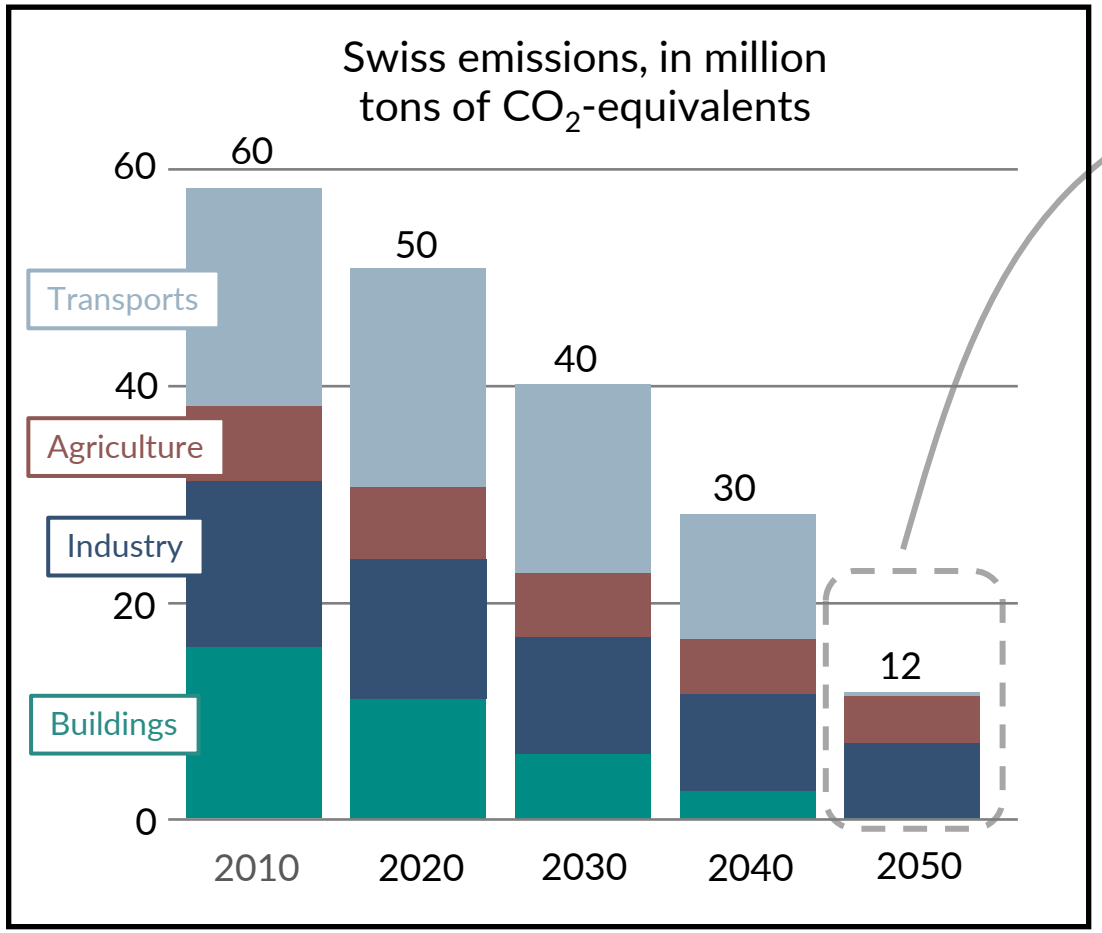
CO_2 capture, transport and storage – How permanent storage of CO_2 could succeed: experiences from Iceland and Switzerland

Marco Mazzotti
ETH Zürich

Net Zero 2024

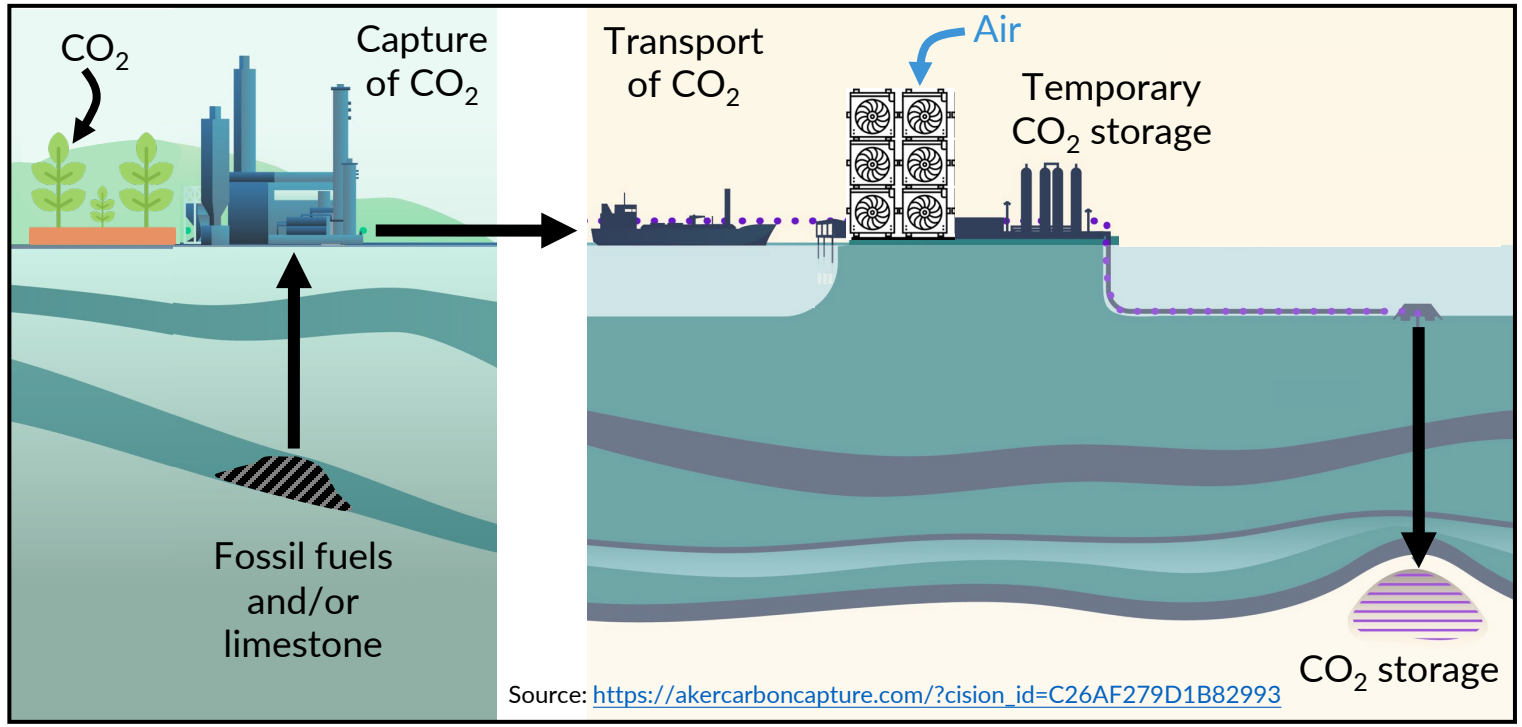
ETH Zürich – January 31st, 2024

Towards net-zero



How to tackle *hard-to-abate* emissions (12 mio. t):

