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Feasibility of a demonstrator for the carbon capture and storage value chain in CH with a waste-to-energy plant

Public project summary

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Executive summary

With carbon capture and storage (CCS) found to be the most promising solution for the decarbonization of waste-to-energy plants in an earlier study, this project set out to investigate the feasibility of the complete CCS chain (capture, transport, storage) for the waste incineration plant KVA Linth in Switzerland. The study was conducted by KVA Linth and the Sustainability in Business Lab at ETH Zürich and funded by Innosuisse and the Association of Operators of Swiss Waste Incineration plants (VBSA). Numerous industry partners provided input and a technical feasibility study was performed as part of the project – please see author page for details.

The project concluded that CCS-based decarbonization is technically feasible for the waste-to-energy plant KVA Linth as soon as a permanent storage location is opened in 2024

An amine-based post-combustion CO2 capture unit to capture 100,000 tons of CO2 per year was designed for KVA Linth and could be operational in 24 months at CAPEX of CHF ~25 million without heat integration and CHF ~30 million with heat integration depending on plant specific configurations

After assessing various transport options for captured CO2, a combination of a liquid-CO2 pipeline to a private SBB loading station and train to Rotterdam at a cost of CHF 78 per ton of CO2 has been identified as the most realistic option for now. At scale, transport via pipeline is the only feasible option

The Northern Lights project offshore of Norway has been identified as a viable CO2 storage site that is most advanced and open to third parties. Expected storage costs ex Rotterdam, are CHF 33-61 per ton of CO2 by 2030

The costs for the first-of-a-kind full CCS-chain have been estimated at around CHF 156-190 per ton of CO2. Currently, none of the potential revenue sources are sufficient and financial support from the government or regulatory changes will be necessary to make the project commercially viable

Switzerland currently lacks regulations for process emissions from CO2 capture plants. To enable transport of CO2 to the Norwegian North Sea, Switzerland needs to ratify the 2009 Amendment to the London Protocol to be allowed to export CO2 for geological offshore storage

The implementation of the CCS chain at KVA Linth requires the public's financial support as well as collaboration and support from a network of policy makers, regulatory bodies, the supply chain industry and other stakeholders, such canton, communes and NGOs

Long-term cost reduction and scale-up of CCS also requires a CO2 pipeline network. Several stakeholder groups – including the waste-to-energy and other industries, federal and regional entities and scientific institutions – are involved in discussions around the possibility of realizing a CO2 collection and transport network

Contents

More extensive deep dives into the individual work streams are available upon request

The goal of this document is to summarize the results of a feasibility study for a demonstration of Carbon Capture and Storage (CCS) process at KVA Linth

Is the ambitious plan to capture and permanently store 100’000 tons of CO2 per year at KVA Linth feasible by 2025?

Contents of the study:

- Basic design and cost calculation of the CO2 capture facility at KVA Linth
- CO2 transport options from KVA Linth and costs
- CO2 storage options and costs
- Revenue streams
- Regulatory aspects
- Industry outreach and partnerships

In order to reach the goal of Net Zero by 2050 in Switzerland, CCS is considered a necessary technology to reduce CO2 emissions and provide negative emissions

- While a number of sectors will be able to reduce CO2 emissions through energy efficiency, electrification or hydrogen, **some industries like waste-to-energy will require CCS** in order to remove and safely store emissions long-term and to realize negative emissions
- Given the long time horizons of large infrastructure and technology projects, **concrete action needs to be taken now**
- The **importance of negative emissions technologies** and the need for their deployment has been recognized by policymakers like FOEN and the media

Innosuisse - Swiss Innovation Agency
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Funded by Innosuisse and the association of waste incineration plants in Switzerland, sus.lab and the waste-to-energy plant KVA Linth conducted a feasibility study of the complete CCS value chain at Linth. The study was performed between Jun '19 and Sep '20.

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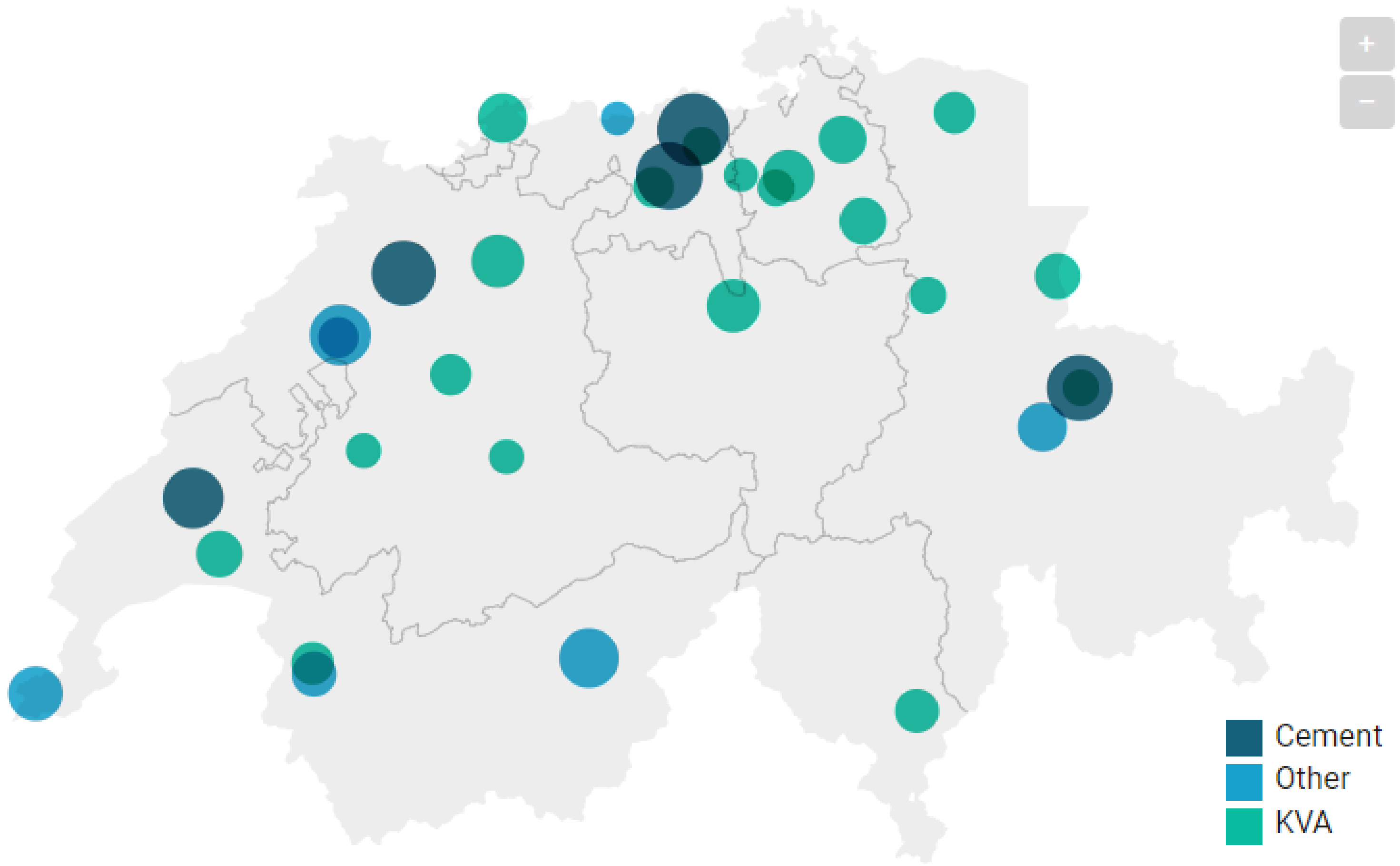
If implemented, large-scale carbon capture for waste incineration and industry in Switzerland could create a triple benefit pathway towards Net Zero emissions

- **Avoid the emission of >5 million tons per year** fossil CO2 from waste-to-energy plants and industry
- Generate **>2 million tons per year of negative emissions** from the biomass in waste, biogas plants, and wood fired power plants
- Open **new pathways for decarbonization of the energy, transport and building sectors** by allowing for zero emissions production of heat for district heating, electricity, as well as hydrogen

For removal of CO2 from the climate-relevant Carbon budget, permanent CO2 storage was found to be the most promising avenue for CO2 produced by waste to energy plants in a previous sus.lab study

Results are relevant as Switzerland's ~30 largest point sources are mainly WtE plants and the cement industry. Together they emit ~7 million tons of CO2 per year

Large CO2-point sources in Switzerland
(>100'000 tons CO2, 2017)

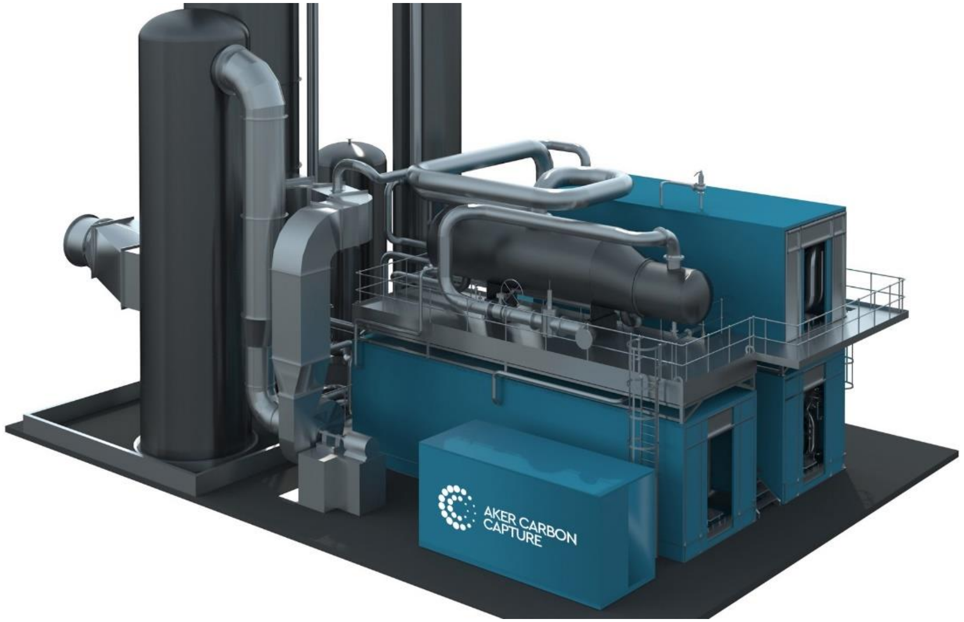


- Switzerland has 32 large emitters. (Point sources with more than 100'000 tons of CO2 per year)
- Together, these 32 large emitters emit 5 million tons of fossil CO2, and 2 million tons of biogenic CO2 (from biogenic waste, like wood or sewage sludge)

Source: VBSA/PRTR

The project investigated CO2 capture at KVA Linth, liquefaction and transport for permanent storage at the Norwegian Northern Lights storage site

