NET ZERO by 2050
Decarbonizing large emitters in Switzerland
Introduce myself and “sus.lab”

Deep dive into CCS in Switzerland – our current project with KVA Linth and future plans

Q&A – discuss what you are most interested in and your questions and help us collect questions!

Inspire you to think about what we all need to be working on today to get to “net zero by 2050”
Agenda & goals

- **Introduce myself and “sus.lab”**
- **Deep dive into CCS in Switzerland** – our current project with KVA Linth and future plans
- **Q&A** – discuss what you are most interested in and your questions

Inspire you to think about what we all need to be working on today to get to “net zero by 2050”
Sus.lab is a “Think- and Do Tank” launched by the Chair for Sustainability and Technology (SusTec) at the Management Department of ETH Zurich

**Our mission**
Real world impact on sustainability based on latest research

**Our history**
- Sus.Lab was founded in 2016 out of a feeling of increasing urgency of global sustainability issues like climate change
- sus.lab brings sustainability research into the real world much faster – building on 15 years of research on sustainability technology, policy and management
In 2018 we delivered a broad range of projects under the umbrella of sus.lab, together with the researchers at SusTec

New products: Scouting and assessment of 100+ innovative construction materials for market potential and sustainability

Climate solutions: opportunity for capture and utilization of CO2 for the industry association of waste to energy plants

Resolving barriers to innovation: Support of the CEFLEX consortium in their 2025 goal to make flexible packaging circular

New business opportunities: Business cases and sustainability assessment for greenhouses for local vegetable production on supermarket rooftops

Sustainability strategy: Co-creation of a sustainability roadmap with the top management of the Swiss Salt makers

New business: Preparation of scale-up of new “insects to protein” solution – comparative assessment to other treatment options

Technology risks: Impact of increasing numbers of electric vehicles on electricity distribution grids for distribution grid operators in Switzerland

Thought leadership: Report on opportunity for blockchain technology for climate action
A new paradigm since 2019: NET ZERO

Required global CO2 reductions to reach 1.5°C target

CO2 in Gt p.a.

- 50% reduction from 2018 to 2030 (global net human-caused CO2)
- ‘Net zero’ by 2050
- Switzerland has committed to this target
- California by 2045 (in regulatory process)
- EU (in process)
- And companies (Nestle, Quantas, HeidelbergCement)...

Source: IPCC Special Report on 1.5 degrees,
Net zero will require fundamentally different approaches

Example: Swiss emissions over the last decade
Mio tons of CO2e

- Over the last decade Switzerland has reduced inland emissions by 5 Mt
- For the building and transport sectors solutions are emerging through district heating, heat pump, better insulation, electrification and hydrogen
- For agriculture, industry and waste no realistic replacement technologies exists to reduce emissions to zero

Check out: climateactiontacker.org
We are working on the “hard to decarbonize” sectors

**Net zero for waste incineration** in CH
- First study: Technology options for the Association of Waste Incineration plants (VBSA), Oct ’18-Jan’19
- Follow up: Feasibility of a full scale demonstration with capture of 120kT of CO2 and transport to the North Sea for storage Jun’19-Jun’20

**Net zero shipping** in the North Sea/ Baltic with a German cargo ship owner
- First study: Report on innovation opportunities launched at dedicated industry event, Jul-Oct ’19
- Follow up: Building an international industry consortium and preparing a 10 mio EU proposal for a full scale demonstration of a net zero ship (Oct ’19 -Jan ’20)

**Net zero for food supply chains**
- First study: Baseline and portfolio of options and case study on three markets with a global consumer goods company (Sept ‘19-April ’20)
And are building our portfolio of projects for circular economy of plastic

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polymers in solution</strong> – Identifying <em>risks and business opportunities</em> of the growing awareness of the risk of polymers in the environment beyond packaging (Industry project)</td>
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<tr>
<td><strong>Recycling in Ghana</strong> – Supporting the demonstration and scale up of ASASE’s first plant with scouting for new applications of recyclate, and development of an environmental assessment</td>
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<tr>
<td><strong>Concept for an Innovation Center for Sustainable Retail (ICSR)</strong> with Swiss Retailers – Funded by ClimateKic</td>
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<tr>
<td><strong>Plastics packaging baseline</strong> – From intuition to hard data in collaboration with Prof. Hellweg and an industry partner (confidential until launch)</td>
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<tr>
<td><strong>Supporting the CEFLEX flexible packaging consortium</strong> with understanding the technical and organizational barriers to re-organization of the value chain</td>
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Agenda & goals