Towards net-zero



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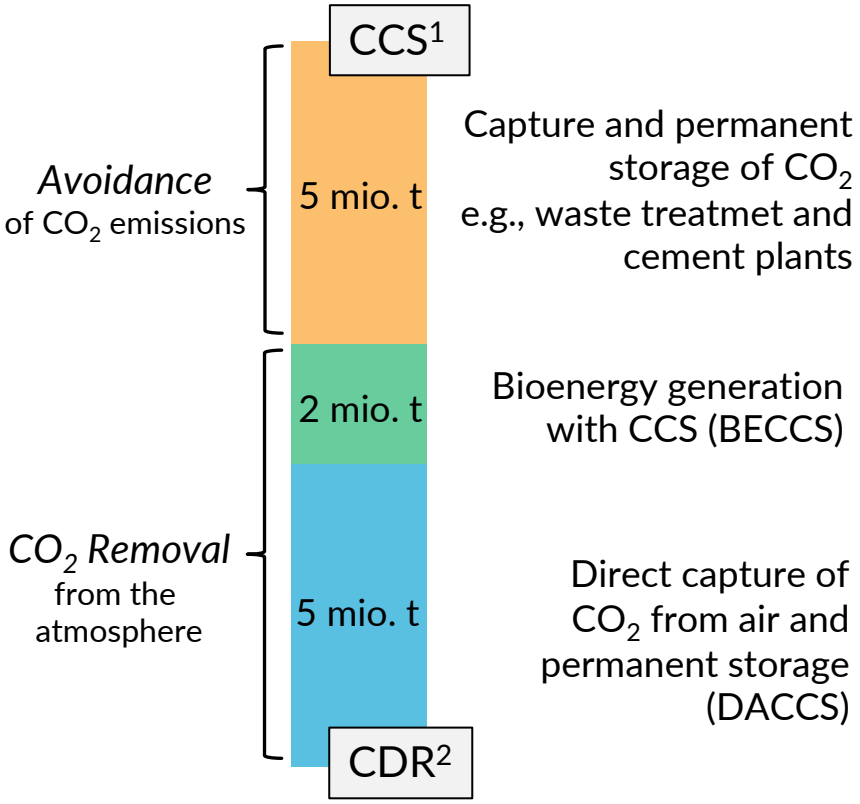
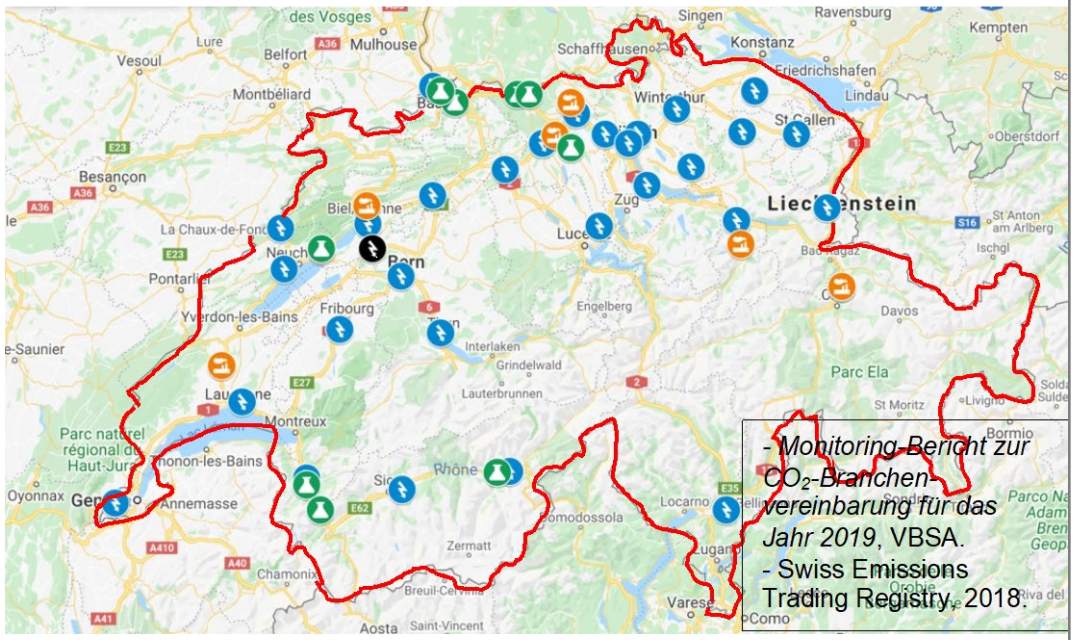


[1]CCS: CO_2 Capture and Storage
[2]CDR: Carbon Dioxide Removal technologies

Towards net-zero

Swiss large CO_2 emitters (today and 2050)



- **Waste-to-Energy** (30 plants) 4.5 Mt CO_2/y
- **Mineral industry** (7 plants) 2.6 Mt CO_2/y
- **Chemical industry** (9 plants) 1.1 Mt CO_2/y

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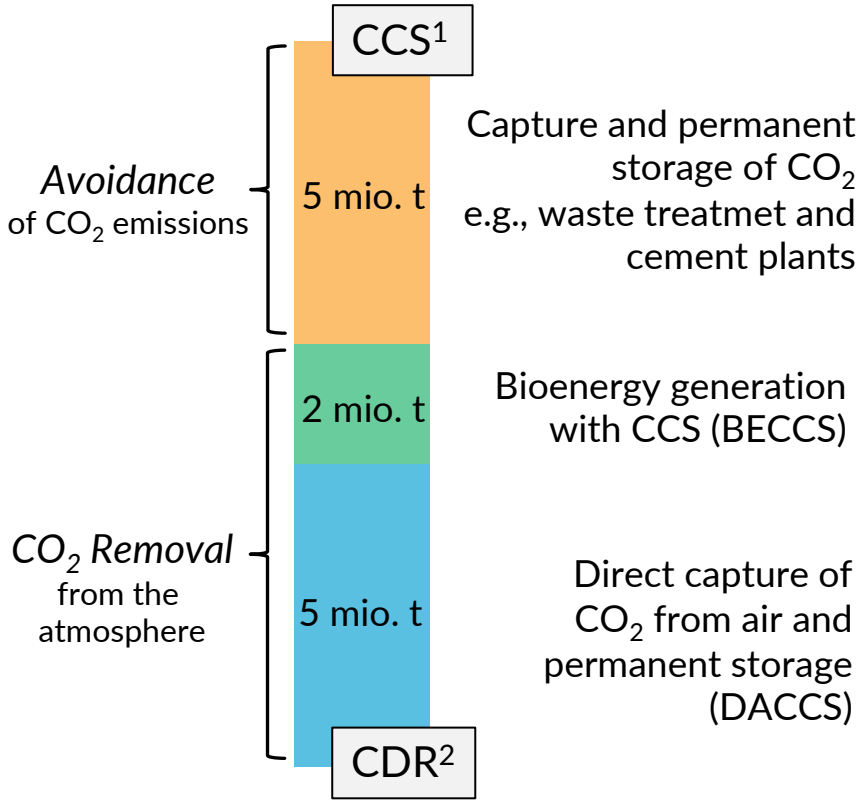

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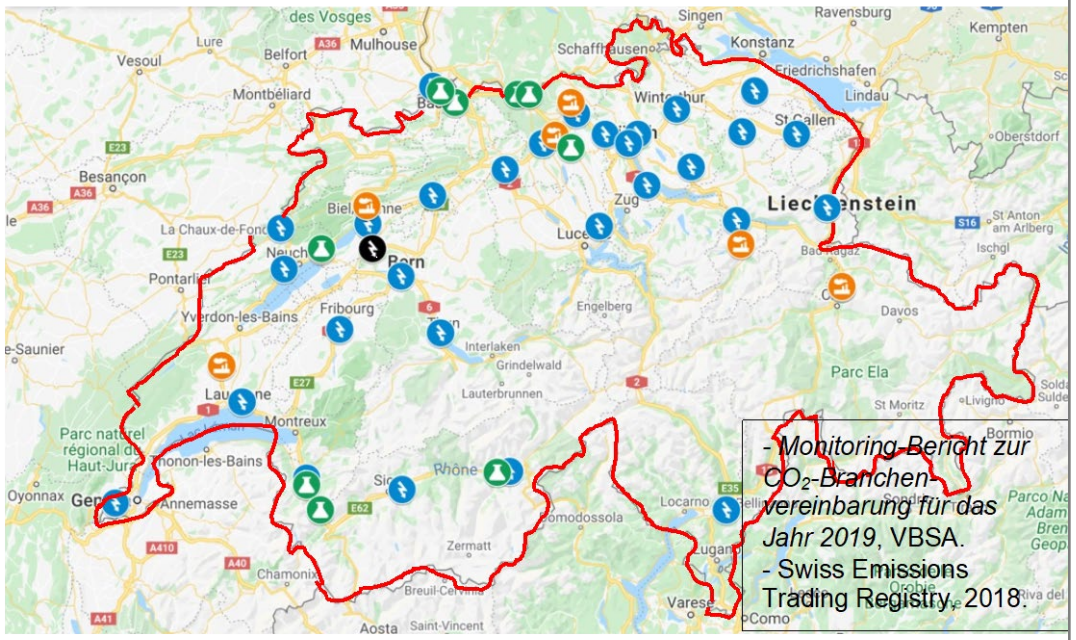

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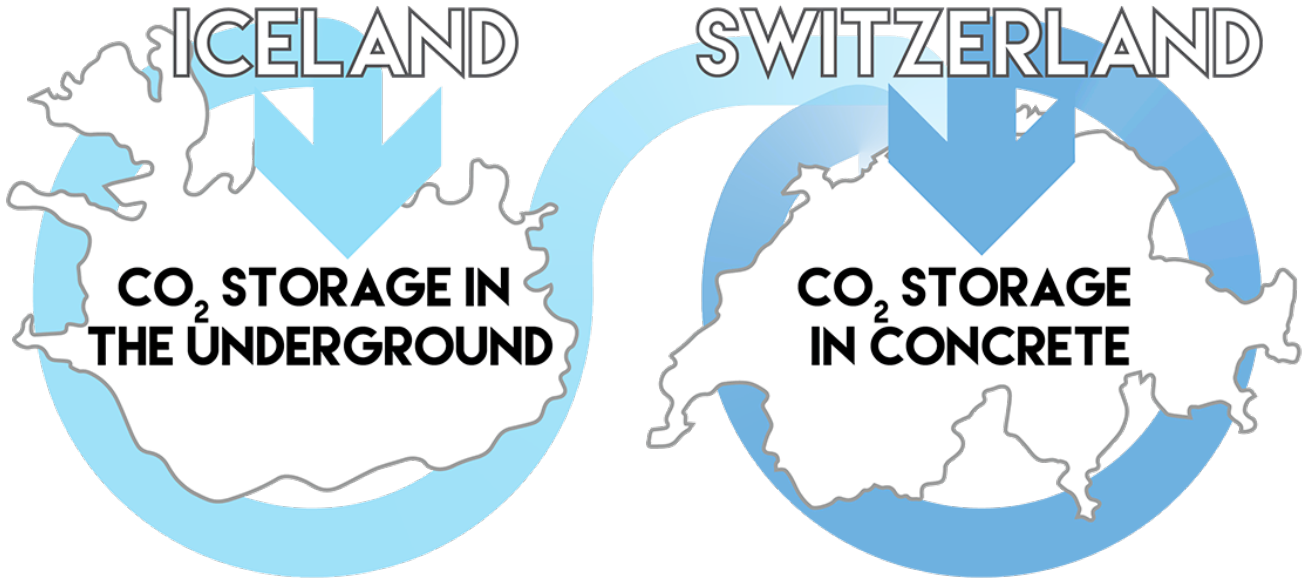
- In 2050, 7 MtCO_2 will have to be captured, transported, and stored, with point sources between 30 and 400 kt CO_2 /y spread all over the country
- CO_2 could be permanently stored:
  - In demolition concrete → a feasible solution with limited capacity
  - In the underground → No near-term, large-scale inland geological storage solution
- Need to establish thousands of kilometre-long supply chains from Swiss emitters to storage hubs, e.g., in the North Sea
- Clear national climate strategy, regulations, and measures toward implementation needed
- *Starting small, thinking big*