CO2 capture, liquefaction and loading for rail transport

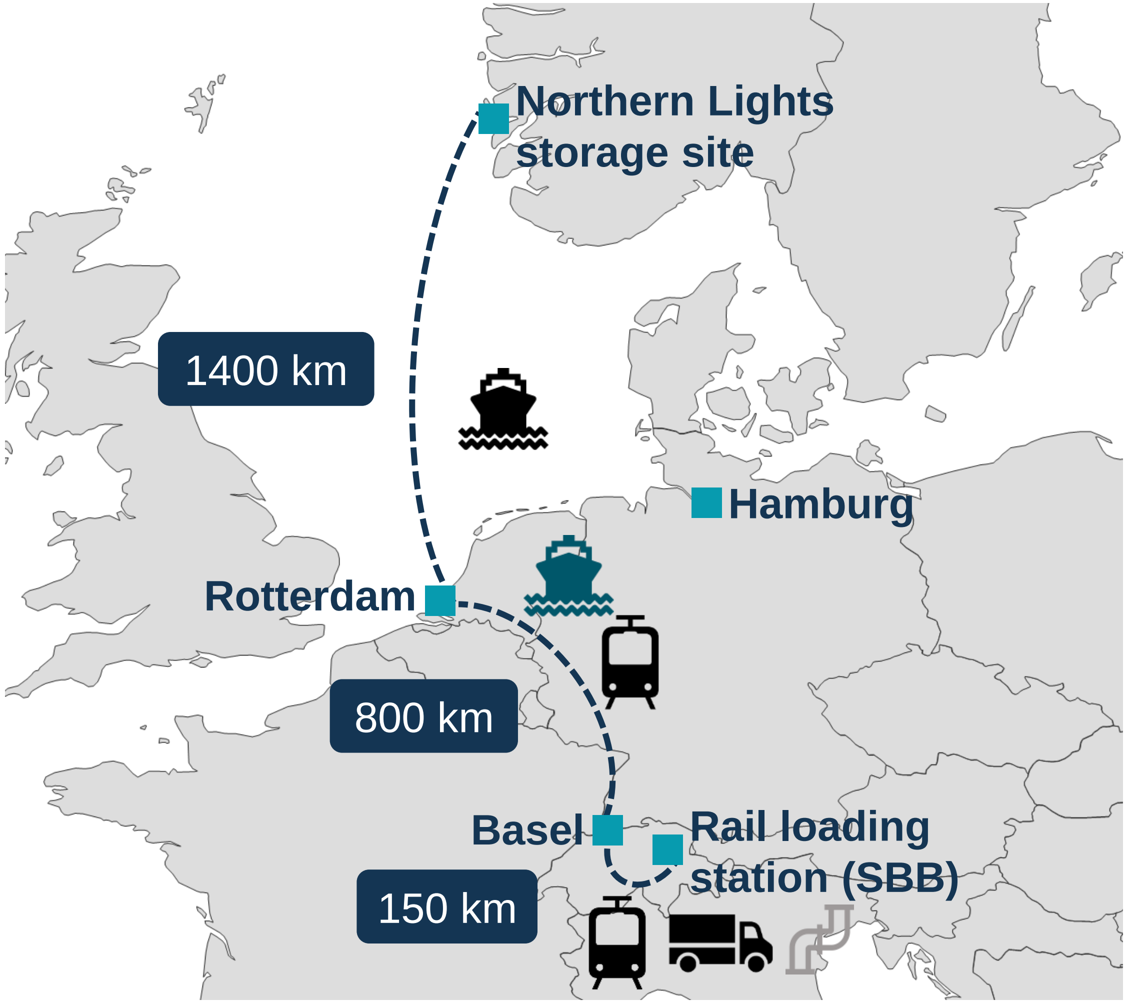


- Truck
- Onshore/ offshore pipeline
- Train
- River barge/ sea vessel

- Route in focus
- Existing solution
- Feasible by 2025

Image credit: Aker Carbon Capture

From the loading station to permanent storage in Norway



version 15.12.2020

Costs per ton of CO2 are likely to fall well below 150 CHF (the current domestic marginal abatement costs) once the CCS chain is operated at scale in EU

Cost calculation for full cost per ton of CO2 from KVA Linth to storage under the North Sea
Please note that cost estimates are indicative

	CO2 capture	Transport to North Sea coast (Rotterdam)	Storage offshore	Total
First of a kind (per ton of CO2) **focus of study**	**45-51 CHF** (incl. opportunity cost for heat and cost of liquefaction)	**78 CHF** (combination of pipeline, train and barge, without intermediate storage)	**33-61 CHF** (Northern lights currently estimates 30-55 EUR per ton as price for transport and storage from hubs along the North Sea coast)	**~156-190 CHF**
At scale (per ton of CO2) **based on literature**	**32-46 CHF** (35-50 USD capture (Global CCS Institute, 2019)	**23-29 CHF** (5-8 CHF transmission, IPCC data, based on onshore pipeline for 10 Mt per year, 0.007-0.01 CHF per ton per km from Basel to Rotterdam, 670 km, ~5 CHF for a smaller collection pipeline of 180 km (ZEP, 2011), 12-15 EUR for compression (Luo et al., 2014))	**13-33 CHF** (ZEP report based on several in depths studies in UK and NL. Offshore incl. offshore transport)	**~68-108 CHF**

Sources: AKER Carbon Capture, KVA Linth, Messer, VTG, Northern Lights, IPCC Special Report on Carbon Dioxide Capture and Storage, 2018, Global CCS Institute: Waste-to-Energy with CCS: A pathway to carbon-negative power generation, 2019; Marginal cost: Kosten und Potential der Reduktion von Treibhausgasen in der Schweiz, Bericht des Bundesrates, 2011; Waste-to-Energy with CCS: A pathway to carbon-negative power generation – Global CCS Institute, 2019; Luo et al., Simulation-based techno-economic evaluation for optimal design of CO2 transport pipeline network, Applied Energy, 132, 2014

For all elements of the CCS chain, the technologies as well as considerable operating experience are available – an overview

	Capture	Transport	Storage
Internationally	+ Large-scale CO_2 capture projects using amine-technology have already been implemented, barriers to scale so far were economics and lack of utilization options for CO_2 + First Capture in a WtE plant started in Netherlands last year – learnings were shared	+ Extensive experience in the US with CO_2 pipeline transport + Northern lights consortium is working on sea transport for pick-up at North Sea coast	+ Norway is planning to open up their offshore geological reservoirs to all European CO_2 emitters by 2024
In Switzerland	+ CO_2 capture at Lonza has been in operation for >60 years + KVA Linth is currently working with a capture provider on design of capture facility for 100'000t CO_2/year	! Rail transport is feasible, however not effective at large scale (million tons) ? All large emitters are connected to the gas distribution grid in Switzerland ? An existing oil pipeline connecting Collombey (VS) to Genoa might be re-purposed for CO_2-transport	? Theoretical (unproven) storage capacity for approximately 2.6 Gt of CO_2 in deep porous geological formations in Switzerland ! Very low exploration maturity (and high cost of exploration) make it an unlikely option for opening in the next 10-20 years

Contents

Summary – CO_2 capture (1/2)

1 **System design**	• **A CO_2 capture and liquefaction unit has been designed for KVA Linth by AKER Carbon Capture to capture and liquefy 100,000 tons of CO_2 per year** • Two system design cases – with and without heat integration – have been considered in detail
2 **CAPEX and OPEX estimates**	• CAPEX for CO_2 capture for 100,000 tons of CO_2 range from CHF ~25 million without heat integration to CHF ~30 million with heat integration, which requires liquefaction on site but decreases thermal energy consumption. Total cost of CO_2 capture are estimated to be: ○ CHF 51 per ton of CO_2 without heat integration ○ CHF 45 per ton of CO_2 with heat integration • The final choice of the system will also depend on the location of the liquefaction site • Low pressure steam requirements is the largest cost element, followed by CAPEX and electricity • CO_2 capture costs may go down in the next years as CO_2 capture at waste-to-energy plants moves to scale
3 **Next steps**	• **Project execution is expected to need approximately 24 months** but may take significantly longer if the option with heat integration is chosen • Before the investment decision can be made, it is necessary to achieve: ○ Clarity on CO_2 transport and storage infrastructure and regulations in CH and Europe ○ Clarity on revenue and funding sources ○ Examination and improvement of public acceptence of CCS • Meanwhile, studies on heating and cooling integration considering KVA Linth heating district expansion and flue gas dispersion modelling may be performed

Summary – CO_2 capture (2/2)

4 **Lessons learned from other plants**	• Dispersion and deposition modelling of NO_2 and nitrosamines and nitramines is an important basis for a discharge permit and different models might give quite different results • Using generic MEA solvents for CO_2 capture at WtE plants leads to issues with corrosion and oxidation • Proprietary solvents (e.g. Shell CanSolv, S-26 by AKER Carbon Capture) have been demonstrated to overcome these issues - 2,000 h pilot test at Fortum Oslo Varme using Shell CanSolv. After 9 months of pilot testing, the technology performed as targeted and no corrosion or extensive amine degradation were observed • Experience has been gained in dispersion and deposition modelling of NO_2 and nitrosamines & nitramines. Norwegian authorities are willing to share • CO_2 capture installation in Twence, Netherlands scheduled to start operations in 2021 using the technology from AKER Carbon Capture will be the next one to watch and learn from experience
Emissions from amine capture	• **Switzerland currently lacks regulations for the CO_2 capture process emissions** and it may be anticipated that future emission limits for solvent amine will be linked to possible atmospheric degradation of amine to nitrosamines and nitramines. Established industry standards and regulations in other countries are available • A flue gas dispersion study may be requested in the future by the authorities • AKER Carbon Capture technology uses ACC^{TM} S26 amine solvent. The relatively low tendency of nitrosamine formation for the S26 solvent compared to MEA was demonstrated in test campaigns at the TCM

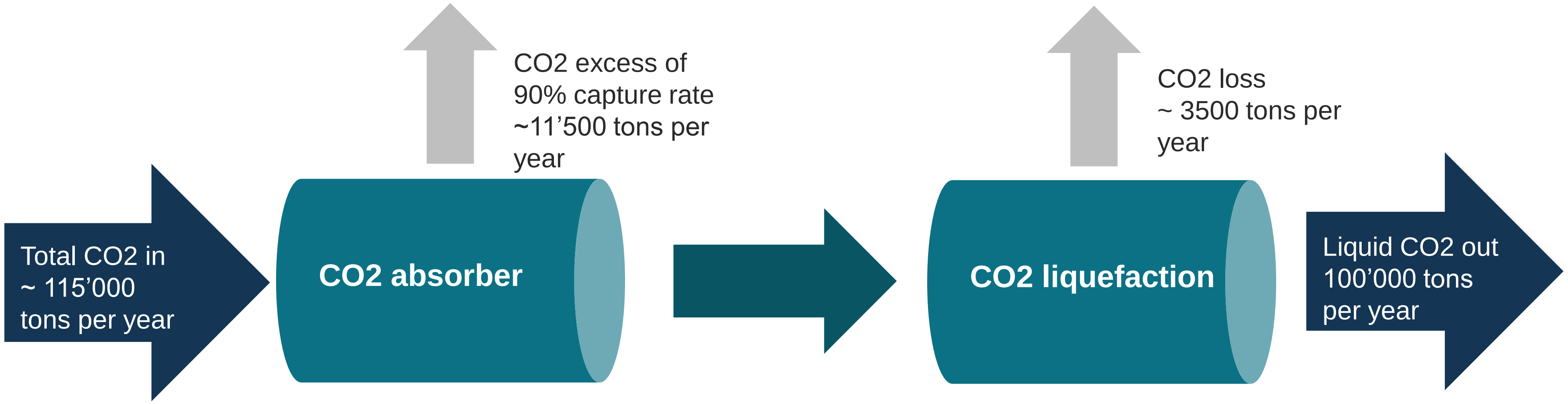
Note: This aspect is not considered in detail in this report; further information are available upon request in “Deep Dive Regulations”

1 CO2 capture unit has been designed for KVA Linth by AKER Carbon Capture to capture and liquefy 100'000 tons of CO2 per year

AKER CARBON CAPTURE

The plant is designed to produce **100'000 tons of** liquid CO2 per year. The proposed **CO2 capture rate is 90%** which will extract roughly 115'000 tons of CO2 per year in order to produce 100'000 tons of liquid CO2 per year

Two cases – with and without heat integration – have been considered in detail



CO2 streams in the CO2 capture and liquefaction process

Source: Integration Feasibility report, Aker Carbon Capture (2020)

