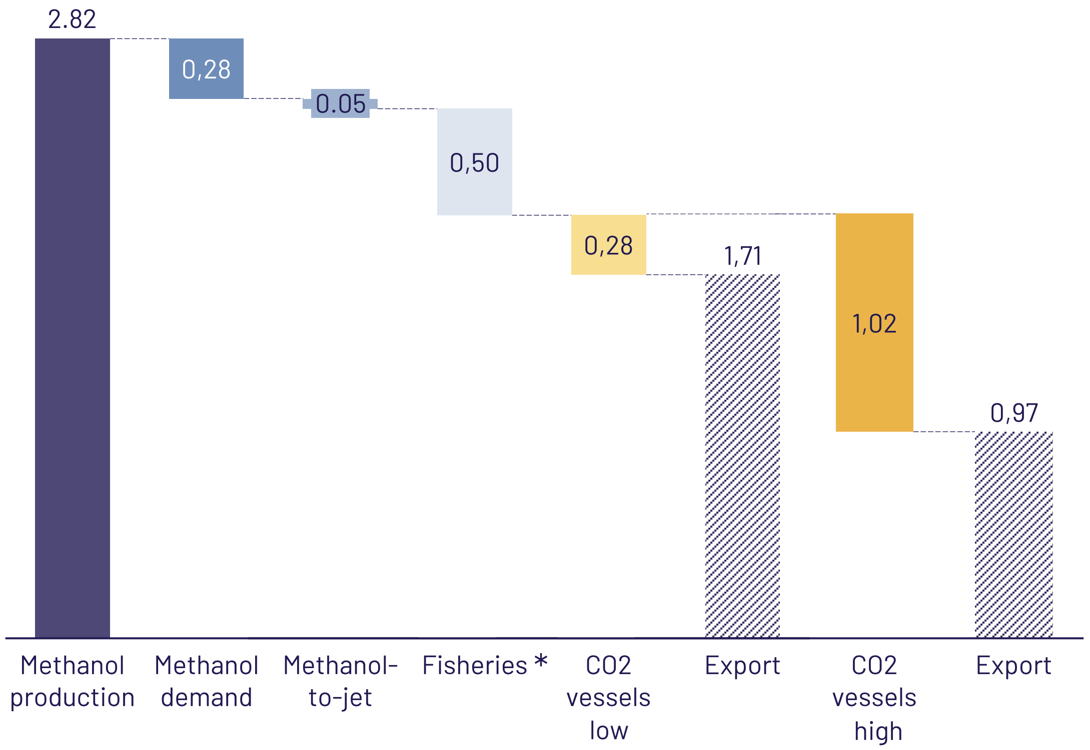
Export potential in 2030 and 2045 based on applications in Open Door Scheme in the NDR
TWh p.a



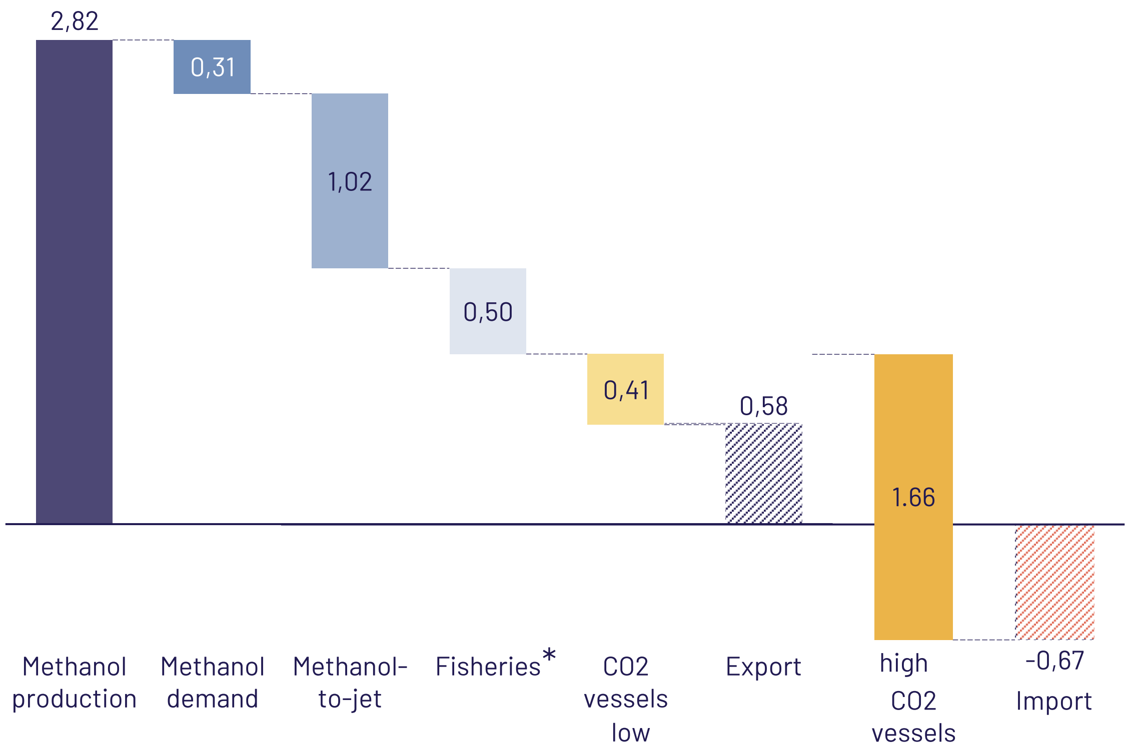
Realisation of methanol projects and potential export options

Realisation of the methanol projects in NDR in 2030 and 2045 would require significant expansion of the new offshore wind capacities, if the ambition is to keep the supply localy. To be precise, this would require 10 times higher capacity than currently approved offshore wind installations. If this is to be realized the potential methanol production is around 2.8 TWh. This will allow for supplying projected demands for methanol in ferries, methanol-to-jet, fisheries in the NDR and methanol demand for CO2 shipping vessels in Hanstholm. The additional methanol could be then offered for bunkering of ferries or other vessels that call by ports in NDR. In 2045, in the high scenario for CO_2 vessels it is not possible to meet the demand, resulting in an import.

Export potential in methanol project scenario for 2030
TWh p.a.



Export potential in methanol project scenario for 2045
TWh p.a.



*Fisheries for NDR are calculated based on the share of income (45%) in the region and total fuel used 100 Mio.litres of diesel by Danish fish boats (495 boats) based on DANSKE FISKEFARTØJERS CO2 -UDLEDNING OG KURSEN MOD ***KLIMANEUTRALITET***
**CO2 vessels data are for year 2040 in 2045 scenario

CO_2 storage and availability for methanol production in the NDR

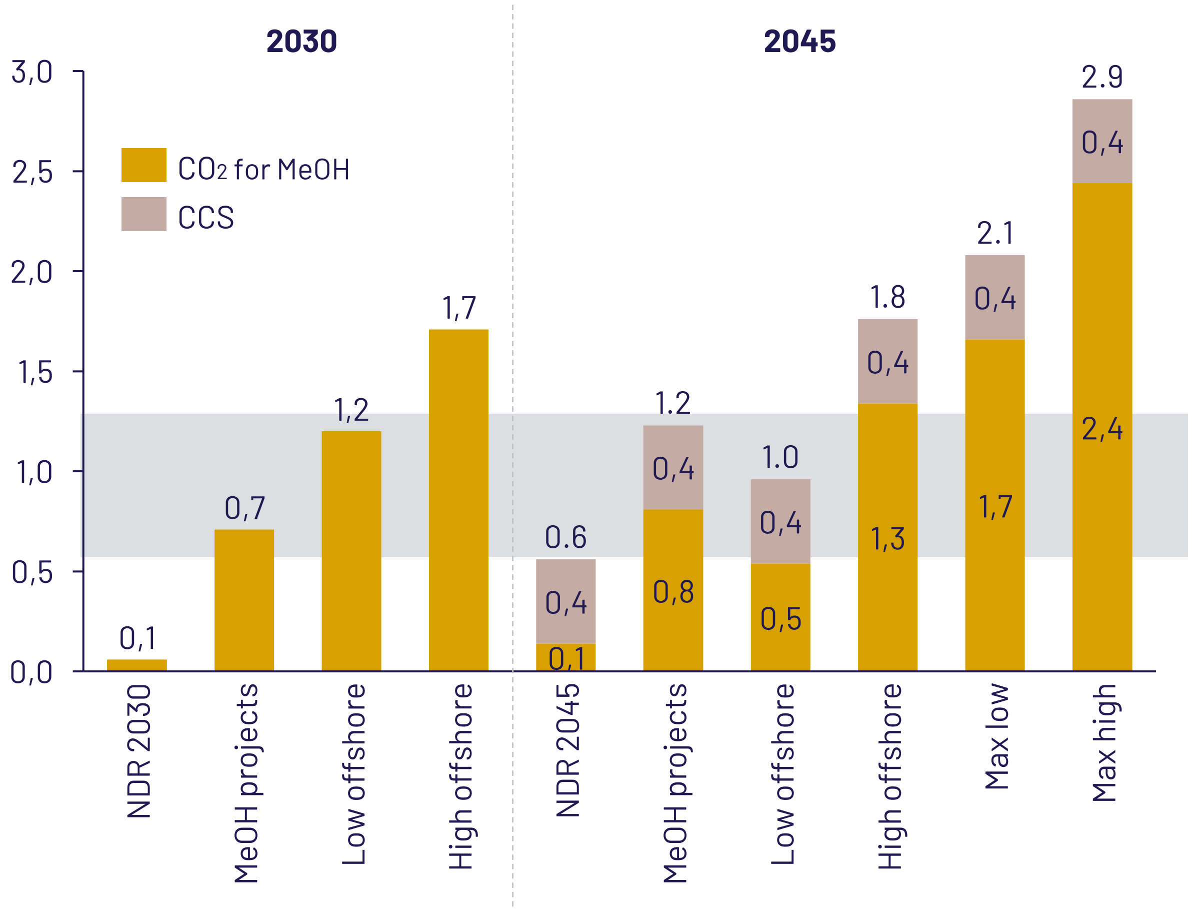
According to the national 100% renewable scenario, it is anticipated that approximately 0.4 million tonnes (Mt) of carbon will be stored (CCS) in the NDR. In the year 2045, around 0.14 Mt of CO_2 is allocated for methanol production. However, if the pipelined projects are to be realized, the demand for CO_2 increases to 0.8 Mt. The highest CO_2 demand reaches 2.44 Mt.

When comparing these figures with the CO_2 point sources in the NDR, it becomes evident that even by 2030 and 2045, the availability of biogenic CO_2 (ranging from 0.6 to 1.3 Mt) poses challenges in certain scenarios. However, if fossil CO_2 is included, there is a possibility to meet the CO_2 requirements for methanol production. Importing CO_2 opens up opportunities for the realization of various scenarios.

It is crucial to address the storage and availability of CO_2 when considering the production of methanol in the NDR. The inclusion of fossil CO_2 and imported CO_2 can potentially mitigate the challenges associated with limited biogenic CO_2 availability.

CCU and CCS demands for 2030 and 2045 in the NDR

Mt p.a



The figure includes range for biogenic CO2 availability in 2030-2045, the lower value is for 2030 and higher value for 2045.

MARCO POLO - DK

METHANOL
Availability Readiness Cost Operationality
Port Logistics - Denmark

Chapter 5

WP4: Applicability to Danish and National Ports

The project has received funding from:

Danish Board of Business Development

THE EUROPEAN UNION
The European Regional Development Fund
Funded as part of the Union's response to the COVID-19 pandemic
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5. Applicability to Danish and International Ports

Several factors such as the need for climate change mitigation, environmental regulations, and the ongoing transition to a more sustainable energy future are pushing for an implementation and roll-out of green fuels for shipping as well as marine transport of CO_2 from producer to either a utilization or a storage site. Ports at both the Danish and Nordic levels, as well as globally, have been actively engaged in facilitating the transition to green marine fuels and implementing CO_2-related initiatives to varying degrees. The speed of implementation and roll-out is affected by an interplay of different factors at both an intra- and inter-port level:

5.1. Infrastructure Development

Generally, ports worldwide need to invest in infrastructure to become green fuel-compatible and/or a CO_2-hub. This includes establishing facilities such as e.g. bunkering of methanol and methanol fueling stations, CO_2 storage facilities, safety upgrades and connection to e.g. a national CO_2 pipeline infrastructure.

Several ports have already initiated pilot projects to test and implement green fuels. The port of Singapore, the world's largest bunkering port, is set for a methanol bunkering pilot in the third quarter of 2023 and aims to develop a technical reference in 2024. The port of Antwerp is involved in the production of a e-methanol facility and witnessed it first methanol bunkering operation in June 2023.

Options such as grants, subsidies and tax breaks may help offset the higher upfront costs associated with developing green fuel infrastructure. These costs are situated not only at ports but also at the surrounding value. Implementation of e.g. methanol as a green fuel requires amongst others the availability of renewable electricity, electrolysis capacity, availability of CO_2, transportation infrastructure for gasses and/or methanol. On a Danish level, funding schemes aimed to promote development in specific regions, such as e.g. the Fund for a Sustainable Transition (Fonden for Retfærdig Omstilling) may help promote infrastructure development related to methanol and CO_2 in the Northern and Southern Jutland. On a Nordic level, the dedicated support from the Norwegian government towards installment of the CCS-chain has been a remarked factor and e.g. the Northern Lights project is playing a strong role in establishment of a CO_2 hub in Norway. On a global level, the US-based Inflation Reduction Act offers significant tax breaks for clean energy production and is showing to be a significant pull factor for green H_2 transport in the US, laying the subsequent foundation for green methanol production. In China, its 2022 national hydrogen industry plan targets 200.000 mt/yr of green hydrogen, while Australia has invested A$1.2 in green hydrogen projects (2023, S&P Global).

Asides from governmentally based initiatives, other economic incentives such e.g. reduced port fees for ships using green fuels, can be decided upon by ports, and may further encourage their adoption.

Finally, the speed of infrastructure development may have a self-enhancing effect. Neighboring ports that are quicker in the roll-out and implementation of methanol as a green fuel may gain a competitive edge, potentially becoming key green fuel hubs with an increased share of visiting vessels. In a Nordic context, the ports of Frederikshavn and Gothenburg share the same marine corridor and may hence be direct competitors for the same vessels. At the same time, it must be highlighted that coordinated implementation by ports can on the contrast also be beneficial for the different ports, as discussed below in point 3.

5.2. Resource availability

The availability of renewable energy (H_2) and CO_2 markedly influences the extent and ease to which ports can or will transition to being an e-methanol or CO_2 hub. This availability reflects a combination of both geographical, economical, and political factors. Geography influences the potential availability of renewable energy from e.g. wind or solar, while its concrete availability is largely influenced by the national policies and investments in e.g. grid infrastructure. Ensuring a CO_2 stream for either PtX purposes or CO_2 export for offshore permanent storage will require both (inter)national policies to support CO_2 capture as well as significant investments in transport infrastructure and development of storage capacities.

Danish and Nordics ports benefit from favorable conditions for offshore wind energy production and national climate goals which foster markets incentives for green marine fuels and CCUS. Solar energy production is considered more in the Southern hemisphere, with e.g. several large projects announced in the Middle-East, Australia and Chile. The latter being one of the first countries to sign the Clydebank declaration to support the establishment of green shipping corridors and has entered joint project with MMM-ZCSC to establish green shipping routes in and out of Chile.

Ports located in countries with a strong gas and oil industry and strong CCS goals are in a frontrunner position to become CO_2 hubs, such as notably Danish and Norwegian ports. Internationally, the CCS market is still in its early phases and is currently dominated by projects in North-West Europe and Northern America.

5.3. Regulatory Support

Governments and regulatory bodies play a crucial role in facilitating the transition to green fuels by providing clear and supportive regulatory frameworks. This includes setting CO_2 emission reduction targets, promoting the use of alternative fuels through incentives and subsidies, and implementing environmental regulations that encourage the adoption of cleaner technologies, as also exemplified above in point 1. Here, it should be highlighted that regulatory stability and consistency are important to provide certainty and encourage investments in green fuel infrastructure. In addition, it also includes ensuring a transparent and timely review of permitting procedures.

The Nordic region and the European Union have been forerunners in terms of environmental legislation and regulatory frameworks, creating incentives for both ports and calling vessels to adapt to e.g. green fuels. Relevant regulations include e.g. the Alternative Fuels Infrastructure Directive and the EU Emissions Trading System. In contrast, the environmental legislation in the European Union is often more encompassing and stringent compared to internationally accepted regulations. The extensive permitting procedure is often named as a significant hurdle to overcome for e.g. PtX-projects and may create a disadvantage for Danish and Nordic ports compared to ports in other parts of the world. In contrast, the evidence-based approach of e.g. the Nordics and EU also creates the opportunity for the adaption of a more tailored regulation – given that all safety and environmental standard can be uphold. This flexibility is highly beneficial given the entirely the new markets that are being created by the CCUS chain and demand for green marine fuels.

Within the national and intranational legislation that each port must abide to, the goodwill and cooperation with the local authorities is however a significant factor that may greatly influence the speed and ease of completing the permitting procedures.

5.4. Collaboration and Partnerships

Collaboration among ports, shipping companies, energy providers, technology developers, research institutions, and government agencies is vital. Platforms such as international forums, conferences, and working groups can facilitate dialogue and cooperation, enabling ports to learn from each other and benefit from shared expertise.

The relevance of collaboration between ports across borders was highlighted by a pre-feasibility study performed by the European Green Corridor Network, consisting of the Port of Gdynia, the Port of Roenne, the Port of Rotterdam, the Hamburg Port Authority, the Port of Tallinn, and the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. The study assessed the feasibility of utilizing green fuels and highlighted the varying levels of port readiness among the participating ports[1]. The results of the pre-feasibility study indicated that the Port of Rotterdam demonstrated a high level of readiness for handling and supplying (bio-)methanol, while the ports of Rønne, Hamburg, Gdynia, and Tallinn showed lower readiness levels. This signifies that although these combined ports have the potential to lead the initial decarbonization efforts in the greater Baltic Sea region, further efforts are required to establish full port readiness across all the ports. The valuable experience gained from the port of Rotterdam, which exhibits a high port readiness level, can be leveraged to enhance the readiness levels of other ports through knowledge sharing and collaboration. By sharing their experiences, the ports can collectively work towards achieving higher port readiness levels, thereby advancing the adoption of green fuels in the maritime sector. How each individual port positions in regards to knowledge exchange will depend both on national ports associations, if existing, as well its geographical local and how it may position for a potential green fuel hub, as the one described above, or a CO_2 hub.

5.5. Guidelines, standards and safety regulations

The transition of the marine sector from fossil to green fuels and the implementation of the CCUS chain requires the establishment of completely new value chains and/or markets. National, international, or industry-wide guidelines and standards on green fuels and CCS are mostly lacking and are rather being defined on a project-based base. First-mover projects such as Greensand and Northern Lights are setting examples, but a coordinated and international streamlining would greatly improve implementation speed of CCS. The close geographical vicinity of Danish ports to the Greensand and Northern Lights project naturally facilitates an easier knowledge exchange between the different stakeholders, but a coordinated standardization effort by an internationally recognized instance would be of greater benefit for both at an intra- and international level. Initiatives are being taken, as e.g. The Methanol Institute, a global trade association for the methanol industry, has published the first guide to methanol as a marine fuel to help stakeholders across the industry access information.

Training programs and educational initiatives among port personnel and stakeholders will be needed to increase awareness about green fuel technologies and CO_2, promote best practices in their handling and use, and ensure proper safety measures are in place. Training can cover aspects such as fueling procedures, maintenance of green fuel infrastructure, and emergency response protocols. It may be expected that ports located in areas that may attract educated personnel will have an advantage when aiming to create a methanol or CO_2 hub. (See chapter 6)

[1] The European Green Corridor Network (2022). Northern European & Baltic Green Corridor Prefeasibility Study. Key learnings, recommendations, and next steps

MARCO POLO - DK

METHANOL

Availability **R**eadiness **C**ost **O**perationality

Port **Lo**gistics - **D**enmark

Chapter 6

Safety & regulatory aspects

The project has received funding from:

THE EUROPEAN UNION
The European Regional Development Fund

Funded as part of the Union's response to the COVID-19 pandemic

Danish Board of Business Development

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Contents

Summary

As part of the safety related tasks of MARCO POLO project scope, DBI was responsible for the reporting of general safety aspects, preliminary risk assessment, mapping of competencies at the selected ports, approval processes and public perception of methanol and CO_2 related future projects at Danish ports.

Methanol is a colourless, water-soluble, flammable liquid that has a mild alcoholic odour. Methanol is an important raw material for the chemical industry as well as the future energy and fuel industry. It burns with flames which are weakly light blue in colour and nearly invisible to the naked eye in daylight because it combusts efficiently and produces little residual products, i.e., soot.

Carbon dioxide is used as a raw material to produce carbon-based fuels such as methanol, gasoline, jet fuel, etc, for Power-to-X (P2X) applications. Carbon dioxide, CO_2, is a colourless, odourless, non-flammable gas. At normal temperatures and pressure, carbon dioxide is a gas.

Preliminary risk assessment for methanol stored at the port of Frederikshavn and CO_2 stored at the port of Hanstholm was performed through preliminary HAZID. Worst-case and most likely scenarios for storage, transportation, and usage were identified for both methanol and CO_2. Next, consequence analysis of select scenarios was performed using PHAST software developed by DNV.

Based on the results for methanol, wind speed and direction play a big role in the dispersion magnitude of methanol, which makes it important to better understand the weather conditions and surroundings. In addition, fuel containment capabilities for storage tanks and temporary placements need to be considered based on expected volume of methanol to be present. In case of CO2, failure mode greatly affects the dispersion area and profile. When there is a sudden release of all CO_2 from the storage tank, the presence of wind affects the area where harmful concentrations accumulate, however, the effects of wind dominate less with the increase of height. On the other hand, during leakage, size and direction of the leak, as well as the wind velocity greatly affect the area and profile of concentrations of CO_2.

Next part of the tasks is identification and mapping of competencies for safe storage, transportation, and usage of methanol and CO_2 at different levels, including port, authority, and tenant, involves considering the specific responsibilities and knowledge required at each level.

Then, approval processes for methanol and CO_2 storage facilities have been laid out. Methanol is classified as a dangerous substance under the Seveso Directive, whereas CO_2 is not classified as a dangerous substance under the Seveso Directive.

Through qualitative work, the section of public perception examines effects of communication on the perception of safety during the transition to e-fuels in two Danish ports. The explorative work provides some examples of the relevance of emphasizing citizen understanding and early stakeholders' involvement. Challenges include defining communication roles, balancing transparency, and addressing societal concerns. The report contains the compilation of various acknowledged practices and strategies to active society engagement to ensure successful green fuels implementation in ports.

Abbreviation list

AR-AFFF - Alcohol Resistant Aqueous Film-Forming Foam

BLEVE – Boiling Liquid Expanding Vapour Explosion

CAPEL-STEL - California PEL – Short Term Exposure Limit

CCU – Carbon Capture and Utilization

LEL – Lower Explosive Limit

LFL – Lower Flammability Limit

NFPA – National Fire Protection Association

P2X – Power-to-X

PEL – Permissible Exposure Limit

PEL-TWA - Recommended Exposure Limit - Time Weighted Average

REL – Recommended Exposure Limit

REL-STEL - Recommended Exposure Limit - Short Term Exposure Limit

UEL – Upper Explosive Limit

UFL – Upper Flammability Limit

1 Task 1. Literature review

As part of the safety related tasks of the project scope, literature review of methanol and CO_2 were done by looking at overall safety and other considerations. Stakeholders need to be aware of specificities of methanol and CO_2 for any future infrastructure projects.

1.1 Methanol

1.1.1 General properties of methanol as a fuel.

Methanol is a colourless, water-soluble, flammable liquid that has a mild alcoholic odour. Methanol also known as methyl alcohol, wood alcohol/spirit with chemical formula of CH_3OH. Methanol is an important raw material for the chemical industry as well as the future energy and fuel industry. There is a growing interest in using methanol as a maritime fuel, as well as Carbon Capture and Utilization (CCU) for the further production of methanol. Some of general properties of methanol are listed in Table 1.

Table 1. Physical and chemical characteristics, retrieved from [1]

Critical temperature	240 °C
Critical pressure	78.5 atm
Freezing temperature	-97.6°C
Boiling temperature	64.6°C (65°C)
Liquid Density at 20°C	792 kg/m^3
Vapor Density (relative to air)	1.1
Minimum Ignition Energy	0.14 mJ
Autoignition Temperature	464 °C (440 °C)
Heat of Combustion	726.1 kJ/mole
Heat of Vaporization	37.34 kJ/mole (at 25 °C)
Heat of fusion	3.215 kJ/mole
Lower flammable limit (LFL) – Upper flammable limit (UFL)	6.0% - 36%
Lower Explosive Limit (LEL) – Upper Explosive Limit (UEL)	6.0% - 36.5% Explosive limits, vol% in air: 6-50%
Flash point (Closed cup)	9.7 °C / 11 °C
Flash point (Open cup)	15.6 °C
Solubility	greater than or equal to 100 mg/mL at 21 °C
Vapour pressure	100 mm Hg at 20 °C; 237.87 mm Hg at 38 °C
Viscosity	0.544 mPa.s at 25 °C
Surface Tension	22.07 mN/m at 25 °C
Recommended Exposure Limit (REL) REL-TWA (Time Weighted Average) REL-STEL (Short Term Exposure Limit)	 200 ppm (260 mg/m^3) 250 ppm (325 mg/m^3)
Permissible Exposure Limit (PEL) PEL-TWA (8-Hour Time Weighted Average) CAPEL-STEL (California PEL – Short Term Exposure Limit) CAPEL-C (California PEL – Ceiling)	 200 ppm (260 mg/m^3) 250 ppm (325 mg/m^3) 1000 ppm
Immediately Dangerous to Life or Health (IDLH)	6000 ppm
Other Standards Regulations and Guidelines Denmark	 TWA 200 (260 mg/cu m)

1.1.2 Flammability characteristics

Methanol is liquid at normal temperature and pressure (NTP) – 293.15 K (20°C) and 1 atm and releases vapour depending on its temperature. In case of a methanol fire, it is the vapours that burn. Methanol has a true vapor pressure of about 100 mmHg at 20 °C, which means that it releases more vapour than diesel but less than gasoline. The flammability of a fuel depends on its tendency to release vapor. Sustained combustion will not take place below the lower flammability limit since the fuel air mixture is too lean. The fuel is too rich, and combustion is quenched when the mixture has higher concentrations that the *upper flammability limit*. The *flammability range* of *methanol* is 6–36 vol%, versus 1.4–7.6 vol% for *gasoline* and 1–6 vol% for *diesel* [2].