Demonstration and upscaling of CO_2 management solutions

Pilot project | Consortium



Academia, research, NGO

Emitters

Solution providers

Climate tech companies

DemoUpCARMA is financed and supported by the Swiss Federal Offices of Energy and for the Environment

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Domestic solution: CO_2 utilization and storage in demolition concrete

CCUS Value Chain

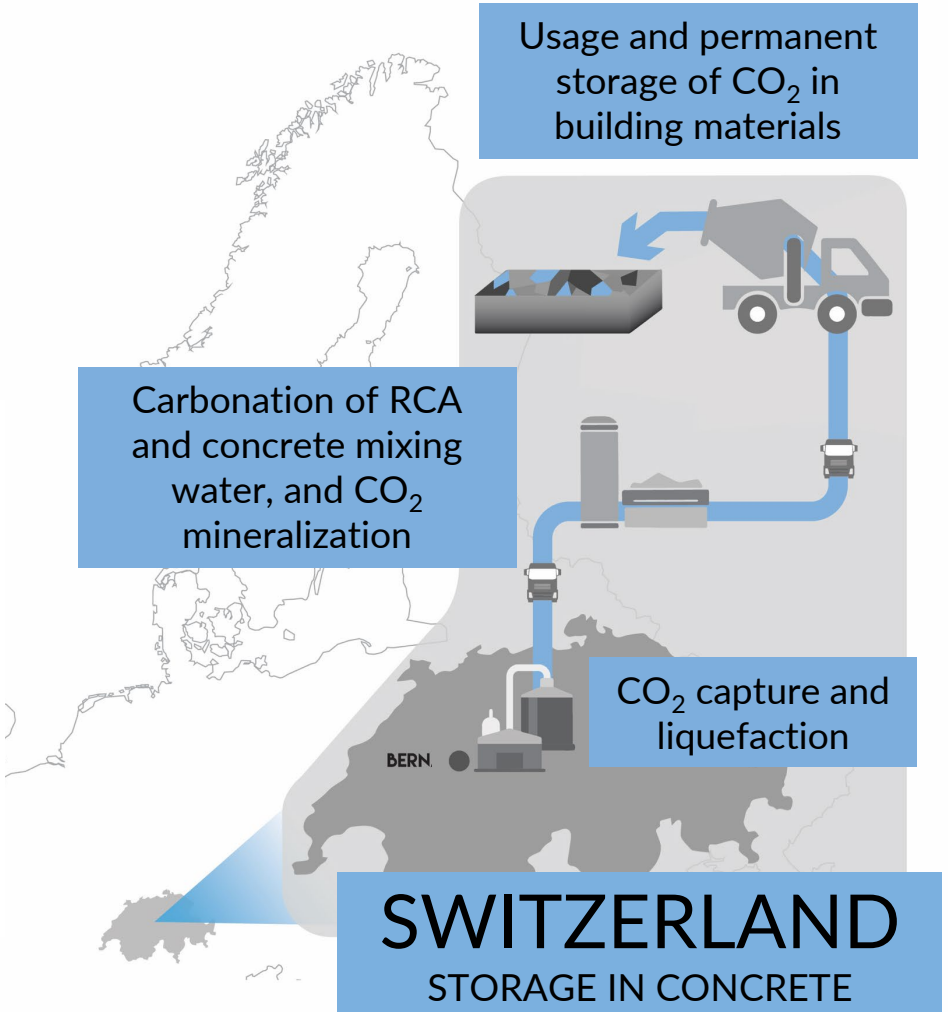
Concrete recycling plant:
Intermediate storage of CO_2

Kästli Bau, Bern, March 2022

CO_2 capture and liquefaction
at a waste-water treatment plant with biogas upgrader


Ara Region Bern

Permanent CO_2 storage
via carbonation of recycling concrete aggregates (RCA) and concrete mixing water



Domestic solution: CO_2 utilization and storage in demolition concrete

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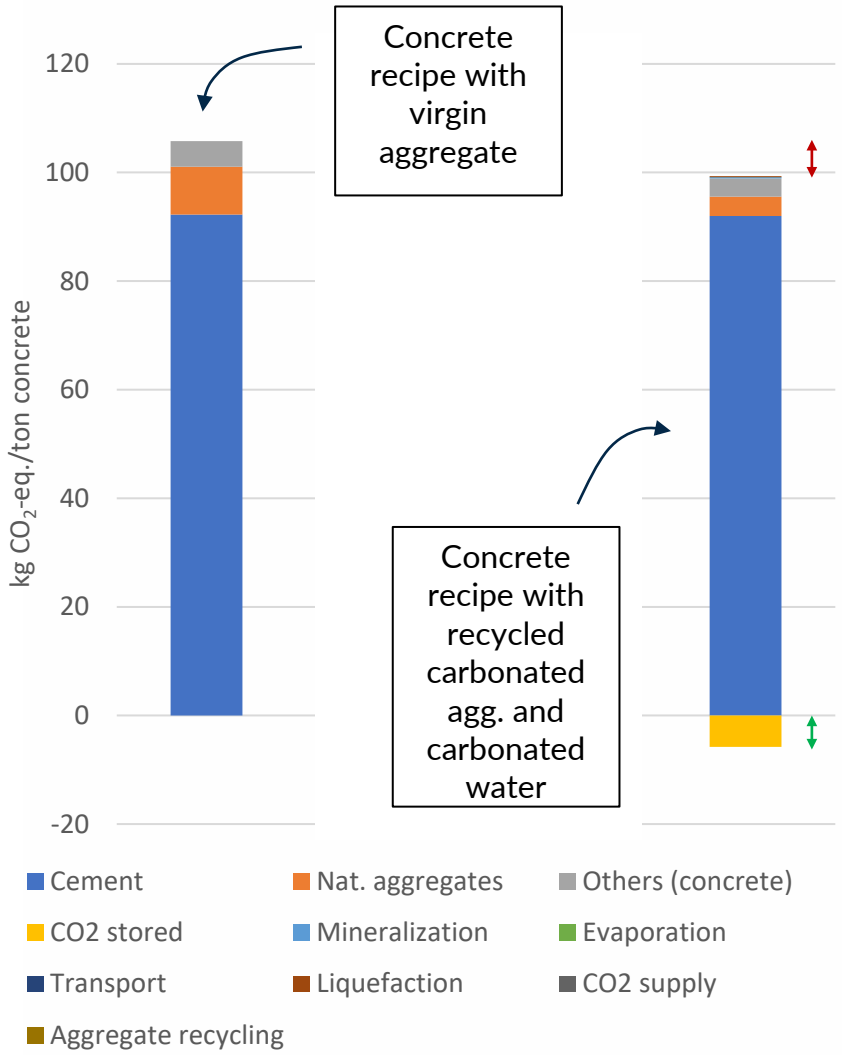
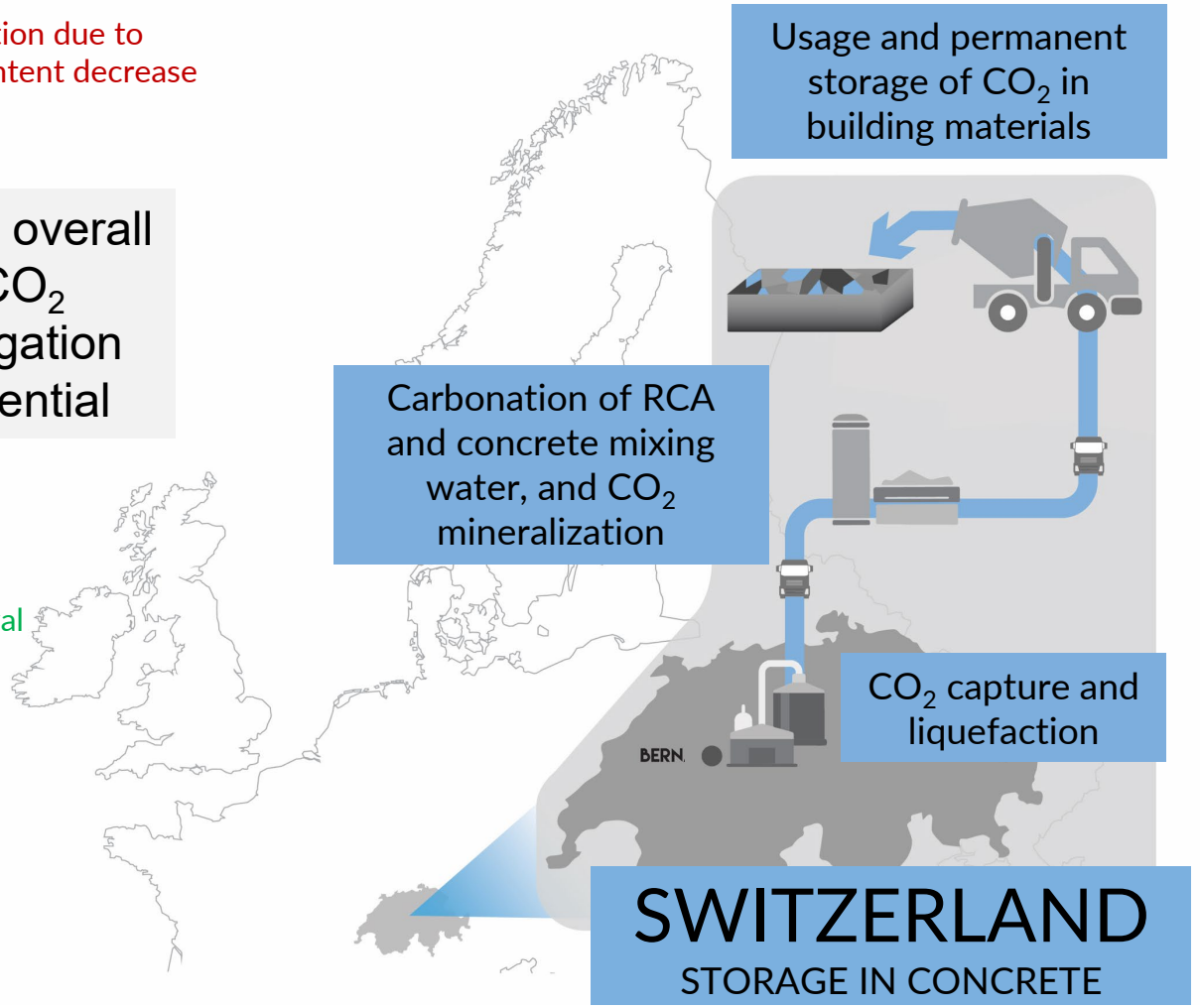