- Introduce myself and “sus.lab”

- **Deep dive into CCS in Switzerland** – our current project with KVA Linth and future plans

- **Q&A** – discuss what you are most interested in and your questions

Inspire you to think about what we all need to be working on today to get to “net zero by 2050”
In all scenarios for 1.5 degrees, carbon dioxide removal is needed, and scenarios include up to 1’218 Gt of total CCS until 2100

Breakdown of contributions to global net CO₂ emissions in four illustrative model pathways
Billion tons CO₂ per year (Gt CO₂/yr)

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>2050</th>
</tr>
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<tbody>
<tr>
<td>CCS required</td>
<td>0</td>
<td>348</td>
</tr>
<tr>
<td>(cumulative GT</td>
<td></td>
<td></td>
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<tr>
<td>until 2100)</td>
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<tr>
<td>Final energy</td>
<td></td>
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<tr>
<td>demand</td>
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<tr>
<td>(vs 2010)</td>
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<tr>
<td>2030</td>
<td>-15%</td>
<td>-5%</td>
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<tr>
<td>2050</td>
<td>-32%</td>
<td>+2%</td>
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<tr>
<td>Renewable</td>
<td></td>
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<tr>
<td>share in</td>
<td></td>
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<tr>
<td>electricity</td>
<td></td>
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</tr>
<tr>
<td>2030</td>
<td>60%</td>
<td>58%</td>
</tr>
<tr>
<td>2050</td>
<td>77%</td>
<td>81%</td>
</tr>
</tbody>
</table>

1 CCS from the 2 mio tons of organic waste incinerated today are “BECCS" - Bioenergy with Carbon Capture and Storage
Source: IPPC “Global Warming of 1.5 degrees" Summary for Policy Makers

- 3 out of 4 of the example scenarios by IPCC require CCS – of cumulatively up to 1218 GT until 2100 – corresponding to ~28 years worth of current global emissions
- Only scenario P1 does not require CCS, but in turn would require final energy demand to shrink by 15% until 2030 and by 30% until 2050, as well as a very fast ramp up of renewable electricity to 60% globally by 2030
Switzerland’s ~30 largest point sources are mainly WtE plants and cement industry. Together they emit about 7 Mt of CO2 per year.

Large CO2-point sources in Switzerland
(>100’000t 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 mio tons of fossil CO2, and 2 mio tons of biogenic CO2 (from biogenic waste, like wood or sewage sludge)
For all elements of the CCS chain, the technologies as well as considerable operating experience is available – overview

<table>
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<th>Capture</th>
<th>Transport</th>
<th>Storage</th>
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<td>+ Large-scale CO2 capture projects using amine-technology have already been implemented, barriers to scale so far were economics and lack of utilization options for CO2.</td>
<td>+ Extensive experience in the US with CO2 pipeline transport</td>
<td>+ Several CO2 storage projects are on the way in Europe, with UK taking a leading position</td>
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<td>+ First Capture in a WtE plant started in Netherlands last year – learnings were shared</td>
<td>+ Northern lights consortium is working on sea transport for pick-up at North Sea coast</td>
<td>+ Norway is planning to open up their offshore geological reservoirs to all European CO2 emitters by 2024 (subject to final approval by 2021)</td>
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</table>

**Internationally**

| + CO2 capture at Lonza has been in operation for >60 years | ! Rail transport is feasible, however not effective at large scale (Mt) | ? Theoretical (unproven) storage capacity for approximately 2.6 Gt of CO2 in deep porous geological formations in Switzerland |
| + KVA Linth is currently working with AKER Solutions on design of capture facility for 100’000t CO2/year | ? All large emitters are connected to the gas distribution grid in Switzerland | ! Very low exploration maturity (and high cost of exploration) make it an unlikely option in the next 10-20 years |

**In Switzerland**

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Details see following pages
Large-scale CO2 capture projects using amine-technology have already been implemented, barriers to scale so far were economics and lack of utilization options for the captured CO2

**Largest operating post-combustion carbon capture project worldwide - Petra Nova CCS - a 240 MW coal power plant retrofit**