Flashpoint is the lowest temperature at which the application of an ignition source causes the vapor of a test portion to ignite and the flame to propagate across the surface of the liquid under the specified conditions of the test. Methanol has a *flashpoint* of 11°C and *boils* at 65°C and therefore falls in the category *highly flammable* (corresponding to NFPA class IB), along with for example gasoline with a flashpoint of -42 °C. Diesel has a *flashpoint* of ≥ 60 °C and is therefore not classified as flammable but as *combustible* [2]. Since normal temperatures can be far above the flashpoint, large amount of vapor can be generated in case of methanol or gasoline that flammable vapours could reach far from the pool surface that could be the cause for flashfire if an ignition source is present. Relatively warm temperatures can generate a vapor plume while low temperatures can cause accumulation in low areas. Thus, methanol is considered to present explosion hazards in confined spaces [3].

Table 2. Comparison of methanol with other fuels [1,2,4].

Property	Methanol	Gasoline	Diesel
Flashpoint	11 °C	-43 °C	60-80 °C
Flammability limits	6 %-36 %	1.4 %-7.6 %	1 % - 6 %
Minimum Ignition Energy	0.14 mJ	0.29 mJ	0.23 mJ
Boiling point	64.6 °C	27-225 °C	180–340 °C
Autoignition temperature	464 °C (440 °C)	300 °C	230 °C

1.1.3 Explosive characteristics

Gases and vapours are commonly classified in Explosion groups (IIA-IIC) and Temperature classes (T1- T6) [2]. Methanol is listed in *the least hazardous group IIA*, depending on the maximum safe gap (affecting the required flame arrestor) and the minimum ignition current (affecting the selection of safe electrical equipment) and *the least hazardous temperature class T1*, due to its high *auto-ignition temperature* is lowest temperature a surface must have to cause spontaneous ignition [2].

In summary, methanol releases vapor depending on the temperature and when reaching 11°C (its flashpoint), sufficient vapor is released to allow ignition above a methanol surface. Higher temperatures can allow ignition far from the liquid, causing a flash fire, and vapor can also be accumulated. Like gasoline, methanol therefore poses an explosion hazard in confined spaces, classified in the least hazardous explosion categories.

1.1.4 Burning behaviour

Pure methanol fires are not like most encountered fires because they produce less heat, transfer less heat to surroundings, and are difficult to see since it is combusted efficiently and produces little residual products, i.e., soot. Methanol burns with flames which are weakly light blue in colour and nearly invisible to the naked eye in daylight (Figure 1). Furthermore, since there are no black residual soot particles present, there is no smoke.

Figure 1. Left: Methanol burning invisibly on a sunny day. Right: Thermal camera imaging

1.1.5 Ignition sources

Since methanol is a potential concern for fire and explosion, ignition sources should be removed to a safe distance from the potential presence of methanol vapours. This is managed by identifying and properly allocating hazardous zones[2]. Avoiding potential ignition sources could be accomplished by:

- Restricting smoking in designated areas
- Controlling and prohibiting vehicle access
- Using non-sparkling tools
- Using equipment that has explosion-proof ratings.

1.1.6 Toxicity

The major issue of alcohols (i.e., methanol) is toxicity both in terms of ingestion, skin or eye contact or inhalation. Although it is readily metabolized in small amounts by the human body, on account of it being found naturally in fruit and vegetables, acute toxic effects can occur with high concentrations of methanol.

Symptoms of acute methanol poisoning from direct ingestion include dizziness, nausea, respiratory problems, coma and finally death which occurs between 10 and 48 hours after ingestion. Skin or eye contact with methanol, as well as inhalation of methanol vapours are generally of much lower concern, as long as it does not persist for hours. The results of animal tests to determine the toxicity of various fuels by inhalation, oral and dermal contact have shown that the toxicity of alcohol fuels is comparable, and in many cases better than that of common gasoline or diesel [5].

1.1.7 Environmental hazards

Since there is an increase in production and use of methanol, the potential for the accidental spill and release also increases. Methanol is completely miscible with water and will rapidly spread from the release point. However, since methanol is flammable, if the spill is ongoing, the area of the spill is still considered as a flammable region. It has been shown that up to 75% of water by volume that is mixed with methanol is flammable. Methanol has high diffusivity and will evaporate quickly depending on the temperature. Hence, due to its miscibility and diffusivity, it is unlikely to accumulate on the water surface which makes it impossible to collect.

1.1.8 Compatibility of methanol with metals

Care should be taken when selecting materials that are exposed to methanol in constant and regular bases. Methanol is highly corrosive to some metals, so the recommended practice is to select the components that are compatible with methanol [6–9]. The overtime formation and presence of corrosion on the equipment or components could result in the reduction of strength. Further discussion on the reduction of strength is discussed in section 2.5. An incident has been reported on the use of aluminium flame arrester on the vent which failed to work. During the design process instead of steel, PVC piping and flame arrestors made of aluminium were approved. In addition, maintenance procedures for the flame arrestor were not considered. This resulted in the explosion inside the steel tank and fire spread through the pipes [10].

1.1.9 Precautions

When dealing with methanol, there are several safety considerations that should be taken into account. These include, but not limited to:

- Prohibit smoking.
- Control vehicle/personnel access.
- Electrical equipment must be explosion-proof to meet national and IMO electrical code requirements.
- Appropriate fire-fighting equipment should be accessible for small fires.

1.1.10 Fire suppression

Fire suppression may use any of several media:

- Alcohol resistant firefighting, fire-extinguishing foam, such as AR-AFFF
- Dry chemical extinguishers (for small fires)
- CO_2
- Water mist spray

Guidelines for foam extinguishing systems with optimum application rates are provided in NFPA 11 (Standard for Low-, Medium-, and High-Expansion Foam) Fixed fire monitors may be used to cool tank walls and to extinguish flames provided at least five parts water is added for every one part of methanol: i.e., methanol concentration is diluted to less than 15 %. Water-methanol solutions are flammable to compositions of about ≈ 80 vol% water.

Some facilities equip methanol tanks with an internal foam delivery system combined with an internal floating roof. Care must be taken to coat the internal floating roof if it is constructed of aluminium or aluminium/magnesium alloy. Methanol is mildly corrosive to aluminium-magnesium, aluminium-copper, and copper-zinc alloys.

1.1.11 Lessons learned from past incidents.

It has been reported [10] that large portion of the incidents that occurred between 1998-2013 involving methanol were in the sectors of industrial, transportation and biodiesel with total percentage of 31 %, 29 %, and 27 %, respectively. Within the total number of incidents, it has been shown that 83 % of the incidents are fire and explosion related. Within the total number of casualties transportation sector takes the lead with 81 % of the total fatalities, and 17 % injuries. A total number of 26 incidents have been reported in transportation sector with a total number of 16 incidents that resulted in fire and explosion, six caused spills, and four resulted in collisions, rollovers, derailment and ships running aground with no significant loss of material. Since transportation sector considers all types of transportation, six of them were shipping incidents [10].

Based on the incident report analysis, the following common contributing factors have been identified [10]:

- Poor understanding of methanol properties
- Integrity of methanol container and/or system components were not preserved
- Accumulation and release of methanol vapours in flammable concentrations
- Insufficient spill containment capabilities
- Insufficient or lack of control of ignition sources, especially during hot work activities
- Improper selection and/or installation of equipment, such as explosion-proof equipment in hazard zones
- Inadequate maintenance of the equipment
- Inadequate work procedures for routine operation or lack of following
- Absence or insufficiency of process safety measures
- Dysfunctional fire prevention systems
- Inadequate emergency response planning and training
- Failure to adequately understand and give a timely response in hazard situations

1.2 Carbon Dioxide (CO_2)

Captured carbon dioxide can be used as a raw material to produce carbon-based fuels such as methanol, gasoline, jet fuel, etc, for P2X applications.

1.2.1 General properties.

Carbon dioxide, CO_2, is a colourless, odourless, non-flammable gas. At normal temperatures and pressure, carbon dioxide is a gas.

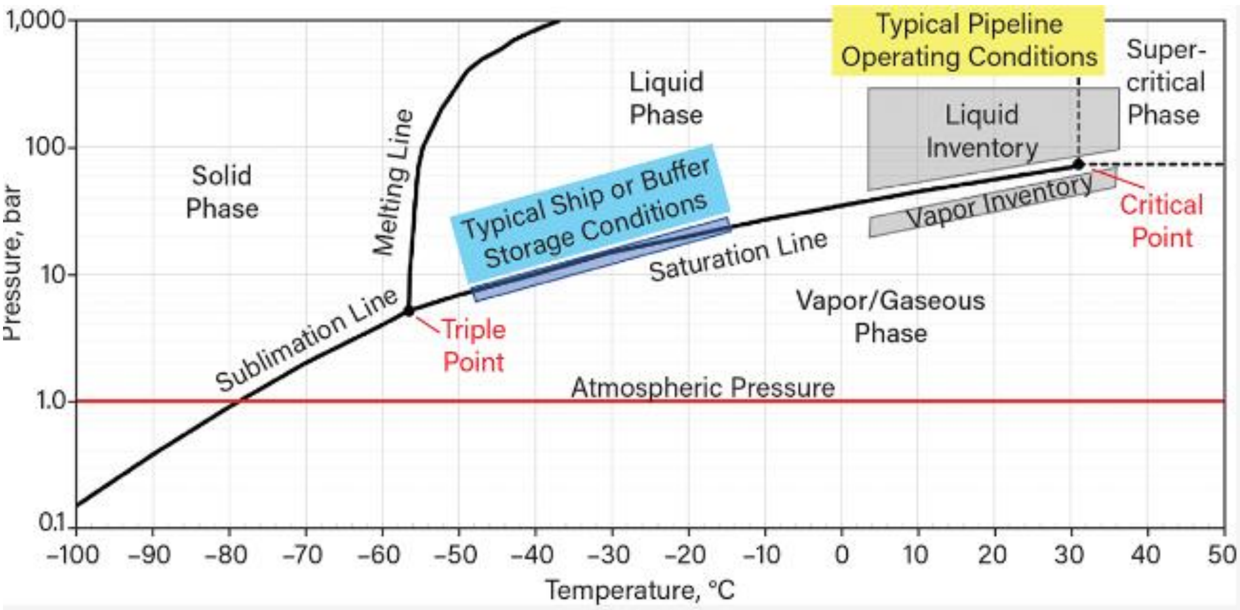

Figure 2.: phase diagram of CO_2 retrieved from [11]

Figure 2 shows the CO_2 phase diagram, it shows that pure CO_2 can exist as vapor, liquid, solid, or supercritical fluid depending on the pressure and temperature. The phase diagram of CO_2 is notable for its triple point – a temperature and pressure point of a substance that can co-exist in all its phases in thermodynamic equilibrium, which is relatively low compared to other substances. The triple point of CO_2 occurs at a temperature of -56.6 °C and a pressure of 5.18 bar. Critical point of CO_2 occurs at a temperature of 31°C and a pressure of 73.8 bar and is a point where boundary of gas and liquid phases disappears. Above the critical point, the system will be in supercritical condition. Supercritical CO_2, also referred to as dense-phase CO_2, has a viscosity similar to gas but a density closer to a liquid.

According to the phase diagram of CO_2, at atmospheric pressure (1 bar), pure CO_2 can only exist as a vapor or as a solid. At atmospheric pressure, solid CO_2 sublimes directly to the vapor while maintaining a temperature of −78.5 °C, the normal sublimation temperature.

Understanding the phase diagram of CO_2 is crucial for applications such as carbon capture, storage, and transportation.

Three categories of temperature/pressure regimes of Liquid CO_2 for transport and temporary storage of captured CO_2 are targeted:

1. Low pressure/Low temperature: 7-10 barg/-50 °C
2. Medium pressure/Medium temperature: 15-20 barg/-30 °C
3. High pressure/Ambient temperature: 40-50 barg/>0 °C

Medium pressure/medium temperature is the most common right now, because of some challenges of liquid CO_2 in low and high pressure.

1.2.2 Hazards

At normal temperature (15°C) and atmospheric pressure, gas density of carbon dioxide is 1.87 kg/m^3, which is 1.5 times heavier than air, hence hazardous amounts can accumulate in low-lying areas, especially in confined spaces [12].

CO_2 is usually stored as compressed gas or liquid under certain pressures, if exposed to heat, it may explode. When CO_2 is stored in large quantities, sudden loss of containment can cause pipework embrittlement [13].

CO_2 that leaks from a pipeline or process vessel will tend to accumulate at low points such as depressions in the ground, manholes, drains and in other confined spaces. Large volumes of CO_2 will tend to roll down hill, displacing air and creating an asphyxia hazard. CO_2 will tend to disperse rapidly, making asphyxia a real but transitory hazard.

1.2.3 Toxicity

In high concentrations carbon dioxide displaces oxygen in the air which can result in asphyxiation. Lack of oxygen can cause permanent damage to humans' brain and heart. Direct skin or eye contact with the liquified gas can cause frostbite and permanent damage to the tissue [14].

1.2.4 Exposure thresholds

Health and Safety Executive of the UK has developed an assessment of Dangerous Toxic Load (DTL) to calculate the exposure limits in terms of concentration and exposure duration [13].

Inhalation exposure time	SLOT*: 1-5 % fatalities		SLOD**: 50 % fatalities	
	CO_2 concentration in air (by vol.)		CO_2 concentration in air (by vol.)	
	%	ppm	%	ppm
60 min	6.3 %	63 000 ppm	8.4 %	84 000 ppm
30 min	6.9 %	69 000 ppm	9.2 %	92 000 ppm
20 min	7.2 %	72 000 ppm	9.6 %	96 000 ppm
10 min	7.9 %	79 000 ppm	10.5 %	105 000 ppm
5 min	8.6 %	86 000 ppm	11.5 %	115 000 ppm
1 min	10.5 %	105 000 ppm	14 %	140 000 ppm

* Specified Level of Toxicity (SLOT) – may cause severe distress, medical attention may be required, likely to cause 1-5 % fatality for highly susceptible people during a single exposure

** Significant Likelihood of Death (SLOD) – may cause 50 % lethality from a single exposure

1.2.5 Sub-zero temperatures

In any case of leakage in the storage vessel or pipeline, (pressure drops to atmospheric pressure of 1 bar) a two-stage process occurs:

- When a liquid in a pipeline or vessel leaks, it rapidly transforms into a gas.
- This transformation leads to the Joule Thomson effect, a change in fluid's temperature as it flows out of high-pressure area to low pressure, which can cause the gas to become extremely cold.

This presents risks to human health, including the potential for asphyxia and freezing, as well as the possibility of structural failure due to the embrittlement of steel caused by low temperatures. Moreover, there is a risk of small solid CO_2 crystals forming, which can result in cold burns if inhaled into the lungs [15].

Figure 3: CO_2 leakage from the rupture of a Denbury Resources CO_2 pipeline in Yazoo County Mississippi, USA 22 February 2020 [16]

1.2.6 Compatibility of carbon dioxide with materials

Carbon dioxide (CO_2) compatibility with materials depends on factors like temperature, pressure, concentration, and exposure duration.

Carbon steel is compatible at moderate conditions but can corrode and become brittle at high temperatures/pressures. Stainless steel is more resistant to corrosion by CO_2, especially at elevated conditions. Aluminium is compatible with CO_2 but can experience localized corrosion in the presence of moisture.

Polyethylene and polypropylene are generally compatible and commonly used for CO_2 pipelines/storage. Fluoropolymers are highly compatible with CO_2, even at high temperatures/pressures. Teflon as a sealing has excellent compatibility and chemical resistance. Graphite is used for high temperature/pressure CO_2 applications [17,18].

1.2.7 Impurities effects on carbon capture storage and transport

During carbon capture, transport, and storage unwanted gases, called impurities, can be present. These impurities can have different types and compositions depending on the method of CO_2 capturing and its source.

Understanding the impact of these impurities is crucial for safety. Some common impurities include water, hydrogen, hydrogen sulfide, carbon monoxide, nitrogen, oxygen, methane, argon, sulfur oxides, and others. However, not all impurities have the same effect on the system. Some impurities, like oxygen, nitrogen, and argon, can change the properties of the CO_2 stream, such as its pressure and temperature, which can affect the behavior of the system during transportation and storage.

Impurities can have both physical and chemical effects on the carbon capture, storage and transport system. The physical effects relate to changes in density and viscosity of the CO_2 stream, while the chemical effects are due to the impurities reacting with the rocks in the storage reservoir. Both of these effects can hinder the proper functioning of the storage and transport system [19,20].

1.2.8 Lessons learned from past incidents

Table 3 presents a summary of accidents related to CO_2 capture, storage, and transport. These incidents highlight the challenges and risks associated with these processes, emphasizing the importance of safety measures, monitoring systems, and continuous improvements in the implementation of CO_2-related projects. Each incident is providing a snapshot of the event, followed by a description, cause and consequences.

Table 3. CO_2 past incident

Incident	Year/Location	Description	Cause	Consequences
Buried pipeline transporting liquefied CO_2 ruptured [11]	2020/ Startia, MS	The pipeline failed on a steep embankment. Heavy rains caused soil subsidence, creating axial strain on the pipeline that resulted in a full-bore rupture girth weld failure.	A girth weld failure	There were no fatalities, but 45 people sought medical attention. The pipeline failed on a steep embankment. Emergency evacuation protocols were activated and approximately 200 residents were evacuated.
CO_2 released accidentally in Mönchengladbach [11]	2008/ Germany	Approximately 15 tons of CO_2 were accidentally released from a fire extinguishing facility in Mönchengladbach, Germany.		no fatalities were associated with this incident, 107 people were affected (19 of whom were hospitalized)
Sleipner platform CO_2 leakage [21]	1991/North Sea	A well blowout during CO_2 injection caused the release of approximately one million tonnes of CO_2 into the North Sea	Equipment failure	Environmental impact on marine life and ecosystem
The catastrophic failure of a liquid CO_2 storage vessel in Worm [11,22]	1988/ Germany	A 30-m.t. CO_2 tank had a catastrophic vessel failure resulting from a cold CO_2 boiling liquid expanding vapor explosion (BLEVE)		The tank shattered, and tank fragments were propelled 300 m, resulting in three fatalities and extensive damage

2 Task 2. Risk and Safety Assessment

The Seveso Directives are the main EU legislation dealing specifically with the control of major accident hazards involving dangerous substances. The Seveso III Directive came into force on 1 June 2015, replacing the Seveso II Directive. Seveso-III gets its name from the Seveso disaster, which occurred in 1976 in Italy. Seveso-III establishes minimum quantity thresholds for reporting and safety permits of dangerous substances that includes methanol. It is necessary to mention that CO_2 is not classified as a dangerous substance under the Seveso Directive. However, for Land Use Planning (LUP) purposes Health and Safety Executive (HSE) uses Dangerous Toxic Load (DTL) to describe a substance's airborne concentration and exposure duration which would produce a particular level of toxicity in the general population [23].

According to the Seveso directive, preparation risk assessment document is a mandatory part of the approval process. Detailed description of necessary considerations for the preparation of risk assessment document can be found in section **Task 4**. Approval process .

2.1 Preliminary risk assessment

As part of MARCO POLO project, two ports, Frederikshavn and Hanstholm were chosen for preliminary and consequence analysis. The port of Frederikshavn was evaluated for storage, transportation, and bunkering of methanol, due to the potential for methanol to become fuel for some of the ferries that operate between Frederikshavn and other ports in Denmark. The port of Hanstholm was evaluated as a potential hub for storage and transportation of CO_2 in Denmark.

As per objective of the project, the preliminary risk assessment only includes storage, transportation and bunkering for methanol and temporary storage and transportation for CO_2. Visual representation of the project scope is given in Figure 4.

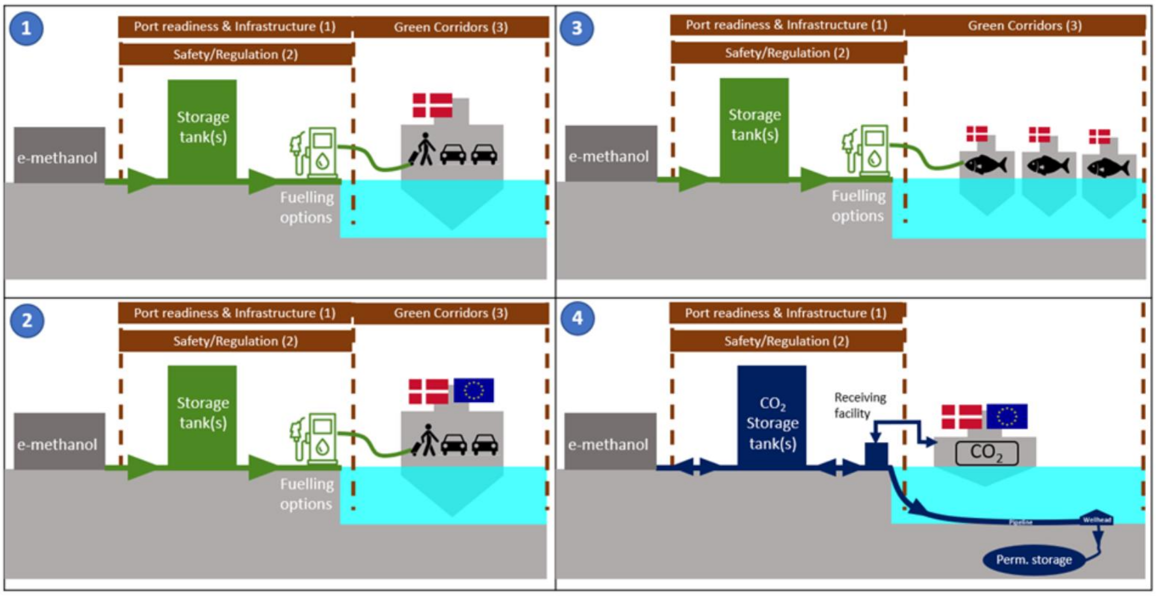

Figure 4. Schematic of MARCO POLO project scope. Preliminary risk assessment is included in the Safety/Regulations part of the whole scope.

Preliminary assessment of potential worst-case events that involve fire, explosion, and toxicity hazards have been identified. These identified events include only rupture and a leak of the storage tank as scenarios due to the early stage of the project and lack of detailed information that is needed for more comprehensive analysis. Thereafter, this assessment is treated as a qualitative risk assessment at this stage of the project that focuses on the bigger picture of major hazards.

The potential events/location of interest were a truck, storage, and bunkering operation. Bunkering operation was split into three modes of transport: via pipe, truck, and a barge.

Some scenarios were chosen to be analysed with the Process Hazard Analysis Software (PHAST) software developed by DNV. It can be used to estimate the magnitude of consequences. The modelling process on the software can account for three phases, discharge, dispersion, and the prediction of the potential consequence. The latest accounts for toxic, radiation, and explosion scenarios [24].

Consequence analysis is done in several stages depending on the type of hazardous material. When the material is flammable liquid, in this case methanol, first step is discharge modelling, second step is cloud formation and dispersion based on the weather conditions. Then, depending on the ignition time and location, methanol could result in pool fire, if ignition happens at the liquid surface early on and could result in vapour cloud explosion (VCE) or flashfire if the ignition is at the cloud source and delayed. In addition, if there is a leak, in case of an immediate ignition or ignition while discharge, there is a possibility of jet fire.

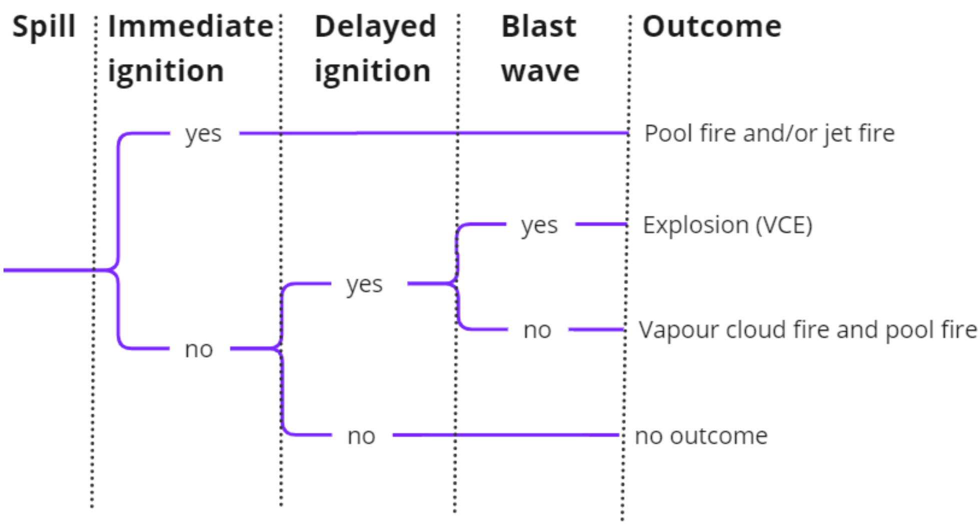

Figure 5. Chain of events for consequences of methanol ignition

In case of CO_2, although it is not a flammable material, it is considered a toxic gas to humans. The analysis principle is similar, discharge and dispersion depending on the weather and other conditions defined.

PHAST uses empirical correlation for modelling analysis of given scenarios; as a result, there are several simplifications and assumptions made for the scenarios as a preliminary work.

2.1.1 Methodology

Based on the objective of the project, the approach for risk assessment and evaluation was split into qualitative and quantitative parts. Qualitative assessment is the preliminary Hazard Identification (HAZID), whereas quantitative is consequence analysis of chosen scenarios based on the preliminary HAZID. Similar methodology for analysis was applied to both methanol and CO_2, however modified based on the common industry practices of transportation, storage and usage of each.

The scenarios for HAZID were chosen to be a transportation of methanol via truck to permanent storage tank, permanent storage of methanol in a quantity similar to the one prescribed by Seveso Directive III. Then, some transportation scenarios from a permanent storage tank to bunkering of a ferry via truck to intermediate tank, pipe to intermediate tank, truck to ferry directly and barge to ferry were assessed.

The scenarios that were assessed were taken as a rupture, which is considered as a worst-case scenario and a leak, which is the most likely scenario. These scenarios were then evaluated based on the potential effects of fire, explosion and toxicity on humans, structure and environment.

HAZID for CO_2 was done considering the transportation of CO_2 to and from storage tank located at the port via truck, and a ship. It is known that storage and transportation of CO_2 is done at sub-zero temperatures and high pressure and based on the past incidents, potential effects of rupture and a leak of CO_2 could result in BLEVE and cold explosion, as well as the toxicity effects of it were considered.

Next, consequence analysis using PHAST software was performed for a rupture and a leak of permanent storage tank of methanol, a rupture of a truck transporting methanol and a rupture of intermediate tank for bunkering purposes were modelled. The modelling was limited to these scenarios due to the scarcity of detailed information related to the scenarios laid out in HAZID.

Similarly, consequence analysis for CO_2 was performed using PHAST, however, only toxicity effects of a rupture and a leak of storage tank was evaluated.

It is important to note that the results of the simulations are **limited to the assumptions and input parameters** of the given scenario and should not be used as grounds for any decision making. In addition, it does not account for the effect of one system failure on other system/s (domino effect).