CO_2 reduction due to cement content decrease

CO_2 removal due to permanent storage of biogenic emissions

-12% overall CO_2 mitigation potential

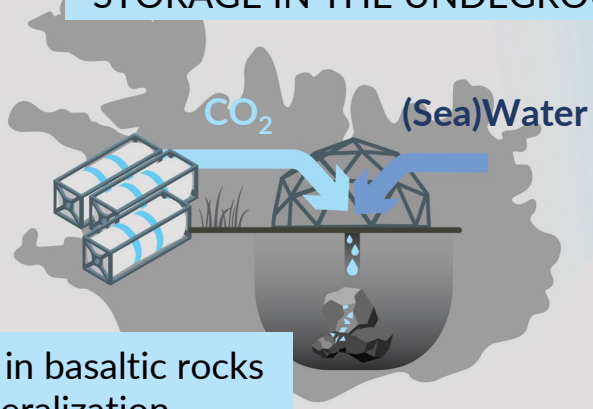


International solution: CO_2 transport and underground storage

CCTS Value Chain

ICELAND

STORAGE IN THE UNDEGROUND



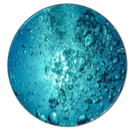
CO_2 injection in basaltic rocks and mineralization

REYKJAVIK

In-situ mineralization reaction:

Basalts and other reactive rock formations

+



CO_2 dissolved in water

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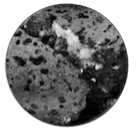


Solid carbonates

Snæbjörnsdóttir, S. Ó., *et al.*, 2020.

ROTTERDAM

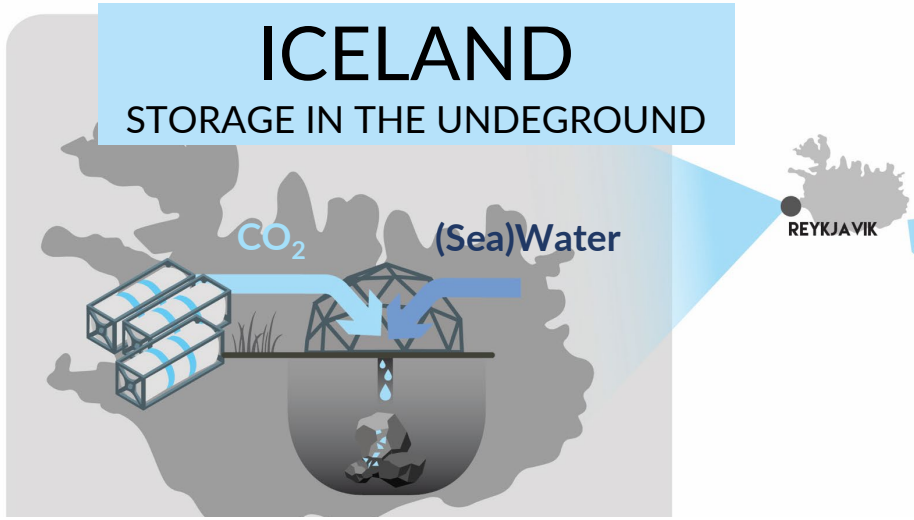
BERN

CO_2 capture and liquefaction

CO_2 container at the injection site, Iceland, August 2022

International solution: CO_2 transport and underground storage

CCTS Value Chain



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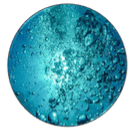

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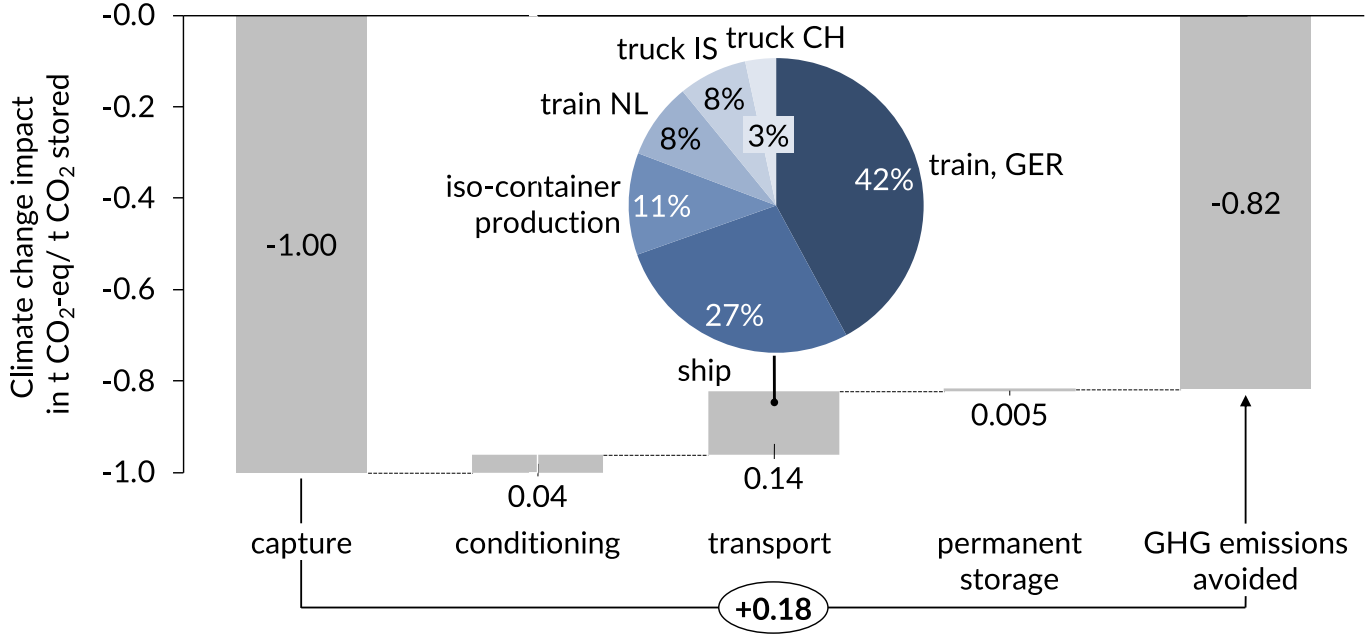
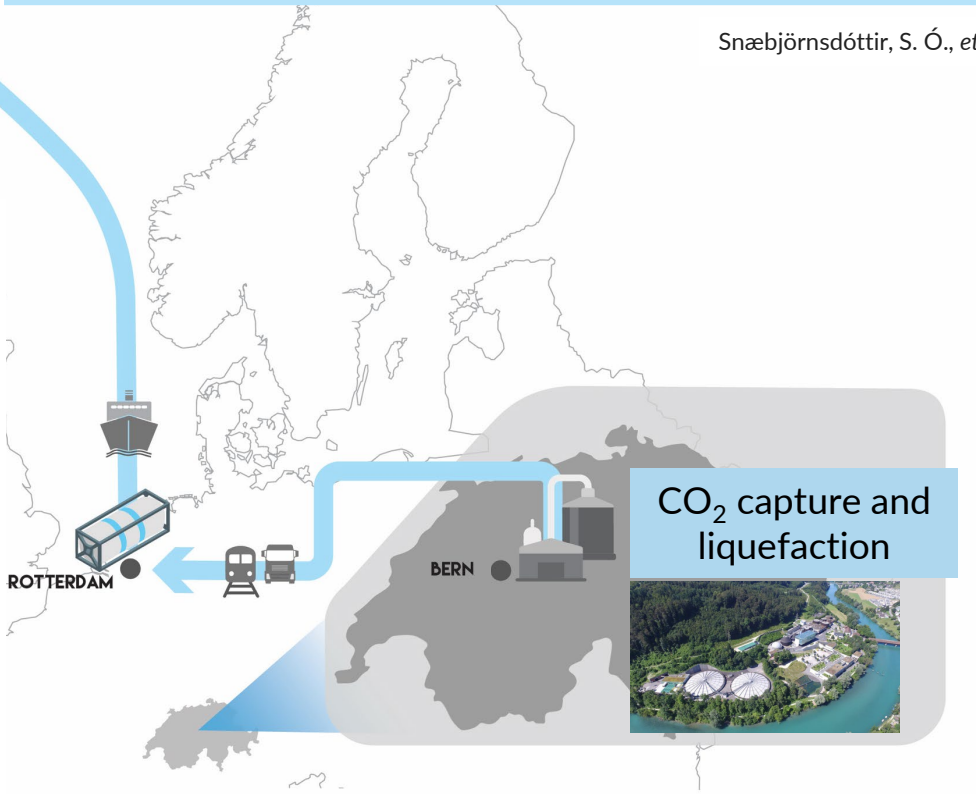