- Amine-based post-combustion capture technology
- CO2 is piped to an oil field for enhanced oil recovery
- Commenced its operation without delays and budget overruns in December 2016, proving the possibility to deploy the technology at large scales

**First post-combustion carbon capture project - 110 megawatt (MW) Boundary Dam plant in Canada**

- Amine based post-combustion capture technology
- Capacity to capture app. 1 Mtpa of CO2 (not used fully)
- Operational since 2014
- Most of CO2 is piped for enhanced oil recovery and part is piped to the Aquistore test project for injecting into a 3400m deep saltwater-infused sandstone
- Some issues with amine degradation, leading to higher operational cost than anticipated

**Main issues so far:**

- Unclear how to use or store the captured CO2 (enhanced oil recovery is the main path but lacks environmental appeal)
- Cost still above CO2 price in most countries
- Societal/political discussion around CO2 storage and questionable sustainability in case of use for enhanced coal + oil recovery

Sources: Global CCS Institute, EIA, JX Nippon Oil & Gas Exploration Company, Aquistore, SaskPower
Carbon Capture has been done for decades, the application to waste-to-energy plants is starting now

### Chemical industry
- **Capture medium:** NH3
- **In operation for 63 years at Lonza**
- **High-pressure process**

### First operational capture at a WtE plant in Europe
- **Plant in Duiven, NL**
- **Operational since 2019**
- **Capture medium:** Generic MEA (monoethanolamine)
- **Corrosion issues in the presence of oxygen**

### Planned WtE plant
- **Plant in Twence, NL**
- **Start of capture in 2021**
- **Capture medium:** Proprietary amine S26
- **Noncorrosive, biodegradable**

Sources: AVR Duiven, AKER Solutions, Lonza
Dutch plant AVR Duiven started operating a capture facility in 2019

**CO2 Capture**

- **Capacity**: 100ktpa (274 t per day) out of 400ktpa total emissions (by a capacity of about 350ktpa waste)

- **Space requirements**: 25x30m (larger space would be better), 30m in height

- **Onsite CO2 storage**: 1000t (4x250t tanks) of CO2 (liquefied)

- **CAPEX**: EUR 20 mn (partially subsidized)

- **Business model**: Partnering with Air Liquid/CO2 sold to greenhouses. Expect to break-even.

Sources: AVR Duiven
STORAGE

Geological storage in Switzerland is unlikely to become realistic in the next 10-20 years

- Theoretical (unproven) storage capacity for approximately 2.6 Gt of CO2 in deep porous geological formations in Switzerland
- This would be equivalent to storing app. 70 years worth of Swiss CO2 emissions*
- Very low exploration maturity and sceptical public opinion make it an unlikely option in the next 10-20 years
- A recently started projects in Jura mountains is injecting CO2 to test for leakage and seismic effects on a very small scale, but will take a very long period to produce conclusive results

Sources: Swiss geology portal (2010), *2016 CO2 emissions excl. land use change of 39 Mt based on the GHG inventory by Federal Office for the Environment (FOEN, 2018), ETH News (2019)
Especially around the North Sea several large storage projects are on the way

- Several projects are planned for CO2 storage in the North Sea with the UK and Norway taking the lead
- Natural gas-to-H2 with integrated carbon capture and storage is becoming a way of making projects economically feasible
- Fossil-fuel companies are actively involved and often in the lead / some projects make use of legacy oil and gas assets

Source: International Association of Oil and Gas Producers (IOGP, 2018)
Norway is planning to open up its offshore geological reservoirs to third parties by 2024 (subject to final approval by 2021)

**Technology description**

- The ‘Northern Lights’ project includes transport, reception and permanent storage of CO2 in the North Sea
- **Equinor’s CCS method is a proven process** – Building on 20 years of injecting CO2 at Sleipner project, started in 1996, with a total of 15.5mt CO2 (0.9 Mt per year)

**Capacity**

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

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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
Operating experience: Much has been learnt 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 mn tons of CO2 stored

Sources: Carbon capture and storage – proven and it works by IEAGHG (2014); Northern Lights project
In the Northern Lights project, extensive testing is currently underway in preparation of opening the first storage site (Aurora)

Tests for the first Northern Lights storage site are already starting

- Exploitation permit EL 001 for CO2 storage in Aurora has been awarded by Norwegian authorities
- CO2 will be injected in the Johansen formation, a saline aquifer sealed with several hundred of meters of cap rock, 1-2,000 m below the seabed
- Drilling of the confirmation well is ongoing
- Negotiations with the Norwegian state on the exact process for long-term responsibility transfer are currently ongoing

Sources: Northern Lights, Furre et al., Building Confidence in CCS: From Sleipner to the Northern Lights Project, Special Topic: Energy Transition, 2019
STORAGE – Regulatory compliance

The site 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

**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.
California has created a framework for permanence certification of CCS, requiring operators to reserve 8-16% of credits, monitoring over 100 years as well as insurance.