2.2 Preliminary Hazard Identification

Table 4. Preliminary Hazard Identification for methanol storage and transportation. Some scenarios were chosen to be analysed with PHAST

								Consequence		
Methanol	**Description**	**Mode of transport**	**Assumptions**	**Scenario**	**Potential cause/ cause of the cause**	**Potential effect fire/explosion/toxicity**	**Presence of humans**	**on humans**	**on environment**	**on structure**
1	Truck	filling the storage tank		1. rupture	1. mechanical failure 2. Accidental collision	fire	Yes	PHAST results	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						BLEVE/ explosion		Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		PHAST results	May contaminate soil	N/A
				2. leak	1. corrosion 2. improper connection (human failure)	fire	Yes	Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		Injury/ fatality	May contaminate soil	N/A
2	Storage	above ground	Storage is located in the port (Seveso Directive, Column II)	1. rupture	1. mechanical failure (overfilling due to level sensor failure, relief valve failure and etc.) 2. improper construction 3. lightning	fire	Probably	PHAST results	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						explosion		Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		PHAST results	May contaminate soil	N/A
				2. leak	1. mechanical failure (overfilling) 2. corrosion	fire	Yes	PHAST results	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		PHAST results	May contaminate soil	N/A
3	Bunkering	storage => truck => intermediate tank => ferry	Sequence of event from storage to ferry	1. rupture	1. accidental collision (truck) during transportation 2. mechanical failure (overfilling due to level sensor failure, relief valve failure and etc.) 3. improper construction (intermediate tank)	fire	Yes	PHAST results	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						BLEVE/ explosion		Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		PHAST results	May contaminate soil	N/A
				2. leak	1. corrosion 2. improper connection	fire	Yes	Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		Injury/ fatality	May contaminate soil	N/A
		storage => pipe => intermediate tank => ferry	Sequence of event from storage to ferry	1. rupture	1. hammer effect of a pipe 2. mechanical failure (overfilling due to level sensor failure, relief valve failure and etc.)	fire	Yes	PHAST results	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						BLEVE/ explosion		Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage

					3. improper construction (intermediate tank)	toxicity		PHAST results	May contaminate soil	N/A
				2. leak	1. corrosion 2. improper connection	fire	Yes	Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		Injury/ fatality	May contaminate soil	N/A
		storage => truck => ferry	Sequence of event from storage to ferry	1. rupture	1. mechanical failure 2. accidental collision during transportation	fire	Yes	Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						BLEVE/ explosion		Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		Injury/ fatality	May contaminate soil	N/A
				2. leak	1. corrosion 2. improper connection	fire	Yes	Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		Injury/ fatality	May contaminate soil	N/A
		storage => barge => ferry	Sequence of event from storage to ferry	1. rupture	1. mechanical failure 2. accidental collision during transportation	fire	Yes	Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						BLEVE/ explosion		Injury/ fatality	Air pollution: CO_2/ CO/ NOx/ VOC	may damage
						toxicity		Injury/ fatality	May contaminate aquatic life	N/A

Table 5. Preliminary Hazard Identification for CO_2 storage and transportation. Some scenarios were chosen to be analysed with PHAST

								Consequence		
CO_2	**Description**	**Mode of transport**	**Assumptions**	**Scenario**	**Potential cause/ cause of the cause**	**Potential effect explosion/toxicity/ sub-zero temp.**	**Presence of humans**	**on humans**	**on environment**	**on structure**
1	Truck	transferring from truck to storage tank	For both Loading/Unloading	1. rupture	1. mechanical failure 2. accidental collision 3. corrosion	BLEVE	Yes	Injury/ fatality	release of excessive amount of CO_2/impurities into the atmosphere	may damage
						toxicity		Injury/ fatality		N/A
						cold explosion		Injury/ fatality		may damage
				2. leak	1. corrosion 2. improper connection (human failure)	toxicity	Yes	Injury/ fatality	release of CO_2/impurities into the atmosphere	N/A
						cold explosion		Injury/ fatality		may damage
2	Ship	transferring from ship to storage tank	For both Loading/Unloading	1. rupture	1. mechanical failure 2. accidental collision 3. corrosion	BLEVE	Yes	Injury/ fatality	release of excessive amount of CO_2/impurities into the atmosphere	may damage
						toxicity		Injury/ fatality		N/A
						cold explosion		Injury/ fatality		may damage
3	Storage	above ground	Storage is located in the port	1. rupture	1. mechanical failure 2. improper construction 3. corrosion 4. lightning	BLEVE	Probably	Injury/ fatality	release of excessive amount of CO_2/impurities into the atmosphere	may damage
						toxicity		PHAST results		N/A
						cold explosion		Injury/ fatality		may damage
				2. leak	1. corrosion 2. improper connection (human failure)	toxicity	Probably	PHAST results	release of CO_2/impurities into the atmosphere	N/A
						cold explosion		Injury/ fatality		may damage

2.3 Consequence modelling with PHAST

Process Hazard Analysis Software (PHAST) was developed by DNV and it can be used to estimate the magnitude of consequences for a range of fuels and scenarios.

2.3.1 Limitations of the software

- Empirical modelling
- Simplified two-dimensional (2D) model approach
- It does not account for location of ventilation route and presence of suppression systems of nearby buildings.

2.3.2 General assumptions and input parameters

a. Methanol

Methanol volume for the simulations was taken as a representative of the volume under the requirements of Seveso III Directive, Column II threshold for methanol. The weather data was taken as an average representative for Frederikshavn area. Summer temperature of 20 ℃ was taken as a worst-case scenario for methanol because methanol has the flashpoint of 11 ℃ , which means it has the higher propensity for flammability as the temperature rises above flashpoint. Two different wind speeds (average for the area evaluated) were chosen because the dispersion pattern will differ based on the wind speed and direction. Wind direction was identified from a windrose diagram for the area.

- Weather parameters:
  - Summer 20℃, wind speed 1.5m/s – night [Category 1.5/F Summer]
  - Summer 20℃, wind speed 5.5m/s – sunny day [Category 5.5/D Summer]
- Predominant wind direction: west
- Storage conditions: 20 ℃, atm.
- Volume of the permanent tank: 700 m^3
- Volume of a truck: 45 m^3
- Volume of a bunkering station: 100 m^3
- Leak size: Ø200mm
- Leak location: 1m above the ground
- Concentration threshold: 6000 ppm (Immediately Dangerous to Life or Health (IDLH))
- A concrete bund around permanent storage tank: 1 m in height and 700 m^2 in area
- A concrete bund around bunkering storage tank: 0.5 m in height and 200 m^2 in area
- Explosion modelling method: multi-energy explosion.
- Method for dispersion: fill-in the obstructions first.

b. CO_2

Due to the lack of information available for the threshold requirements of CO_2 volume for the simulations, volume was taken similar to the ones available in the industry now. The weather data was taken as an average representative for Hanstholm area. Average temperatures representative of various weather conditions was chosen for the area evaluated. Three different wind speeds (average for the area evaluated) were chosen because the dispersion pattern will differ based on the wind speed and direction. Wind direction was identified from a windrose diagram for the area.

- Weather parameters:
  - Summer, 20 ℃ – wind speed 5.9 m/s - [Category 5.9/D Summer – 20C]
  - Winter, 3℃ – wind speed 8.5 m/s - [Category 8.5/D Winter – 3C]
  - Average, 9.85 ℃ – wind speed 1.5 m/s - [Category 1.5/F – 9.85C]

- Predominant wind direction: west
- Storage conditions: -30 ℃, 15 bar.
- Volume of the tank in the tank room: 2100 m^3
- Leak size: Ø100mm
- Leak location: 1 m above the ground
- Concentration threshold: 84000 ppm (corresponds to 1hr exposure with 50% lethality probability from a single exposure, 5 min exposure with 1% fatality)
- Method for dispersion: fill-in the obstructions first.

2.3.3 Scenarios

Chosen scenarios are considered as the worst case because they account for the catastrophic rupture of the tanks and sudden release of all methanol and CO_2 from the tanks. This will give maximum amount of vapour cloud formation within a short period of time which then can be used for estimation of dispersion, fire, and explosion consequences for methanol and dispersion consequences for CO_2 in the given areas. In addition, one leakage scenarios were evaluated for each fuel.

a. Methanol

I. Scenario 1 (SM-1). The immediate release of all methanol from a permanent storage tank due to a catastrophic rupture
II. Scenario 2 (SM-2). Leakage from a permanent storage of methanol
III. Scenario 3 (SM-3). The immediate release of all methanol from a truck due to the catastrophic rupture
IV. Scenario 4 (SM-4). The immediate release of all methanol from a bunkering station tank due to the catastrophic rupture

b. CO_2

I. Scenario 1 (SC-1). The immediate release of all CO_2 from a permanent storage tank due to a catastrophic rupture
II. Scenario 2 (SC-2). Leakage from a permanent storage of CO_2

2.4 Results

a. Methanol

I. Scenario 1 (SM-1). The immediate release of all methanol from a permanent storage tank due to a catastrophic rupture

Table 6. Legend for methanol PHAST simulation results.

Legend	
(blue)	Summer 20˚C, wind speed 1.5m/s – night
(green)	Summer 20˚C, wind speed 5.5m/s – sunny day

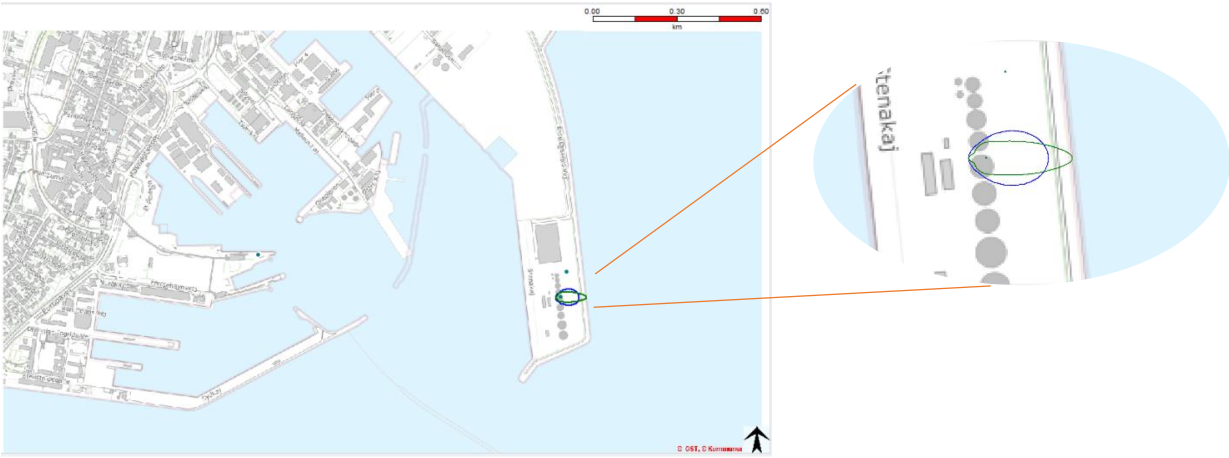

Figure 6. SM-1. Cloud maximum footprint contour of 6000ppm on the map of Frederikshavn port with prevailing west winds at the ground level.

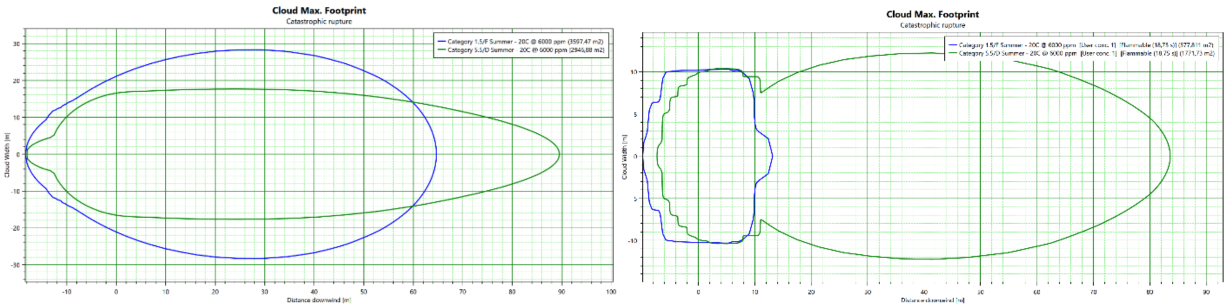

Figure 7. SM-1. Cloud maximum footprint diagraph for 6000ppm shown with the downwind distance. Left: at the ground level (h=0m). Right: at 2m height

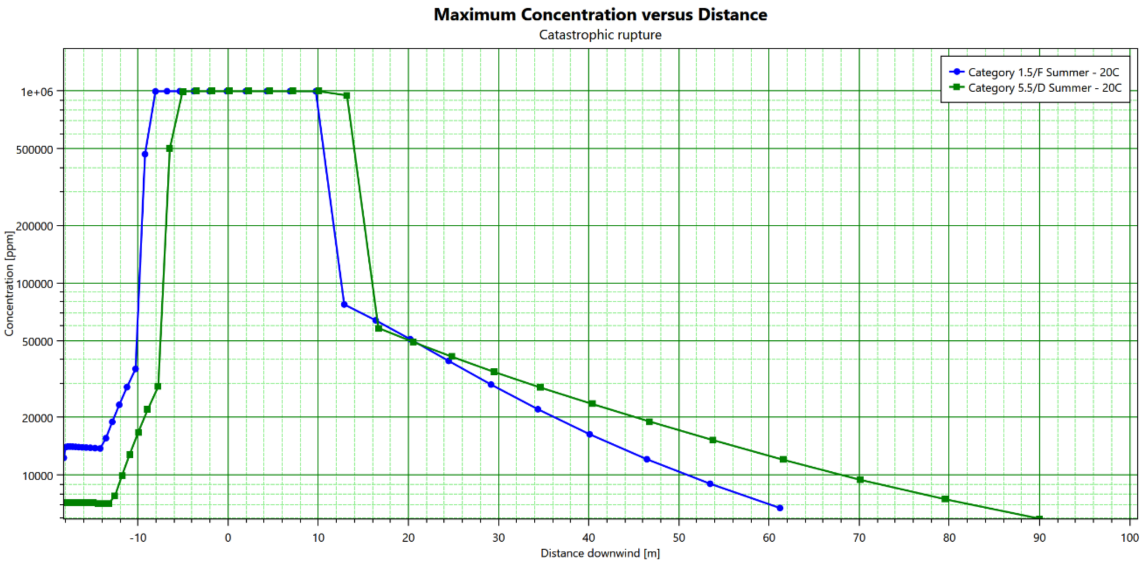

Figure 8. SM-1. Concentration of methanol over a distance at the ground level.

II. Scenario 2 (SM-2). Leakage from a permanent storage of methanol

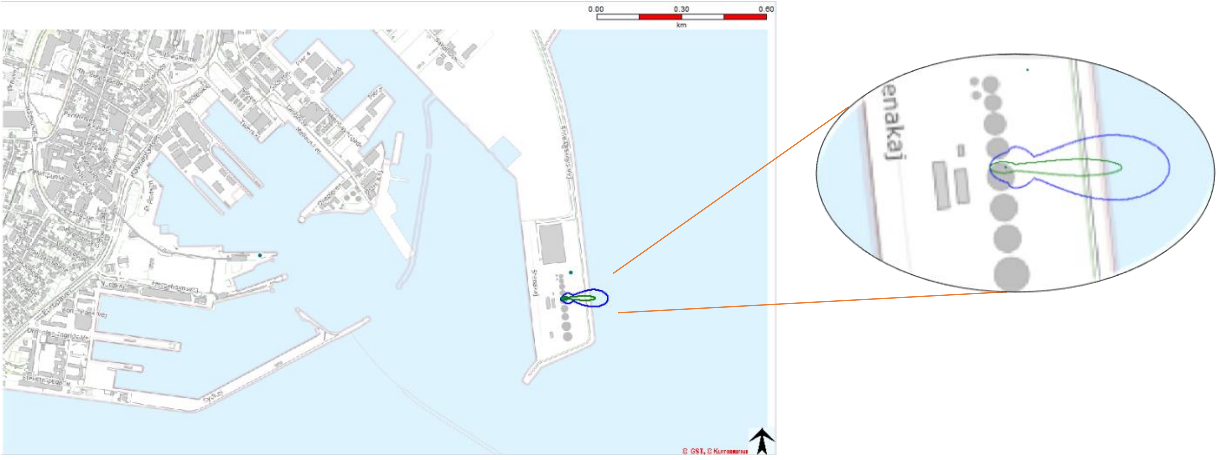

Figure 9. SM-2. Cloud maximum footprint contour of 6000ppm on the map of Frederikshavn port with prevailing west winds at the ground level.

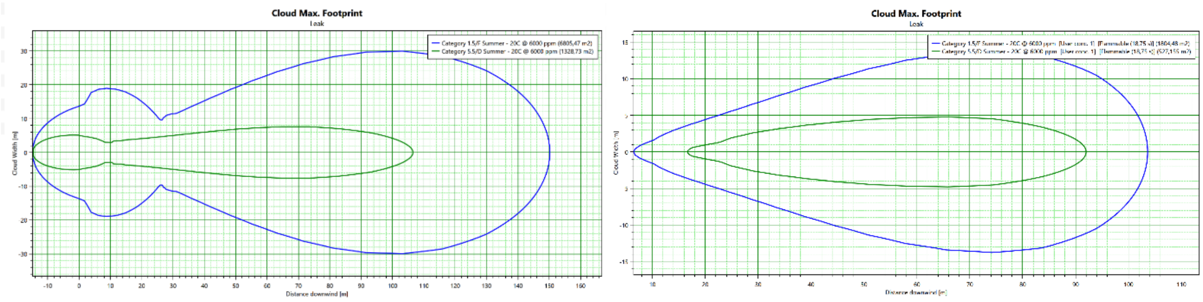

Figure 10. SM-2. Cloud maximum footprint diagraph for 6000ppm shown with the downwind distance. Left: at the ground level (h=0m). Right: at 2m height

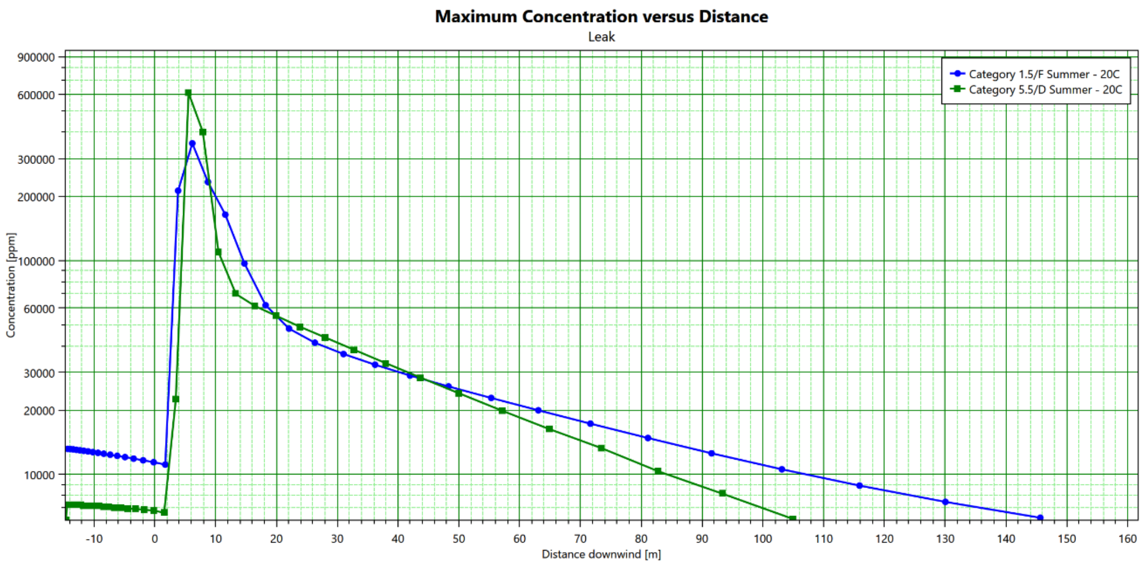

Figure 11. SM-2. Concentration of methanol over a distance at the ground level.

III. Scenario 3 (SM-3). The immediate release of all methanol from a truck due to the catastrophic rupture

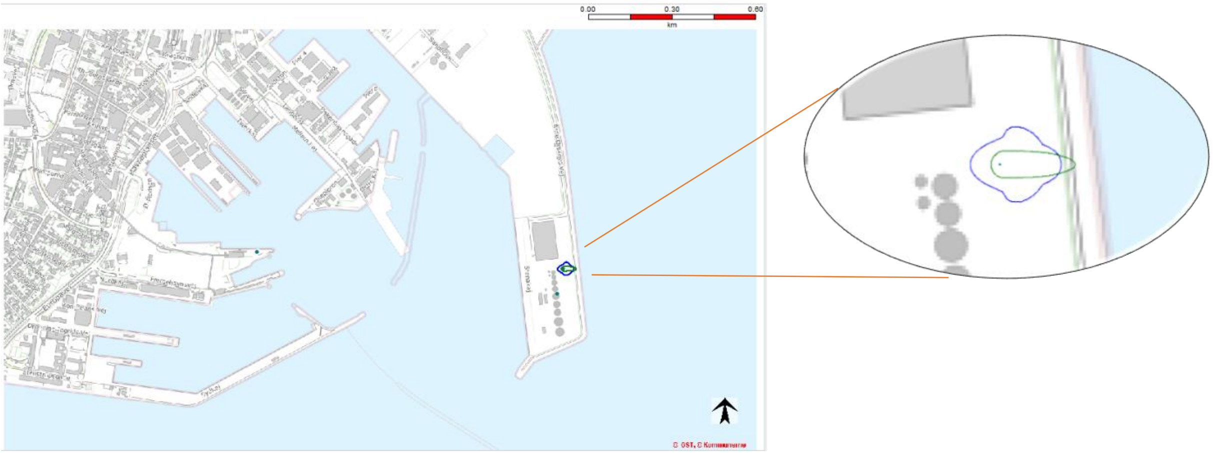

Figure 12. SM-3. Cloud maximum footprint contour of 6000ppm on the map of Frederikshavn port with prevailing west winds at the ground level.

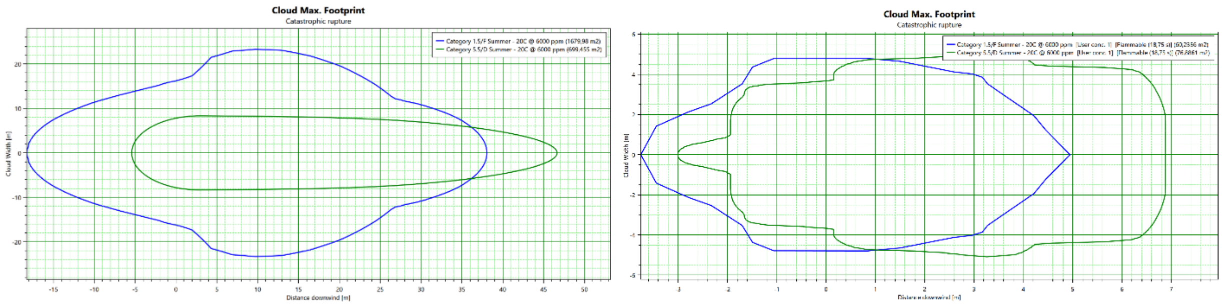

Figure 13. SM-3. Cloud maximum footprint diagraph for 6000ppm shown with the downwind distance. Left: at the ground level (h=0m). Right: at 2m height

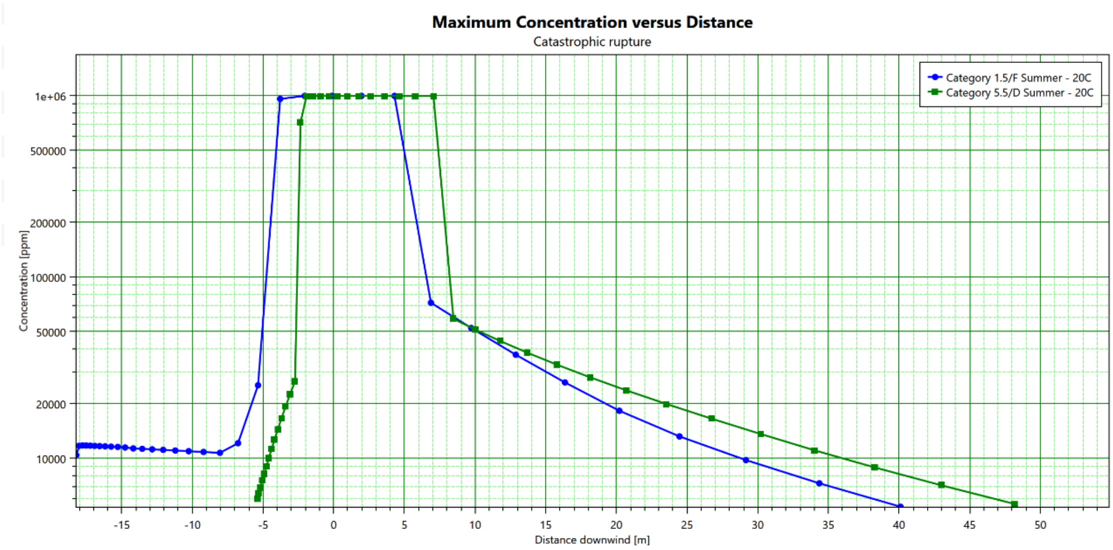

Figure 14. SM-3. Concentration of methanol over a distance at the ground level.

IV. Scenario 4 (SM-4). The immediate release of all methanol from a bunkering station tank due to the catastrophic rupture

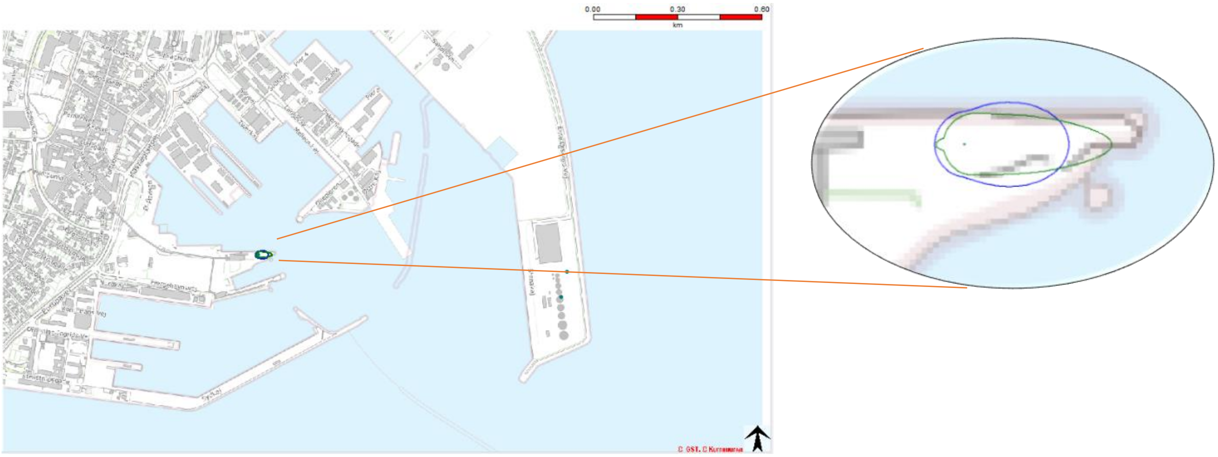

Figure 15. SM-4. Cloud maximum footprint contour of 6000ppm on the map of Frederikshavn port with prevailing west winds at the ground level.