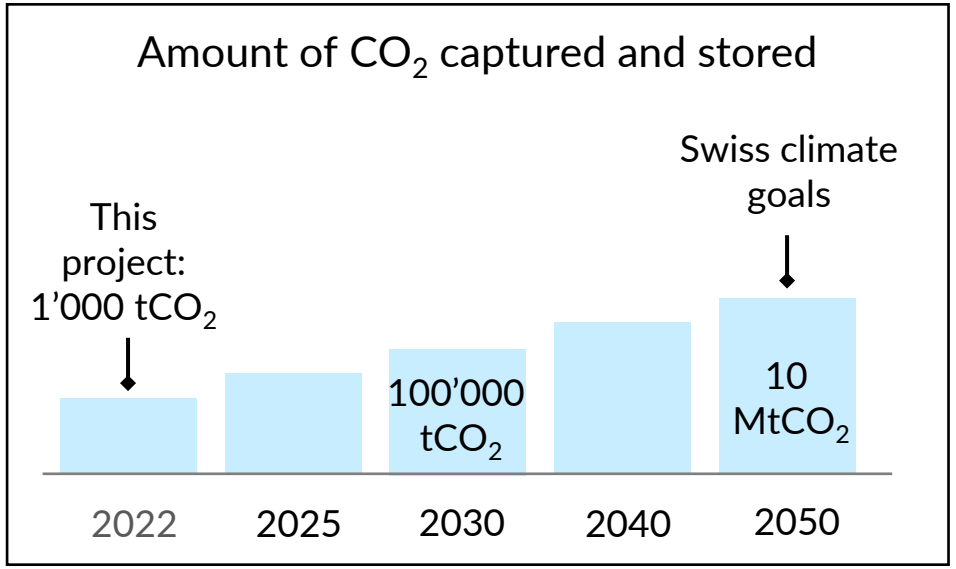


Demonstration and Upscaling of Carbon Dioxide Management Solutions for a net-zero Switzerland

Pilot project | 2021-2023

Capture

Transport and storage



Others

Climate policies and regulatory aspects
Financing mechanisms
Public perception

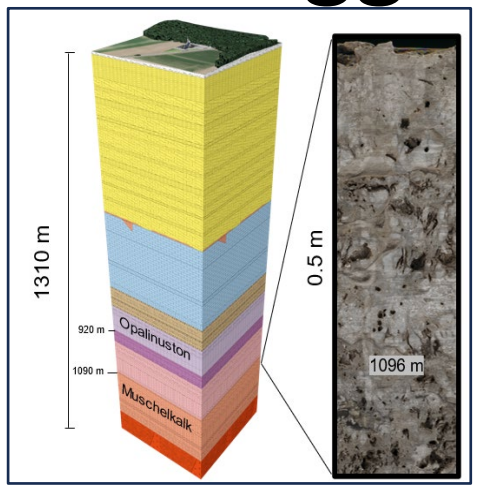
ETH Zürich and Swiss research contributions:

- **Fundamental scientific knowledge** in the natural, engineering, and social sciences
- Ability to identify effective solutions through a deep **systemic understanding** of global problems
- Excellent ability to **innovate and transfer knowledge** into practice and toward industry
- **Extensive network** of national and international collaborations and cooperation
- Creativity, enthusiasm, and motivation of researchers and students in working on scientific projects that tackle global problems

The Domino effect:

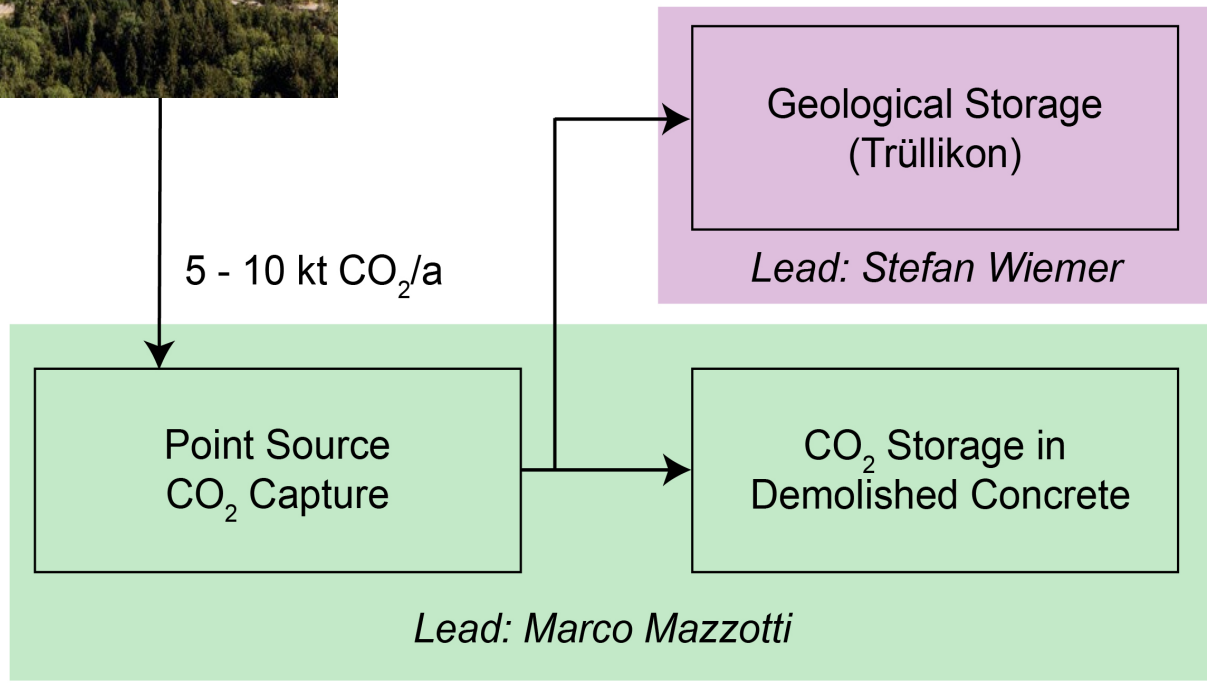
- City of Zürich (WtE plants) seeks CO_2 transport and storage service providers through tendering call
- Swiss Federal Admin evaluates borehole feasibility for CO_2 injection pilot
- The Climate Cent Foundation funds 5 CO_2 removal projects for ca. 50 MEUR

Follow-up: Towards net-zero at ETH Hönggerberg



Capturing (using membranes) and storing (in waste concrete) up to 5 kt/y of CO_2 (50% biogenic) for a major reduction of ETH scope 1 emissions (7.5 kt/y).

- **CITru**: the first, full-scale sequestration pilot in Switzerland injecting and monitoring 10 kt CO_2 into the Muschelkalk, through an existing NAGRA borehole in Trüllikon, ZH.
- Building on DemoUpCarma, with partners from Academia (ETH, EPFL, PSI, EAWAG, Uni Bern, Uni Neuchatel), Industry (cemsuisse, KVA/ERZ), Federal offices (BFE, BAFU, swisstopo).