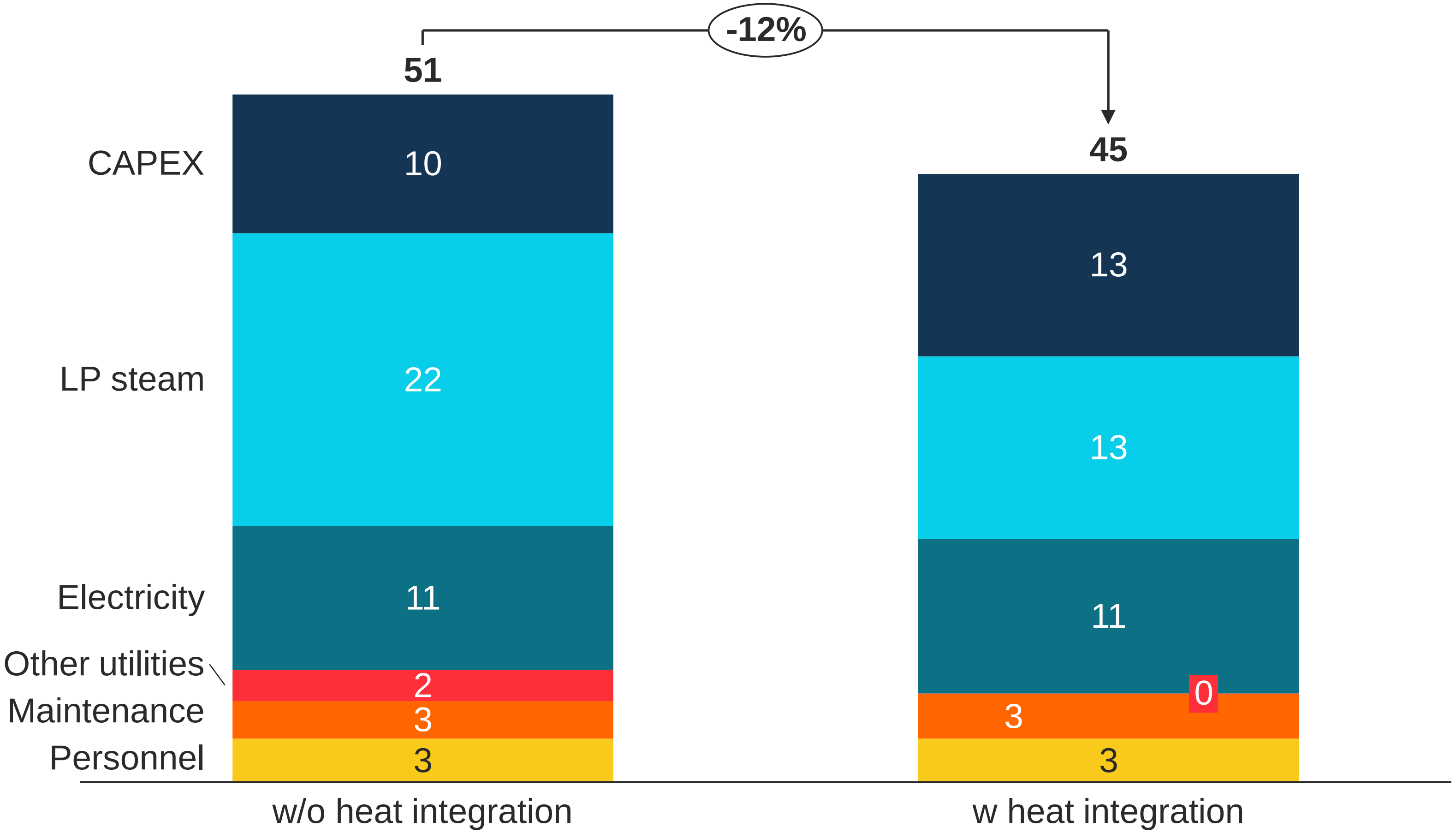
1 CO2 capture unit has been designed for KVA Linth by AKER Carbon Capture to capture and liquefy 100’000 tons of CO2 per year

Source: KVA Linth

2 The cost of one ton of CO2 captured and liquefied is expected to be in the range from CHF 45 (with heat integration) to CHF 51

Cost estimates for CO2 capture w/o and w heat integration at KVA Linth

CHF, per ton of CO2 captured and liquefied, excluding transport to railway station



Source: CAPEX: Integration Feasibility report, Aker Carbon Capture (2020), OPEX: KVA Linth internal data

Total cost of CO2 capture:

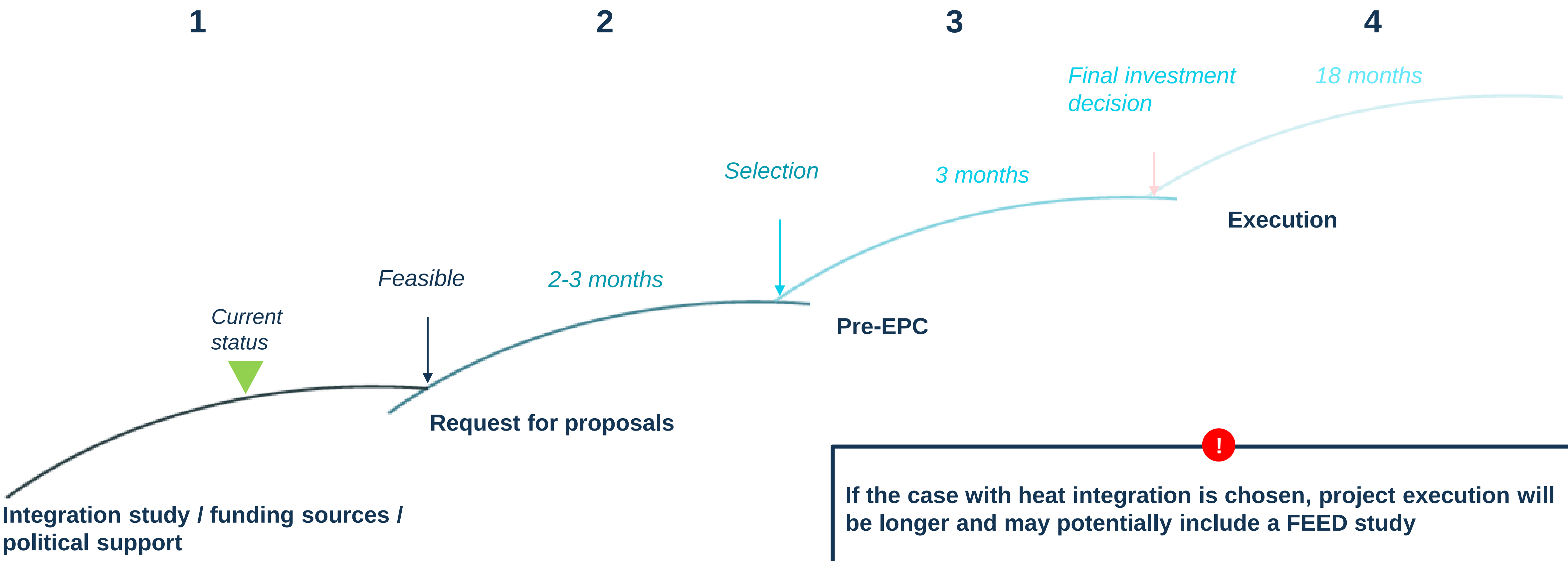
- **CHF 51 per ton or CHF 5.1 million (w/o heat integration) per year for 100,000 t of CO2 captured and liquefied**
- **CHF 45 per ton or CHF 4.5 million (w heat integration) per year for 100,000 t of CO2 captured and liquefied**

Financing costs are excluded due to high uncertainty of the funding mix at the moment

3 Project execution is expected to need approximately 24 months but may take significantly longer if the option with heat integration is chosen

Illustrative timeline of project development

AKER CARBON CAPTURE



!

If the case with heat integration is chosen, project execution will be longer and may potentially include a FEED study

Source: Integration Feasibility report, Aker Carbon Capture (2020)

4 Additional lessons were collected from other WtE plants with experience in planning and running CO2 capture

Key lessons learned – issues identified

- **Technology performance is proven** / will be proven at WtE in several cases by 2024/2025
- **Costs are highly dependent on energy requirements** – integration with WtE operations is important
- Important KPIs for choosing amines include: (i) capture rate; (ii) energy requirements, (iii) solvent degradation / corrosiveness; (iv) solvent emissions
- **Solvent emissions will likely require cooperation with the regulator**
- System for process control, measurement and sampling is an important aspect to be well thought-through

Source: discussions with Fortum Oslo Varme, AVR Duiven, AKER Carbon Capture

4 Fortum Oslo Varme WtE plant has completed successful pilot testing with WtE flue gases with the goal to start capturing 400’000 tons of CO2 per year

fortum Oslo Varme

Capacity	• Pilot for ~3.5 tons of CO2 per day • Goal to capture about 400’000 tons CO2 per year
Techno-logy	• 90% capture of CO2, technology supplier with full scale experience (Shell), EPC contractor TechnipFMC
Installation size	• Pilot size 150-200m2 plus space for backstay supports
Economics	• Undisclosed, but expected energy requirements are 2.5-3.0 GJ/t CO2 captured for the full scale plant

Source: Fortum Oslo Varme

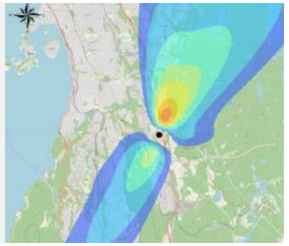
4 After 9 months of pilot testing, the technology performed as targeted and no corrosion or extensive amine degradation were observed

Source: Fortum Oslo Varme

- **No unexpected or concerning results in 9 months (over 2,000 hours) of testing**
- Technology was qualified
- CO_2 purity as expected
- Good CO_2 capture efficiency (met the expected energy requirements)
- Observed amine degradation below expected limits
- Main sources for degradation:
  - Oxidative degradation (avg. at plant 11%)
  - NO_2 (avg. at plant 1.2 mg/Nm3)
  - Heavy metals (esp. iron)
  - Thermal degradation
  - Other sources negligible
- Amine emissions within limits targeted at a total of 0,4 ppmv on average, including nitrosamines met with 0.018 ppmv median during test campaign (also increased with dust and sudden changes in flow)
- Water wash - Low concentration of amine: avg. 0.12 wt-% - *And quite high water consumption*

4 Experience has been gained in dispersion and deposition modelling of NO2 and nitrosamines & nitramines. Norwegian authorities are willing to share

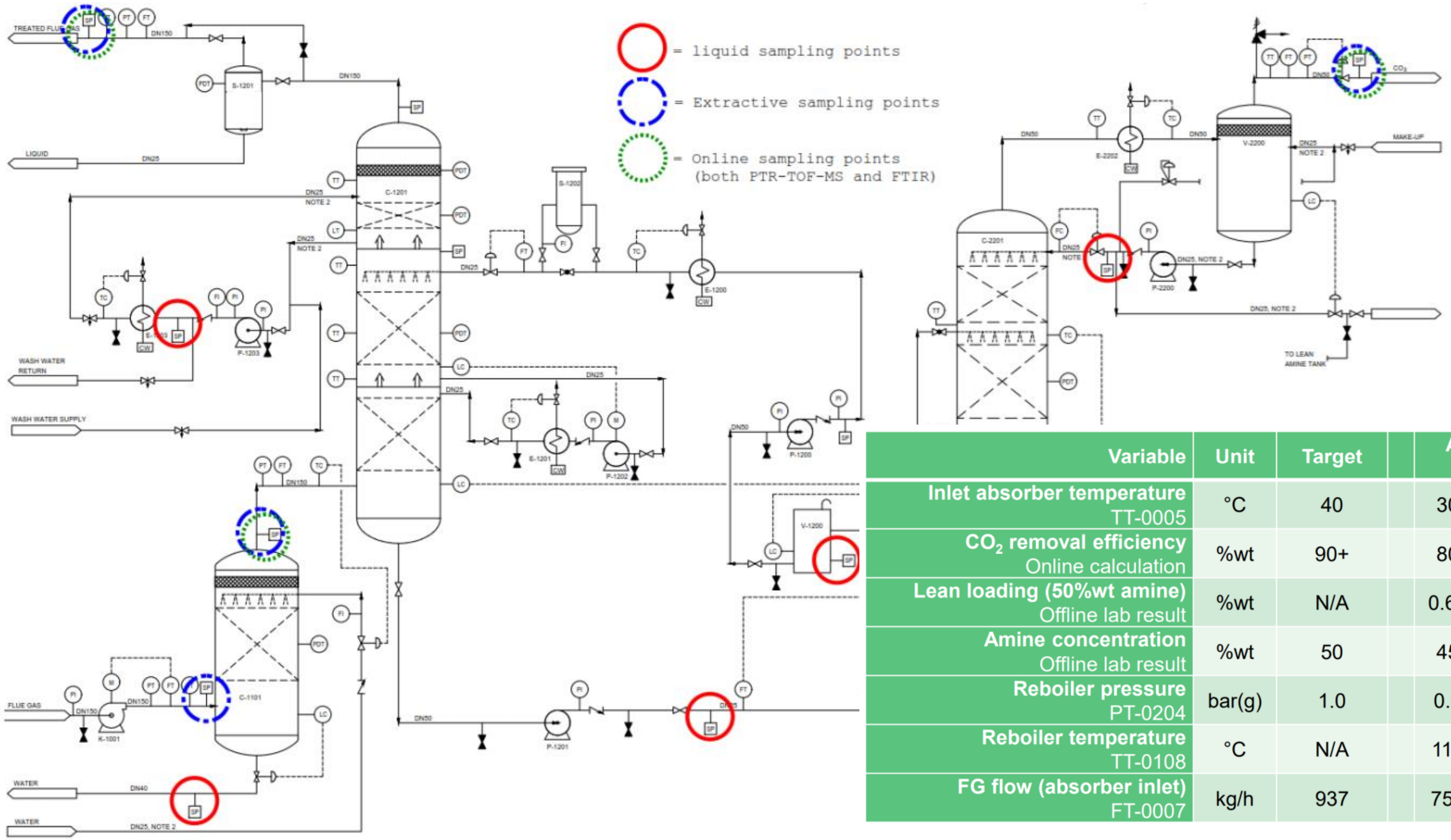
Context	• NILU (Norwegian Institute for Air Research) carried out dispersion and deposition calculations before start of the pilot and set a target value of 0.4 ppmv of total amine emissions from the pilot • Norsk Energi/CERC engaged in modelling of emissions of NO2 and nitrosamines + nitramines
Method	• Modelling was based on the given target value (0.4ppmv) to compare the model used by NE/CERC and NILU • Modelling based on experienced conservative figures from the pilot (0.2ppmv) was also carried out
Results	• **The model used by NE/CERC (ADMS5) gave significantly higher values, but the level based on figures from the pilot was lower than the guideline threshold values to both air and water**
Conclusions	• Different models might give quite different results – it is important that both the applicant and the pollution control authorities feel confident that the assessments submitted are representative • Experience from a pilot provides increased assurance that the levels used for modeling dispersion are achievable