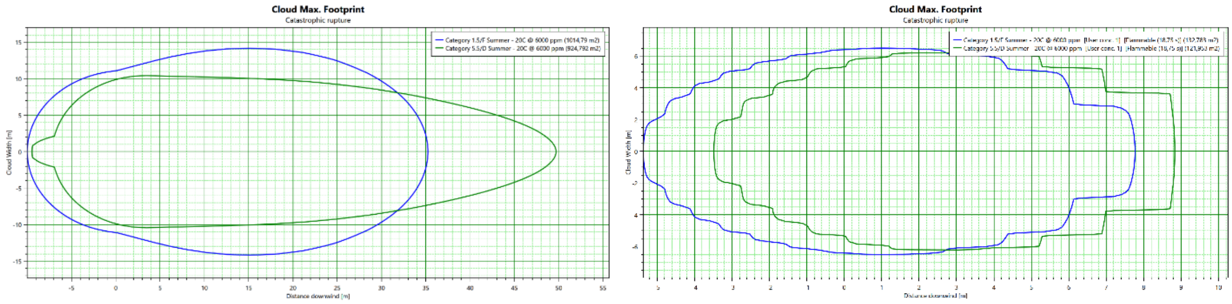

Figure 16. SM-4. Cloud maximum footprint diagraph for 6000ppm shown with the downwind distance. Left: at the ground level (h=0m). Right: at 2m height

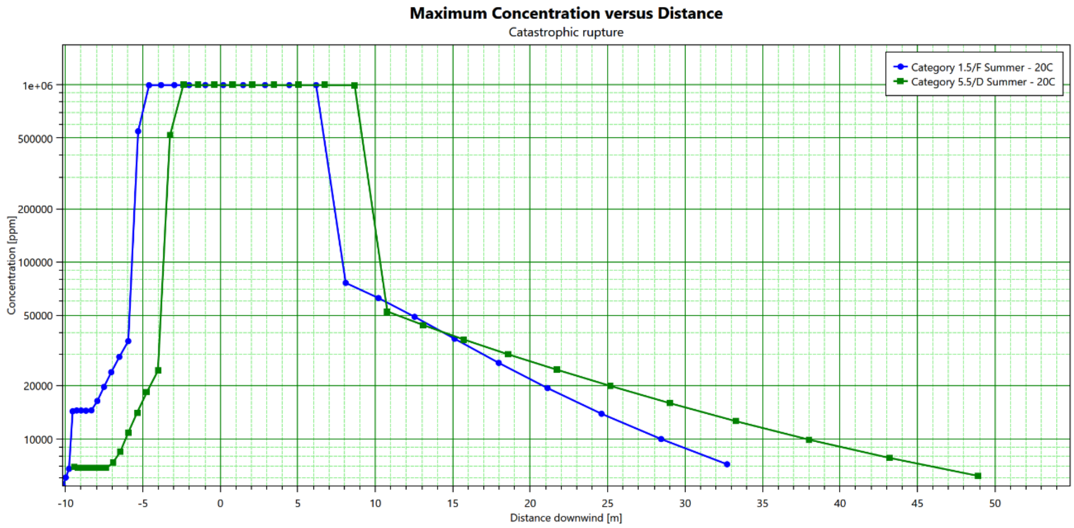

Figure 17. SM-4. Concentration of methanol over a distance at the ground level.

- Radiation heat flux

Table 7. Radiation heat flux threshold distances.

Scenarios	Type of hazard	Weather type	Safety distance [m] (Radiation heat flux – 5 kW/m2)	Safety distance [m] (Radiation heat flux – 1.5 kW/m2)
Scenario 1 (SM-1)	Late pool fire		50	53.5
			49	51
Scenario 2 (SM-2)	Late pool fire		41	44
			41	43
	Jet fire		56	76
			53	69
Scenario 3 (SM-3)	Late pool fire		50	52
			49	51
Scenario 4 (SM-4)	Late pool fire		27.5	29
			27.5	29

b. CO_2

I. Scenario 1 (SC-1). The immediate release of all CO_2 from a permanent storage tank due to a catastrophic rupture

Table 8. Legend for methanol PHAST simulation results.

Legend	
(blue)	Average, 10˚C – wind speed 1.5m/s
(green)	Winter, 3˚C – wind speed 8.5m/s
(red)	Summer, 20˚C – wind speed 5.5m/s

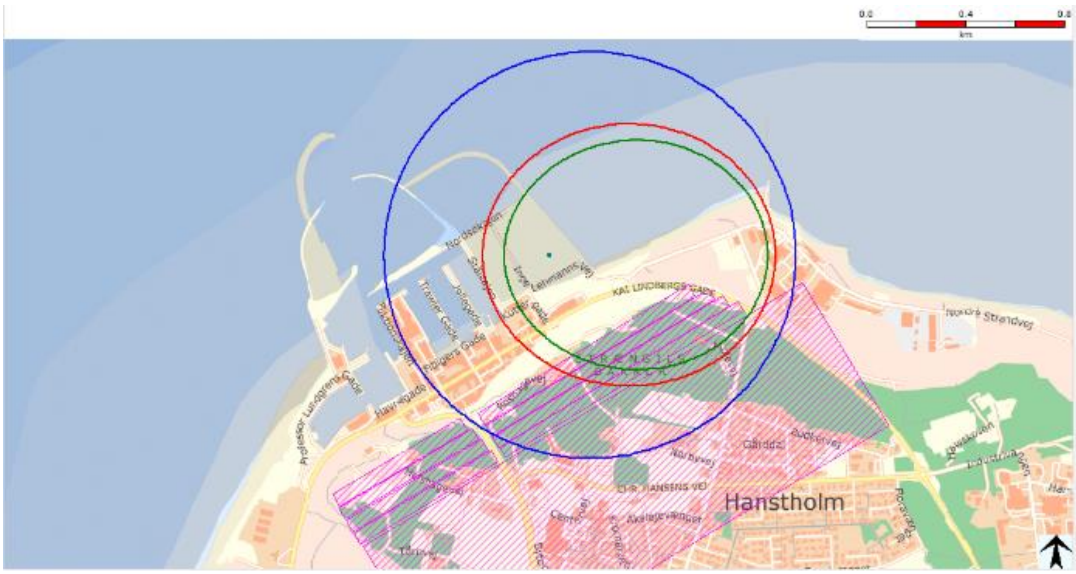

Figure 18. SC-1. Cloud maximum footprint contour of 84000ppm on the map of Hanstholm port with prevailing west winds at the ground level.

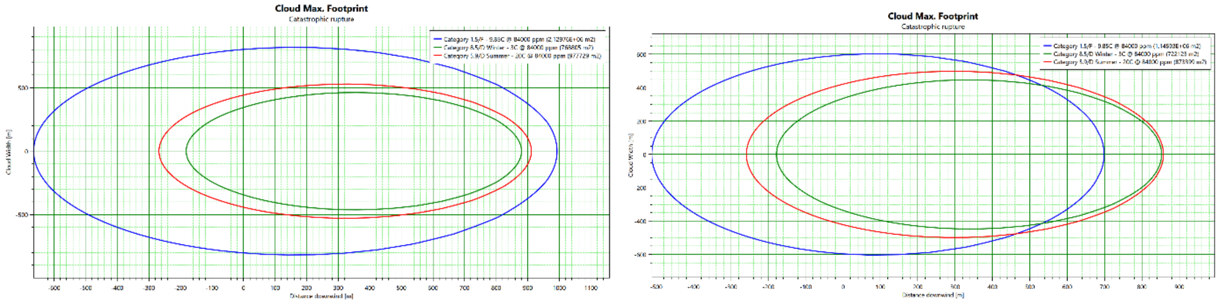

Figure 19. SC-1. Cloud maximum footprint diagraph for 84000ppm shown with the downwind distance at the ground level. Left: at the ground level (h=0m). Right: at 2m height

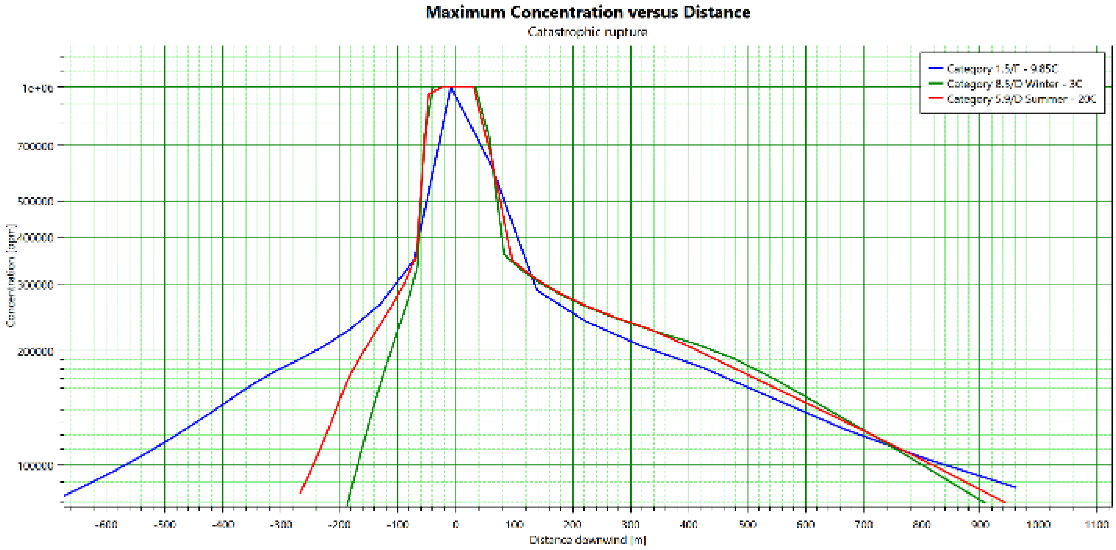

Figure 20. SC-1. Concentration of CO_2 over a distance at the ground level.

II. Scenario 2 (SC-2). Leakage from a permanent storage of CO_2

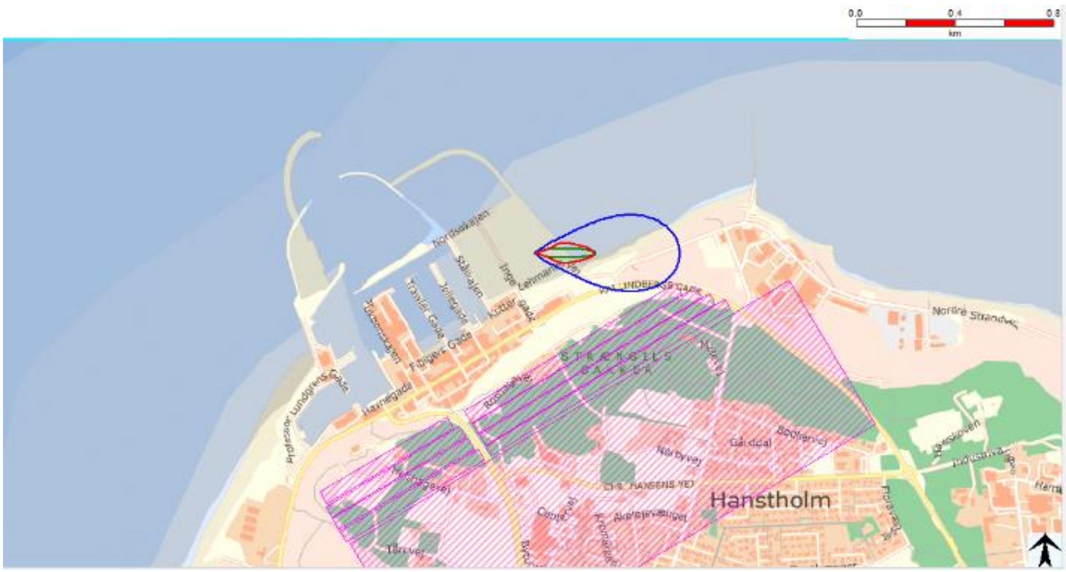

Figure 21. SC-2. Cloud maximum footprint contour of 84000ppm on the map of Hanstholm port with prevailing west winds at the ground level.

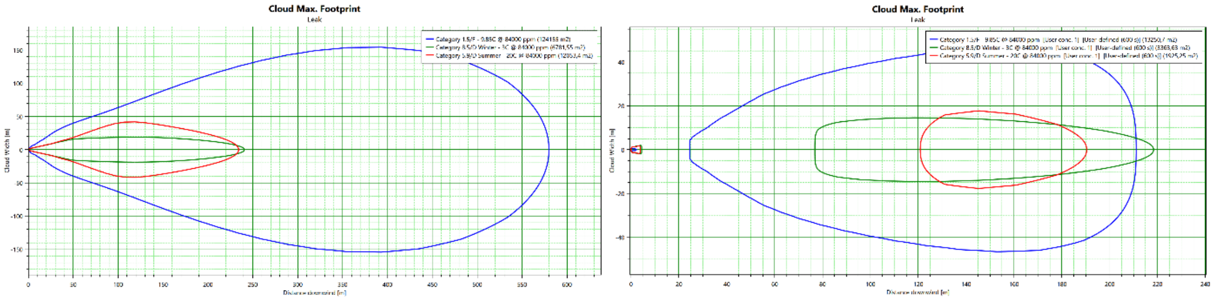

Figure 22. SC-2. Cloud maximum footprint diagraph for 6000ppm shown with the downwind distance at the ground level. Left: at the ground level (h=0m). Right: at 2m height

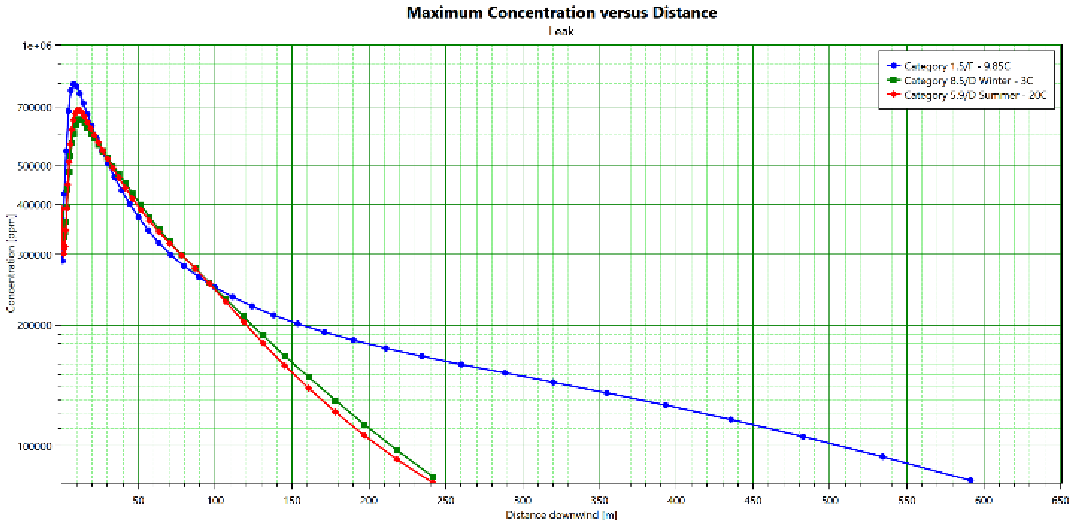

Figure 23. SC-2. Concentration of CO_2 over a distance at the ground level.

2.5 Discussion

a. Methanol

- Cloud footprint concentration levels

The threshold for the evaluation of concentration levels on humans was taken as 6000 ppm, which is considered as the immediate danger to human life within the vicinity. The graphs showing the distances can be found for each scenario in section a.

Based on the input parameters and assumptions made for this set of modelling, the scenarios (SM-1) with catastrophic rupture of a tank with the largest amount of methanol, hazardous concentrations could go up to 110 meters in length and 40 meters in width in case of high wind velocity and 85 meters in length and 60 meters in width in case of low velocity winds at the ground level. The elevation profile changes based on the velocity of the wind. Since the flashpoint of methanol is 11 °C, at the modelled condition, methanol starts quickly vaporizing and dispersing. However, since the methanol vapor is relatively denser than air, vapours tend to disperse on the lower areas, compared to vapours that are lighter than air, which readily disperse into the atmosphere. As a result, harmful concentrations of methanol at 2 meters height shows smaller area for low wind velocity case as a result of dispersion on the lower areas. Whereas when there is a high wind velocity, the vapours tend to move along the downwind distance even at 2-meter elevation.

A leak of methanol from storage tank (SM-2) was modelled as the highly likely scenario resembling real-life situation. Based on the input parameters and assumptions, as expected, for a continuous flow of methanol will result in high concentration in the vicinity and direction of the leak when the velocity of the wind is low. Whereas harmful concentrations disperse readily in high velocity winds. For comparison, at the ground level, minimum 6000 ppm concentration could go up to 165 meters in length and 60 meters in width when there is low velocity wind. Whereas same concentration goes up to 120 meters in length and 20 meters in width when velocity of the wind is high.

It is important to note that the permanent storage tank was modelled with a concrete bund around it with a height of 1 m. This is a standard practice when designing tanks in industrial applications, in order to minimize the pool radius.

A truck carrying 45 m^3 of methanol (SM-3) is modelled to include the worst-case consequence of rupture during transportation. As expected, the presence of wind and its velocity play role in the area of harmful concentration in the area. Less or no wind means harmful concentrations of methanol accumulate in the low laying areas twice as much as during the presence of wind.

And finally, a rupture of a bunkering station of 100 m^3 volume (SM-4) to show the consequences of harmful concentrations because a bunkering station is considered to be in close proximity to the ferries and ships that need to be frequently bunkered. Harmful concentrations are accumulated in 60 m by 20 m area in high velocity winds and 45 m by 30 m area in low velocity winds. The concentration profile being similar at 2 m height. Similar to SM-1, this scenario was modelled with a concrete bund around its perimeter for fuel containment purposes.

It is clear that the wind speed and direction play a big role in the dispersion magnitude, which makes it important to better understand the weather conditions and surroundings, when making the design decision for these types of projects. In addition, fuel containment capabilities for storage tanks and temporary placements need to be considered based on expected volume of methanol to be present.

- Radiation heat flux

Radiation heat flux is an important parameter that is evaluated for flammable materials. Assessing the distance to which humans would be in danger of skin burn injuries is done by evaluating heat flux values that are considered tolerable to human skin. Various standards and regulations suggest different heat flux levels depending on the conditions evaluated [25]. Although it is an arguably discrepant value to use for the evaluation of skin burn level, a common acceptable heat flux level based on several standards and regulations is 5 kW/m^2. However, the European Standard, EN 1473, specifies that 5 kW/m^2 is applicable for industrial areas and 1.5 kW/m^2 for unshielded areas where people generally are without protective clothing [25,26]. It has been shown that the tolerance time for radiation of less than 2.5 kW/m^2 is 5 minutes or more, whereas more than that would result in tolerance time of 30 seconds [27]. The results for distance to the radiation heat flux thresholds can be seen in Table 7.

Since methanol is a liquid fuel, in case of ignition in an open space, the resulting hazard is most likely to be a pool fire. Since rupture means an immediate release of all fuel from a storage medium, scenarios SM-1, SM-3 and SM-4 were evaluated for a radiation heat flux of an ignited pool. Scenario SM-2 is a leak which means ignition of fuel in this case could be a pool fire in case of late ignition of a pool or a combination of jet fire and a pool fire in case of immediate ignition.

All scenarios except SM-3 have concrete bunds around its perimeter in order to contain the maximum expected fuel volume in the tanks. As a result, even though, volume of the modelled truck carries 15 times more fuel than what is contained in the permanent storage tank, the modelled spill is free to flow in any direction. Hence, safety distances based on the radiation heat fluxes for SM-3 are almost as long as SM-1. In reality, transferring operations for trucks that are designated for the transportation of flammable fuels like methanol should be performed in the area with sufficient containment capabilities.

b. CO_2

- Cloud footprint concentration levels

The threshold for the evaluation of concentration levels that could adversely affect humans are given in section 1.2.4. The graphs showing the distances can be found for each scenario in section b.

The density of CO_2 is higher than air, which means vapours tend to disperse on the lower areas. In addition to that, CO_2 is stored at sub-zero temperatures and high pressure which means it starts quickly expanding and dispersing during at unscheduled events like rupture and leaks. For this set of simulations, three weather conditions were simulated to overview variety of conditions in case of CO_2 system failure.

Given CO_2 storage conditions and means of failure, the computer modelling shows that CO_2 starts quickly expanding and dispersing when the storage tank undergoes catastrophic failure. Based on the input parameters and assumptions made for this set of modelling, the scenarios with catastrophic rupture of a tank (SC-1) with the largest amount of CO_2, hazardous concentrations could go up to 1700 meters in length and 1600 meters in width in case of low velocity wind at the ground level. These values are somewhat smaller for the cases with stronger winds. As such, when the wind velocity is 5.9m/s the distance where CO_2 disperses is nearly 1200 meters in length and 1000 meters in width. When the velocity is 8.5m/s, the dispersion distances are nearly 1100 meters and 950 meters. The elevation profile changes because of CO_2 property of being heavier than air, which results in accumulation in low lying areas. However, based on the simulations with given assumptions, even at 20 meters height, the CO_2 harmful concentrations are still present within 200-meter radius.

A leak of CO_2 from storage tank (SC-2) was modelled as the highly likely scenario. Based on the input parameters and assumptions, as expected, for a continuous flow of CO_2 will result in high concentration in the vicinity and direction of the leak when the velocity of the wind is low. As such the concentration threshold is reached at a distance 580 meters downwind length and 300 meters in maximum width. The concentrations sharply go down in the presence of strong winds compared to the former case. In case of both, 5,9m/s and 8,5m/s winds, the distance are nearly identical reaching the distance close to 240 meters in length and less than 100 meters in width at the ground level. At the height of 2 meters, the concentrations are present in the area with 185 meter in length and nearly 90 meters in width when there is low velocity winds and 140 meters in length and 30 meters in width when the wind is the highest. When the wind is 5.9m/s, CO_2 concentrations disperse in all directions quicker than when the strongest wind, making the area of harmful concentrations 1.5 times smaller.

This shows that, failure mode in case of CO2 storage in large quantities greatly affects the dispersion area and profile. When there is a sudden release of all CO_2 from the storage tank, the presence of wind affects the area where harmful concentrations accumulate, however, the effects of wind dominate less with the increase of height. On the other hand, during the failure mode in the form of leak, size and direction of the leak, as well as the wind velocity greatly affect the area and profile of concentrations of CO_2.

2.6 Future work

It is important to note that the results of the simulations are limited to the assumptions and input parameters of the given scenarios and should not be used as grounds for any decision making. The volumes of the storage and bunkering tanks, as well as the means of transportation including the capacities need to be redefined. A further risk assessment should be conducted based on the availability of more detailed data, project drawings/documents and a detailed system design.

2.7 Recommendations and conclusion

Through preliminary HAZID, hazardous scenarios were identified for various modes of storage and transportation for both, methanol and CO_2. Consequence analysis of selected scenarios were performed with PHAST software. Based on the results of the preliminary HAZID and consequence analysis and general safety practices it is recommended, but not limited to:

Methanol

- Proper selection and design of the equipment based on the flammable and explosive characteristics of methanol.
- Design of the sufficient spill containment capabilities
- Identification and zoning of hazard areas and selection of explosion-proof equipment in hazard zones
- Regular maintenance
- Proper staff training
- Sufficient safety measure in case of emergency
- Awareness and control of possible ignition sources, especially during hot work activities
- Availability and regular maintenance of firefighting equipment at the site
- Limited access to the site
- Proper emergency response planning

CO_2

- Proper selection and design of the equipment
- Presence of emergency evacuation protocols
- Sufficient safety measure in case of emergency
- Regular maintenance
- Limited access to the facility
- Proper staff training

3 Task 3. Mapping Competencies

Mapping competencies involves identifying the skills, knowledge, abilities, and behaviours required for success in that particular role. Mapping competency for safety in methanol and CO_2 handling at different levels, including port, authority, and tenant, involves considering the specific responsibilities and knowledge required at each level based on OSHA, NFPA 55, etc.

3.1 Port/Operator:

When mapping safety competency at the operator level for methanol and CO_2 handling, it is crucial to consider individuals directly involved in day-to-day operations. Here are key competency areas for operators:

a. Knowledge of methanol and CO_2 Properties and Hazards:

Operators should have a solid grasp of the properties, such as flammability, toxicity, and reactivity for methanol, and physical and chemical characteristics for methanol and CO_2. They must be aware of potential hazards associated with these substances and practice safe handling procedures, including managing exposure risks, fire prevention, and minimizing environmental impact.

b. Safe handling procedures:

Operators need to be knowledgeable about proper storage, transportation, and transfer methods for methanol and CO_2. They should understand the importance of using appropriate equipment, such as approved containers, pumps, ventilation systems for methanol, and pressure vessels, valves, and piping systems for CO_2. Additionally, operators should be proficient in using personal protective equipment (PPE) like gloves, goggles, and respiratory protection.

c. Emergency response:

Operators should be trained in specific emergency response procedures for incidents involving methanol and CO_2. This includes recognizing and effectively responding to leaks, spills, fires, and releases. They should understand how to use fire extinguishers for methanol incidents and how to shut off or isolate CO_2 sources, follow emergency shutdown procedures, evacuate when necessary, and communicate with emergency responders.

d. Risk assessment and mitigation:

Operators must possess the competence to conduct risk assessments and implement effective mitigation measures. This involves identifying potential hazards, evaluating associated risks, and employing appropriate control measures to minimize accidents. Understanding control hierarchy, implementing engineering controls, and practicing good housekeeping to reduce spills and exposure risks are important. Operators should also be aware of ventilation requirements and the importance of monitoring CO_2 concentrations in work areas.

e. Communication and reporting:

Operators should demonstrate strong communication skills to effectively convey safety concerns, incidents to supervisors, colleagues, and relevant personnel. Familiarity with reporting channels, emergency service contact information, and notification protocols is vital for efficient and timely communication, contributing to hazard prevention and mitigation.

f. Training and continuous learning:

Operators should actively participate in regular training programs to enhance their knowledge and skills in methanol and CO_2 handling safety. Attending safety workshops, staying updated on safety procedures, regulations, and industry best practices are essential. Continuous learning ensures operators remain competent and informed about new safety technologies, procedures, and regulations.

Ensuring competency at the operator level can be achieved through a combination of formal training programs, on-the-job experience, mentorship, and assessments. Regular performance evaluations, refresher training, and opportunities for professional development play a significant role in maintaining and improving operator competency in methanol and CO_2 handling safety.