First CCS project in the City of Zürich

Stadt Zürich
Tiefbau- und
Entsorgungsdepartement

29. Januar 2024

Netto-Null: Stadt will Projekt zur CO2-Abscheidung umsetzen

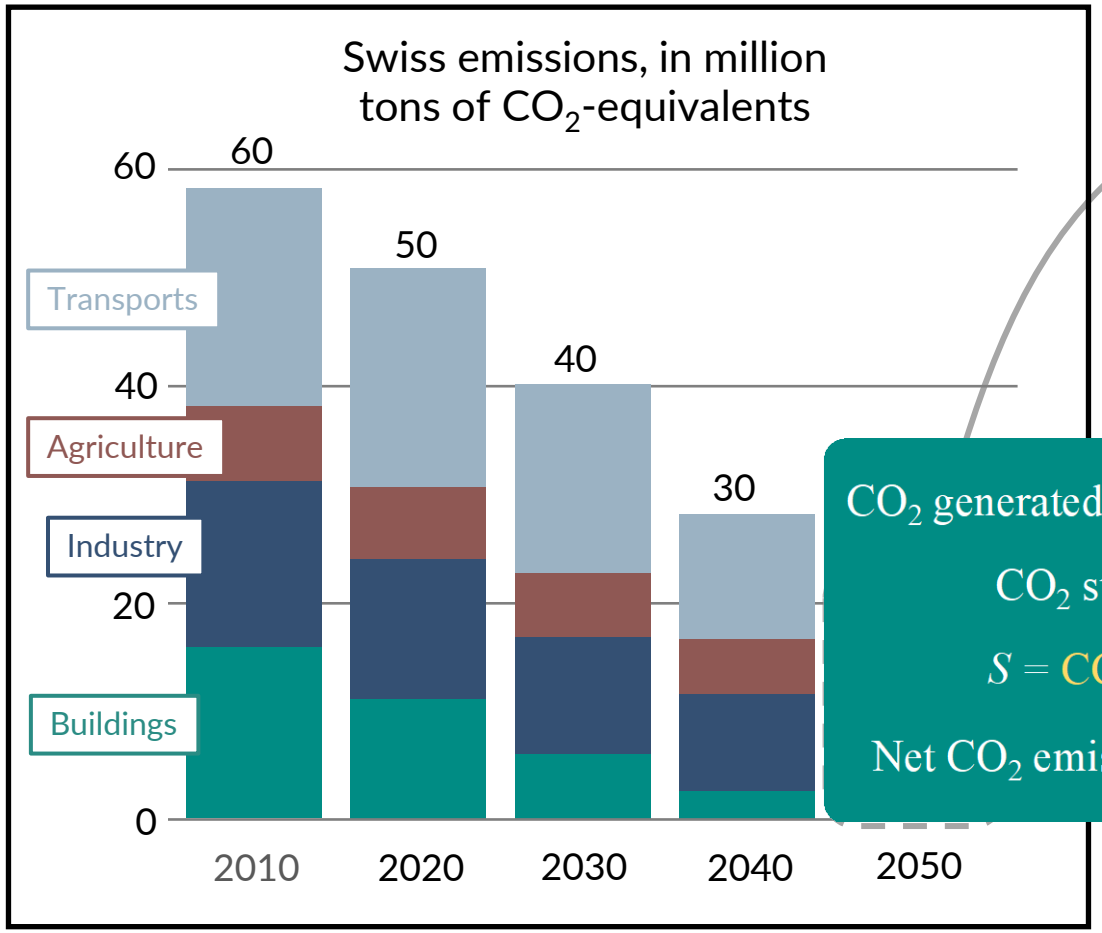
Um klimaneutral zu werden, benötigt die Stadt Zürich CO2 Negativemissionen. Dazu will der Stadtrat das CO2 der Klärschlammverwertungsanlage ab dem Jahr 2028 abscheiden und dauerhaft speichern. Für dieses Vorhaben beantragt er dem Gemeinderat zuhanden der Stimmberechtigten neue einmalige Ausgaben von 35 474 000 Franken und ab 2028 neue wiederkehrende Ausgaben von jährlich 14 212 000 Franken.

Potenzial von 25 000 Tonnen CO_2 pro Jahr

Speicherung in Recyclingbeton und unter dem Meeresboden

DEMO UP CARMA

Net-zero: are we on track?



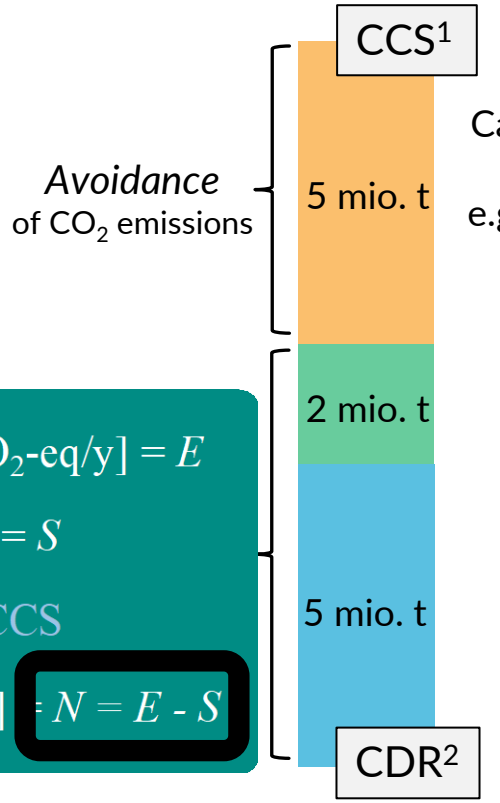
CO_2 generated, w/o storage [Gt CO_2-eq/y] = E

CO_2 stored [Gt CO_2-eq/y] = S

S = CCS + BECCS + DACCS

Net CO_2 emissions [Gt CO_2-eq/y] = $N = E - S$

How to tackle *hard-to-abate* emissions (12 mio. t):



Avoidance of CO_2 emissions

Capture and permanent storage of CO_2 e.g., waste treatmet and cement plants

Bioenergy generation with CCS (BECCS)

Direct capture of CO_2 from air and permanent storage (DACCS)

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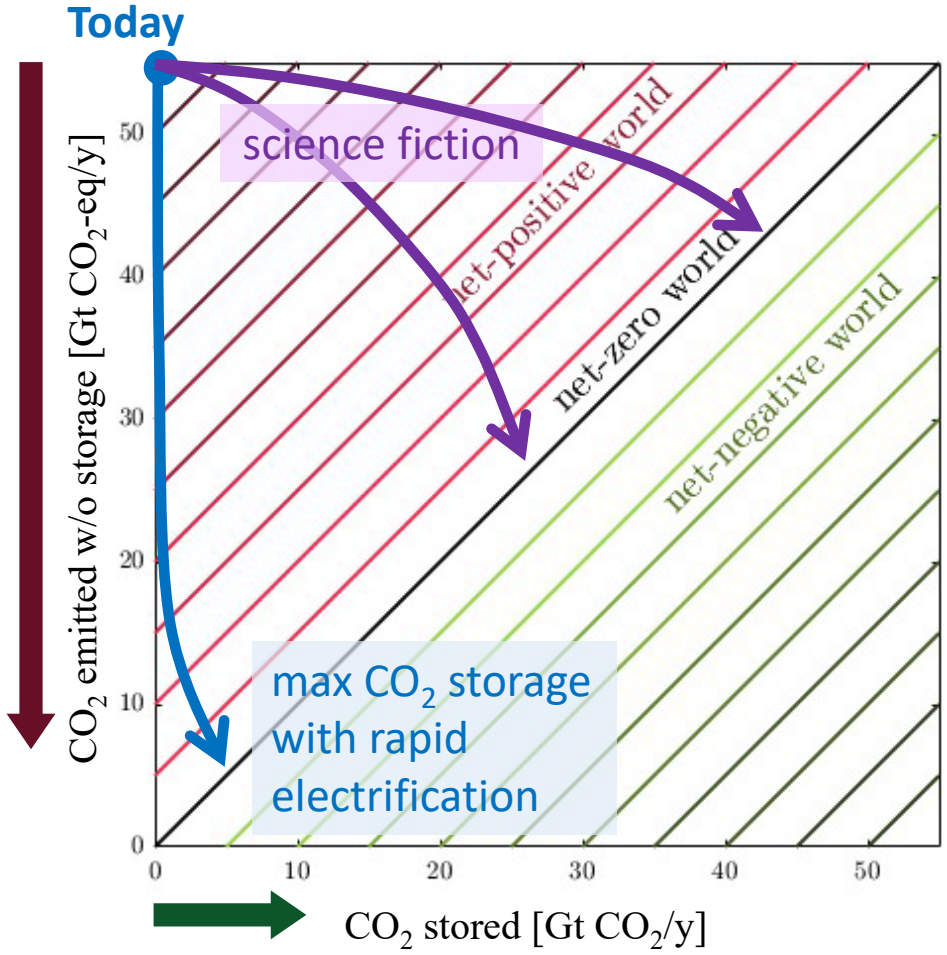
Net-zero: are we on track?



- In a CO_2-storage constrained world the climate impact of CCS and CDR (= DACCS + BECCS) is the same, but only CDR can deliver a net-negative world.
- Each CO_2 molecule stored counts, no matter what its origin is (CDR or CCS): the storage space available should be occupied by the cheapest (CO_2 from biogas, CCS from point sources including BECCS, DACCS).
- Much larger role to be played by CO_2 avoidance than by CCS + NET.