**Policy description**
- Low Carbon Fuel Standard (“LCFS”) is one of several policies in California
- Amended in 2018 to allow CCS projects that (i) reduce emissions associated with the production of transport fuels sold in California, and (ii) that directly capture CO2 from the air to generate LCFS credits
- To qualify, projects need to meet the requirements of the CCS Protocol and receive Permanence Certification

**Permanence Certification**
- Operators must monitor the site for at least 100 years post-injection
- Financial instruments are required to ensure availability of funds for remedial action for the full period
- The credits have been trading on average between $122/tCO2 and $190/tCO2 in the past 12 months to February 2019

**Geological certainty**
Only sites in which the fraction of CO2 retained in the storage complex is very likely to exceed 99% over 100 years post-injection will be approved

**Certainty of funds for corrective action**
- **Buffer Account**: Operators must reserve between 8% and 16.4% of the credits they generate
- **Insurance**: A financial instrument, such as insurance, that covers the cost of corrective action based on third party costs even if the operator goes bankrupt is required

Source: The LCFS and CCS Protocol: An overview for policymakers and project developers – Global CCS Institute, 2019
Chosing the transport modes between KVA Linth and Rotterdam/Norway requires an assessment of technical requirements, costs and emissions.

**Possible transport modes**

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing solution</td>
</tr>
<tr>
<td>Truck</td>
<td></td>
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<tr>
<td>Onshore/offshore pipeline</td>
<td></td>
</tr>
<tr>
<td>Train</td>
<td></td>
</tr>
<tr>
<td>River barge/sea vessel</td>
<td></td>
</tr>
</tbody>
</table>

**Transport – Linth Case**

1. Distance between KVA Linth and Weesen: 6 km.
2. Distance between Rotterdam and Weesen: 1400 km.
   - Distance between Basel and Weesen: 150 km.
   - Distance between Rotterdam and Basel: 800 km.
A combination of truck, train and Rhine barge appears to be the cheapest option for transport to Rotterdam.
A combination of onshore pipeline, train and offshore pipeline appears to be the lowest-emissions options from KVA Linth to the Northern Lights site.

Lowest-emissions option: 6.3 ktCO₂/y = 6% of transported CO₂

Does not include energy for liquefaction and leaks

- Truck: 45 tCO₂
- Train: 200 tCO₂
- Barge: 5,500 tCO₂
- Sea vessels: 3,000 tCO₂

Annual emissions for transport:

- Existing solution
- Feasible by 2025
- Long-term solution
Due to different capacities, interlinking of transport modes requires intermediate storage of liquefied CO₂

<table>
<thead>
<tr>
<th>Truck</th>
<th>Capacity per truck¹: 20-25 tCO₂</th>
<th>12-15 trucks/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Due to the weight limit of 40 t for road trucks, containers cannot be completely filled.</td>
<td></td>
</tr>
<tr>
<td>Train</td>
<td>Capacity per wagon²: 60 tCO₂</td>
<td>5 rail wagons/day</td>
</tr>
<tr>
<td></td>
<td>Intermediate buffer storage needed until enough containers for full train.</td>
<td></td>
</tr>
<tr>
<td>Barge</td>
<td>Capacity per barge³: 5,400 tCO₂</td>
<td>~1 barge every 2 weeks</td>
</tr>
<tr>
<td></td>
<td>Intermediate buffer storage needed until enough containers for full barge.</td>
<td></td>
</tr>
</tbody>
</table>

Does the CO₂ stay in the same container along the whole route, or is it transferred to a new container for each mode change?

Sources: ¹ASCO, Peacock; ²VTG; ³PortLiner. Assumes transport requirement of 108,000 tCO₂/year.
Transport by rail is feasible and done today, at scale pipeline transport will be the most economical/feasible option.