3.2 Authority

When it comes to mapping competency for safety in methanol and CO_2 handling at the authority level, it typically involves individuals who are responsible for regulating, overseeing, and enforcing safety standards. Here are some key competency areas for authorities involved in methanol and CO_2 handling safety:

g. Regulatory knowledge:

Authorities responsible for methanol and CO_2 handling safety should have a deep understanding of relevant regulations, standards, and guidelines. This includes knowledge of national or regional regulatory frameworks, industry-specific regulations, and international standards related to the safe storage, transportation, and handling of methanol and CO_2. Staying updated on any changes to these regulations is essential.

h. Risk assessment and management:

Competence in verifying comprehensive risk assessments is crucial. Authorities should be able to identify potential hazards associated with methanol and CO_2, evaluate risks, and develop appropriate risk management strategies. This includes understanding the properties and characteristics of methanol and CO_2, assessing potential exposure pathways, and implementing risk mitigation measures.

i. Inspection and compliance:

Authorities need expertise in conducting inspections and audits to ensure compliance with methanol and CO_2 safety regulations. This involves assessing storage facilities, transportation vehicles, handling practices, and emergency response plans. Competency in identifying compliance gaps, issuing permits, and taking appropriate enforcement actions when necessary is vital.

j. Emergency response and incident management:

Authorities should have knowledge and experience in emergency response and incident management specific to methanol and CO_2 incidents. This includes understanding proper protocols for handling spills, or release, coordinating with relevant emergency services, and overseeing the containment, cleanup, and disposal of methanol and associated hazardous materials.

k. Training and education:

Competence in developing and delivering training and educational programs is crucial. Authorities should be capable of designing training materials, conducting workshops, and providing guidance to organizations and individuals involved in methanol and CO_2 handling. This includes promoting awareness of safety best practices, personal protective equipment (PPE) usage, and emergency response procedures.

l. Collaboration and communication:

Authorities should possess strong collaboration and communication skills to work effectively with stakeholders such as industry representatives, regulatory agencies, emergency services, and the public. This involves engaging in dialogue, disseminating safety information, and fostering partnerships to enhance methanol and CO_2 handling safety.

Competency development for authorities often involves a combination of education, experience, and ongoing professional development. Training programs, seminars, conferences, and participation in industry associations can help authorities stay updated on the latest safety practices, technologies, and regulatory developments related to methanol and CO_2 handling.

3.3 Port tenants

When mapping competency for safety in methanol and CO_2 handling at the tenant level, it refers to individuals or organizations leasing or occupying a space where methanol or CO_2 is used, stored, or handled. Here are key competency areas for tenants:

m. Knowledge of methanol and CO_2 properties and hazards:

Tenants should have a basic understanding of the properties and hazards of methanol and CO_2. This includes knowledge of its flammability, toxicity, and potential health effects for methanol and CO_2's asphyxiating properties, its potential to displace oxygen in confined spaces, and the risks associated with high concentrations of CO_2. Awareness of the risks associated with methanol handling helps tenants make informed decisions regarding their own safety and the safety of others in the vicinity. Also understanding the physical and chemical properties of CO_2 is crucial for safe handling.

n. Safe handling practices:

Competence in safe handling practices is important to prevent accidents and maintain a safe environment. Tenants should be familiar with proper storage, transportation, and usage guidelines for methanol and CO_2.

o. Emergency response awareness:

Tenants should be aware of emergency response procedures to methanol/CO_2 incidents. This includes knowing the location of emergency exits, fire extinguishers, and emergency shutdown systems. They should understand how to report incidents, raise alarms, and evacuate safely in case of a methanol-related emergency.

p. Communication and reporting:

Tenants should possess effective communication skills to report safety concerns and incidents to the appropriate authorities or building management. They should be familiar with reporting channels, contact information for emergency services, and protocols for notifying relevant personnel. Prompt reporting and clear communication can help prevent or mitigate hazards.

q. Compliance with regulations and safety standards:

Competence in complying with applicable regulations and safety standards is crucial. Tenants should be familiar with local regulations, permits, and codes related to methanol handling and storage. They should ensure their operations align with these requirements and follow recommended safety practices to minimize risks.

Tenants can demonstrate competency through adherence to safety protocols, regular participation in safety meetings or drills, and maintaining records of safety inspections or incident reports. Collaboration with building management, regulatory agencies, and other stakeholders can contribute to a safe environment for methanol and CO_2 handling at the tenant level.

4 Task 4. Approval process

4.1 Methanol

The approval process needs to meet some required safety and environment standards. A stepwise process for methanol storage establishment is presented in Figure 24 with each step's consideration.

Step1:

Before initiating an application process, the project owner must carefully consider several factors that can impact the process. These factors include:

Scope of the project: Determine the project's building scope, area requirements, and production capacity to identify the relevant permits, approvals, and authorities involved.

Location: Collaborate with the municipality to identify a suitable project location. Conduct studies to assess if there are any immediate usage restrictions, presence of protected species or habitats, potential impacts on water resources, adherence to nature conservation regulations, and protection of cultural heritage sites.

Necessary infrastructure: Assess the availability of essential infrastructure such as electricity, water supply, wastewater management, and transportation routes.

Investigation of soil and groundwater conditions: Conduct preliminary investigations to understand the soil and groundwater conditions at the project site, which will inform the project's construction phase planning.

Necessary permits and approvals: Identify the specific permits and approvals required for the project, considering factors like location, facility type, and storage of hazardous substances.

Timetable: Engage in dialogue with relevant authorities to estimate the processing time for the project and develop a timetable for the application process.

It is essential to provide comprehensive information and documentation to the authorities before submitting the application. It is advisable to consult with the authorities regarding application content and guidelines. Written guidance on application requirements can be obtained from most authorities.

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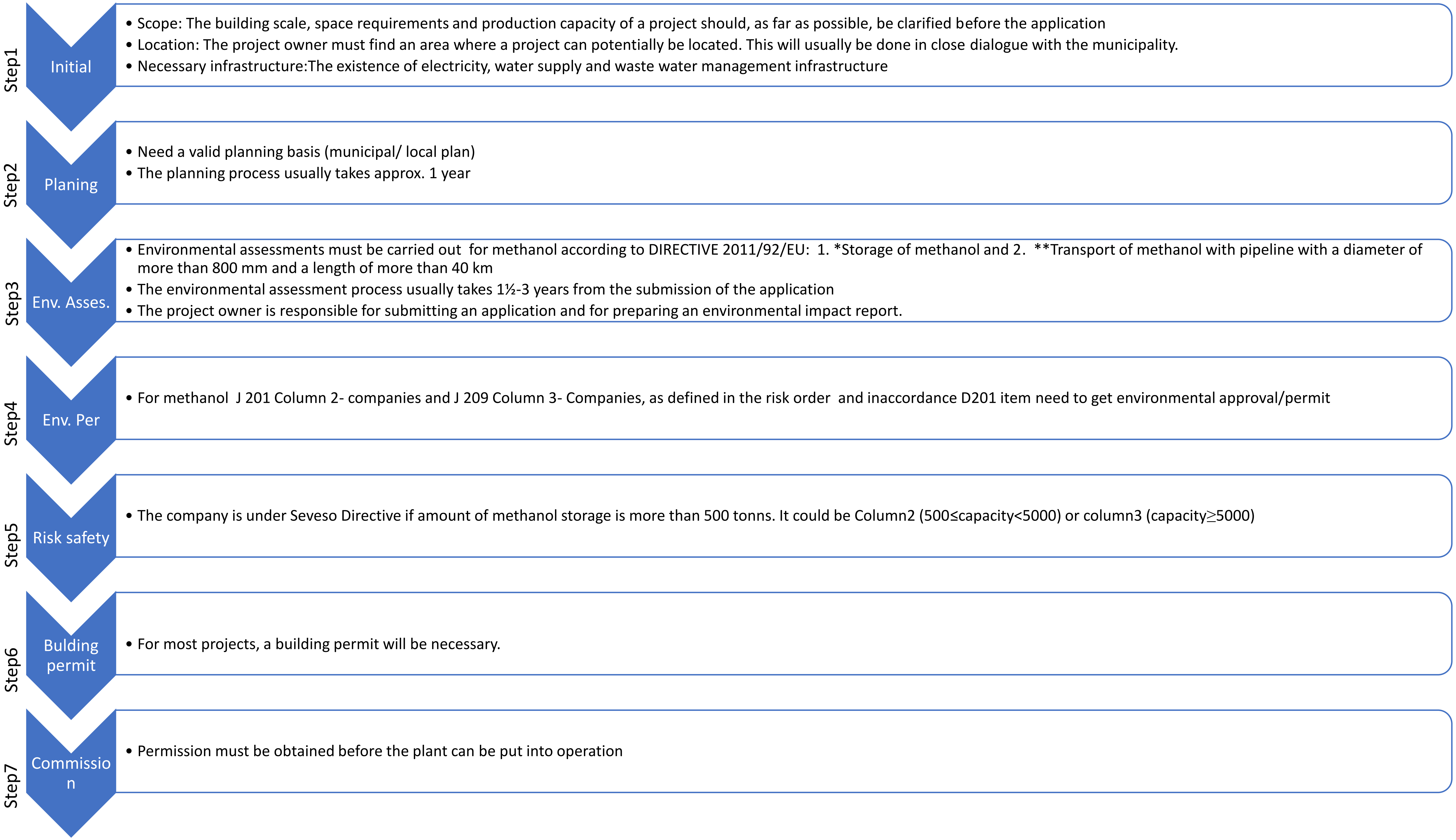

Figure 24. Stepwise approval process for methanol storage

* Annex1 sections 22 and of Annex2 section 6-C [28]

** Annex1 section 16 of [28]

Step 2:

Establishing methanol storage facilities requires proper planning, including municipal and local plans. In some cases, a planning process must be initiated to accommodate the facility. Municipalities have the responsibility of planning land use and establishing frameworks in their plans. When selecting a location, it is essential to determine if the existing plans can support the storage facility or if new planning is necessary. Early dialogue with the municipality is useful to discuss planning conditions. Methanol storage facilities are typically considered industrial and are ideally located in urban business zones with access to infrastructure. New areas allocated for storage should be connected to existing urban development. The process involves publishing proposals, setting consultation periods, administrative and political processing, and a 4-week appeal period. The preparation of a local plan includes clarifying the need, preparing reports, proposal treatments, public consultations, and addressing other legislative provisions. The planning process generally takes about a year.

Step 3:

For projects involving methanol storage with high capacity, in some cases that are listed below, it is necessary to conduct an environmental assessment to evaluate their impact on the environment. This assessment is required for plans, programs, and projects that are expected to have a significant environmental impact. The need for an environmental assessment should be determined through a screening process for both local and municipal plans. The Danish Environmental Protection Agency (miljøvurderingsmyndighed) or the municipality serves as the environmental assessment authority.

According to the Environmental Assessment Act, the following items specify in which cases the Environmental Assessment for methanol transport or storage should be done:

I. For all projects that appear in Annex 1 of the Environmental Assessment Act (miljøvurderingslovens bilag 1) [28], an environmental assessment of the specific project must be carried out:

16. ***Pipelines with a diameter of more than 800 mm and a length of more than 40 km:***
a) for the transport of gas, oil, chemicals.

22. Facilities for the storage of oil products as well as petrochemical or chemical products with a capacity of 200,000 tonnes or more.

II. For all projects that appear in Annex 2 of the Environmental Assessment Act (miljøvurderingslovens bilag 2) [28], a screening process must be carried out to assess whether an environmental assessment of the specific project must be carried out:

6. The chemical industry (projects not covered by Annex 1)
c) Facilities for the storage of oil and petrochemical and chemical products.

The environmental assessment process differs for plans and projects. In the case of plans, the municipal planning authority screens for the need of an environmental assessment, prepares a draft delimitation memorandum, and consults relevant authorities. An environmental report and draft plan are then prepared, followed by public consultation and the adoption of a final plan with an accompanying environmental report.

For projects, the project owner is responsible for submitting a permit application and preparing an environmental impact report. There are two public hearings where consultation responses are processed, and an environmental impact report and draft permit are developed. The final decision is made, considering the consultation responses and summary assessment.

The entire environmental assessment process typically takes 1.5 to 3 years, depending on the project's size and complexity. If both a local plan and project assessment are required, efforts are made to run the processes concurrently.

Step 4:

In some cases, methanol storage projects, require environmental approval and other permits. Environmental approval is necessary for most projects and is granted under Section 33 of the Danish Environmental Protection Agency [29]. Annexes 1 and 2 of the approval order [30] provide a list of activities that require environmental approval. For methanol storage in any of these cases:

Annex 2:

D 201. Companies that use physical processes to produce organic or inorganic chemical substances, products or intermediate products, including enzymes, where the production may give rise to significant pollution. <u>Storage of liquid organic or inorganic chemical substances</u>, products or intermediate products, including enzymes, where the storage may give rise to significant pollution, with the exception of liquid nitrogen-containing fertilisers.

J 201 Column 2 - companies, as defined in the risk order on control of the risk of major accidents involving dangerous substances.

J 209 Column 3 - companies, as defined in the risk order on control of the risk of major accidents involving dangerous substances.

Before starting construction, projects requiring environmental approval must obtain it.

The environmental authority responsible for granting environmental approval is generally the municipality unless marked otherwise.

Step 5:

Special requirements may apply to the storage of substances and preparedness for fire and explosion risks. The Seveso directive [31] categorizes storage facilities as either "column 2" or "column 3" businesses based on the maximum amount of hazardous substances present, including stocks and materials in pipes, pumps, and reactors. The larger the circulation, the greater the potential impact of fires or explosions, leading to distinct requirements for column 2 and column 3 companies. Column 3 companies have additional obligations for both the company and the authorities involved.

Annex 1, Part 2 of Seveso specifies the substances and quantities covered. If multiple substances are stored, a specific formula outlined in the Seveso's appendix 1, note 4, should be used to determine whether the company falls under the risk notice requirements.

Seveso III Directive

Based on the quantity of a substance under Seveso III Directive, companies have to prepare documents to be approved by the relevant authorities. The current project considers the material to be methanol with a quantity equal or more than 500 tonnes and less than 5000 tonnes, which puts this establishment into a column 2 of Seveso Directive requirements whereas methanol with a quantity equal or more than 5000 tonnes puts the establishment into a column 3.

The flowchart in Figure 25 illustrates the procedures for implementing the Seveso Directive in, outlining the responsibilities of both the company and the authorities involved. The company's responsibilities are represented by the yellow-coloured elements, while the green-coloured elements indicate the responsibilities of the authorities.

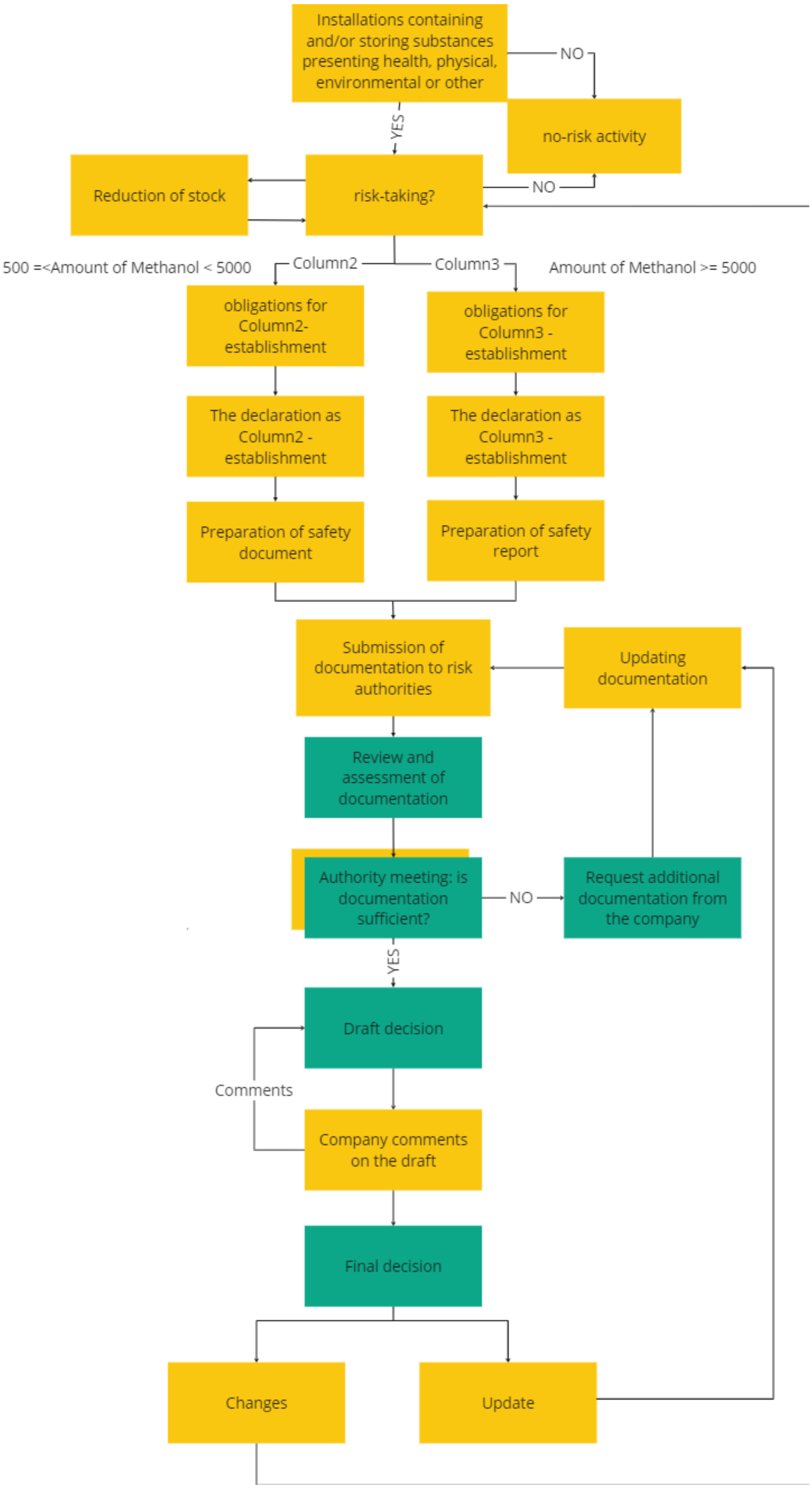

Figure 25: Flowchart of Seveso Directive [32]

Column 2:

The diagram in Figure 26 illustrates the process for subsequent regulatory action, highlighting the responsibilities of both companies (yellow) and authorities (green). Companies are required to submit a notification (Anmeldelse) to the municipal authority, following Annex 2 (bilag 2) before establishing, significantly expanding, or modifying their operations. The general obligations, outlined in Section 7 (§ 7) [31], emphasize that companies must take necessary measures to prevent major accidents and implement the safety measures specified in their safety document.

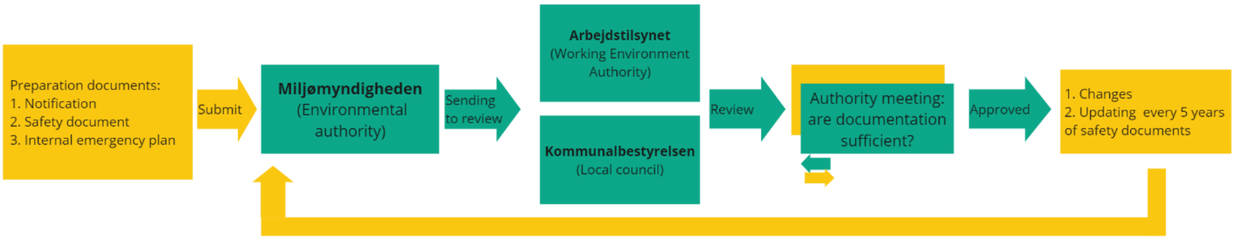

Figure 26. Process for Column 2 actions with involving authorities.

A prevention plan, outlining objectives and principles to reduce the risk of major accidents, should be developed and systematically implemented. Companies must also prepare a safety document, according to Annex 3 (bilag 3) [31]. Prior to establishment, expansion, or modification. The safety document should include the prevention plan and is submitted to the local authority. An internal emergency plan, in accordance with the Danish Working Environment Authority's regulations, should be created and can be submitted along with other materials to the environmental authority.

Any changes including discontinuation, must be immediately reported to the environmental authority, which then informs other coordinating risk authorities. The safety document should be regularly reviewed and updated every five years or as necessary. Changes in hazardous substances, safety components, barriers, safety management systems, or organizational responsibilities may trigger updates. The updated safety document or a justified conclusion that an update is unnecessary must be submitted to the environmental authority.

The risk authority may also request the company to assess new circumstances and update the safety document if required, based on information from previous accidents or similar establishments. However, changes in the planning of a high-risk establishment do not trigger new assessments by the company. In the event of a major accident, the company must immediately contact emergency services and implement the internal emergency plan. Details of the accident should be promptly communicated to the risk authorities following Annex 7 (bilag 7) [31].

In column 2, authorities are:

- The Municipal Environmental Authority (Miljømyndigheden)
- The municipal board (Kommunalbestyrelsen)
- Danish Working Environment Authority (Arbejdstilsynet)

Column 3:

Procedure for Column 3 is almost same as Column 2 with some differences in required document and involving authorities that are listed below:

1. Instead of a safety document for Column 2 companies, a safety report is needed for Column 3 companies with high level of protection for people and the environment in accordance with Appendix 4 (Bilag 4) [31]
2. An internal emergency plan in accordance with Annex 5 [31]
3. An external emergency plan in accordance with Section 15 (§ 15) [31]
4. Involving police (Politiet) and The National Emergency Management Agency (Beredskabsstyrelsen) authorities by sending external emergency plan (

5. In accordance with Section 11 and Annex 6, Part 1 (§ 11 og bilag 6, del 1) [31]. The vulnerability assessment must be prepared in order to avoid internatinal harmful actions

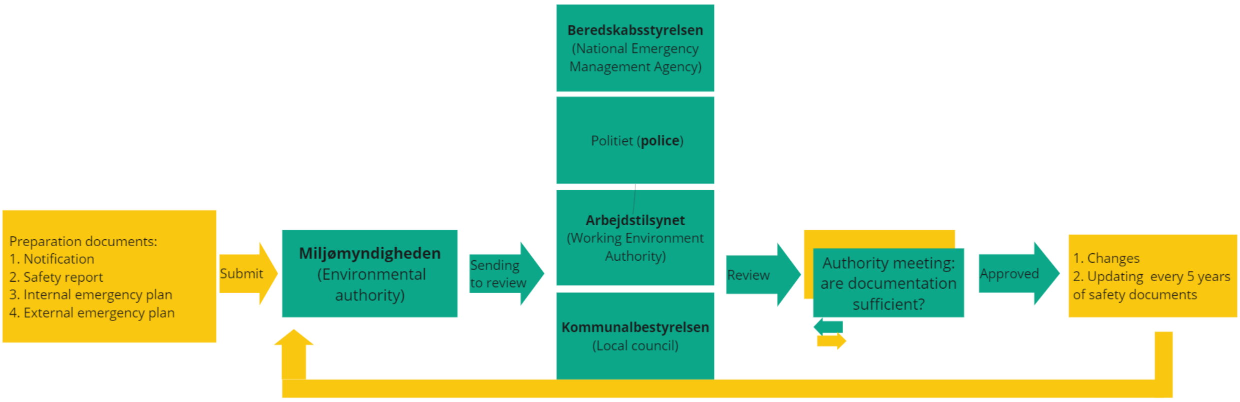

Figure 27: Process for Column3 actions with involving authorities.

Step 6:

A building permit is typically required for most projects. The application for a building permit should be submitted through the digital platform "byg og miljoe" [33]. Construction work should not commence until the building permit has been issued.

The municipality can only grant a building permit if the project complies with relevant legislation, or if exemptions from those conditions are obtained. The municipal authority is responsible for investigating whether the construction work is subject to other legislation that could hinder its execution. The building permit remains valid for one year from the date of issue.

To obtain a building permit, a decision must be made in accordance with the Environmental Assessment Act, and a planning basis must be available. Before construction begins, the work must be reported to the Working Environment Authority (Arbejdstilsynet).

Step7:

Before a plant can be put into operation, permission must be obtained. This involves reporting the completion of the construction project to the municipality and submitting documentation for the completed construction. Based on this notification, the municipality issues a commissioning permit to allow the use of the finished building.

Additionally, before the final operation, the project owner needs to obtain permits from Energinet, including a voltage setting permit, a temporary operating permit, and a final operating permit.

In terms of pressure-bearing systems, the Working Environment Authority (Arbejdstilsynet) is responsible for the installation and use control of pressure-bearing equipment. Equipment classified under control class A and B requires an installation check before being put into use for the first time.

This installation control must be carried out by an accredited inspection body. It is recommended to contact an inspection body early on to arrange the installation control process.

4.2 Intermediated storage of CO2

CO2 is not classified as a dangerous substance under the Seveso Directive. And the approval process for the intermediate storage and utilization of CO_2 is a little different than methanol. A stepwise process for CO_2 storage establishment is presented in Figure 28 with each step's consideration.

Step 1:

Same as Step 1 for methanol

Step 2:

Same as Step 2 for methanol

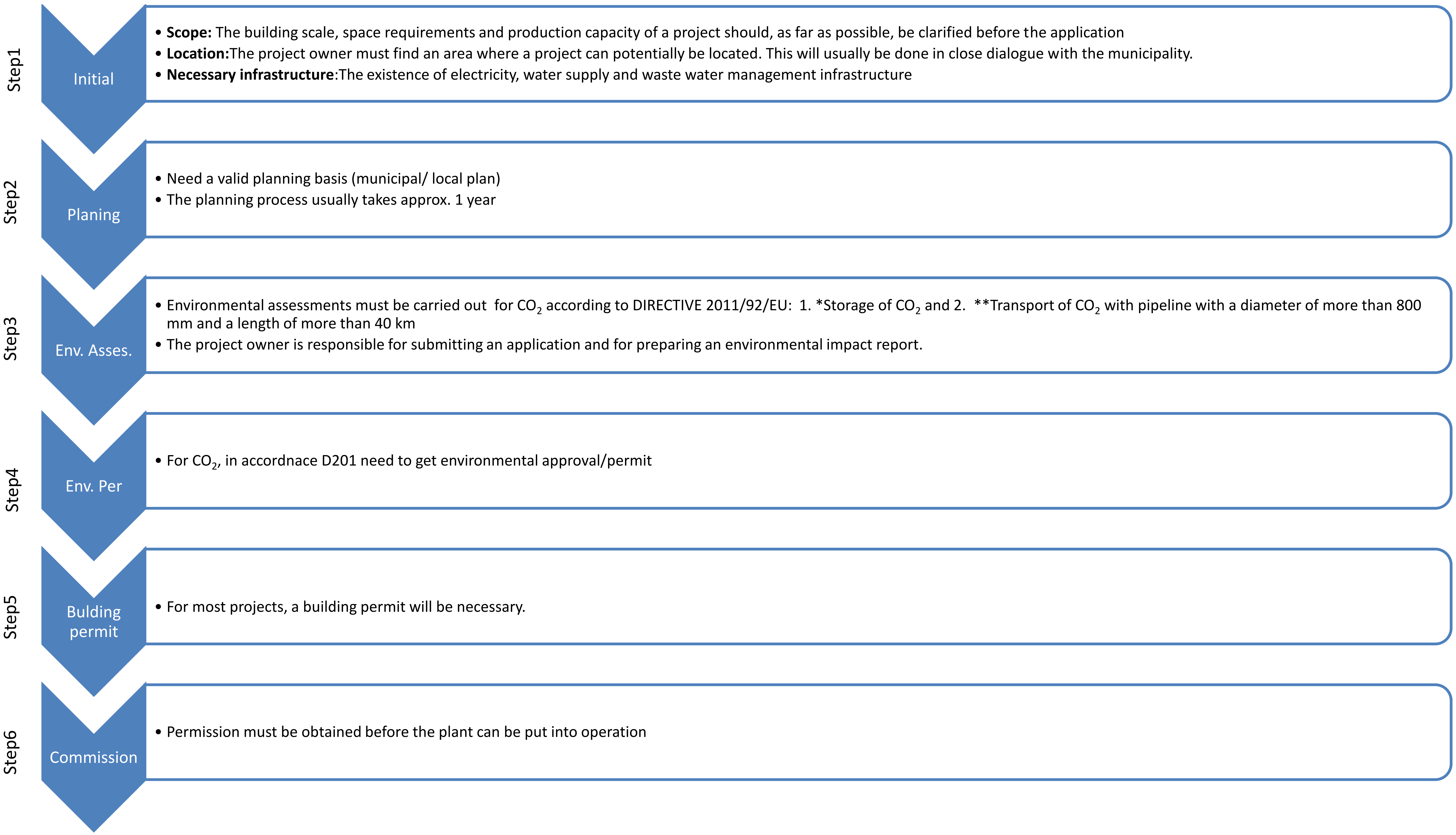

Figure 28: Stepwise approval process for CO_2 storage

* Annex1 section 24, Annex2 section 3-k [28]

** Annex1 section16-b, Annex2 section 9-i of [28]

Step 3:

For projects involving CO_2 handling, in some cases as listed below, it is necessary to conduct an environmental assessment to evaluate their impact on the environment. The Danish Environmental Protection Agency (miljøvurderingsmyndighed) or the municipality serves as the environmental assessment authority.