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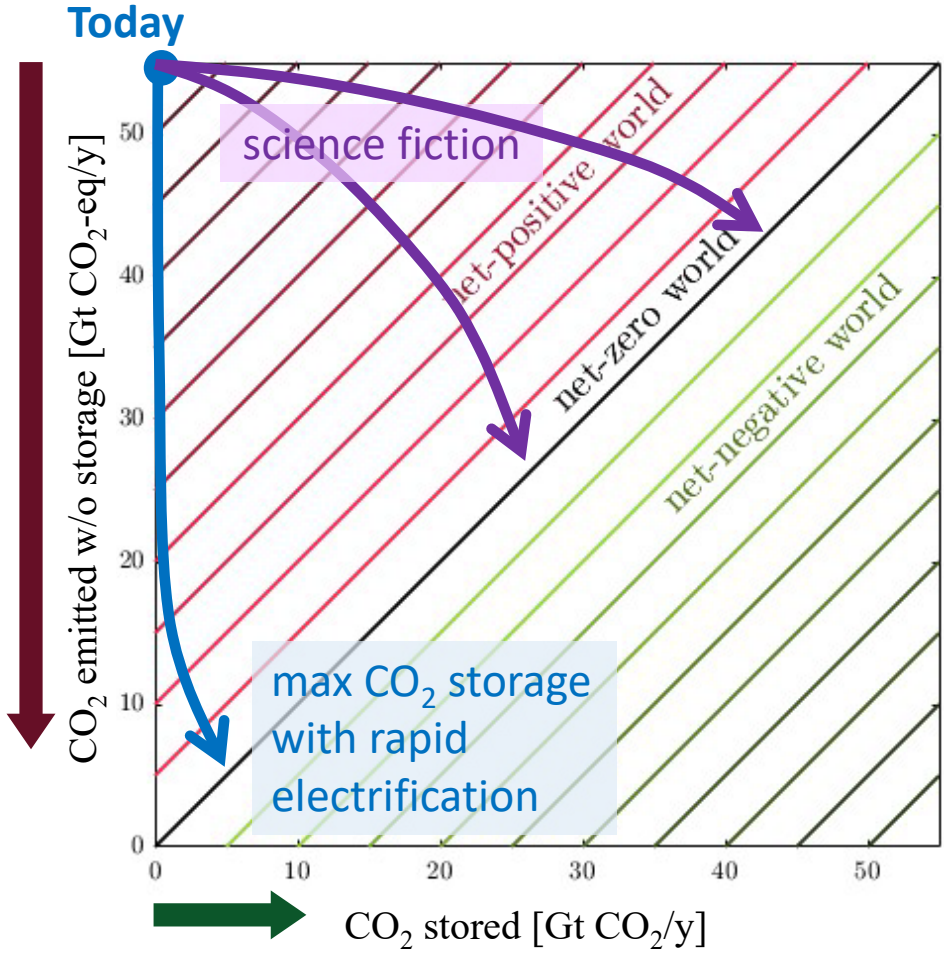
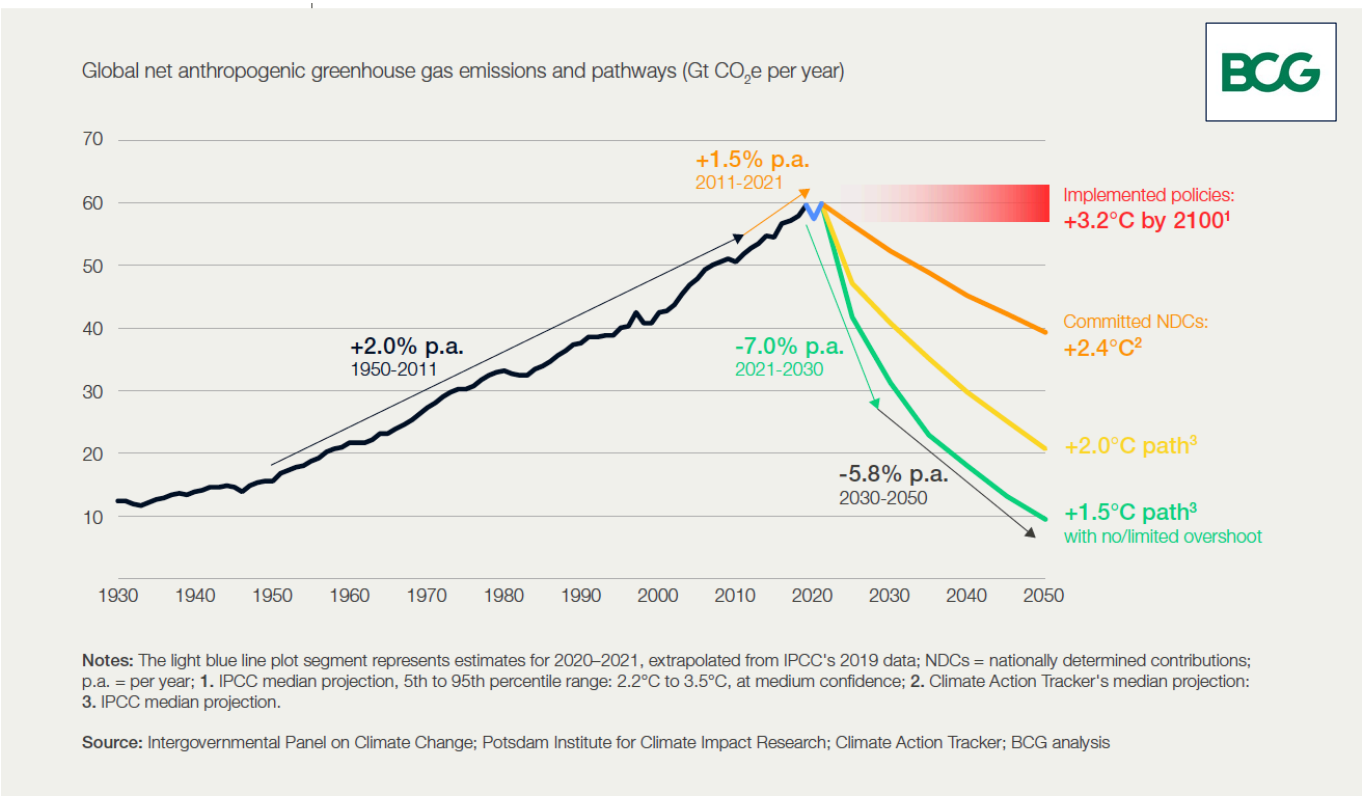




https://www.bcg.com/about/partner-ecosystem/world-economic-forum/ceo-guide-net-zero#bold-measures-to-close-the-climate-action-gap

Net-zero: are we on track?

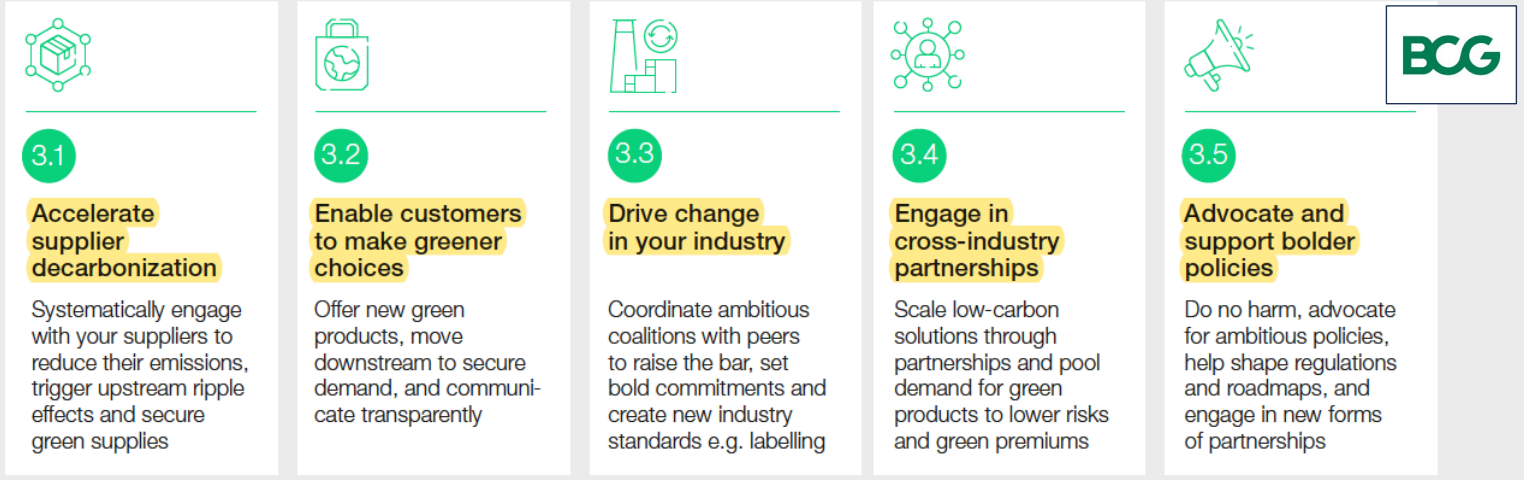
"2.5 Implementing hard technology bans and decarbonization mandates"

Five priorities for government action

"... the irreversible changes to the climate triggered by past inaction will require trillions of dollars in adaptation efforts. ... the cost of inaction will not only increase, but it will also far exceed the costs of bringing down emissions."

https://www.bcg.com/about/partner-ecosystem/world-economic-forum/ceo-guide-net-zero#bold-measures-to-close-the-climate-action-gap