Source: Fortum Oslo Varme

4 The first pilots also created non-obvious experience/learnings on the system for process control, measurement points and sampling that should be built on

Example of a process control, measurement and sampling system at Fortum Oslo Varme



Variable	Unit	Target		Acceptable range		
Inlet absorber temperature TT-0005	°C	40		30	-	50
CO_2 removal efficiency Online calculation	%wt	90+		80	-	100
Lean loading (50%wt amine) Offline lab result	%wt	N/A		0.60	-	1.90
Amine concentration Offline lab result	%wt	50		45	-	55
Reboiler pressure PT-0204	bar(g)	1.0		0.9	-	1.1
Reboiler temperature TT-0108	°C	N/A		115	-	130
FG flow (absorber inlet) FT-0007	kg/h	937		750	-	1124

Source: Fortum Oslo Varme

- **Part of the measurement system will need to be designed in cooperation with the regulatory authorities to ensure future compliance**
- **Technology Center Mongstad in Norway has extensive experience and can be consulted in case of questions**

Agenda

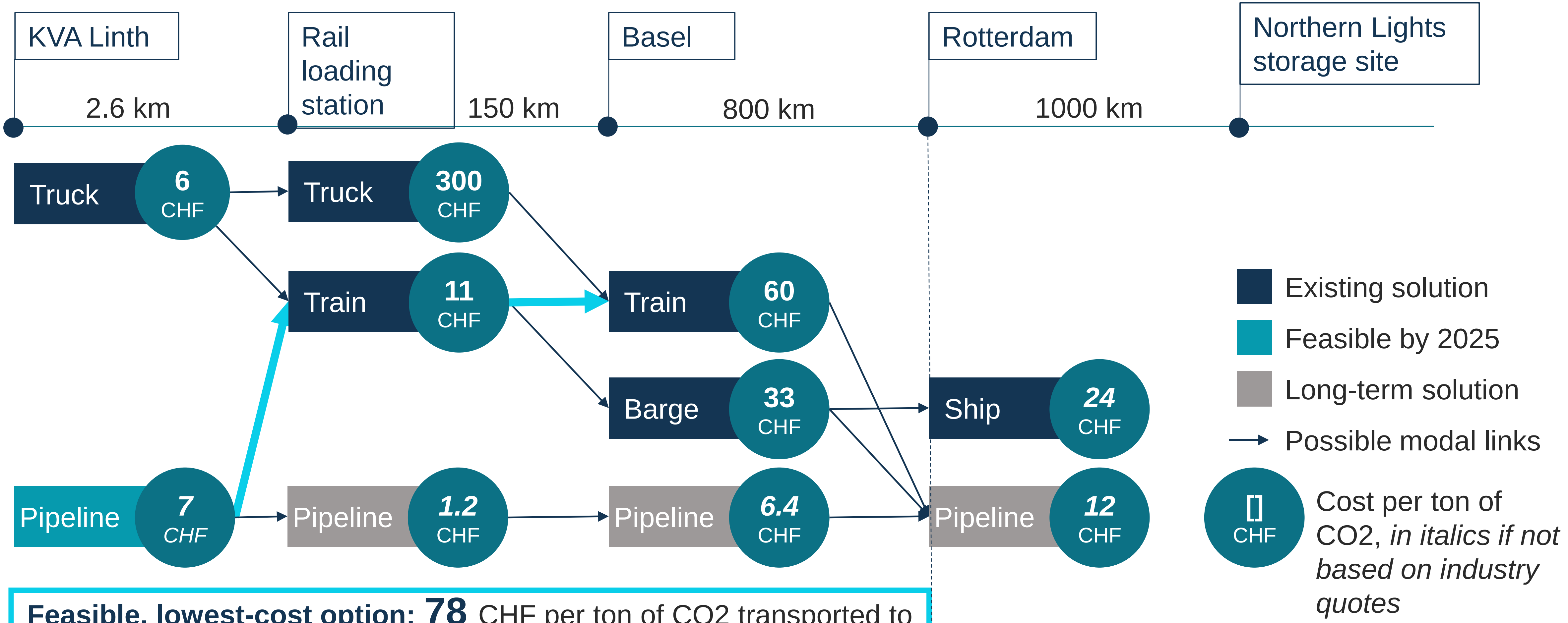
- Introduction
- CO2 capture
- **CO2 transport**
- CO2 storage
- Revenue streams
- Regulatory aspects
- Industry outreach

Summary – CO2 transport

1 **Selected transport chain**	• **After assessing various transport options for the captured CO2, a combination of a liquid CO2 pipeline to and train from a private SBB rail loading station to Rotterdam has been identified as the most realistic option for now** • **The overall cost is approx. CHF 78 per ton of CO2** • Transport would create emissions of app. 60 kg per ton of CO2 transported to the Northern Lights location, equivalent to around 6% of the transported volumes
2 **Loading station and pipeline**	• **A pipeline to the nearest train station where a private loading station is necessary** • A private railway connection is necessary because liquid CO2 is classified as a dangerous transport good • Once the location has been identified and secured, further detailed planning will be necessary to optimize liquefaction location, choose the resulting type of pipeline, find the right path for the pipeline, secure the necessary permits, etc. • Execution of this part of the project is very complex dependent on public support and may take substantial amounts of time
Rail transport	• **For the transport of 100'000 tons of CO2, up to 60-70 wagons (specific for CO2 transport in liquid form) will be necessary** • It may be difficult to rent this amount of wagons from rental companies but necessary because of the relatively high variability in wagon trip times. Potential solutions are long-term contracts and potential government support • Wagons may need to be ordered 2-2.5 years in advance. Negotiations with potential rental providers will be necessary before the order • The main technical issues to be managed in the transport chain are blow-outs and dry ice formation and can be solved through well-insulated containers and performance standards in the rental contract • **It is crucial to start planning the pipeline to the loading station as well as the loading process / required equipment several years before project execution**
3 **Long-term considera-tions and next steps**	• **The scale-up of CO2 capture facilities at large emitters requires a pipeline network** • If CO2 export is scaled up to the order of 10 Mtpa, transport by truck, railway and barge will face capacity issues and risk of service interruptions • Therefore, a pipeline network between large point sources will be necessary, which could ideally use the right of way of the existing high pressure natural gas pipeline network

INDICATIVE

1 Rail transport from an SBB loading station expected to cost CHF 78 per ton of CO_2

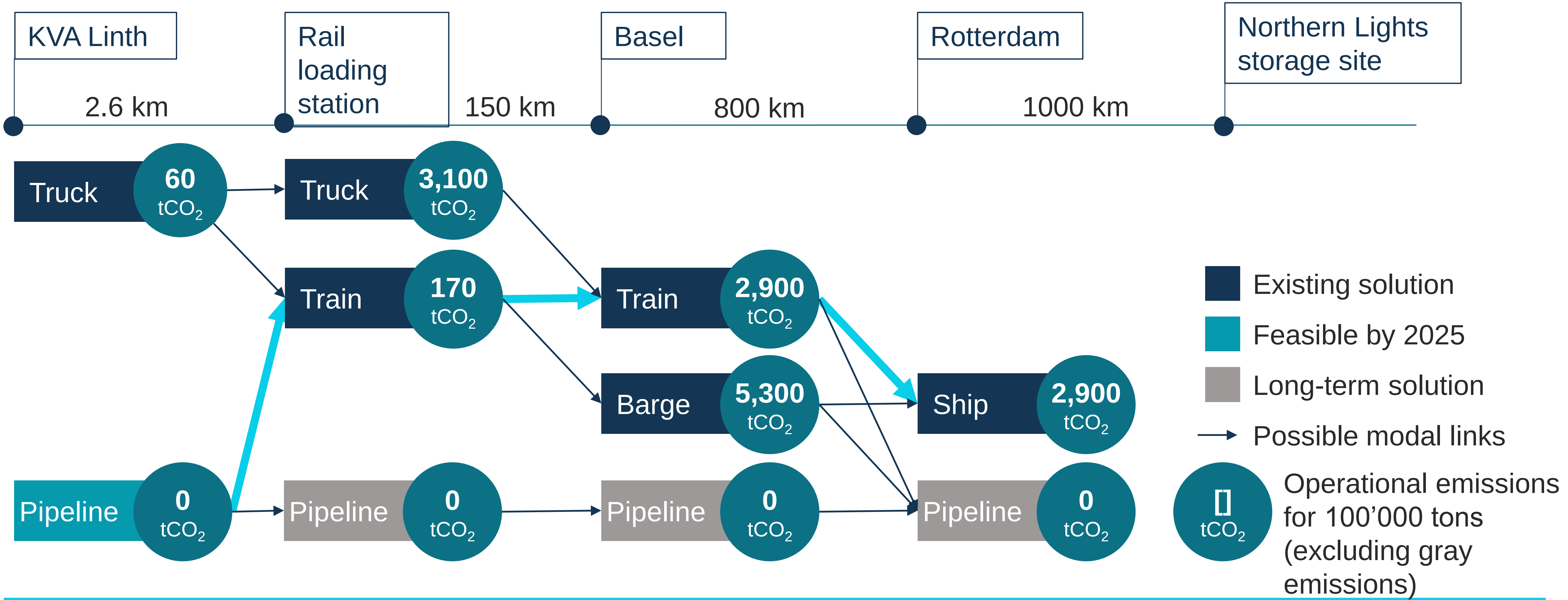


Feasible, lowest-cost option: 78 CHF per ton of CO_2 transported to Rotterdam where it is picked up by the Northern Lights project

Source: Multiplication of unit transport cost (see slide 8) with roundtrip distances (assuming empty trip back).

INDICATIVE

1 A transport chain by pipeline, train and ship would result in emissions equivalent to ~6% of the CO2 transported



Feasible, lowest-emission option: 6’000 tons of CO2 of operational emissions per year ≙ **6%** of transported CO2

Source: Multiplication of operational emission factors (see slide 8) with roundtrip distances (assuming empty trip back).

2 The CO2 needs to be liquefied for transport with trains, river barges and the planned offshore ships

	Transport mode	Pressure (bar)	Temperature (°C)
	Onshore pipeline (supercritical)	85-150[1,2]	12-55 °C[1,2]
	Onshore pipeline (gaseous)	10-20[2]	12-55 [1,2]
Liquefied CO_2	Truck	15-20[3]	-20 to -35[3]
Liquefied CO_2	Railway	15-20[3]	-20 to -35[3]
Liquefied CO_2	River barge	15-20[3]	-20 to -35[3]
Liquefied CO_2	Offshore vessel	7-9 (ideal), 15-20 (now)[2]	-50 (ideal), -30 (now)[2]
	Offshore pipeline (supercritical)	250[2]	4-15[2]

Sources: [1]Institute for Energy and Transport (2011). Technical and economic characteristics of a CO2 transmission pipeline infrastructure; [2]ZEP (2011) The Costs of CO2 Transport. Post-demonstration CCS in the EU; [3]VTG, Peacock and Lonza specification sheets and interviews.

2 The transport for Linth requires 2 blocktrains of 20 rail tank cars per week, each blocktrain is filled within 7:30 hours

Step 1

Arrival of the empty blocktrain.

Loading zone: 11 filling stations

Blocktrain: 20 RTCs (Rail Tank Cars)

Step 2

Disconnecting blocktrain, shunting and connecting to filling stations.

Time requirements for filling one blocktrain:

Disconnecting train and shunting: 15 min
Connecting to filling stations: 1h

Step 3

3a) First 10 RTCs are filled.
3b) Second 10 RTCs are filled.