According to the Environmental Assessment Act, the following items specify in which cases the Environmental Assessment for CO_2 transport or storage should be done:

I. For all projects that appear in Annex 1 of the Environmental Assessment Act (miljøvurderingslovens bilag 1), an environmental assessment of the specific project must be carried out:

16. Pipelines with a diameter of more than 800 mm and a length of more than 40 km:
b) for the transport of carbon dioxide streams (CO_2) for the purpose of geological storage, including associated pumping stations.

24. Facilities for the collection of CO_2 flows from facilities covered by this annex for the purpose of geological storage pursuant to Directive 2009/31/EC, or where the total collection of CO_2 annually is 1.5 megatons or more.

II. For all projects that appear in Annex 2 of the Environmental Assessment Act (miljøvurderingslovens bilag 2), a screening process must be carried out to assess whether an environmental assessment of the specific project must be carried out:

3. The energy industry
k) Facilities for the collection of CO_2 flows from facilities not covered by Annex 1, with a view to geological storage pursuant to Directive 2009/31/EC.

9. The rubber industry

i) Construction of oil and gas pipelines and pipelines for the transport of CO_2 flows for the purpose of geological storage (projects not covered by Annex 1).

The environmental assessment process differs for plans and projects. In the case of plans, the municipal planning authority screens for the need of an environmental assessment, prepares a draft delimitation memorandum, and consults relevant authorities. An environmental report and draft plan are then prepared, followed by public consultation and the adoption of a final plan with an accompanying environmental report.

For projects, the project owner is responsible for submitting an application and preparing an environmental impact report. There are two public hearings where consultation responses are processed, and an environmental impact report and draft permit are developed. The final decision is made, considering the consultation responses and summary assessment.

The entire environmental assessment process typically takes 1.5 to 3 years, depending on the project's size and complexity. If both a local plan and project assessment are required, efforts are made to run the processes concurrently.

Step 4:

In some cases, for CO_2 storage same as methanol storage projects, require environmental approval and other permits. Environmental approval is necessary for most projects and is granted under Section 33 of the Danish

Environmental Protection Agency [29]. Annexes 1 and 2 of the approval order [30] provide a list of activities that require environmental approval. For methanol storage in any of these cases:

Annex1:

6.9. Collection of CO_2 streams from facilities covered by Directive 2010/75/EU on industrial emissions with the aim of geological storage in accordance with Directive 2009/31/EC on geological storage of carbon dioxide.

Annex 2:

D 201. Companies that use physical processes to produce organic or inorganic chemical substances, products or intermediate products, including enzymes, where the production may give rise to significant pollution. Storage of liquid organic or inorganic chemical substances, products or intermediate products, including enzymes, where the storage may give rise to significant pollution, with the exception of liquid nitrogen-containing fertilisers.

Before starting construction, projects requiring environmental approval must obtain it.

The environmental authority responsible for granting environmental approval is generally the municipality unless marked otherwise.

Step 5:

Step 5 for CO_2 is the same as Step 6 of methanol.

Step 6:

Step 6 for CO_2 is the same as Step 7 of methanol.

4.3 Conclusion and recommendation

The procedures for approving storage facilities for methanol and CO_2 have been established. Methanol is labelled as hazardous under the Seveso Directive, while CO_2 isn't considered hazardous by the same directive. A company falls under the Seveso Directive if it stores 500 tons or more of methanol. This can be in Column2 (500 tons ≤ capacity < 5000 tons) or Column3 (capacity ≥ 5000 tons). The approval process also involves an environmental assessment and approval/permit in certain cases. If capacity of methanol storage is equal or more than 500 tons, both of these are necessary for methanol storage. For CO_2, an environmental assessment and environmental approval are required before storage.

The estimated time for the approval process for methanol storage under the Seveso directive is approximately 4-5 years, and for CO_2, it's 1.5-2 years. A suggestion to expedite the approval process for methanol is to store less than 500 tons, which only requires local permission, and to use a tube line for transfer. The distance between the production site and port must be less than 40 kilometres, and the pipeline should be smaller than 800mm to avoid the need for an environmental assessment document.

5 **Task 5.** Feasibility plan

5.1 Introduction

First and foremost, it is imperative to establish robust safety measures for the handling and storing of any green fuels. Still, it is also crucial not to overlook the safety perceptions held by local communities. To ensure a successful transition to green fuels, engaging citizens in the decision-making processes is essential. Far too often, cancellations of green initiatives and Renewable Energy Technologies (RET) projects have occurred due to local resistance, and effective communication and collaboration between the communities and companies can be the key to preventing such setbacks from occurring. Therefore, this report section focuses on the human perspective of transitioning to green fuels in Danish ports. Specifically, it examines the safety perceptions and communication practices of three distinct ports: the Port of Frederikshavn, the Port of Hanstholm, and the Port of Esbjerg. The objective is to provide recommendations for best practices regarding communicating safety and shed light on potential challenges that may arise.

Initially, the Port of Esbjerg was not involved in the project. The original plan was to conduct a desk exploration of the Frederikshavn Port and Hanstholm Port in order understand the societal arrangements that are part of the port’s infrastructures. This information was intended to provide a comprehensive understanding of these ports' contexts and historical background. Thus, it aimed to identify key participants who could be invited to a future scenario workshop, allowing for valuable insights into the perspectives of local stakeholders. Subsequently, the gathered data would be analyzed to generate recommendations for effective communication strategies, with the goal of facilitating better communication of safety measures to the local communities.

During the course of the project, certain modifications were made. The Port of Frederikshavn was withdrawn from the project early on after the desk exploration phase, and instead, we included the port of Esbjerg which kindly accepted to collaborate with the project and through interviews with representatives from both the port and the company Høst, we gained insights into various practices, potential challenges, and successful experiences. Furthermore, the original plan of conducting a future scenario workshop in Hanstholm was altered. Instead, we attended the special event 'Thisted Business Day' at the Port of Hanstholm, where we acquired knowledge of the port's recent developments, plans for evolution, and strategies, as well as insights into the overall communication dynamics between the port, businesses, and the community.

5.2 The three ports

This section is a short presentation of the three ports that have participated in the fieldwork. It is essential to mention that Denmark has different categories for ports: state port; municipal port; self-governed municipal port; a private limited company owned wholly or partly by a municipality; or a private limited company. Each category enables a clear distinction between their respective contexts and their structure of work. The ownership status of a port influences the decision-making processes, future plans, projects, and operational procedures such as communication. Furthermore, the ports differ from each other through how they specialize in different areas of the maritime industry. Thus, distinct scenarios and context-dependent approaches will be presented, highlighting the diversity of the ports addressed in this report.

5.2.1 Frederikshavn

As mentioned before, Port of Frederikshavn was initially part of the Micro Polo project but got withdrawn early in the process. Thus, the information collected initially remains relevant for the project.

With a rich history dating back to 1812, the Port of Frederikshavn holds a prominent position as the largest ferry port in Denmark, serving as a vital link between Scandinavia and the rest of Europe. Having played a significant role in the Danish maritime industry for over two centuries, the port has established itself as a key hub for ferry traffic to and from Gothenburg, Oslo, and the Danish Island of Læsø. Equipped with five ferry berths featuring ramps and three Roll-on Roll-off (RoRo) berths, the port efficiently caters to the needs of its users and their customers.

One of the remarkable advantages of the Port of Frederikshavn is its logistics infrastructure, providing direct access to Europe's extensive motorway and railway networks. This connectivity enhances the port's efficiency and ensures seamless transportation of goods and passengers. Strategically, the Port of Frederikshavn focuses on several key areas. Firstly, it prioritizes the development of tourism and ferry traffic, recognizing the importance of providing convenient and reliable transportation services for travelers. Additionally, the port actively supports the conventional harbor industry, fostering growth and facilitating trade activities.

With a strong commitment to environmental sustainability, the Port of Frederikshavn dedicates efforts towards environmental protection and recycling practices. By promoting eco-friendly initiatives, the port aims to minimize its ecological footprint and contribute to a cleaner, greener maritime industry. Furthermore, the port actively supports the maritime service industry, offering a wide range of specialized services to cater to the diverse needs of its clients. This comprehensive approach positions the Port of Frederikshavn as a multifaceted hub, fostering economic growth, and serving as a catalyst for greener maritime-related businesses.

It is important to note that the Port of Frederikshavn operates autonomously. While it is owned by the municipality, it functions as an independent entity with separate finances from the municipality. This autonomy grants the port the authority to make decisions and manage its obligations, ensuring efficient and effective operations within the maritime sector.

Overall, the Port of Frederikshavn stands as a historical, well-connected, and versatile port, making significant contributions to the Danish maritime industry and serving as a gateway between Scandinavia and Europe.

5.2.2 Hanstholm

The Port of Hanstholm holds a prominent position as one of Denmark’s leading fishing ports and serves as the home of Denmark's largest fish auction. The port's vision is to become the premier destination for trade, fish processing, and fish farming in the country while also aiming to be Europe's greenest and first CO_2-neutral port. Moreover, the Port of Hanstholm has identified three nearby areas suitable for potential CO_2 storage, aligning with its objective of becoming Europe's greenest fishing port. The port envisions itself as a hub for handling significant amounts of CO_2, contributing to the reduction of atmospheric CO_2 levels.

Strategically positioned in direct connection to the North Sea's 'blue motorway,' the Port of Hanstholm benefits from its convenient location. Additionally, numerous local transport and logistics companies specialize in cargo handling, enhancing the port's capacity to efficiently manage goods and services. In recent years, the port has witnessed a substantial increase in cargo volume, reaching approximately 453,000 tons in 2021. Furthermore, the port plays a crucial role in the local economy, generating approximately 2,300 jobs in the Municipality of Thisted. Of these, around 1,000 individuals are directly employed at or near the port, while an additional 1,300 people find employment in related businesses. In terms of governance, Port of Hanstholm transitioned from being an autonomous port to a municipal port due to financial challenges faced by the port.

The Port of Hanstholm focuses on several key areas, including fishing (fish auctions), aquaculture, renewable energy, land and sea transport, and maritime services. Hanstholm Fish Auction, with an annual turnover exceeding 70 million Euros, serves as Denmark's largest fish auction, supplying customers throughout Europe.

Aquaculture, the environmentally friendly method of breeding quality fish in on-land facilities, is an integral part of Hanstholm's activities. Two aquaculture companies, Royal Danish Fish A/S and Sashimi Royal A/S, operate within the port, contributing to the local aquaculture sector's growth and development.

Various stakeholders have raised concerns in the city of Hanstholm regarding its low population. Many individuals opt to relocate to larger cities, primarily for educational opportunities, resulting in limited migration to Hanstholm. Initially, the city's infrastructure was designed to accommodate a larger population, creating apprehension among local residents and business owners. Moreover, the local population expresses a keen interest in attracting more tourists to the area, leveraging the appeal of the 'Cold Hawaii' slogan. However, this industry is hindered by two factors: tourists note odours naturally derived from an active fishing port, and there are restrictions on establishing summer houses. The residents believe that increasing attractions for both locals and tourists would help draw more people to the city. Conversely, business owners assert that the key to attracting people lies in the creation of new jobs, necessitating the expansion of businesses, which could potentially hinder tourism efforts.

5.2.3 Esbjerg

The Port of Esbjerg, established in 1874, has grown to become a vital maritime trade and shipping hub connecting Denmark with the global community. Spanning an expansive 4.5 million square meters, the port accommodates over 200 companies, offering employment to approximately 10,000 individuals. Between 2003 and 2014, substantial investments totaling around one billion DKK were made to expand the port's infrastructure, primarily to meet the demands of the offshore industry. This growth positioned the Port of Esbjerg as Denmark's largest port, seamlessly facilitating international transport connections.

Esbjerg emerged as a prominent center for oil, gas, and wind power activities in Denmark. Recognized as a leading European hub for handling and shipping wind power, as well as the primary RoRo port in the country, the port has made significant strides in sustainability. Through the establishment of a carbon management system, the port has invested in onshore power supply, enabling companies within the port to shift from ship generators to green wind energy. This transition offers advantages such as cost savings, reduced noise, and decreased emissions of $CO2$ and particulates.

In alignment with its commitment to sustainability, the Port of Esbjerg joined the global 'Getting to Zero Coalition' in 2020, a collective effort initiated by prominent players in the shipping industry. The port's sustainability strategy encompasses efficient and eco-friendly port operations, environmentally conscious goods transportation, support for the green transition, socio-economic contributions, occupational health and safety, as well as minimizing the climate and environmental impact of port-related operations. In November 2022, the port entered into a collaborative partnership with 38 organizations from the Netherlands, Germany, and Denmark, united in their dedication to mitigating the impact of shipping and port activities on the natural environment. This joint declaration signifies a commitment to enhanced engagement and sustainable management within the Wadden Sea region.

It is worth noting that while companies operating within the port consider themselves as landowners and are responsible for communicating and complying with regulatory requirements, the Port of Esbjerg itself does not directly participate in the development and implementation of public communication plans for these businesses. The companies primarily engage with the municipality, with limited interaction with the port authorities.

5.3 Qualitative field work

The examination is grounded in qualitative research methods, including fieldwork, observations, and semi-structured interviews. Initially, we conducted interviews with representatives from Port of Esbjerg, and the HØST project, which is managed by Copenhagen Infrastructure Partners (CIP) in Esbjerg Port. Some of these interviews were also conducted virtually with the aim of obtaining an overview of the ports' and companies' perspectives on the safety of e-fuels and their communication strategies in this regard.

Subsequently, we conducted a field trip to Port of Esbjerg, allowing us to directly observe the harbor, its surroundings, and engage in discussions with two key stakeholders: the manager of the port, and two representatives from the company Høst, one person with technical background and one person in charge of interinstitutional affairs, citizens engagement and social appropriation. Additionally, we conducted fieldwork at Hanstholm Harbor, where we gained a comprehensive understanding of the facilities and the surrounding area. In Hanstholm, we conducted interviews with various individuals, including business owners affiliated with the port, local politicians, local service providers, and a representative from the citizens organization. Consequently, we obtained in-depth insights into the two ports' perspectives on safety and their perceptions of their own communication practices regarding the local community.

Following a comprehensive analysis of the outcomes derived from our fieldwork, we have identified several areas requiring attention regarding public perception of Safety, and as part of our interaction we identified some good communication practices that can serve as sources of inspiration for future projects. The last chapter includes a table with a list of useful methodologies for interaction with the public. The idea with the table is to make more visible the options but also to reflect on the convenience and utility they have depending on the stage or maturity of the project.

5.4 Perceptions of safety communication

Transitioning to hydrogen-based fuels (e-fuels) in the maritime industry requires careful consideration of safety aspects to ensure the well-being of ports and surrounding communities. Effective and transparent risk communication plays a pivotal role in this transition. Thoroughly informing and educating ports and communities about the facilities, associated risks, and safe handling practices of hydrogen-based fuels is crucial. By prioritizing clear and comprehensive[1] safety communication, stakeholders can collaborate to enhance safety measures and minimize potential risks. This proactive approach fosters a sense of shared responsibility, empowering all parties to actively contribute to the secure implementation of hydrogen-based fuels in the maritime industry.

Insufficient information and communication regarding the properties, risks, and safe handling practices of hydrogen-based fuels can give rise public concern and resistance. Misconceptions and unwarranted fears about these fuels may hinder their adoption in the maritime industry, impeding infrastructure development, delaying progress, and undermining the realization of their significant environmental and economic benefits.

Various factors, including unattended points of contact and unintentional miscommunication, influence the perception of safety. It's essential to recognize that interactions with the public occur not only in formal settings such as offices, meeting rooms, or public hearings but also in informal environments like restaurants, markets, or beaches. Seizing these interactions as pivotal moments for shaping public perception is crucial. A coherent narrative can be co-created by actively listening, answering questions, and incorporating public

[1] comprehension should be understood as a state of mind wherein a person is aware of something, is able to think about it, and knows how to deal with it. M, E. (2016, June 8). Difference Between Apprehension and Comprehension. Difference Between Similar Terms and Objects. http://www.differencebetween.net/language/difference-between-apprehension-and-comprehension/.

feedback into decision-making processes, instilling a sense of ownership, and understanding among all stakeholders. Positive and constructive engagement can foster trust and enhance the public's confidence in safety measures. On the other hand, any mishandled or neglected points of contact can have adverse effects on public perception, potentially eroding trust and creating barriers to acceptance.

1.1.1 Role and responsibilities

During our conversations with representatives from the Port of Esbjerg, we gained valuable insights into their perspective on their role and responsibilities concerning safety measures and communication strategies. They emphasized the challenge of striking the right balance between protecting the city and meeting the needs of the businesses, as the primary role of the port is to support and facilitate commercial activities. The representatives assured us that the port is committed to being honest and transparent about its intentions and actions. However, they acknowledged that it can be difficult to satisfy all parties involved, as there will inevitably be complaints that cannot always be resolved by the port. It is important to note that the port views itself as a landlord rather than an authority. Consequently, they consider safety to be primarily the responsibility of the relevant authorities, rather than an issue directly managed by the port. Their role is to lease the area to companies, offering guidance within the framework of the authorities' regulations. However, the port does not have the authority to grant approvals or permissions.

One significant challenge highlighted by the port is the potential for misunderstandings regarding whom to contact in case of citizen complaints. In such instances, the port refers individuals to the municipality, while the municipality may redirect them back to the port. The port can only address complaints if they pertain to breaches of established rules and regulations. If the activities are within the prescribed limits, the port's ability to intervene is limited. Overall, the representatives from the Port of Esbjerg emphasized the complexity of their role, striving to navigate the balance between commercial interests and the welfare of the city. While they are committed to open communication and addressing concerns within their scope of license, they recognize the limitations of their role as a landlord and the primary responsibility of the authorities and private companies in ensuring safety.

1.1.2 A balanced communication

During our discussions with representatives from HØST, a leading Danish Power-to-X (PtX) project within the CI Energy Transition Fund 1 (ETF) managed by Copenhagen Infrastructure Partners (CIP) and that will produce green ammonia for fertilizer and green fuel for shipping, they highlighted the complexities surrounding safety communication. Given the sensitivity of the topic, HØST has been cautious in addressing safety concerns, fearing potential misinterpretations and unintended consequences in their messaging. The project's uncertain life cycle poses challenges, which makes it difficult to provide definitive answers regarding safety measures. The representatives acknowledged the importance of addressing the public's safety questions but expressed initial uncertainty about how to communicate the safety measures. Consequently, they chose not to delve into the details, as they believed it could mistakeably amplify concerns rather than alleviate them. They cited the example of unconsciously creating fear by mistakenly signaling higher danger levels when attempting to communicate additional security measures.

However, the HØST representative also shared a constructive suggestion for effectively addressing safety concerns. Despite seeming dangerous and unfamiliar to some, they highlighted that ammonia can be found in everyday household items such as cleaning sprays. Emphasizing this familiarity aims to create a sense of safety and trust, making ammonia less foreign and more relatable to a lay person[2].

Overall, HØST recognizes the importance of safety communication but aims to find a balanced approach that fosters understanding and confidence without inadvertently triggering unnecessary fears or misconceptions.

1.1.3 Early stages of developing e-fuels

During our visit to Hanstholm, we engaged in conversations with various local stakeholders, including a local politician, to gather insights on the transition to e-fuels. The politician expressed great interest in this transformation; however, it became evident that there is limited knowledge regarding the full potential and associated risks due to the early stage of the process. The politician emphasized the importance of an open dialogue regarding safety measures, advocating for transparency and communication at multiple levels, although specific details were not provided. This notion of discussing e-fuels and communication strategies in a preliminary manner, merely scratching the surface, aligns with the information shared by representatives from the Port of Hanstholm. They explained that due to the novelty of the technology, comprehensive storytelling about P2X safety is challenging as there is still much to be understood. Despite being primarily a landlord, the port recognizes its responsibility for the facilities on its sites and aims to contribute to safety measures actively.

We also engaged in conversation with a high executive of Lingbank, a vessels company located at the port of Hanstholm. We inquired about his preferred approach to receiving safety-related information relating to the port, where he believed that relying solely on simplistic solutions should be avoided. Instead, he emphasized the significance of thoughtful deliberation and comprehensive communication. In particular, he highlighted the effectiveness of public meetings as a means to benefit both businesses and foster community engagement. The owner highlighted the importance of adopting a holistic perspective, ensuring that technical, economic, and regulatory elements, as well as safety measures and risks, are adequately considered. Furthermore, other business owners at the port confirmed this sentiment, expressing positive feedback regarding the public meetings and hearings organized by the municipality and recognizing the port's critical role as a valuable hub for individuals and organizations interested in its development.

1.1.4 Citizen’s perspectives

While the companies perceived the public meetings as beneficial, it was apparent that not all local citizens shared the same feeling. Some individuals we spoke with expressed the view that these meetings were mere formalities, lacking consideration for the opinions of the locals. According to their perspective, the purpose of these meetings was solely to present predetermined facts and plans without actively involving citizens in decision-making processes or genuinely listening to their thoughts and viewpoints. The feeling of being unheard and disregarded is a key factor contributing to skepticism towards the projects. Even though it was explicit that the purpose of the session was not to have discussions beyond a business networking setting, the port's representative or municipality's representative could have been aligned on how to handle these situations—maybe inviting them to other shared spaces instead of disregarding their interventions.

For instance, we observed a sense of discord during the questions and answers sessions between the locals and businesses at the event. Certain local citizens expressed dissatisfaction with the requirement that all businesses at the port must be related to port activities. They expressed a need for services such as restaurants or hairdressers that would benefit the local community, reducing the need to travel to larger

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[2] A lay person is a person who is not trained, qualified, or experienced in a particular subject or activity. Collins COBUILD Advanced Learner’s Dictionary. https://www.collinsdictionary.com/dictionary/english/lay-person#:~:text=A%20lay%20person%20is%20a,a%20particular%20subject%20or%20activity.

nearby cities for everyday deeds. Although this matter may not be directly tied to safety and safety communication, there are valuable insights to be gathered from the communication strategies employed. We noticed the emergence of a perceived divide between the "angry citizen" and the "superior landowner," which can pose challenges in the long term. If local citizens feel overruled by a more powerful entity, they are less likely to offer their support to the projects.

5.5 Good practices of communication

Based on the insights and knowledge gathered from conducting field work at the port of Esbjerg and port of Hanstholm alongside our previous research on public perception and public acceptance of renewable energy technologies, we have created a list of good practices of communication. The prime focus of these recommendations lies in addressing the challenges identified within the port settings, thereby serving as a valuable source of inspiration and guidance.

5.5.1 Make a clear strategy

Effective communication with citizens is crucial when introducing e-fuels and Power-to-X (PtX) technologies to the general public. Clear and transparent communication plays a vital role in educating citizens about the purpose, benefits, and safety measures associated with PtX, thereby increasing acceptance and support for these initiatives. Citizens may naturally be concerned about these new technologies' potential impacts on their communities, such as safety risks, environmental effects, or changes in the local landscape. Engaging in open and honest communication allows for directly addressing these concerns, providing accurate information, and dispelling any mistaken beliefs that may arise.

A clear and streamlined strategy for communication is fundamental to avoid misunderstandings and effectively transmit safety-related information. By having a well-defined approach to safety communication, potential risks can be clearly communicated, ensuring that citizens have accurate information and reducing the likelihood of misconceptions or unfounded fears. If necessary, find inspiration for the strategy and methods via the scheme at the end of this chapter.

5.5.2 Stay friends with the citizens

Citizens hold significant influence and have the potential to obstruct projects if they effectively organize and exploit legal loopholes that could delay progress. However, as previously mentioned, such situations commonly arise when citizens perceive themselves as being disregarded by a more powerful entity, leading to feelings of being unheard and marginalized. Therefore, fostering a positive and robust relationship with citizens becomes critical. It is important to acknowledge that individuals can possess expertise in different domains, and local citizens themselves possess valuable knowledge regarding public perception. They are the experts on the needs and requests from a local perspective to strengthen the community on a humanitarian level. Recognizing this, both parties should view each other as allies working towards a shared objective. Rather than developing a project solely for the citizens, a preferable approach is to involve citizens in the project's creation. By actively engaging citizens and incorporating their insights, concerns, and aspirations, a collaborative environment can be established. This approach values the expertise and input of citizens, positioning them as co-creators rather than passive recipients that might feel unsatisfied with the outcome. This not only enhances the overall quality and relevance of the project but also ensures that citizens feel a sense of ownership and investment which is a key factor in public support.

In summary, maintaining a strong and positive relationship with citizens is essential. By considering citizens as partners and recognizing their expertise in public perception, projects can benefit from their valuable contributions. Collaboratively developing projects with citizens, rather than solely for them, promotes a sense of shared ownership and increases the likelihood of successful outcomes and support.