Five priorities for corporates to achieve outsized systemic impact



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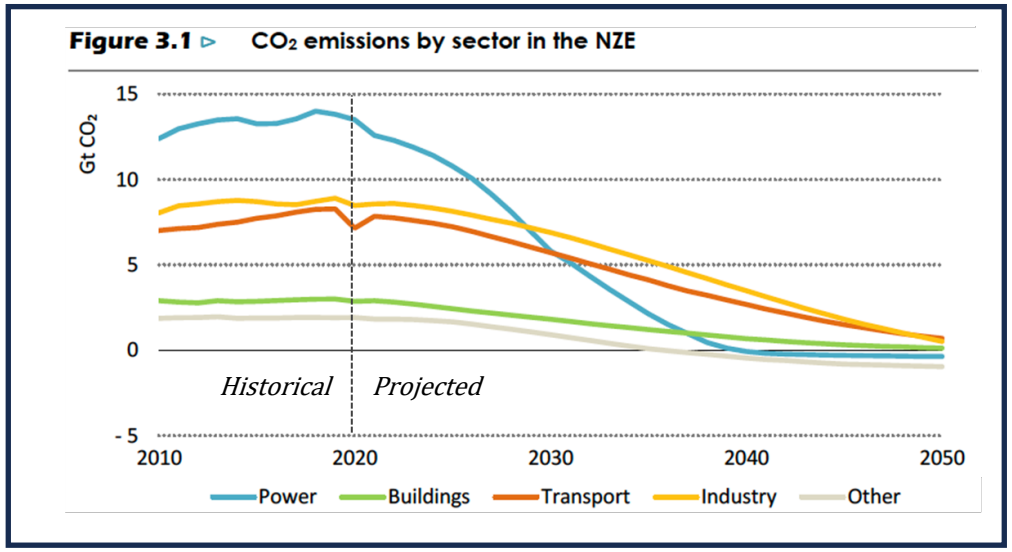
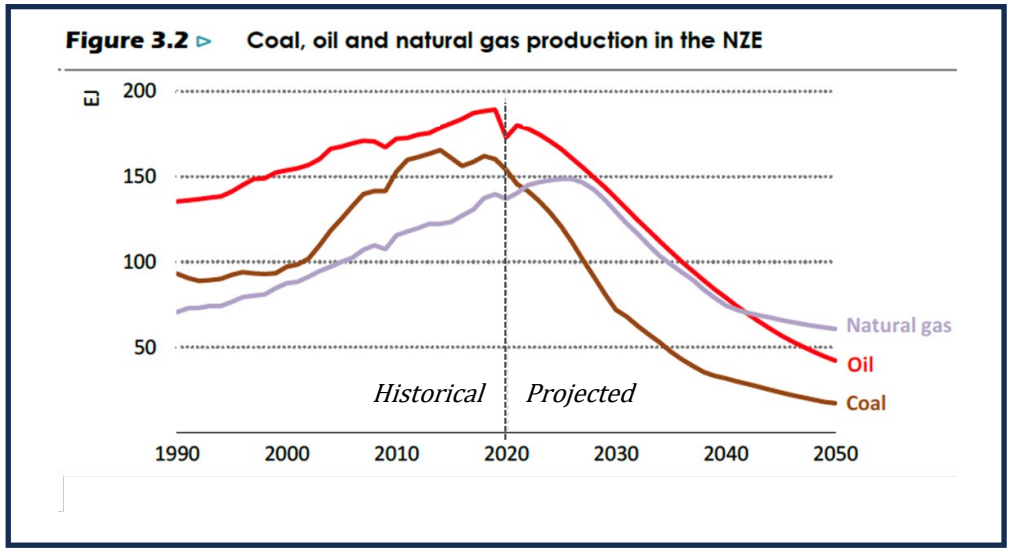


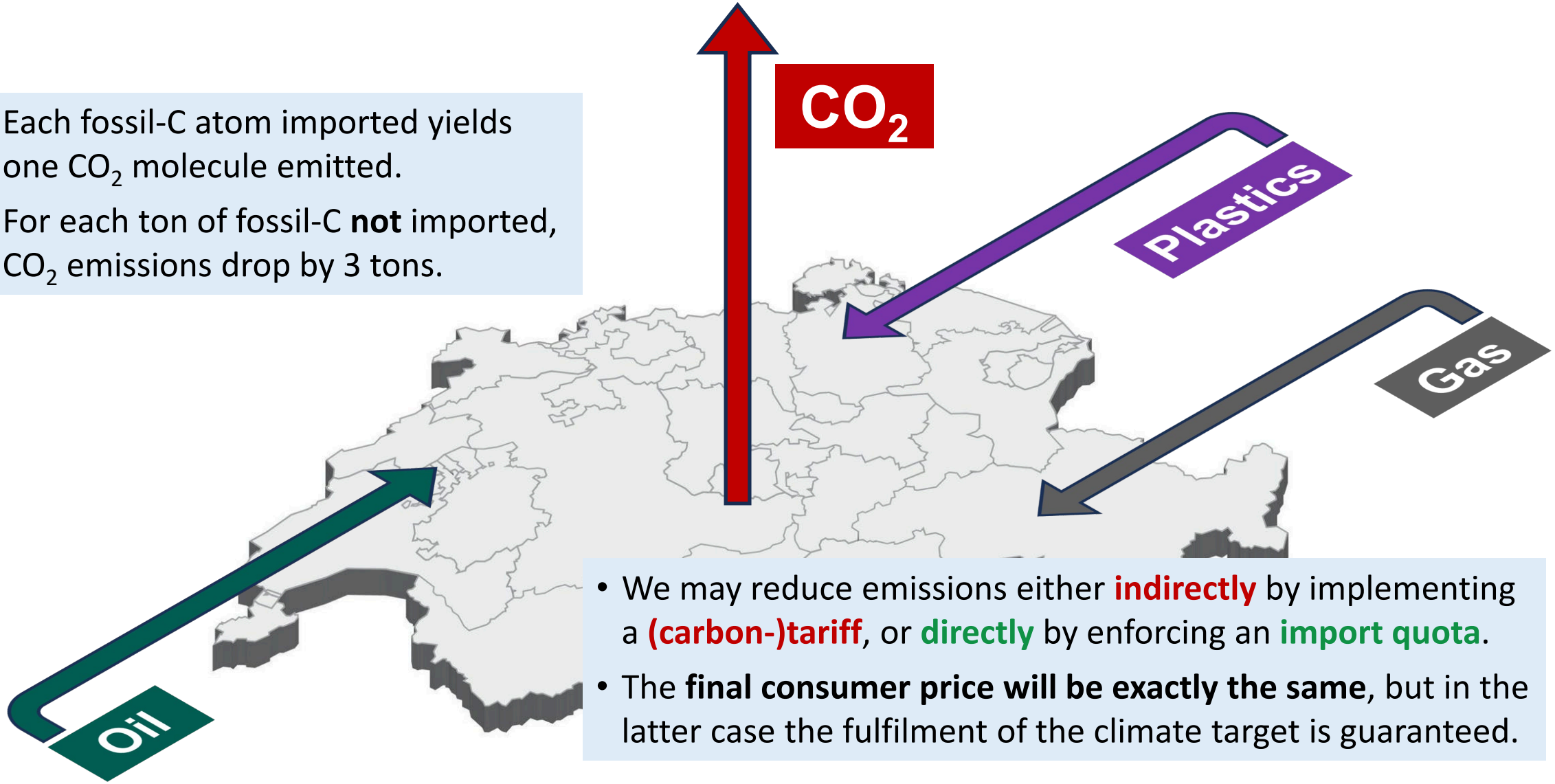


- In the net zero pathway, global energy demand in 2050 is ca. 8% smaller than today, but it serves an economy more than twice as big and a population with 2 billion more people.
- Net zero means a huge decline in the use of fossil fuels. They fall from ca. 80% of total energy supply today to ca. 20% by 2050.
- New jobs and investments in the clean energy sector will outpace losses in the fossil fuel sector; the associated drop in air pollutants will result in 2 m fewer premature deaths per year globally.

International Energy Agency, *Net Zero by 2050: a roadmap for the global energy system* (2021)

Net-zero: are we on track?

- Each fossil-C atom imported yields one CO_2 molecule emitted.
- For each ton of fossil-C **not** imported, CO_2 emissions drop by 3 tons.



- We may reduce emissions either **indirectly** by implementing a **(carbon-)tariff**, or **directly** by enforcing an **import quota**.
- The **final consumer price will be exactly the same**, but in the latter case the fulfilment of the climate target is guaranteed.

Take-home messages

1. Pilot projects help **identifying shortcomings,** offer **crucial insights**, and provide **powerful momentum** for the establishment of a new industry.
2. The CO_2 management solutions demonstrated in DemoUpCARMA are both **techno-economically and environmentally viable**; both solutions are needed to meet climate goals.
3. The DemoUpCARMA project has contributed significantly to:
    - Creating a **platform for national stakeholders** to exchange nationally and internationally;
    - **Capacity building** through the formation of 30+ students in the CO_2 management space.
4. Upscaling CCTS/CCUS presents several challenges that require a **systemic approach** for resolution.
5. As of today, there is unfortunately **no clearly viable business model** for the implementation of CCTS or CCUS for Swiss emitters.
6. As the United Nations Secretary-General, Mr. António Guterres, aptly stated in 2018, "**Climate change is the defining issue of our time**", posing a **direct existential threat** that moves faster than our collective response. Nonetheless, "**We have the tools to make our actions effective**".