Filling: 2h per 10 RTCs
Buffer: 1h per 10 RTCs

Step 4

Disconnecting from filling stations, shunting, re-connecting and departure as blocktrain.

Disconnecting from filling stations: 1h
Shunting and re-connecting train: 15 min

Total time required: 7h 30 min

Source: KVA Linth

2 It is crucial to start planning the pipeline and loading station several years before the start of capturing

Pipeline and loading station

- Final loading location needs to be chosen / land secured
- Pipeline planning, community approvals, etc.
- Submission of the siding application to SBB Cargo, approvals for the pipeline
- ! This process may take several years before execution

Securing wagons

- ! Wagons may need to be ordered 2-2.5 years in advance
- Negotiations with potential rental providers will be necessary before the order

Scale-up planning

- Discussions and further studies to eventually develop:
  - Swiss CO2 pipeline network that connects large point emitters (currently ongoing)
  - Pan-European CO2 network: transport optimization model assuming participation from all large point-CO2 emitters in Europe (includes pipeline considerations)

3 At scale, pipeline transport is expected to be the most economical and feasible option

For 10 million tons of CO2 (all waste to energy, cement, biomass plants plus growth)

10 million tons per year

≙ **50%** of Swiss annual exports[1]

A pipeline infrastructure is needed for the export of such large quantities of CO2

- **Large emitters** are already today connected to **gas pipeline** infrastructure
- **Repurposing** existing gas pipelines could potentially be done at **25% of the costs**[2] (UK-based study), but needs investigation

~1600 trucks/day

≙ **70%** of current exports by road

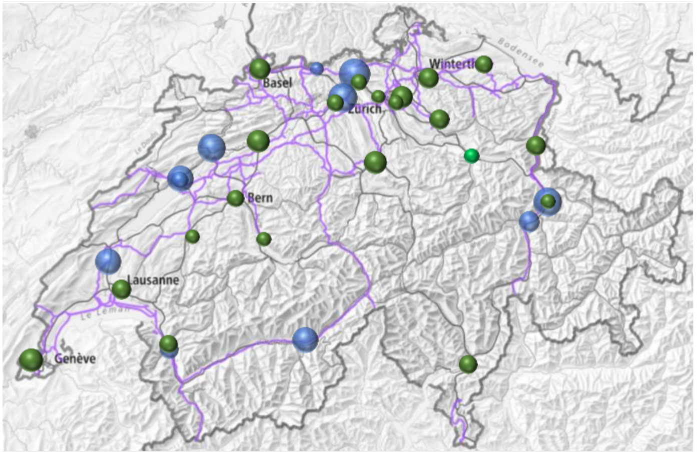
~550 rail cars/day

≙ **500%** of current exports by rail

~11 barges/day

≙ **1400%** of current exports by water

Existing Swiss gas pipelines and large emitters[3]



- Transmission grid (>5 bar): 2'243 km
- Distribution grid (<5 bar): 17'684 km

Sources: [1]Eidgenössische Zollverwaltung (2019), [2]ACT Acorn Feasibility Study (2018), [3]Gazenergie, Swisstopo, SFOE

Contents

Summary – CO2 storage

1 Storage site selection

- **The Northern Lights project offshore of Norway has been identified as the most realistic CO2 storage site for KVA Linth**
- Northern Lights is a joint venture between Equinor, Total and Shell, subsidized by the Norwegian government
- The site is expected to be opened to foreign CO2 emitters in the beginning of 2024
- The operators of Northern Lights can draw on 20 years of experience with injecting CO2 at the Sleipner project, started in 1996, with a total of 15.5million tons CO2 (0.9 million tons per year)

2 Offtake conditions and potential issues

- CO2 can be handed over to the Northern Lights project in Rotterdam or Hamburg. Later on, an inland location along the Rhine (e.g. Duisburg) might be created in the scope of Northen Lights
- **All-in cost for handling CO2 ex Rotterdam is expected at CHF 33-61 by 2030**
- Operational CO2 emissions for Northern lights CCS are estimated to be around 0.5 tons per 1 mio tons of injected CO2
- When gray emissions are taken into account (accounting for materials in well construction, pipelines etc.), preliminary estimates show approx. 0.05% of injected CO2, i.e., 500 tons per 1 million tons of CO2 injected
- Key potential issues identified:
  - Execution of the Northern Lights project is subject to successful testing at each step but positive investment decisions by the Norwegian Government and all project partners have been made 2020 and some alternative sites may become available before 2030
  - The offtake contract length is expected to be 15 to 20 years, but there may be some flexibility for smaller volumes

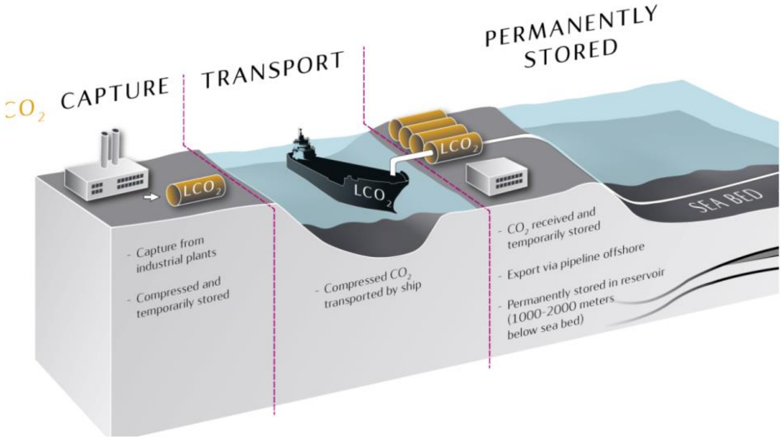
1 The ‘Northern Lights’ project – including transport, reception and permanent storage of CO_2 in the North Sea – seems as the best option for KVA Linth

equinor Shell TOTAL

Equinor, Shell and Total have signed MoU with 7 European companies[1] to develop CCS value chains supported by the Norwegian State

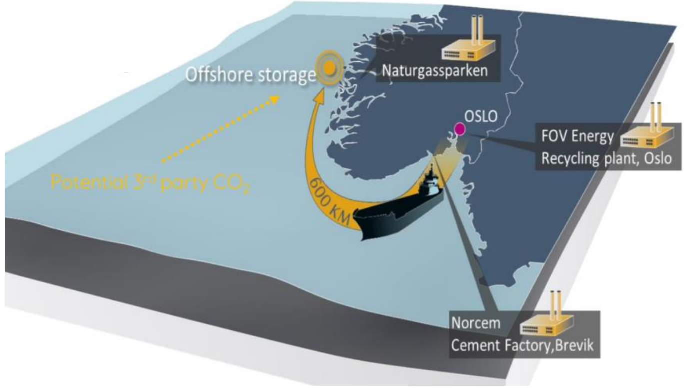
Technology description

- The ‘Northern Lights’ project includes **transport, reception and permanent storage of CO2** in the North Sea
- **The operators of Northern Lights can draw on 20 years of experience** with injecting CO2 at the Sleipner project, started in 1996, with a total of 15.5 million tons CO2 (0.9 million tons per year)



Capacity

- 1,000-2,000 m below the North Sea bed
- Norwegian offshore CO2 storage capacity estimated at 70’000 million tons – Providing space for 20 years of EU 28 direct CO2 emissions



[1] Air Liquide, Arcelor Mittal, Ervia, Fortum Oyj, HeidelbergCement AG, Preem, and Stockholm Exergi

Source: Press research and interviews, H21 North of England, 2018, Images Goassnova, Northern lights, Statoil [renamed to Equinor], MIT, Sintef (2018), direct CO2 emissions of EU 28 (excl. land change and aviation) were 3.5 Gt in 2016 according to the European Environmental Agency

1 The Northern Lights project is designed to have spare capacity for volumes beyond the design capacity, which is to store at least 100 million tons of CO_2 over 25 years

1996-2020
Experience (2 million tons per year) - In operation

- Safe CO2 storage demonstrated
- 1st generation transport solutions
- Post-combustion capture from gas based power production qualified

2020-2025
Open storage hub (5 million tons) – Value chain demonstration

- Multi-sourcing of CO2 and future CO2 logistic chains
- Reduce cost for expanding Northern Lights
- Scale-up CO2 storage on the Norwegian continental shelf and/or international qualify capacity, integrity & monitoring methods

2025-2030
Expand network (>20 million tons per year) – Large scale implementation

- Offshore receiving and offloading concepts
- Qualify several storage hubs in North Sea to serve de-carbonization of first CCS industry and hydrogen projects

2030-2040
Further expand (>100 million tons per year) – Large scale implementation

- Multi-source, multi-store logistics concepts
- CCS cost significantly reduced: learning by doing and sharing of infrastructure

2040-2050
Low carbon competitiveness – Large scale implementation

- CO2- negative and CCS chains
- Technologies for efficient global CO2 storage exploration and field development

Source: DNV.GL

1 Several other projects are on the way in Europe – costs are not clear yet

1 Humber Project (UK)

- Capture CO2 from industry around Humber estuary
- Transportation of CO2 via pipelines and storage in naturally occuring Aquifiers under southern North Sea
- **Possibility to store CO2 from elsewhere transported by ship or CO2 pipeline infrastructure**
- Start year: 2027

4 Cork CCS Project (Ireland)

- Capture of CO2 at refineries and power stations and transport to an offshore depleted gas field
- Development of connection for backup storage capacity in EU through ship transport

2 ACORN CO2 Sapling (UK)

- Repurpose oil & gas infrastructure for CO2 storage
- **Storage solutions for the UK and North Sea neighbours**
- Storage sites loacted beneath central North sea
- Start year: 2024

3 Net Zero Tesside (UK)

- Industrial Cluster aiming for Net Zero emissions
- CO2 storage in underground reservoir in North Sea
- Building of new gas fired power station for low carbon power and back-up renewable energy sources
- Start year: mid 2020

5 Athos Consortium (Netherlands)

- Uses depleted offshore fields or saline formation for the storage of CO2 at a depth of 3000 – 5000m under the North Sea
- Transportation of captured CO2 through existing underground pipelines
- Start year: 2027

Source: Zero emissions platform, A Trans-European CO2 Transportation Infrastructure for CCUS: Opportunities & Challeneges, 2020

1 Major cost drivers for CO2 storage include field location and reservoir capacity

Cost Drivers for Storage

- Field Capacity – higher costs for smaller reservoirs
- Onshore & offshore location – higher costs offshore and in EU/Norway
- Injectivity
- Cost of liability
- Well trajectory
- No. of new observation wells
- No. of new exploration wells
- Field knowledge level – higher for depleted oil and gas fields than for saline aquifiers
- Measurement Monitoring and Verification (MRV)
- Weighted average cost of capital

Source: DNV.GL

1 Five aspects form the basis for safety of CCS – climate perspective, physical basis of the process, operational and monitoring experience and regulation