5.5.3 Say something rather than nothing.

One prevalent mistake that companies often make is withholding information from citizens due to the fear of communicating incorrectly. It is understandable that companies face challenges in articulating safety measures when dealing with a new technology that still holds many uncertainties. However, disregarding the safety concerns raised by local communities will only make them question why safety is not being addressed. Even though there may be limitations in fully addressing safety aspects, it is essential to acknowledge and engage with the community's safety-related inquiries. Failing to do so may create an impression that safety is being overlooked, even though that is not the case. In this regard, it is better to provide some information than none. Therefore, if you possess the necessary information, it is advisable to ensure open access to it. Conversely, in situations where complete details are lacking, it is recommended to place reliance on authoritative entities and refer to their expertise. Sharing what is known and doing so early in the process contributes to fostering a positive relationship and building trust between the company and the citizens.

By proactively addressing safety concerns, companies demonstrate their commitment to transparency and open communication. This approach acknowledges the importance of community involvement and promotes an atmosphere of trust and collaboration. It also allows for the mitigation of potential misunderstandings and fosters a sense of shared responsibility for safety.

5.5.4 Don’t tell them, ask them

Additionally, establishing trust between project developers and citizens is of great importance. This can be accomplished by actively involving the community in the decision-making process, attentively listening to their feedback, and incorporating their concerns into the project plans. By fostering a sense of trust and collaboration, a positive relationship can be nurtured, ultimately bolstering the overall credibility of the project.

During our interviews, one of the business owners expressed the perspective of "Don't ask them, tell them." However, based on our expertise, we believe this approach can be precarious as it may hinder the citizens' sense of ownership and engagement with the projects. Instead, we recommend the opposite approach: "Don't tell them, ask them." It is vital to prioritize listening to the opinions and perspectives of the local communities and indicate openness. Nonetheless, it is important to note that decision making should not be solely left to the citizens. As mentioned earlier, companies and communities possess expertise in different domains. Therefore, working together as a collaborative team to find the best solutions for all parties involved is central.

By embracing a collaborative approach and actively seeking input from the citizens, project developers can build a sense of shared ownership and mutual understanding. This inclusive process not only enhances the outcomes of the project but also strengthens the relationship between the companies, the municipalities, the port, and the community, fostering a harmonious and sustainable partnership.

5.6 Catalogue of methodologies

Through our interviews and fieldwork, we discovered recurring communication and interaction methods employed by the companies. The table below provides a concise description of these practices, along with insights regarding their implementation opportunities and the necessary considerations for their effective use.

Method	Description	When to start	Be aware of
Public hearing	A formal gathering where members of the public are	Facilitate early and inclusive involvement of	Promote transparency while taking care to

	invited to be informed about a project and voice their opinions and concerns on matters of public interest. It provides an inclusive platform for individuals and groups to share their perspectives with decision-makers and stakeholders.	the population, including them in the decision-making process. To establish a strong connection between the project and citizens, it is crucial for individuals to feel a sense of ownership and investment in the project right from the beginning.	respect and acknowledge the opinions of local citizens. Foster an environment that encourages participants to freely ask questions and express their interests, needs, and curiosity.
School fairs	An offer to conduct guest speaker sessions at schools, where representatives from, e.g., a company, can present and demonstrate new technology. This provides kids with firsthand exposure to novel technology and allows them to interact in conversations while creating a safe space. The idea is these conversations can transcend the school to the families and friends.	This step can be taken after the project planning phase but prior to execution. Guest speaker sessions are intended to minimize misunderstandings and foster trust through early familiarization.	Demonstrating consistent language and alignment with academic topics enables schools to provide concrete, real-life examples. Failure to do so may lead to confusion among students and potentially create unnecessary disagreements with teachers who prefer not to be put in a compromising position in front of their students.
Museum exhibitions	Through collaboration with local museums, companies have the opportunity to communicate new technology to the local population in an engaging manner. Through installations, the senses can be stimulated, enabling a unique and enjoyable approach to disseminating knowledge and plans.	This approach can also be employed in the intermediate phase between project planning and completion. It is crucial to demystify new technologies prior to implementation, ensuring that citizens will accept and provide support for the projects.	Make the exhibition content clear and easily understandable for visitors of different ages, backgrounds, and levels of technical knowledge. Use language and visuals that are accessible to a wide audience, avoiding technical or sophisticated terms.
Courses/workshops	Courses and webinars provide a focused platform for intensive exploration of specific topics, allowing participants to delve deep into the technicalities of a given project. This is especially valuable for individuals with a keen interest and existing knowledge in the technical aspects, as it offers them an opportunity to indulge their enthusiasm and further expand their expertise.	When there is sufficient interest and demand in the local community for the new technical project. Consider factors such as the project's development stage, local market readiness, and the availability of necessary resources.	Identify your target audience for the courses and workshops. Determine whether they are professionals, students, enthusiasts, or a combination of different groups. This will help you tailor the content and approach accordingly. Also, it is always a good idea to incorporate interactive elements, group discussions, and practical exercises to foster a dynamic learning environment.

Information days	An event that invites citizens, local businesses, and other stakeholders for a tour and presentation of an upcoming project. Incorporating multiple speakers who offer diverse perspectives, such as those focused on location, safety, environmental impact, and more, can be advantageous.	It is possible to host information days at different stages of the project. Consider hosting an information day during the early stage of the project when the plans and objectives are being formulated. This allows you to provide an overview of the project, share the vision and goals, and gather initial feedback and input from the attendees.	Ensure that sufficient time is allocated for audience questions during the event. While responding to their inquiries, strive to maintain an open and kind behaviour, fostering a friendly environment surrounding the project.
Installations	At the Port of Hanstholm, an informative installation has been set up in old containers near the port. The objective is to facilitate informal communication, allowing local residents to engage at their convenience.	This initiative can be implemented during the project execution phase when there is curiosity among individuals about ongoing activities. Although it doesn't necessarily need to be the initial step, incorporating it early on remains beneficial.	While this installation cannot serve as a standalone communication method, it can provide a valuable supplementary element alongside more official communication channels. Adding a playful touch to the installation can enhance engagement, particularly among children and young people.
Web page	By communicating your project through a website, you create the opportunity for everyone to have access to information regardless of time and place. It is a great opportunity to create communication through visualizations such as images and videos, which help the reader to form understanding.	From the project's inception, it is advantageous to establish a dedicated web page. Regardless of potential changes in decisions, allowing the public to follow the process is beneficial. Maintaining transparency throughout fosters a sense of attachment between citizens and the project.	It is crucial to maintain a balance in the communication strategy, striving for simplicity and accessibility while preserving professionalism that exudes credibility and expertise.
Webinars	A webinar serves a similar purpose to courses and workshops, with the distinction that it takes place online. This format liberates participants from the constraints of physical attendance, allowing them to access and engage in learning from any location.	When there is interest and demand from the local community for the new technical project, it is preferable to organize different webinars. This format allows for hosting webinars at various stages of the project, including updates throughout its duration.	To enhance participant engagement in webinars, it is beneficial to include interactive exercises and utilize the platform's features to create activities. This transforms the webinar from a one-way communication into an interactive learning experience.

Guided tours	Arrangements during a whole journey where stakeholders from a port can gather and experience the routines of the port. Some companies show their facilities and present their main projects and challenges.	After the completion of the project, it is possible to utilize this approach as a means of maintaining communication with local citizens and offering updates on the project's effectiveness. This allows for ongoing engagement and transparency, ensuring that the community remains informed about the outcomes and impact of the project.	These guides should possess a deep understanding of the port operations, projects, and challenges, as well as be capable of answering questions from the stakeholders. Incorporate opportunities for discussion and networking among the participants.

5.7 Conclusions

When Danish ports have to transition to green fuels, it is essential that the local population in the impacted areas gain insights into the new technologies that are to be installed. It is important that citizens feel secure about the safety measures behind the new technology, which is causing a lot of excitement and anxiety among citizens. The optimum would be if the citizens felt involved in the process and the decisions, so that they feel committed to the projects and thus more inclined to support them. This project aims to examine safety communication in three selected ports to draw preliminary conclusions regarding challenges and best practices.

Through interviews with the Port of Esbjerg, we found challenges in the port's role and associated responsibilities for safety communication. Since the port sees itself as being solely a landowner who takes care of and protects the businesses that rent areas at the port, they do not consider safety to be one of their areas of responsibility. On the other hand, they refer to the municipality as being the supporting authority, but since the municipality often refers the other way, namely to the port, confusion can arise. Additionally, challenges were found at HØST, where striking the balance between saying nothing and saying something incorrect poses difficulties. They fear making mistakes in their safety communication to such an extent that they avoid saying anything at all. This doubt and frustration are understandable, but in the end can bring even more problems, as it has an exclusionary effect on the local population, who want answers to their questions. If safety considerations are not explicitly stated, it may give the impression that safety is being disregarded. Similar insights were gained from the Port of Hanstholm, which also faces challenges due to the early development of the technologies involved. It is difficult to tell the population anything yet and it is still too early to deal concretely with a communication strategy. They do agree that communication must be open and transparent, but weave around what this concretely entails. However, they find their communication through public hearings beneficial and useful. They experience a good response and consider this a good form of communication. Nevertheless, the local population holds divided opinions on this matter, expressing criticism regarding decisions made without citizen involvement, which fosters a sense of being disregarded. Their aspirations for the future of the city and the port feel overlooked.

Based on these insights, four focal points have been identified for consideration when implementing e-fuels in a port. First of all, it is important to create a clear and streamlined strategy for communication. If you are in doubt about what this could entail, there is inspiration to be found in our catalog of methods. As the catalog also shows, it is extremely important to put the citizen at the center of the communication, which means that you always focus on the needs of the citizen. In order to maintain a good relationship with the local population, it is important to incorporate their insights and attitudes by showing openness. This is the best way to ensure citizens' support for a project, which can be crucial, as they can end up having great power over the course of the project. Moreover, it is important to share what is known about safety with citizens rather than remaining silent. If information is limited, referring to authorities or acknowledged expert institutions (i.e., Danish GTS institutes[3], innovation clusters) and expressing confidence in their expertise can be appropriate. Above all, actively listen to citizens, seek their perceptions, address their concerns, and embrace their curiosity. Mere dissemination of information without considering their input can foster exclusion. Strive to involve citizens as much as possible.

The fieldwork is structured based on initial interviews followed by field visits to facilitate comprehensive data collection. While the current study has focused on perspectives from two primary ports, it is evident that a future iteration of the project should encompass a broader range of ports. By expanding the scope to include additional ports, a more strategic and enriching analysis can be achieved, allowing for a more comprehensive understanding of the subject matter.

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MARCO POLO - DK

METHANOL
Availability Readiness Cost Operationality
Port Logistics - Denmark

Chapter 7

Roadmap for how the results of the MARCO POLO DK will be progressed into subsequent project.

The project has received funding from:

Danish Board of Business Development

THE EUROPEAN UNION
The European Regional Development Fund
Funded as part of the Union's response to the COVID-19 pandemic
Investing in your future

7 Roadmap for how the results of the MARCO POLO DK will be progressed into subsequent project

Continued research and development efforts are still necessary to improve the efficiency, safety, and scalability of green marine fuels. This includes research and development activities across the scales of the

- technology readiness level (“Can we build it?),
- the regulatory readiness level (“Can we accept it?”)
- port readiness level (“Are there customers?”)
- the market readiness level (“Will they adopt it?”).

The Marco Polo team has had an internal workshop about needed next step (-s). The output of this is 3 project scopes.

At the final conference we had also arranged a workshop with the participants about their challenges and needs to meet the green transition in the marine sector.

7.1. Output from the final conference:

At the conference we had prepared 3 questions for the audience, which were discussed in smaller groups;

1. What do you see as a next step for Marco Polo to move forward towards the green transition in the Ports / Marine sector?
2. What is the main challenge you face in your business (port or related business) to join the green transition, and which could be a research/development/demonstration project?
3. What are the main barriers to move forward for the marine industry?

The next step for continuing the green transition in the marine sector was very clear. **Demonstration, demonstration, demonstration, showcases is very needed.**

- Green logistics
- Sustainability demands
- Which solution will be the most attractive (E-fuel, FC, electric, combination)
- Crew Transfer Vessels, Fishing fleet, Ferries (smaller vessels)
- More knowledge between port and developers
- Public awareness / openness
- Mapping of projects and production facilities

The main challenges are:

- Market requirements; different customer profiles / different needs for at greener transition.
- Moving from desktop to reality / operation.
- No PtX without power, roll out of offshore wind, (Open door projects being closed)-> no E-fuel!
- Offtake level of costs, investment uncertainty >how do you incentivize >business case thresholds?
- Going from one role to another. Bunkering companies are unsure how to be a player in the new arena.
- Investments in new infrastructure - ammonia

The main barriers are:

- Lack of a direct business case.
- Cost and safety.
- Political.
- Who will be the right and/or the first mover (company) to take the decision?
- Fisheries vessel -> have a specific profile of activities.
- Different geographies depending on the type of vessel fish.
- Different locations for green bunkering.
- Cheaper vessels compare to other vessel in the maritime.

7.2. Scopes from the Marco Polo team:

7.2.1. CO_2 Hub Hanstholm

Purpose

CO_2 Hub Hanstholm is investigating the concrete need to be able to receive and temporarily store CO_2 at Port of Hanstholm and transport CO_2 for storage in the Inez, Jammerbugt or Lisa structures in the North Sea.

Challenges

Lack of knowledge in the industry of Port of Hanstholm as an obvious CO_2 Hub may cause investors and business partners to choose other solutions and locations.

Goal

Port of Hanstholm, businesses and citizens are being prepared for the Port of Hanstholm to become a CO_2 hub for the storage areas close to Hanstholm.

State-of-the-art

Technologically speaking, a CO_2 terminal is relatively mature, as the technology builds on experience from the oil and gas sector including LNG. However, CO_2 transport and intermediate storage is a new industry that no one in the local area has experience with, and for which the port has no existing facilities. It is therefore necessary that the Port of Hanstholm will be prepared to be included in the CO_2 value chains with regard to both technical facilities, competences, safety and acceptance in the local area.

Innovation

Bringing the ports and decisionmakers closer to the actual decision, project planning, and implementation of a CO_2 hub for import and export of CO_2.

Success criteria

The overall success for the entire project is that Port of Hanstholm is ready to enter into a contract with the license winner.

Status

The project has been applied for at FRO aug ’23, (Fonden for retfærdig omstilling).

7.2.2. Value chain for methanol in fishing industry

Purpose

To map the value chain for methanol of a specific port (Hanstholm), from generation of electricity, over production of methanol, to transformation of the fishing fleet. The mapping defines the value chain, and outlines the cost element through the chain, making it clear, what investments are necessary to realize the transformation of a fishing fleet from fossil fuel to green fuel.

Challenges

- Ensuring involved partners across the whole value chain.
- Making partners commit to actual costs throughout the value chain.
- Guaranteeing the value add of the outcome, as it will depend on how it is received by politicians/authorities.

Goal

A complete mapping of the value chain covering methanol from energy generation, over methanol production to conversion of the fishing fleet. Including cost gap analyses, outlining the total investment needed, to implement the value chain, hence converting the fishing fleet from fossil to green fuel.

State-of-the-art

No such value chain and cost gap analysis has been made for any related value chain in Denmark. There exist some fragments of it but not the complete overview.

Innovation

Bringing the ports and decisionmakers closer to the actual decision, project planning, and implementation of a methanol value chain, transforming the fishing industry in Hanstholm from fossil to green. With the opportunity to copy the approach and methodology to other ports or industries.

Success criteria

A recommendation on how, and at what cost, to transform the fishing industry of Hanstholm from fossil to green, providing a clear how-to for the port, and making it clear what the necessary investments are, enabling decisionmakers to make a fact-based decision on whether to invest in the transformation.

Status

EnergyCluster Denmark is preparing an EU-application and searching for partners.

7.2.3. Guideline for ports on handling methanol

Purpose

A bespoke guideline assisting ports (internationally) in the process of handling methanol to be able to offer operators green fuels, as well as promoting a common approach across ports leading to easier approval processes, and easier operation for port users. This has the overall purpose of accelerating and streamlining the implementation of green fuels across ports. The guideline should enable ports to reach port readiness level 7, and include and build upon:

a) Standards

b) Test, cfd-modelling, simulations (lab scale)

c) Risk assessment

d) Competence training (for handling methanol)

e) Public perception

f) Actual tests

As part of this project, the methodology and content of the guideline will be demonstrated on three different case ports to illustrate usage and outline any variances in approach depending on type of port, amount of methanol to be handled, etc.

Challenges

- Problem owner – who will be the most suitable problem owner for this project?
- Authorities are not ready – the outcome of this project will have to convince the authorities of which way to go.
- 'Landlord mentality' of the ports. There is a tendency, at least in many Danish ports, that the owners have a 'landlord mentality', making it difficult to make them take responsibility and action on the port development, as they usually refer to the operators.
- There is a GAP in competencies and a need for more employees

Goal

A bespoke guideline enabling ports to reach port readiness level 7 in terms of handling methanol. This to accelerate and streamline the approach to implementing methanol across international ports.

State-of-the-art

Currently three ports around the world have implemented methanol bunkering facilities (being Goteborg, Rotterdam, and Ulsan), with individual approach. Many other ports are planning to follow suit but do usually not know where and how to get started. Furthermore, the average port, will most likely not have the same size or authority (as the three mentioned ports) to follow through with their own interpretations of what needs to be in place to handle methanol. Therefore, there is a need for common ground for the ports to be successful with the implementation of methanol bunkering. Currently, no such common ground or guideline exists.

Innovation

The value-add this project brings to the table is the guideline. A how-to for ports to become ready to handle methanol. It will accelerate the transition to more green fuels across ports.

Success criteria

A bespoke and thorough guideline providing a 'how-to' for ports, guiding them through all the necessary steps to be able to successfully handle methanol. Including the relevant variances that may occur.

Status

EnergyCluster Denmark is searcing project partners/problem owners.

7.3. The work continues.

The team with EnergyCluster Denmark as lead will continue to scope new relevant projects in the context of Marco Polo, with focus on the above mentioned needs, challenges and barriers and involve demonstration.

Each project will search for one or more problem owners and relevant participants as well as the best funding opportunities relevant for each scope.

MARCO POLO - DK

METHANOL
Availability **R**eadiness **C**ost **O**perationality
Port **Lo**gistics - **Den**mar**k**

Chapter 8

Conclusion

The project has received funding from:

THE EUROPEAN UNION
The European Regional Development Fund

Funded as part of the Union's response to the COVID-19 pandemic

Danish Board of Business Development

Investing in your future

8 Conclusion

Purpose

The scope of the MARCO POLO DK project is to make a feasibility study as to how ports (both the specific as well as from a more generic point-of-view) can be an integrated part of the green transition, especially with focus on Power-to-X (PtX).

The project has investigated four archetypes of ports in the Northern part of Jylland;

- International ferry port
- Domestic ferry port
- Fishing port
- CO2 import/export port

The result of the project is 5 reports:

1. Description of methanol option for selected ports
2. Summary of major risk factors and recommendations for way forward
3. Draft guidance paper on approval processes for methanol handling
4. Options for ports to import/export in relation to PtX
5. Roadmap for how the results of the MARCO POLO DK will be progressed into subsequent project

All collected in this final report.

8.1. ROPAX Green Corridor

Four Green Corridor Technical Assessments have been carried out in the MARCO POLO-DK project, including two dedicated assessments for the domestic RoPAX Corridor (Frederikshavn <-> Læsø) and international RoPAX Corridor (Frederikshavn <-> Gothenburg) respectively. The RoPAX-specific analyses have delivered a decarbonization roadmap and a corresponding, phased future Methanol demand for each Corridor - estimated initially at 3,444t with the potential to reach 4,028t for the domestic RoPAX Corridor, and similarly estimated initially at 20,5314t with the potential to reach 47,300t for the international RoPAX Corridor. The Technical Assessments have been supplemented with dedicated Business Case analyses for the roll-out of Phase 1, comparing the total cost of the domestic and international RoPAX Corridors on LSFO compared to Methanol over the 25-year lifetime of their assets. The analyses indicate that one-way ticket prices would initially need to be increased by approximately 1.3 to 4.6USD/ PAX on the domestic RoPAX Corridor (current cost: 19.5USD equivalent), and by approximately 3.5 to 14USD/PAX on the international RoPAX Corridor (current cost:22.5USD equivalent).

The Port of Frederikshavn is the common denominator between the two Corridors and forms part of both assessments. The Port Interplay Assessment indicates that the port can become a bunkering hub for either or both Corridors - for vessels operating via Gothenburg, this would require however operational adjustments to be made to provide sufficient time to bunker in Frederikshavn. As a result, the port can benefit from the steady demand associated with the RoPAX Corridors and aggregate volumes to reduce uncertainty and risk in terms of the CAPEX investments – ranging from 47,064t in Phase 1 of both Corridors to 51,328t when both Corridors are fully decarbonized. The actual methanol bunkering demand will ultimately depend on whether other ports on the different routes make methanol available for bunkering, as well as the associated fuel price offered.

8.2. CO_2 Transportation – Import Corridor

The Project has carried out a Technical Assessment for CO_2 Transportation based on the import volume and locations modelled in the MARCO POLO-DK project. The analysis has modelled CO_2 Transportation using vessels operating in a pipeline simulation approach, where vessels are deployed dedicatedly between the different export ports identified in Chapter 5 and the port of Hanstholm at a pre-determined utilization and returning in ballast. The project has delivered a set of two sub-assessments, namely one with a 10K carrying capacity vessel and one with a 25K carrying capacity vessel. Each analysis includes import operational conclusions on the number of vessels required to import the modelled CO_2 into Denmark, as well as quantifying the necessary number of ports calls, daily arrivals and volume of methanol needed at Hanstholm to accommodate the import of CO_2 into the Port of Hanstholm.

8.3. Green Corridors; The fishing fleet

With the port of Hanstholm as the proxy port for the Fisheries Green Corridor, the project has developed a decarbonization roadmap and associated, phased future fuel demand for the fishing fleet operating out of Hanstholm. Based on an analysis of deployment data, and in particular 1) the volume of annual port calls per asset (most frequently visiting asset made 119 visits in 2022), and 2) the distribution of the assets under the different flags, the project recommends to pursue a 3-phased approach to decarbonize the fishing fleet calling the Port of Hanstholm, starting at 12 vessels in Phase 1, adding an additional 31 vessels in Phase 2 and the remaining 207 vessels in Phase 3. The associated future fuel demand (in litres of diesel) for all the vessels has been estimated at 1,331,000l in Phase 1, 11,005,000t in Phase 2 and 111,531,000l in Phase 3 – albeit the full amount for Phase 3 would require all fishing vessels, including 1-time visitors, to fully bunker at Hanstholm year-round. The Technical Assessment has been combined with a Business Case Assessment, indicated that the incremental cost per ton of fish landed only for Phase 1 would range between 41 and 87 USD/ton.

8.4. Projected CO_2 imports to Denmark & e-Methanol Production in the Northern Denmark Region- Nordic and regional CCUS perspectives

It has been analysed from where and how much CO2 can be imported to Denmark. It has also been mapped how much is biogenic CO2, since there are different interests for fossil versus biogenic CO2. The focus has been on Finland, Sweden, Norway, Germany, the Netherlands, Poland, UK, and the Baltic states. The research scrutinized CO2 sources from the industrial and energy sectors in these countries, estimating their capturability and potential export volumes to Denmark.

The purpose of this data has been to outline the potential sizes of inflows (CO_2 and H_2), to get a sense of the required infrastructural requirements, for the investigated scenarios.

The CO_2 demand required to cover the methanol for importing CO_2 to Denmark averages 1,79 % of the imported CO_2. It is an important figure when evaluating the overall business potential of importing CO_2. For distances significantly larger than those used in this scenario, the conclusion would likely be different.

Scenario	Vessel size	Year	CO_2 import [Mt]	Methanol demand [kton]	Req. CO_2 [Mt]	Req. Hydrogen [Mt]
Standard scenario	10k	2030	16	231,6	0,32	0,04
		2035	28	392,3	0,54	0,07
		2040	37	519,3	0,71	0,10
	25k	2030	16	140,2	0,19	0,03
		2035	28	219,8	0,30	0,04
		2040	37	282,9	0,39	0,05
0,3 std. Scenario	10k	2030	3	52,4	0,07	0,01
		2035	5	90,5	0,12	0,02
		2040	7,66	133	0,18	0,03
	25k	2030	3	50,6	0,07	0,01
		2035	5	71,2	0,10	0,01
		2040	7,66	87,3	0,12	0,02
0,5 std. Scenario	10k	2030	8	122,2	0,17	0,02
		2035	14	212	0,29	0,04
		2040	18,5	275,6	0,38	0,05
	25k	2030	8	87,3	0,12	0,02
		2035	14	124,1	0,17	0,02
		2040	18,5	150,5	0,21	0,03
High scenario	10k	2030	21	314,1	0,43	0,06
		2035	36	488,7	0,67	0,09
		2040	46	617,0	0,85	0,12
	25k	2030	21	185,2	0,25	0,03
		2035	36	272,4	0,37	0,05
		2040	46	341,2	0,47	0,06

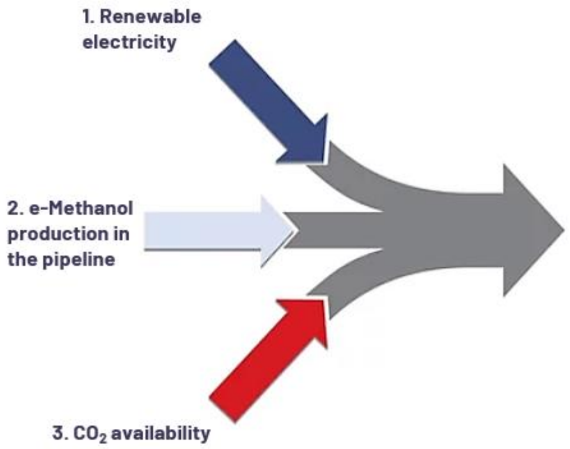
8.5. Regional CCU value chains for e-Methanol

The analysis reveals that the key elements necessary for the successful implementation of e-Methanol projects in the North Denmark Region (NDR) region are expected to converge within the timeframe of the announced projects. The planned offshore projects under the Open-Door Scheme within the NDR have the potential to adequately meet the demand generated by e-methanol production, including the required electrolysis process. However, it is important to note that the government has recently decided to drop a large offshore energy hub project in its current form.

The estimated total e-Methanol production from the planned projects in the NDR amounts to 466,000 tonnes, with a projected completion date of 2030. The realization of all the planned projects within the specified timeframes is subject to uncertainty, but if they are realized, methanol provided is possible to cover the demands for fisheries, ferries and CO_2 vessels in the 3 ports analysed.

Furthermore, the availability of CO_2 surpasses the demand for the e-methanol projects, particularly through the utilization of Carbon Capture and Utilization (CCU) technologies. The analysis indicates that the NDR will develop a sufficient supply of biogenic CO_2 within the region to support the methanol production in the pipeline.

These findings highlight the favorable conditions for the successful realization of e-methanol projects in the NDR region. The convergence of factors such as wind farm capacity, e-methanol production, and CO2 availability bodes well for the implementation of PtX projects, positioning the NDR as a potential hub for methanol production and associated activities.