**Implications of 10 Mtpa**

- **950-1,350 trucks per day**
- **~11 barges per day**
- **~450 rail cars per day**

**Sources:** Swisstopo, SFOE, ACT Acorn Feasibility Study (2018), Gazenergie

- The total quantity of exported goods from Switzerland is currently about 20 Mtpa.
- 10 Mtpa of CO2 would correspond to >450 rail cars per day.
- Large emitters are already today connected to gas pipeline infrastructure.
- Repurposing existing gas pipelines could be done at **25% of the costs** (UK based study).
A European network for CO2 transport is starting to emerge – Project “Northern lights” is developing ships for pick-up around the North Sea Coast.

Northern Lights storage site is already working with industry located along the European shoreline:

- 15 partners
- 7 countries
- 3 reciprocal alternative storage sites

Sources: Equinor, map adapted from Bellona (2018), Northern Lights
For Switzerland, according to a very rough estimate, the total investment for capture and collection infrastructure for 10 Mtpa CO2 is estimated at around 1.1 bn CHF.

**COST IMPLICATIONS FOR SWITZERLAND**

**Sources:** AVR Duiven, VBSA estimates

**CAPTURE & LIQUEFACTION UNITS**

~40 UNITS à 20 mio
~800 mio CHF

**TRANSPORT AND INTERMEDIATE STORAGE INFRASTRUCTURE**

~300 MIO CHF

Better estimates based on an engineering study are needed
Costs per ton of CO2 are likely to fall below 150 CHF (the current domestic marginal abatement costs) once the CCS chain is operated at scale in EU.

Example cost calculation for full cost per ton of CO2 from Switzerland to storage under the North Sea.

Please note that cost estimates are highly preliminary and will be updated throughout or project.

<table>
<thead>
<tr>
<th>CO2 capture &amp; liquefaction</th>
<th>Transport to North Sea Coast (Rotterdam)</th>
<th>Storage offshore</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>80-130 CHF (quote from a Swiss provider, incl. opportunity cost for thermal energy of 44-75 CHF)</td>
<td>50 CHF (combination of train and barge, without intermediate storage)</td>
<td>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)</td>
<td>~165-240 CHF</td>
</tr>
<tr>
<td>50 CHF (incl. 17 CHF for liquefaction)</td>
<td>10-13 CHF (5-8 CHF transmission, IPCC data, based on onshore pipeline for 10 Mton 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))</td>
<td>13-33 CHF (ZEP report based on several in depths studies in UK and NL. Offshore incl. offshore transport)</td>
<td>~85-125 CHF</td>
</tr>
</tbody>
</table>

COST IMPLICATIONS FOR SWITZERLAND

Such a large investment in green infrastructure is not without precedent

- The waste water infrastructure consists of ~800 treatment plants and 40-50'000 km public waste water pipelines
- The cost for build-up were between 40 and 50 bn CHF, around 80-100 bn CHF today

Source: Federal Office for the Environment
We started in 2018 – and a demonstrator for the full CCS chain with KVA Linth is currently in preparation

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### Core team

**Funded by**

- VBSA
- ASIR
- MAVT
- SBB CFF FFS Cargo
- equinor
- Shell
- VTG

### Other involved/supporting partners

**Funded by**

- Innovus - Swiss Innovation Agency
- Confederazione svizzera Confederazione svizzera

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**ONGOING ACTIVITIES**

**We started in 2018 – and a demonstrator for the full CCS chain with KVA Linth is currently in preparation**

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- equinor
- Shell
- VTG

**Other involved/supporting partners**

**Funded by**

- Innovus - Swiss Innovation Agency
- Confederazione svizzera Confederazione svizzera
Several other CCS projects are already under way. They aim at transforming Waste-to-Energy plants into energy hubs, with CO2, H2 and Methanol production.