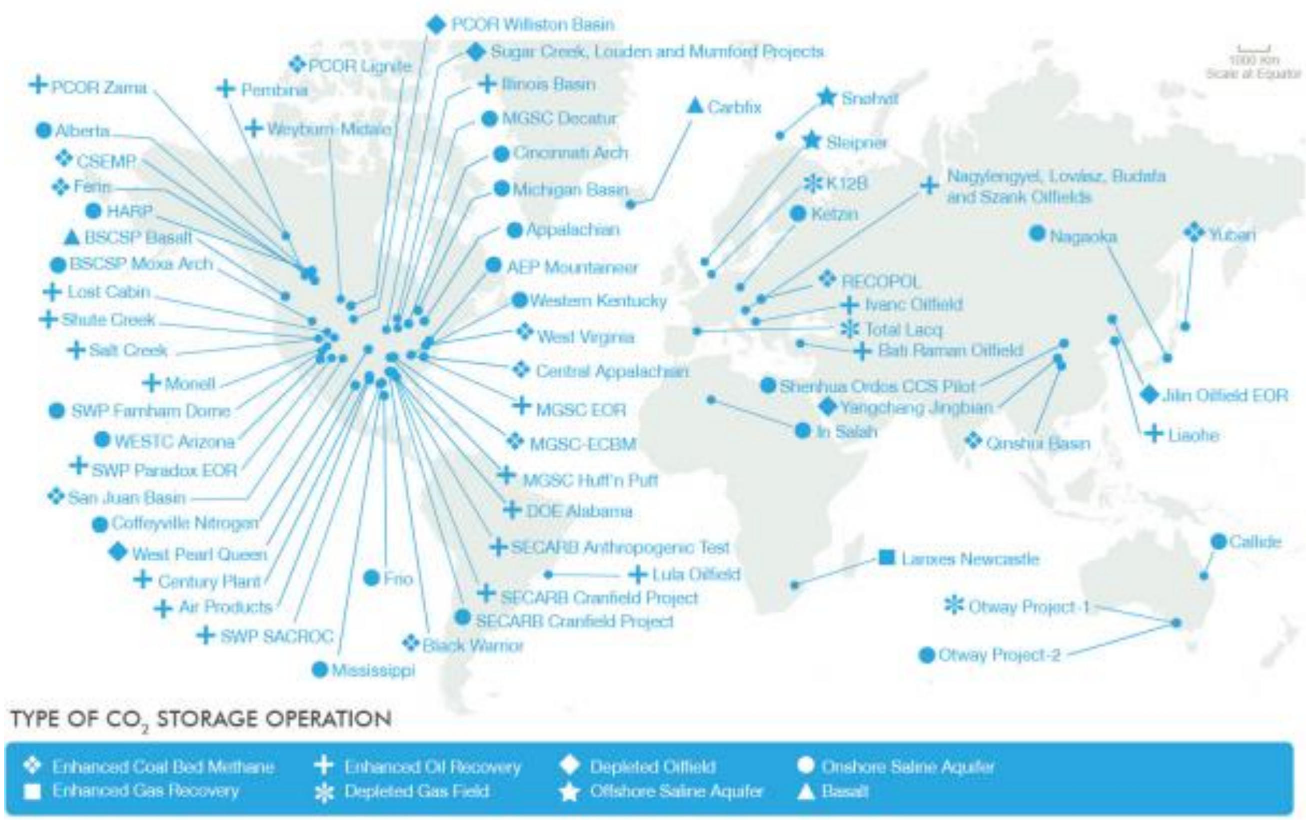
Climate protection	Putting CO2 in deep geological formations is a lot safer and better than putting the same CO2 into the atmosphere
Physical basis	CO2 is trapped in microscopic rock pores and sealed with a cap rock. Similar formations have stored natural gas for millions of years. CO2 dissolves in the water and ultimately precipitates as a solid mineral
Operational experience	More than 20 years of operations at Sleipner show that CCS works
Geophysical monitoring	CO2 can be tracked and monitored in the subsurface to ensure conformance with the expected behavior, thus providing assurance of permanent storage
Regulatory compliance	Storage sites and processes need to conform with the Norwegian and EU CO2 storage directives

Safety of CCS particularly means confidence that the stored CO2 remains trapped over long time horizons without leakage

Source: Adapted from Furre et al., Building Confidence in CCS: From Sleipner to the Northern Lights Project, Special Topic: Energy Transition, 2019

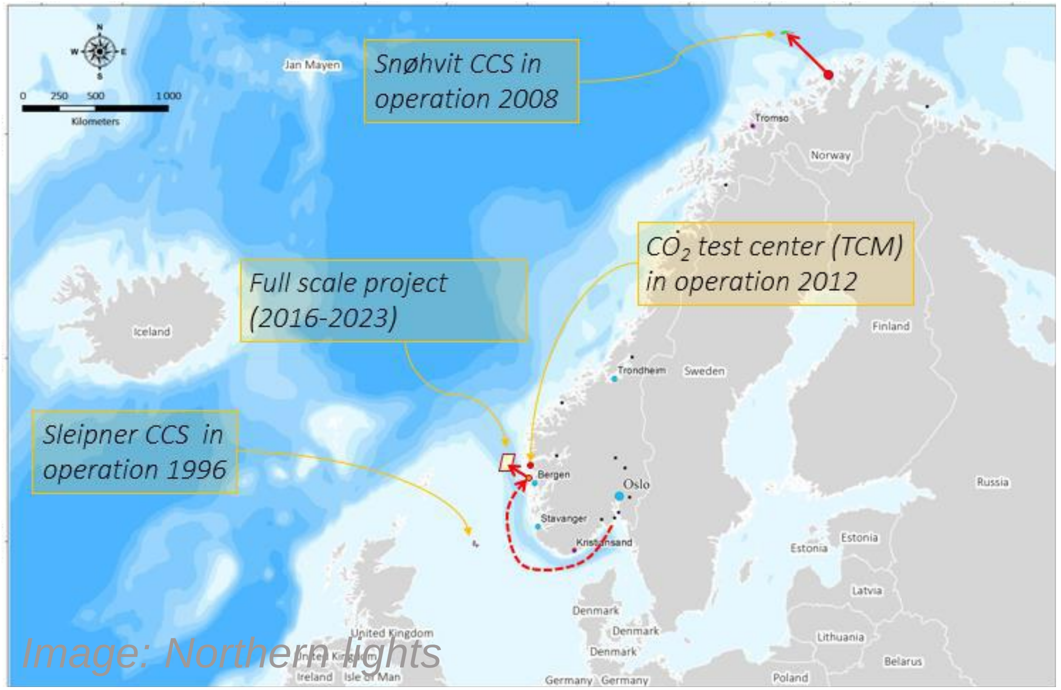
1 Operating experience: Much has been learned from test, pilot and commercial scale CO2 injections in different types of geologic formations globally

Global CCS experience



Norwegian CCS experience

~23 years of successful industrial experience resulting in 23 million tons of CO2 stored



Sources: Carbon capture and storage – proven and it works by IEAGHG (2014); Northern Lights project

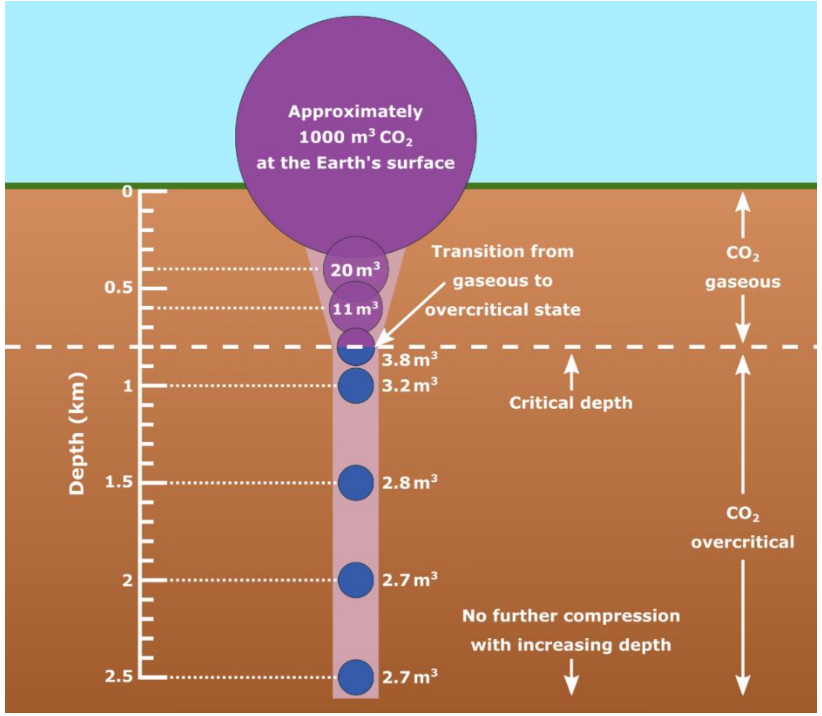
2 CO2 is stored as a result of four trapping mechanisms

State of CO2 while storage

- The CO2 is injected into the reservoir rock under pressure. The injection pressure must be higher than the pressure in the reservoir to displace the water in the storage rock but should be below the fracture limit of the storage and barrier rock
- Gaseous CO2 is compressed further until it enters "**supercritical phase**" where the volume of the stored CO2 is reduced to a fraction of the volume of the surface

CO2 during the storage process

- **Accumulation below the barrier rock** (structural trapping) : Injected CO2 displaces the salt water in the pores of reservoir rock
- **Binding in small pores** (residual trapping): If the rock pores are really small, part of the rising CO2 is captured by capillary forces
- **Solution in the salt water of the reservoir rock** (solubility trapping): A part of the injected CO2 dissolves in the salt water of the reservoir rock. This increases the density of the salt water so that it slowly sinks to the bottom
- **Mineral precipitation** (mineral trapping): In the long term, part of CO2 is converted by chemical reactions into minerals called carbonates



Source: ETH Zurich

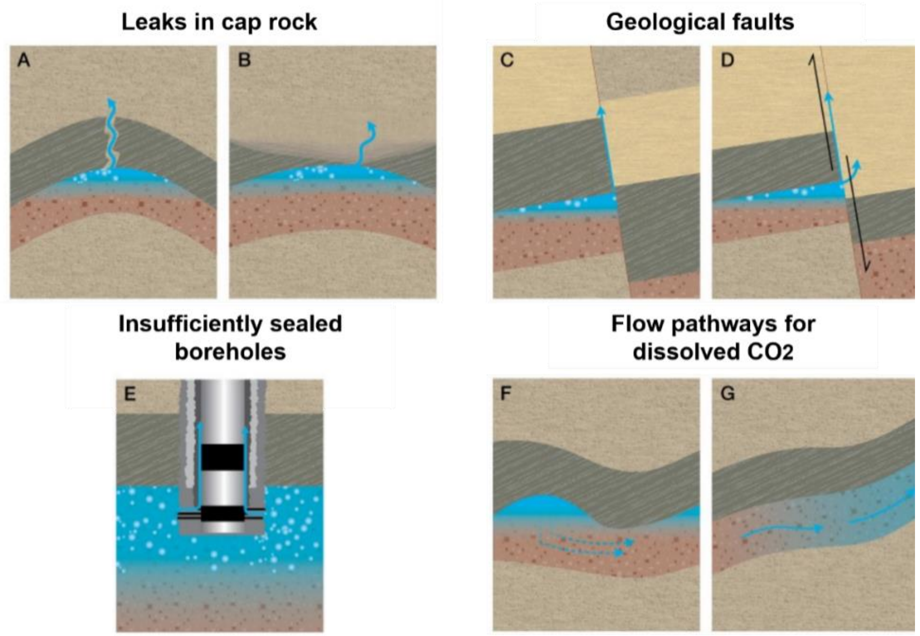
2 To minimise the risks of potential leakage, the right site must be chosen and then monitored. Reliable methods to seal potential leaks exist

Careful selection of CO_2 reservoirs and monitoring of the sites are necessary to ensure that risk of leaks is very low

Techniques used to monitor during and after CO_2 injection are:

- **Geological methods**: used to map the properties of the rock layers and geological faults to assess the suitability of a potential reservoir for CO_2 storage
- **Computer models of CO_2 storage facility**: models the dispersion of the CO_2 in the rock to understand the behavior and movement of the CO_2 over hundreds of years
- **Continuous measurements at the surface and in the wells**: to detect escaping of CO_2

Possible mechanisms that could cause leaks leading to a slow release of the stored CO_2



Method to seal leaks:

- Injection of cement or smart polymer gels
- Pumping out CO_2 via injection wells and storing in another reservoir

Source: ETH Zurich

Contents

Summary – Revenue streams (1/2)

1 **Overview**	• **In total, we expect the cost per ton of CO2 captured, transported and permanently stored to be at CHF 156-190 for the first-of-a-kind project at KVA Linth** • For the KVA Linth CCS chain, potential revenue sources include: o Selling CO2 credits (various markets exist) o Potentially avoided taxation in the future o Selling CO2 to the market for use o Increasing the price of waste treatment to its customers • Given current regulatory and marker environment, **none of these revenue sources are sufficient** and **financial support from the government or regulatory changes will be necessary to make the project commercially viable**
2 **Sale of CO2 credits**	• When implemented, the CCS project could bring revenues to KVA Linth via sale of CO2 credits. For every ton of CO2 captured, we expect, on a very indicative basis, 0.8-0.9 tons worth of CO2 credits, but it will depend on the final methodology • Two types of credits – for CO2 reductions and for CO2 removal – could be created at KVA Linth • **The only economically close-to-viable option would be to sell CO2 credits to KliK or a similar organization at CHF 150 (expected to rise to CHF 300)**. However, given the lack of options to do CCS in the past in Switzerland**, CCS is currently not included in the scope of eligible projects for KliK**. The Federal Office for the Environment and the Swiss Federal Office of Energy have been notified and acknowledged this situation

Summary – Revenue streams (2/2)