According to the national 100% renewable scenario, it is anticipated that approximately 0.4 million tonnes (Mt) of carbon will be stored (CCS) in the NDR. In the year 2045, around 0.14 Mt of CO_2 is allocated for methanol production. However, if the pipelined projects are to be realized, the demand for CO_2 increases to 0.8 Mt. The highest CO_2 demand reaches 2.44 Mt.

When comparing these figures with the CO_2 point sources in the NDR, it becomes evident that even by 2030 and 2045, the availability of biogenic CO_2 (ranging from 0.6 to 1.3 Mt) poses challenges in certain scenarios. However, if fossil CO_2 is included, there is a possibility to meet the CO_2 requirements for methanol production. Importing CO_2 opens up opportunities for the realization of various scenarios.

It is crucial to address the storage and availability of CO_2 when considering the production of methanol in the NDR. The inclusion of fossil CO_2 and imported CO_2 can potentially mitigate the challenges associated with limited biogenic CO_2 availability.

8.6. Applicability to Northern and international ports

Several factors such as the need for climate change mitigation, environmental regulations, and the ongoing transition to a more sustainable energy future are pushing for an implementation and roll-out of green fuels for shipping as well as marine transport of CO_2 from producer to either a utilization or a storage site. Ports at both the Danish and Nordic levels, as well as globally, have been actively engaged in facilitating the transition to green marine fuels and implementing CO_2-related initiatives to varying degrees. The speed of implementation and roll-out is affected by an interplay of different factors at both an intra- and inter-port level:

1. Infrastructure Development
2. Resource availability
3. Regulatory Support
4. Collaboration and Partnerships
5. Guidelines, standards and safety regulations
6. Research and Development

A lot is happening around the world to meet these needs. The latest has the world second largest shipping company Mærsk and A.P. Møller Holding announced their new company C2X, which will produce E-Methanol for their coming fleet. The first container ship of theirs sailing on green methanol was named on September 16th 2023 in Aarhus.

8.7. Risk and safety assessment

Methanol is a colourless, water-soluble, flammable liquid that has a mild alcoholic odour. Methanol is an important raw material for the chemical industry as well as the future energy and fuel industry. It burns with flames which are weakly light blue in colour and nearly invisible to the naked eye in daylight because it combusts efficiently and produces little residual products, i.e., soot.

Carbon dioxide is used as a raw material to produce carbon-based fuels such as methanol, gasoline, jet fuel, etc, for Power-to-X (P2X) applications. Carbon dioxide, CO_2, is a colourless, odourless, non-flammable gas. At normal temperatures and pressure, carbon dioxide is a gas.

Risk Assessment

Preliminary risk assessment for methanol stored at the port of Frederikshavn and CO_2 stored at the port of Hanstholm was performed through preliminary HAZID. Worst-case and most likely scenarios for storage, transportation, and usage were identified for both methanol and CO_2. Next, consequence analysis of select scenarios was performed using PHAST software developed by DNV.

Based on the results for methanol, wind speed and direction play a big role in the dispersion magnitude of methanol, which makes it important to better understand the weather conditions and surroundings. In addition, fuel containment capabilities for storage tanks and temporary placements need to be considered based on expected volume of methanol to be present. In case of CO2, failure mode greatly affects the dispersion area and profile. When there is a sudden release of all CO_2 from the storage tank, the presence of wind affects the area where harmful concentrations accumulate, however, the effects of wind dominate less with the increase of height. On the other hand, during leakage, size and direction of the leak, as well as the wind velocity greatly affect the area and profile of concentrations of CO_2.

Based on the results of the preliminary HAZID and consequence analysis and general safety practices it is recommended, but not limited to:

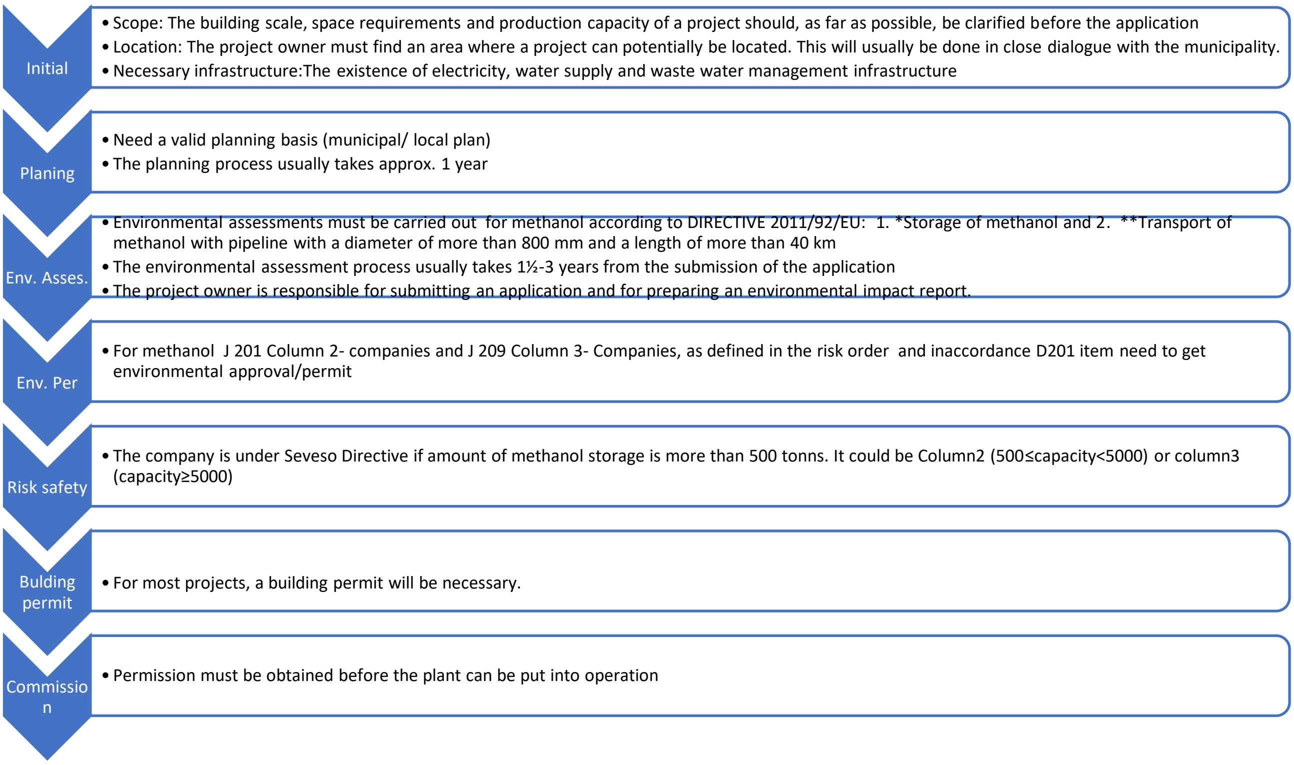
- **Methanol**
  - Proper selection and design of the equipment based on the flammable and explosive characteristics of methanol.
  - Design of the sufficient spill containment capabilities
  - Identification and zoning of hazard areas and selection of explosion-proof equipment in hazard zones
  - Regular maintenance
  - Proper staff training
  - Sufficient safety measure in case of emergency
  - Awareness and control of possible ignition sources, especially during hot work activities
  - Availability and regular maintenance of firefighting equipment at the site
  - Limited access to the site
  - Proper emergency response planning
- **CO_2**
  - Proper selection and design of the equipment

- Presence of emergency evacuation protocols
- Sufficient safety measure in case of emergency
- Regular maintenance
- Limited access to the facility
- Proper staff training

Competencies and approval processes

Identification and mapping of competencies for safe storage, transportation, and usage of methanol and CO_2 at different levels, including port, authority, and tenant, involves considering the specific responsibilities and knowledge required at each level.

Then, approval processes for Methanol and CO_2 storage facilities have been laid out. Underneath is shown for Methanol:



The procedures for approving storage facilities for methanol and CO_2 have been established. Methanol is labelled as hazardous under the Seveso Directive, while CO_2 isn't considered hazardous by the same directive. A company falls under the Seveso Directive if it stores 500 tons or more of methanol. This can be in Column2 (500 tons ≤ capacity < 5000 tons) or Column3 (capacity ≥ 5000 tons). The approval process also involves an environmental assessment and approval/permit in certain cases. If capacity of methanol storage is equal or more than 50 tons, both of these are necessary for methanol storage. For CO_2, an environmental assessment and environmental approval are required before storage.

The estimated time for the approval process for methanol storage under the Seveso directive is approximately 4-5 years, and for CO_2, it's 1.5-2 years. A suggestion to expedite the approval process for methanol is to store less than 500 tons, which only requires local permission, and to use a tube line for transfer. The distance between the production site and port must be less than 40 kilometres, and the pipeline should be smaller than 800mm to avoid the need for an environmental assessment document.

Public perception

Through qualitative work, the section of public perception examines effects of communication on the perception of safety during the transition to e-fuels in two Danish ports. The explorative work provides some examples of the relevance of emphasizing citizen understanding and early stakeholders' involvement.

Challenges include defining communication roles, balancing transparency, and addressing societal concerns. Based on these insights, four focal points have been identified for consideration when implementing e-fuels in a port. First of all, it is important to create a clear and streamlined strategy for communication. If you are in doubt about what this could entail, there is inspiration to be found in our catalog of methods. As the catalog also shows, it is extremely important to put the citizen at the center of the communication, which means that you always focus on the needs of the citizen. In order to maintain a good relationship with the local population, it is important to incorporate their insights and attitudes by showing openness. This is the best way to ensure citizens' support for a project, which can be crucial, as they can end up having great power over the course of the project. Moreover, it is important to share what is known about safety with citizens rather than remaining silent. If information is limited, referring to authorities or acknowledged expert institutions (i.e., Danish GTS institutes[1], innovation clusters) and expressing confidence in their expertise can be appropriate. Above all, actively listen to citizens, seek their perceptions, address their concerns, and embrace their curiosity. Mere dissemination of information without considering their input can foster exclusion. Strive to involve citizens as much as possible.

[1] https://gts-net.dk/english/the-gts-institutes/

Marco Polo

METHANOL **A**vailability **R**eadiness **C**ost **O**perationality for **Po**rt **Lo**gistics – **D**enmar**k**

Chapter 2 – Appendix 2.1

RoPAX Pre-Feasibility Methodology

Produced by

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMM)

RoPAX

Maturation level: Pre-Feasibility
Phase: Study
Version date: 09/2023

Objectives:

- Assess the **potential of a route to form a green corridor** based on the interplay between its assets, operators and fuel consumption
- Provide an **initial quantification of potential fuel demand** by the RoPAX segment and **possible interplay of ports** on the route

6 steps to make a green corridor operational - here we focus on Pre-Feasibility

Focus in this document: Pre-Feasibility

Project phases

Pre-Feasibility	Feasibility	Select	Define	Construct	Operate
Project baselining Value chain mapping and initial engagement with relevant regulatory bodies and government Establish screening criteria (selection framework and justification) High-level screening of potential corridors Consortium Incubation Workshop (CIW)	Technical and regulatory feasibility, and cost assessment Risk registry and mitigation plan Outline of decisions and commitments required by stakeholders Roadmap and milestones up to operation	Definition of criteria for selecting final concept Deep dive on key elements from Feasibility phase as relevant to ranking criteria Rank of concepts based on criteria and selection of final concept outlined in the Feasibility Study	FEED[1], detailed engineering design, and detailed commercial design related to (infrastructure, production, vessels, etc.) Contractual commitments between stakeholders, before final investment decisions (FID)	Finalized project details Project com-missioning and execution Preparation for handover	Operation of green corridor

Uncertainty

Investment / Commitment

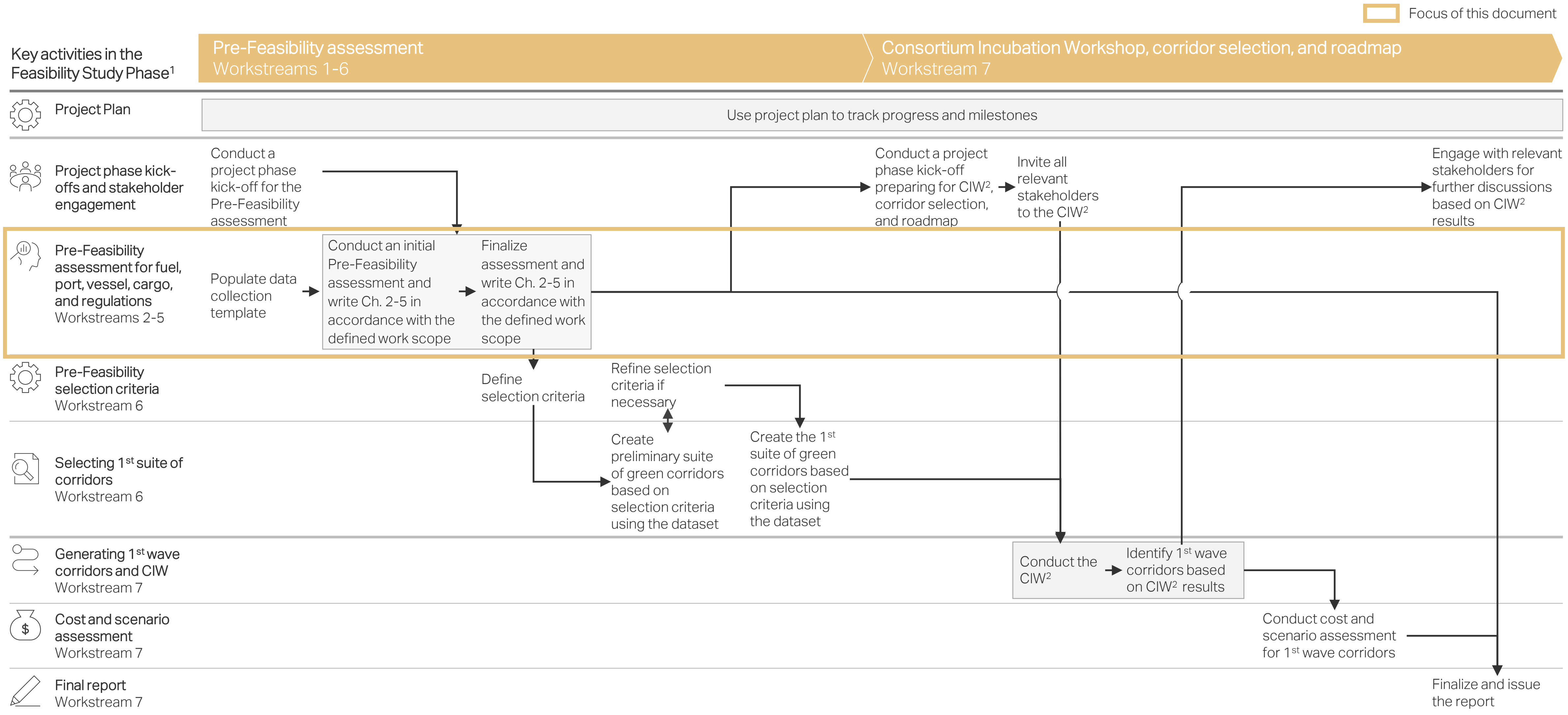
1. Front-end engineering and design

The RoPAX guideline is a specific RoPAX route assessment led by Workstream Lead 4

	1	2	3	4	5	6	7
Work-streams	Introduction, vision and project setup	Alternative fuels	Port, storage, and bunkering infrastructure	**Trade routes, vessels, cargo and services**	Policy, regulation, and funding	Selecting 1st suite of corridors	Generating 1st wave corridors and issuing final report
Stake-holders	All stakeholders	Fuel producers	Port and bunkering operators	Shipowners and operators	All stake-holders, incl. regulators	All stakeholders	All stakeholders
Scope	**Introduction** to area and constraints **Decarbonization vision** for area **Objectives** and introduction to project **governance**	**Preliminary assessment** of the main components of possible green corridors in a region to **outline the most promising and viable corridors**, incl. value chain mapping and the establishment of screening criteria (selection framework and justification)				**List of recommended corridors** based on selection criteria, incl. **initial hypothesis on 1st wave corridors**	**Consortium Incubation Workshop** **List of 1st wave corridors** to be refined based on CIW **Final report** incl. necessary Appendix, initial cost estimate and CO2 abatement potential **Initial engagement with stakeholders** for potential green corridors **Proposed way of moving forward** into Feasibility Phase

Steps 2-5 run in parallel

The RoPAX guideline is part of the Pre-Feasibility assessment



1. Not each activity / step in the flowchart is required for every project. Some may be left out depending on project scope / consortium members, etc.
2. Consortium Incubation Workshop

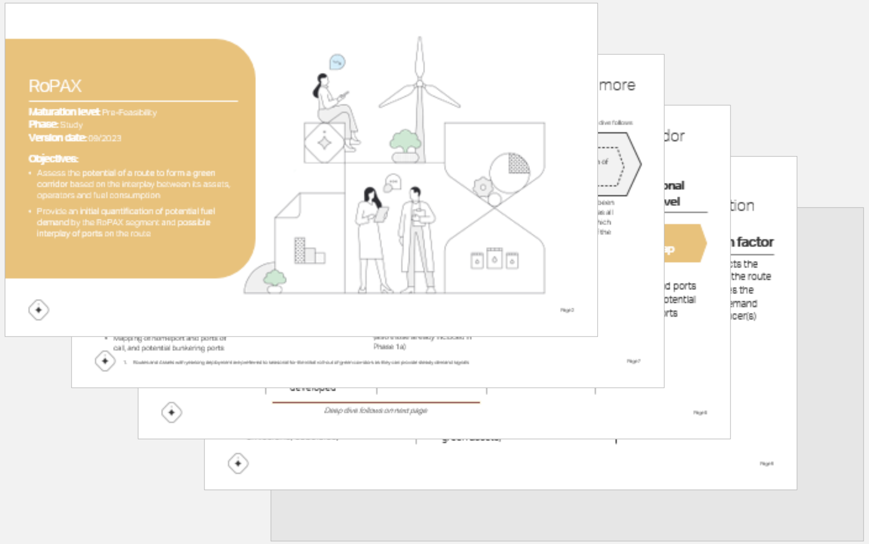
The RoPAX assessment facilitates the selection of potential green corridors in cases where RoPAX has been identified as a vessel segment of interest

Focus of this guideline

Pre-requisites for guideline

- Completion of the Pre-Feasibility Scoping Phase
- RoPAX identified as relevant vessel segment

RoPAX assessment



Purpose

- Input to the selection of the 1st suite of green corridors

Importance of this guideline: The RoPAX assessment guideline should be applied when RoPAX has been identified as a relevant vessel segment to be examined further within the consortium. In those cases, the RoPAX assessment can help the project team assess the potential of a RoPAX route to form a green corridor and further provide an initial quantification of potential fuel demand and possible interplay of ports on the route (requires close alignment with Workstreams 2-3).

The RoPAX guideline enables the prioritization and/or selection of one or more routes, and provides a preliminary, phased future fuel demand

Deep dive follows

RoPAX guideline applied in Feasibility assessment if necessary (Workstream 4) → **Comparison and prioritization of potential routes** → **For each route: Asset decarbonization trajectory** (**Phase 1**: Decarbonization of prioritized vessel(s) on the route; **Phase 2**: Decarbonization of all vessels on the route)

The RoPAX guideline is an **add-on to the Blueprint** and applied in the assessment of **green corridors with RoPAX.** The assessment is **led by Workstream 4** and includes

- Mapping of route(s)
- Scoring of assets and operators on each route
- Prioritization of routes based on scoring
- Phased future fuel demand based on asset decarbonization trajectory
- Mapping of homeport and ports of call, and potential bunkering ports

Based on the RoPAX assessment per route, the project team is able to **compare and prioritize** among multiple routes to identify the most suitable one to form a green corridor

Phase 1: All assets that are in operation and have a year-long deployment are prioritized (to account for seasonality[1])

Phase 1a: In case of multiple assets, the asset scoring enables the selection of the first vessel to decarbonize on the route. The remaining assets will be moved to Phase 1b

Phase 1b: This includes the decarbonization of all vessels that are deployed year-long on route (also those already included in Phase 1a)

Phase 2: All assets that have been prioritized in Phase 1, as well as all other vessels on the route, which contribute to total demand of the route

1. Routes and Assets with yearlong deployment are preferred to seasonal for the initial roll-out of green corridors as they can provide steady demand signals

The RoPAX guideline is a 5-step process aimed at facilitating green corridor route selection and RoPAX vessel deployment

RoPAX Pre-Feasibility: Assessment

RoPAX Pre-Feasibility: Additional analyses on asset and port level

Step 1: Route Mapping

Key route data points as reference for further assessment

Step 2: Scoring

A Scoring of asset(s) on each route based on the criteria developed

B Scoring of operator(s) on each route based on the criteria developed

Step 3: Prioritization

Prioritization of routes based on Route Scoring and Fuel Consumption

Preliminary Asset Decarbonization Trajectory for each route

Step 4: Potential fuel demand

Phased fuel demand in each route based on its Asset Decarbonization Trajectory

Also includes insights into annual, and minimum and maximum monthly demand

Step 5: Port overlap

Mapping of homeport and ports of call, and potential bunkering ports

Deep dive follows on next page

Six criteria have been developed to guide the route scoring, which jointly integrate strategic opportunities and challenges for the segment's transition

A Asset criteria

A1 **Deployment Type (Yearlong)** of all assets directly demonstrates the seasonality of route

A2 **Age of Asset** reflects the route's aggregate maturity and susceptibility / likelihood to transition to green assets

A3 **Asset Flag** reflects how all assets, and in aggregate the route economically impacts countries involved, and vice versa (incl. emissions, subsidies)

B Operator criteria

B1 **Operator Route Coverage** reflects route's susceptibility to change and possibility for cost-sharing

B2 **Operator Regional Presence** accounts for operators' commitment to and assets in the region (incl. possibility for asset swaps)

B3 **Operator Decarbonization Commitment** accounts for operators' activity within decarbonization (incl. green assets)

Fuel consumption factor

Fuel Consumption reflects the CO_2 emission impact of the route itself, as well as quantifies the potential corridor fuel demand placed on the fuel producer(s) and port(s)

Selected explainers
- Step1 to Step 5

Step 1: Route mapping – Data collection for RoPAX assessment

Step 1: Route Mapping								
Unique Route Nr.	Route Type (Single or Multi)	Nr. of Ports on Route	Domestic / International	Route Config	Nr. of Operators on Route	Operators on Route	Nr. of Assets on Route	Assets on Route
1								

Route configuration refers to the ports on route (port name / port code)

The assessment is conducted for each selected route

One operator can have multiple assets on the route

Step 2: Scoring of asset and operator criteria as well as the fuel consumption factor from 0-3 - Rationale

The Scoring Mechanism follows a **Showstopper to Best Case approach** (0 to 3), with a scoring scale tailored to each criterion (A1 to B3)

Explainer 1: Scoring

Scoring Mechanism	Asset Criteria (A)			Operator Criteria (B)			Fuel Consumption Factor
	A1. Deployment Type (Yearlong)	A2. Age	A3. Flag	B1. Operator Route Coverage	B2. Operator Regional Presence	B3. Operator Decarb Commitment	
Project Showstopper						Blacklisted	Divide Total by Fuel Consumption
Asset Showstopper -> 0	No						
1		0-14	Flag ≠ Operating countries	<50%	1-2	Neutral	
2		15-30		>=50%	3-5	Open Commitment	
Best Case-> 3	Yes	>30	Flag = Operating countries	100%	>5	Orderbook / Green Fleet	

Stops the assessment. Blacklisted means operators that are openly against or not interested in decarbonization/ developing a green corridor

Asset does not proceed to Phase 1, but fuel demand of asset is still included in the Phase 2 total fuel demand

Refers to number of assets in region

Step 3: Prioritization of routes and/or assets based on criteria scoring and fuel consumption

Step 2: Scoring							->	Step 3: Prioritization			
Asset Criteria (A)			Operator Criteria (B)			Fuel Consumption Factor		Scoring Outcome		Fuel Consumption Factor	
A1. Deployment Type (Yearlong)	A2. Age	A3. Flag	B1. Operator Route Coverage	B2. Operator Regional Presence	B3. Operator Decarb Commitment			Asset Score for Phase 1 Max Score: 3	Route Score for Phase 1 Max Score: 3	Fuel Consumption Factor - Phase 1	Fuel Consumption Factor - Phase 2

Route Score used to compare and prioritize routes:
Average of all Asset Scores for all assets on the route with A1 (Deployment Type) = 3

→

Fuel Consumption Factor – Phase 1:
Sum of the fuel consumption factor for all assets on the route with A1 (Deployment Type) = 3. This reflects the consumption of the corridor in the initial roll-out

Asset Score used to 1) generate Route Score, and/or 2) inform the asset decarbonization trajectory on prioritized routes:
Average of all asset and operator criteria scoring

→

Fuel Consumption Factor – Phase 2:
Sum of the fuel consumption factor for all assets on the route. This reflects for the long-term impact and consumption of the route

Step 4: Potential fuel demand for vessels sequenced into Phases 1a, 1b, and 2

Fuel Demand								
Phase 1a			Phase 1b			Phase 2		
Total Annual Fuel Demand	Peak Monthly Fuel Demand	Min. Monthly Fuel Demand	Total Annual Fuel Demand	Peak Monthly Fuel Demand	Min. Monthly Fuel Demand	Total Annual Fuel Demand	Peak Monthly Fuel Demand	Min. Monthly Fuel Demand

Reminder: Assets that are not year-long deployed cannot proceed into Phase 1

Phase 1: All assets that are in operation and have a year-long deployment are prioritized (to account for seasonality[1])

Phase 1a: In case of multiple assets, the asset scoring enables the selection of the first vessel to decarbonize on the route. The remaining assets will be moved to Phase 1b

Phase 1b: This includes the decarbonization of all vessels that are deployed year-long on route (also those already included in Phase 1a)

Phase 2: All assets that have been prioritized in Phase 1, as well as all other vessels on the route, which contribute to total demand of the route

1. Routes and Assets with yearlong deployment are preferred to seasonal for the initial roll-out of green corridors as they can provide steady demand signals

Step 5: The scoring of the port relations in each route generates a visualization of the port interplay and potential for bunkering on the route

Overview of possible interplay of ports on route

Visual Output of Port Overlap **When aggregated, this enables Route Interconnectivity Potential to be mapped**			
Port On Route: 1 **[Int. Port Code]**	Port On Route: 2 **[Int. Port Code]**	Port On Route: 3 **[Int. Port Code]**	Port On Route: 4 **[Int. Port Code]**

Add port code / port name and score the port from 1-3 for each asset

In case of single-stop, only the two first columns need to be filled

The color-coding generates a visualization of assets operations and bunkering potential for the route, but can also be used to compare and aggregate across multiple routes assessed.

Scoring

Score	Rationale[1]
1	Multi-stop and insufficient time to bunker
2	Single-stop (but not homeport) or multi-stop with sufficient time to bunker
3	Homeport

1. Step 1 of each Route and Asset Assessment provides information on whether the route is Single or Multi-stop