- First commercial power to gas plant in Switzerland (Dietikon)
- H2 generated with electricity from WtE plant, combined with methane and CO2 from the waste water plant
- Under construction, start in autumn 2020

- Cooperation with Climeworks (delivery of heat for regeneration of CO2 absorber)

- Project for utilization of CO2 from waste treatment plant of ara Bern in construction material startup Neustark

- Vision for the WtE plant as an energy hub for heat, power, H2, O2 and CO2 for use and sequestration, with steam delivery to a close-by industrial site as next step
- First thoughts about utilizing the unused oil pipeline from Collombey to Genoa for CO2 transport

Source: Limeco, Satom presentation, Neustark
**We should now scale up our effort and start with a more structured effort to design a CCS- System for Switzerland**

<table>
<thead>
<tr>
<th>Implementation of demonstrator</th>
<th>Linth demonstrator</th>
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<tbody>
<tr>
<td></td>
<td>Supporting Linth with the build-up of the transport infrastructure for the demonstrator, incl. permitting, contracts with transport/infrastructure providers like SBB, Shipping, storage sites</td>
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<tr>
<td>Measurement and certification</td>
<td>Development of a methodology – Ideally on Linth case</td>
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<table>
<thead>
<tr>
<th>Designing a transport network</th>
<th>Collection infrastructure</th>
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<tbody>
<tr>
<td></td>
<td>Feasibility of a pipeline network using current infrastructure/routings, required permits/process together with current gas pipeline owners, CAPEX and OPEX estimates</td>
</tr>
<tr>
<td>Transmission Infrastructure</td>
<td>Concept for transmission logistics from Switzerland to storage sites, incl. technical feasibility/cost of reusing the existing oil pipeline Monthey/Genoa, options for contracting the pipeline for CO2</td>
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<table>
<thead>
<tr>
<th>Capture scale up</th>
<th>Capture readiness</th>
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<tbody>
<tr>
<td></td>
<td>Share knowledge and coordinate feasibility studies for CCS at each of the 32 large emitters</td>
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</table>

<table>
<thead>
<tr>
<th>Regulatory, contracting and finance</th>
<th>Coordination with “transit countries” and “storage countries”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Securing rights for cross border transport</td>
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<tr>
<td></td>
<td>Coordinating with other national collection/transmission infrastructure plans (Germany, France)</td>
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<td></td>
<td>Agreements with storage countries on volumes, costs, and liabilities for long term storage</td>
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<tr>
<td>Ensuring regulatory frameworks are in place</td>
<td>Developing the basis for regulation under Swiss CO2 law, industry regulations, and in the context of Paris</td>
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</table>
Our national CCS collection system could act as the seed of a continental CCS-System and accelerate progress towards climate goals

- Current projects in Europe focus on sites around the North Sea coast
- Switzerland could act as the seed for a continental network connecting the large industrial hubs in Germany, France and Italy both towards the North and later possibly to sites via the Mediterranean Sea
Agenda & goals

- Introduce myself and “sus.lab”
- Deep dive into CCS in Switzerland – our current project with KVA Linth and future plans
- Q&A – discuss what you are most interested in and your questions

Inspire you to think about what we all need to be working on today to get to “net zero by 2050”
Five aspects form the basis for safety of CCS – The climate perspective, the physical basis of the process, operational and monitoring experience and regulation

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Description</th>
<th>Source: Adapted from Furre et al., Building Confidence in CCS: From Sleipner to the Northern Lights Project, Special Topic: Energy Transition, 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate protection</td>
<td>Putting CO2 in deep geological formations is a lot safer and better than putting the same CO2 into the atmosphere</td>
<td>Safety of CCS means especially confidence that the stored CO2 remains trapped over long time horizons without leakage</td>
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<tr>
<td>Physical basis</td>
<td>CO2 is trapped in microscopic rock pores by the same process that has trapped natural gas for millions of years</td>
<td>Safety of CCS means especially confidence that the stored CO2 remains trapped over long time horizons without leakage</td>
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<tr>
<td>Operational experience</td>
<td>More than 20 years of operations at Sleipner show that CCS works</td>
<td>Safety of CCS means especially confidence that the stored CO2 remains trapped over long time horizons without leakage</td>
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<tr>
<td>Geophysical monitoring</td>
<td>The location of the CO2 underground can be measured (with some uncertainty) to confirm it is safely stored in the intended reservoir unit</td>
<td>Safety of CCS means especially confidence that the stored CO2 remains trapped over long time horizons without leakage</td>
</tr>
<tr>
<td>Regulatory compliance</td>
<td>Storage sites and processes need to conform with the Norwegian and EU CO2 storage directives</td>
<td>Safety of CCS means especially confidence that the stored CO2 remains trapped over long time horizons without leakage</td>
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