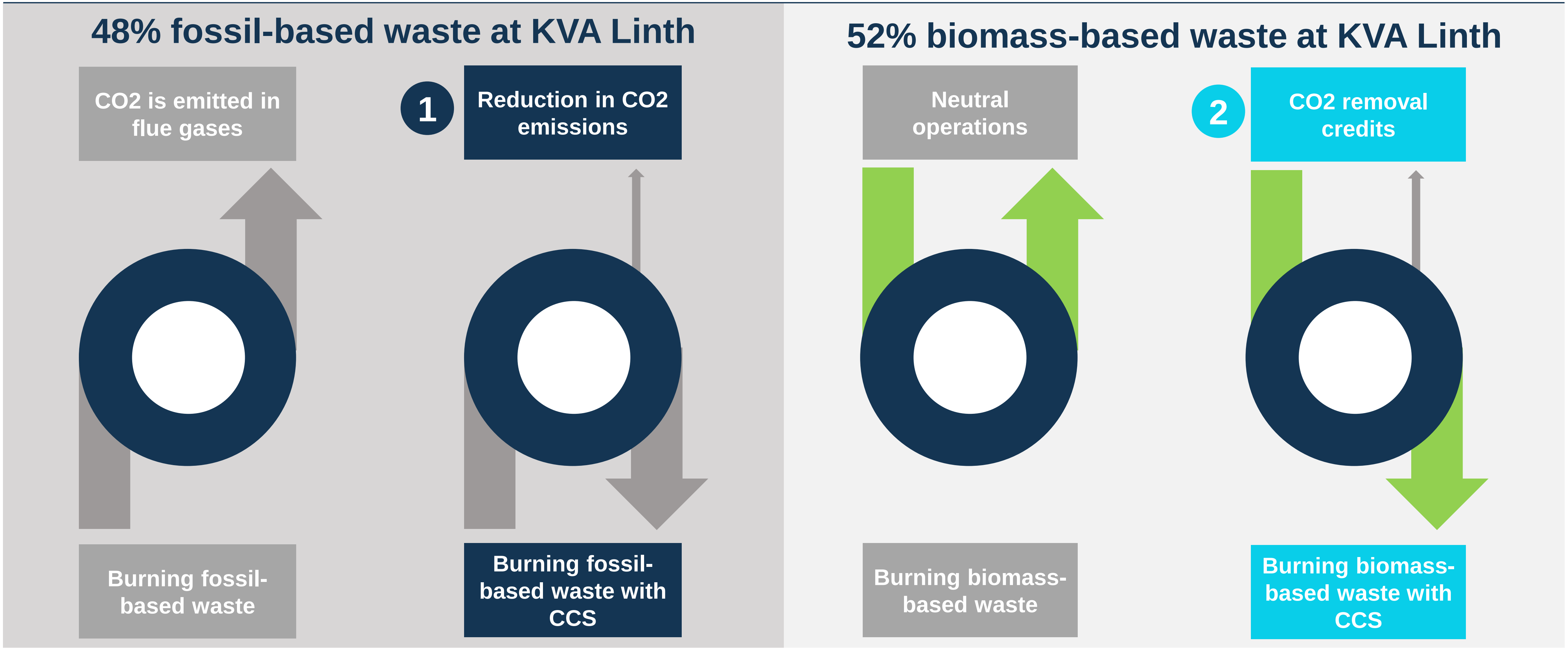
2 **Sale of CO2 credits (cont.)**	• **Given the current regulatory environment, only voluntary CO2 credits can be generated, however they would be insufficient to cover the costs**: ○ Prices at the international CO2 credit market are almost negligibly low at CHF 3-5 per ton of CO2 ○ Swiss CO2 credit market would attract higher prices, but the size of the market is too small to count on
Avoided taxation	• WtE plants are currently not taxed for CO2 emissions in Switzerland, although this may change in the future
3 **Sale of CO2**	• **The CO2 market size in Switzerland is too small and too unstable to guarantee income, although could be used to complement revenues if available**
Increased customer charges	• CO2 capture and storage costs can only be partially passed on to customers if KVA Linth is legally required to apply CCS to their plant • It is highly unlikely that the cost would be passed on to customers, but for illustrative purposes, we estimate CHF 0.6-0.8 increase in cost required per 35L bag

1 Government support is necessary to make the project commercially viable

Revenue type		Current status (per 1 t credited)	Potential future price and demand	Comments
CO2 credits	Compliance CO2 market (A)	**CHF 0** *No market is currently accessible*	From CHF 150 Expected to rise up to CHF 300 Long term contracts possible	Current compliance market for inland credits (KliK) is undersupplied at CHF 150
CO2 credits	Voluntary CO2 market (B)	**CHF 3 – 1,100** *Methodologies needed but can be developed*	From CHF 20 Long term contracts only possible for low prices	Market size for higher priced credits is too small to count on
Avoided taxation		**CHF 0** *WtE plants not taxed for CO2 emissions*	From CHF 87	Expected taxes unlikely to be lower than current avg. CO2 tax level in the country
Selling CO2 No climate benefit (!)		**Up to CHF 225** *Market size: 33,000 t p.a.*	Highly uncertain / market too small to count on	Market oversaturation is expected to push the price down significantly
Increased customer charges		**CHF 0** *WtE customers are not charged for CO2 capture*	Highly uncertain / increase eq. to CHF 0.6-0.8 per 35 L bag* would be necessary	Can only be partially passed on to all customers if CO2 capture is a legal requirement

*Assuming 5kg in weight of trash and 5 kg in weight of CO2 produced by each 35L bag

2 Two types of credits – For CO2 reductions and for CO2 removal could be created at KVA Linth with CCS



Source: adapted from Ecofys 2010

2 Carbon credits can be sold to either voluntary or compliance markets with the key difference being the fact that compliance markets are regulated

Two types of carbon markets

COMPLIANCE

Stiftung Klimaschutz und CO_2-Kompensation KliK

EU ETS European Union Emission Trading System

United Nations Climate Change

- In compliance markets, issuance of credits and **their quality is regulated** and the **credits are used to meet CO2 reduction obligations imposed on the emitters**
- Compliance market examples: Stiftung KLIK, EU ETS, Kyoto protocol market (expected to be replaced after 2020)
- Typical sectors - power generators, oil refineries, iron and steel production, cement, glass and ceramics and the paper and pulp

VOLUNTARY

Gold Standard for the Global Goals

puro

SOCIALCARBON®

- Voluntary market serves the purpose of **businesses, government departments, NGOs and single individuals wanting to offset their carbon footprint beyond regulatory obligations**
- Various international standards, such as Gold Standard exist to monitor and verify the quality and validity of the carbon credits

2 Only voluntary markets are available for KVA Linth in the current regulatory environment. The Swiss domestic market is more profitable than international

	Market	Description	Eligibility	Price and outlook
COMPLIANCE	Stiftung klimaschutz und CO_2-Kompensation Klik	• Carbon offsetting mechanism for Swiss motor fuels • No premium for CO2 removal credits	! **CCS based projects are currently not included** – regulatory/ legislative changes necessary	+ **CHF 152 per ton of CO2 for reduction in CH** and expected to rise + **Large unmet market demand**
COMPLIANCE	EU ETS	• EU emissions trading system, CH joined on 01.01.2020	! Pipeline transport required for CCS ! Waste-to-energy not included / CO2 removal not included	! Around **CHF 27 per ton of CO2, volatile** ! Kyoto-based credits **may not be accepted post-2020**
VOLUNTARY	International	• Global market for voluntary CO2 reduction credits • Special market for CO2 removal credits exists	! Methodologies for verified CCS credits need development, but expected soon	! Average price around **USD 3 per ton of CO2** ! CO2 removal credits **at CHF 21 per ton of CO2**
VOLUNTARY	Swiss-based	• Market for CO2 reduction credits generated in Switzerland	! Methodologies for verified CCS credits need development, but expected soon	! **Market volume is extremely small** + **At least 5x premium for Swiss credits**

Sources: KliK, myClimate, ClimeWorks, puro.earth

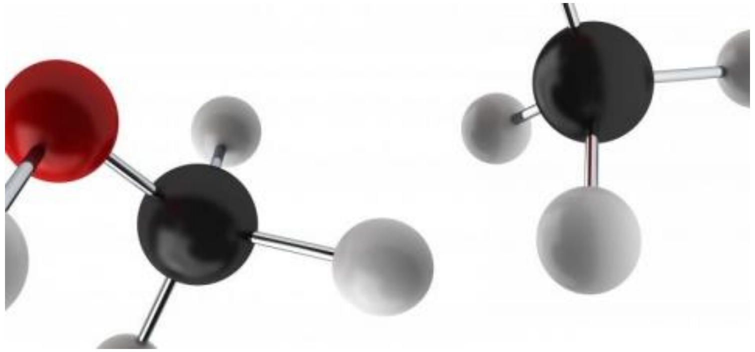
3 The CO2 market size in Switzerland is too small and too unstable to guarantee income, although it could be used to complement revenues if available

Food market

Sale of CO_2 to the food market (eg. carbonated drinks):

- + Price fluctuates with some sources citing numbers **up to CHF 225 per t** in times of shortages (summer months)
- ! Current market size in Switzerland estimated to be **33,000 t of CO2 per year** which would be **immediately oversaturated by less than one WtE plant with CO2 capture**
- ! **Climate benefit uncertain**

Production of renewable C-fuels or polymers



Sale of CO_2 to produce C-fuels or polymers:

- ! Currently, **there is no market in Switzerland** for these uses
- ! According to IEA, the number of commercial projects in this field is limited, often only viable in unique niche circumstances and most are at technology readiness level (TRL) 5 or less. Hence**, we expect a very limited market in the next 10 years**
- ! **Climate benefit highly uncertain**

Carbonated building materials

Sale of CO_2 to incorporate additional CO_2 into concrete:

- *Not expected to be a large market in the next 10 years*

Greenhouses

Sale of CO_2 for plant growth in greenhouses:

- *Small market in CH (max. 16,000 t CO2/y) with little demand close to KVA Linth*

Sources: Messer, IEAGHG technical review (2018) – Greenhouse Gas Emissions Accounting for Carbon Dioxide Capture and Utilization (CCU) Technologies, KVA Linth/Carbagas: Kostenabschätzung und weiterführende Unterlagen (2020)

Contents

Summary – Regulatory aspects

1 **Capture**	**Energy efficiency ratio** The **VVEA regulation** requires a minimum net energy efficiency (ENE) of 55% for waste-to-energy plants. The current assumption is that the energy consumption for carbon capture is considered as **outside energy use,** in which case, it will help KVA Linth increase its ENE to ~80-90% (projected based on 2019 data as well as potential future district heating network expansions). **Emissions from amine capture** • Amine-based carbon capture systems can emit nitrosamines and nitramines with possible health impacts • Emissions can be mitigated by choosing an appropriate amine solvent and integrating emission reduction technologies • **Switzerland currently has no regulation on maximum concentrations and monitoring of stack emissions of these compounds** • Norway could offer an example for regulation
2 **Transport**	• **Liquid CO2 transport by road, rail and inland waterways in Switzerland and across the EU is regulated as carriage of dangerous goods** – specific regulations need to be complied with • Switzerland has to ratify the 2009 Amendment to the **London Protocol** to be allowed to export CO2 for geological offshore storage
3 **CO2 safety**	• **CO2 presents a significant danger to humans at concentrations > 8 vol.%** • Adaptation of safety best practices from the existing CO2 industry allows for the safe design of carbon capture systems
4 **CO2 storage**	• Northern Lights will need to comply to the EU CCS Directive from 2009 on Geological Storage of Carbon Dioxide which was adopted and integrated in the Norwegian regulation framework

1 The net energy efficiency (ENE) is the ratio of the energy exported to the energy content of the waste, and must be higher than 55%

$$\text{ENE} = \frac{(2.6 \ * \text{Energy exported as electricity} + 1.1 \ * \text{Energy exported as heat}) - \text{Energy imported}}{0.97 \ * \text{Energy contained in the waste}}$$

VVEA Regulation:

- At least **55% of the input energy content** has to be used outside of the waste-to-energy plant.[1]
- Since the carbon capture unit is **not a legally required part** of the waste-to-energy plant, its energy consumption falls under **outside use**

ENE at KVA Linth:

- If the outside use consideration is confirmed by the regulators, CO2 capture may whelp KVA Linth to increase its ENE to ~80-90% (projected based on 2019 data as well as potential future district heating network expansions).

Source: BFE and BAFU; 1SR 814.600 (Verordnung über die Vermeidung und die Entsorgung von Abfällen, VVEA), article 32

1 Nitrosamines and nitramines have possible adverse health impact and are unregulated in Switzerland

	Ammonia !	Amines !	Nitrosamines and nitramines
Health impacts	Irritation of respiratory tract and eyes, MAK* (CH) = 14 mg/m^3	MEA: irritation of respiratory tract, MAK* (CH) = 5 mg/m^3	Possible carcinogens. Toxicity of many of the individual compounds is not well understood
Regulation	Concentration limit of 5 mg/Nm^3 specified in Luftreinhalteverordnung	No specific regulation on emission limits exists in Switzerland	
Monitoring	Standard reference methods established	No standard reference methods for stack emission monitoring High variability and inconsistency in data reported by pilot projects	

*Maximum workplace concentration

Source: Scottish Environment Protection Agency, 2015: "Review of amine emissions from carbon capture systems"; [1]EC No 205-483-3

2 Transport of liquid CO_2 is regulated as transport of dangerous goods

Regulations

- **Regulation concerning the International Carriage of Dangerous Goods by Rail (RID) applies to international traffic of CO_2 in Switzerland and the EU** (Directive 2008/68/EC transposes RID into the EU's internal law, including for national transport)
- The provisions on the carriage of dangerous goods by rail are also harmonised with the provisions for road transport and inland waterways transport

Implications

- Loading, unloading and storage of wagons can only take place in designated areas (e.g. **CO_2 cannot be loaded at regular SBB Cargo stations**)
- **It is crucial to avoid any blow-outs of CO_2 along the way to avoid payments for fire brigades**
- **Significant documentation required**

Sources: Intergovernmental Organisation for International Carriage by Rail, SBB Cargo

2 For international transport aimed at geological CO2 storage, Switzerland needs to ratify the 2009 amendment to the London protocol

London Protocol (1996)	2006 amendment	2009 amendment	Resolution on the provisional application of the 2009 amendment (11 October 2019)	**Switzerland needs to ratify the 2009 amendment**
• **Global treaty** of 51 Parties to **control pollution of the sea** and protect the marine environment • Replacement of the 1972 London convention	• Permission for **offshore geological storage** of CO2	• Allowance of **CO2 export** for geological storage offshore • **Not ratified** by the required two thirds of parties to the London protocol	• All countries who have **ratified the 2009 amendment** are **allowed to export and receive CO2** for offshore geological storage	• By **ratifying the 2009 amendment** to the London Protocol, Switzerland will gain access to the 2019 resolution for provisional application of the 2009 amendment • This will **allow the export of CO2 captured at KVA Linth** for geological offshore storage

Source: IEAGHG

3 CO_2 presents a significant danger to humans at concentrations > 8 vol.%

Effects of CO_2 on human health

0.04 vol.% — The air we breathe contains about 0.04 vol.% of CO_2. Carbon dioxide is an odourless, tasteless and colourless gas. It is classified as non-hazardous under the UN Global Harmonised System

3-5 vol.% — Exposure to an atmospheric CO_2 concentration in the order of 3 – 5 vol.% leads to headaches, respiratory disturbances and discomfort

> 8 vol. % — At concentrations above 8 vol. % cramps, unconsciousness, respiratory arrest, and eventually death can occur

At atmospheric pressure, CO_2 has a density 1.5 times higher than air. It therefore **flows downhill and collects in depressions, pits or basements**

Sources: European Chemicals Agency, Health and Safety Executive, Linde Gas, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5380556/

3 Adaptation of safety best practices from the existing CO2 industry allows for the safe design of carbon capture systems

Globally, 230 mllion tons of CO2 are used every year in the fertiliser industry, for enhanced oil recovery, food and beverage production, and other industries. Therefore, extensive experience and regulation for large-scale handling of CO2 exists.

The design principles developed for the existing CO2 industry can largely be applied to carbon capture systems:

1. **Avoid enclosed spaces and hollows** where CO2 can accumulate in the system design. Where this cannot be avoided, conduct risk assessments to identify mitigation strategies
2. **Establish leak detection procedures:**
   - Sight and sound
   - Hand-held detection
   - Fixed detection (for confined spaces)
3. **Avoid material failure** by prior tests under specific operation conditions (where no standard certification exists)
4. **Avoid material corrosion** through formation of solid CO2
5. **Include blow down lines** for emergency depressurisation

Sources: International Energy Agency: “Putting CO_2 to Use”, 2019; Energy Institute: “Good plant design and operation for onshore carbon capture installations and onshore pipelines”, 2010.

4 Northern Lights is regulated in accordance with the EU CCS Directive from 2009 on Geological Storage of Carbon Dioxide which was adopted and integrated in the Norwegian regulation framework

EU CCS Directive (also integrated in the Norwegian regulations)

Permitting	• **Storage sites require permits** the contents of which are specified in the EU CCS Directive and **deal with the entire lifetime of the storage site**
CO2 injection	• CO2 streams shall consist overwhelmingly of CO2 and **CO2 composition should verified** to be in line with the regulations **prior to injection**
CO2 storage	• **EU CCS Directive on Geological Storage of Carbon Dioxide** (Directive 2009/31/EC), from 25 June 2009 regulates all CO2 storage in geological formations in the EU

Process	Requirements
Operations	• **Operations need to be monitored**, including whether CO2 is behaving as expected, and detailed reports must be submitted to the competent authority • Routine (at least once a year) and non-routine inspections by the competent authority shall be executed and **inspection reports shall be made public**
Closure	• The operator shall be responsible for sealing the storage site and removing the injection facilities • After a storage site has been closed, the operator remains responsible for monitoring, reporting and corrective measures until transfer of responsibilities • The competent authority may at any time require the operator to take the necessary corrective measures. **If the operator fails to take the necessary corrective measures, the competent authority shall take them itself.**
Transfer of responsibility and long-term liability	**Responsibility can be transferred to the competent authority** only if the following conditions are demonstrated: • **All available evidence indicates that the stored CO2 will be completely and permanently contained** (conformity of the actual behaviour of the injected CO2 with the modelled behaviour; absence of any detectable leakage; storage site is evolving towards a situation of long-term stability) • **Minimum period of 20 years** has elapsed (unless the competent authority is convinced that the criterion referred to in point (a) is complied with before the end of that period) • Operator has made a financial contribution to at least cover the **anticipated cost of monitoring for a period of 30 years** • The site has been sealed and the injection facilities have been removed

Source: EU Directive 2009/31/EC

Agenda

- Introduction
- CO2 capture
- CO2 transport
- CO2 storage
- Revenue streams
- Regulatory aspects
- **Industry outreach**

Summary – Industry outreach

1 Stakeholder involvement

- **Implementation of the pioneering CCS chain for KVA Linth requires support from large number of stakeholders** whose involvement has already grown significantly during the project
- **In particular, long term cost reduction also requires a CO2 transport network** – several stakeholder groups are already involved in dicussions on this topic
- Waste-to-energy, cement and chemical industries have been targeted in the course of this project for collaboration on a CO2 transport network. In addition, close dialogue has been established with political stakeholders at various levels
- The project has also contributed to raising awareness of this decarbonisation option in Switzerland and in September 2020, the Federal Council approved a report on negative emissions prepared by FOEN listing CCS on municipal waste to energy plants as one of the top priorities

2 Next steps

- **CO2 collection network study for Switzerland is carried out by Saipem (funding by VBSA, SFOE, ERZ)**
- Targeted meetings will be organised during the upcoming year with various stakeholders groups in order to communicate project findings, advance government action and form an «industry coalition» for CO2 transport network collection

1 The implementation of the pioneering CCS chain for KVA Linth requires support from large number of stakeholders

Project stakeholders

kva linth energie+recycling	Regional support	Technology providers	Transport solution providers	National support	International support
• Management board • Employees • End customers	• Inhabitants of the region • Municipal authorities • Stakeholders in new infrastructure (CO_2 pipeline, new railway connection)	• CO_2 capture providers • Adjacent technology providers (e.g. measurement, monitoring, storage, liquefaction equipment)	• SBB Cargo / ChemOil • Pipeline owners • CO_2 wagon rental companies • Other equipment providers (e.g. filling stations)	• Swiss people • SFOE, FOEN, the Federal Government and political parties • Potential funding providers (e.g. KLiK, Southpole) • NGOs (e.g. Greenpeace)	• Norwegian government as well as the Northern Lights project (managed jointly by Equinor, Shell and Total) • Germany, Netherlands (CO_2 transport path) • EU

1 List of potential project partners for next steps: all identified stakeholder groups have already been contacted and partnerships are in formation

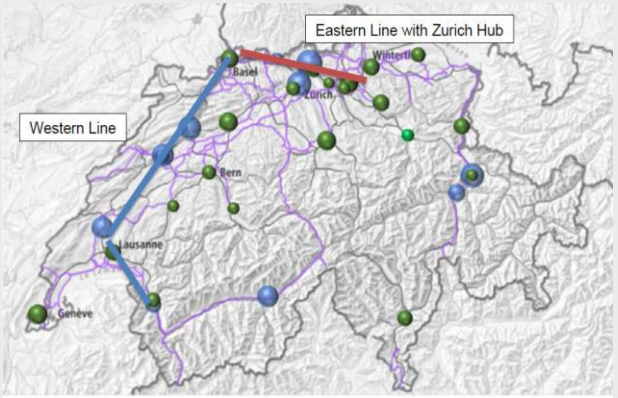
	Description	Status
CO_2 capture & related technology providers	• CO_2 capture solution providers or providers to CO_2 capture solution providers (e.g. Sulzer) • Providers of related equipment (e.g. storage)	+ Ongoing dialogue
CO_2 transport network providers	• Truck, rail and potentially barge owners and infrastructure operators • Pipelines owners, builders and adjacent technology providers	+ Ongoing dialogue
CO_2 emitters / owners / users	• Largest point sources of CO_2: Waste to energy and cement plants • Bio-CO_2 "owners": Biogas / waste water treatment plants, ClimeWorks • Other industry and industry associations (e.g. VBSA, Science Industries)	+ Ongoing dialogue
Local municipalities	• Cities and cantons with high climate ambition	+ Ongoing dialogue
Government	• Swiss Federal Offices and political parties	+ Ongoing dialogue
International partners	• Northern Lights project • EU, Norwegian, German, Dutch governments • Large industry stakeholders (i.e. automotive companies)	+ Ongoing dialogue

2 Next steps: ETH sus.lab is already engaged in several further industry/academic inititiatives aimed at CCS transport network creation

Industry-based CCS pipeline network design study

Already ongoing

- **Saipem** has been engaged to provide a **conceptual study for a CO2 collection network in Switzerland**



Involved stakeholders

- Funded by VBSA, SFOE, ERZ
- Study provider: Saipem
- Study coordinator: ETH sus.lab

Academic studies on CCS network optimization

Already ongoing

- **Building optimization model for a CCS network in Switzerland/EU** – in progress at Separation Processes Labotary led by Prof. Mazzotti together with Reliability and Risk Engineering Group led by Prof. Sansavini at ETH (with contribution from ETH sus.lab
- **Application for H2020 funding** with a large consortium led by SINTEF outstanding and **includes modelling of the European CCS network as a core component**

Involved stakeholders

- ETH Zurich
- H2020 application: over 18 partners representing industry and research institutions

Targeted stakeholder meetings

Already ongoing

- **Targeted stakeholder meetings and initiatives (for discussion):**
  - Communication of results to other WtE plants in Switzerland
  - Further meetings with pipeline network stakeholders e.g. in other hard-to-abate industries
  - Ongoing discussions with a large automotive owner in Germany to accelerate pipeline network work across the EU

Involved stakeholders

- Organized by ETH sus.lab / KVA Linth / VBSA

2 Next steps: With feasibility of the CCS value chain demonstrated for WtE, further work is required to facilitate broader CCS deployment in CH and beyond

Key actions for progress on CCS adoption:

- Investigating the potential and feasibility of CCS to decarbonize other hard-to-abate sectors, e.g. cement, steel
- Engaging with European stakeholders on options for a European-wide CO2 transport infrastructure (incl. governance and regulation)
- Developing clarity on CCS project financing (from first of a kind to scale up) and revenue sources including the potential for negative emissions in various CCS applications
- Examining current public sentiment towards CCS together with relevant stakeholders (e.g. NGOs)

Authors and project

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Additional input and support in the project:

- CO2 capture and integration: AVR Duiven, Lonza, Fortum Oslo Varme
- CO2 transport: SBB Cargo, ChemOil, VTG, Carbagas, ETH Separation Process Laboratory (Chair Prof. Marco Mazzotti)
- CO2 storage: Northern Lights project
- CO2 revenues: South Pole

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