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BioCUBES

Biogenic CO_2 capture and utilization from Swiss biogas plants: Technical, economical and environmental analysis

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Summary

Switzerland aims for carbon neutrality by 2050. Carbon capture and utilization (CCU) plays a key role in achieving this by capturing and recycling CO_2. Biogas plants offer an opportunity to contribute, as they produce biogenic CO_2 that is often not valorised. Using this CO_2 in various applications can reduce fossil CO_2 emissions and improve the economic viability of the plants.

The main goal of this study is to assess the potential for CO_2 capture in Swiss biogas plants and evaluate its use in current and emerging applications through a market study to gauge demand. The environmental impact of various CO_2 capture and utilization pathways will be estimated by quantifying CO_2-equivalent reductions. Finally, the key barriers to CCU implementation will be identified, and recommendations to address regulatory, technical, and economic challenges will be given.

This intermediate report covers the literature review on the technical framework, international realisations, and the Swiss situation regarding biogenic CO_2 capture from biogas plants.

Zusammenfassung

Die Schweiz strebt bis 2050 Klimaneutralität an.Carbon Capture and Utilization (CCU) spielt dabei eine Schlüsselrolle, indem CO_2 abgeschieden und recycelt wird. Biogasanlagen bieten eine Möglichkeit, hierzu beizutragen, da sie biogenes CO_2 produzieren, das oft nicht verwertet wird. Die Nutzung dieses CO_2 in verschiedenen Anwendungen kann fossile CO_2-Emissionen reduzieren und zugleich die Wirtschaftlichkeit der Anlagen verbessern.

Das Hauptziel dieser Studie ist es, das Potenzial für die CO_2-Abscheidung in Schweizer Biogasanlagen zu bewerten und dessen Verwendung in aktuellen und neu entstehenden Anwendungen durch eine Marktstudie zur Nachfrageermittlung zu evaluieren. Die Umweltauswirkungen verschiedener CO_2-Abscheidungs- und -Nutzungspfade werden durch die Quantifizierung von CO_2-Äquivalent-Reduktionen geschätzt. Schliesslich werden die wichtigsten Hindernisse für die Implementierung von CCU identifiziert und Empfehlungen zur Bewältigung regulatorischer, technischer und wirtschaftlicher Herausforderungen gegeben.

Dieser Zwischenbericht umfasst die Literaturübersicht zum technischen Rahmen, zu internationalen Realisierungen und zur Schweizer Situation bezüglich der biogenen CO_2-Abscheidung aus Biogasanlagen.

Résumé

La Suisse vise la neutralité carbone d'ici 2050, et la capture et l'utilisation du carbone (CCU) joue un rôle clé dans la réalisation de cet objectif en capturant et en recyclant le CO_2. Les installations de biogaz offrent une opportunité de contribuer à la réduction des émissions, car elles produisent du CO_2 biogène, qui n'est souvent pas valorisé. L'utilisation de ce CO_2 dans diverses applications peut réduire les émissions de CO_2 fossile et améliorer la viabilité économique des installations.

L'objectif principal de cette étude est d'évaluer le potentiel de capture du CO_2 dans les installations de biogaz suisses et d'évaluer son utilisation dans des applications actuelles et émergentes à travers une étude de marché visant à évaluer la demande. L'impact environnemental des différentes voies de capture et d'utilisation du CO_2 sera estimé en quantifiant les réductions équivalentes de CO_2. Finalement, les principaux obstacles à la mise en œuvre de CCU seront identifiés et des recommandations seront formulées pour relever les défis réglementaires, techniques et économiques.

Ce rapport intermédiaire couvre l'analyse documentaire sur le cadre technique, les réalisations internationales et la situation suisse en matière de capture du CO_2 biogène provenant des installations de biogaz.

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List of abbreviations

BECCUS	Bioenergy with carbon capture and storage
CCS	Carbon capture and storage
CCU	Carbon capture and use
CHP	Combined heat and power
CIA	Climate and Innovation Act
CO_2	Carbon dioxide
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
SFOE	Swiss Federal Office of Energy

1 Introduction

1.1 Context and motivation

Carbon dioxide (CO_2) is the largest contributor to anthropogenic greenhouse gas emissions, accounting for approximately 72% of global greenhouse gas (GHG) emissions in 2022 [1]. Despite extensive global mitigation efforts, the Intergovernmental Panel on Climate Change (IPCC) projects that, if current trends persist, Earth's temperature will increase by 1.5°C between 2030 and 2052.

In this context, the Swiss Federal Council has committed to achieving carbon neutrality by 2050, aligning with international efforts to limit global warming to 1.5°C above pre-industrial levels. To reach this objective, Switzerland must significantly reduce GHG emissions by transitioning away from fossil fuels, developing renewable energies, and improving energy efficiency. After having fully tapped the potential of these measures, carbon capture and storage (CCS) technologies, which involves capturing CO_2 from local sources or the atmosphere and storing it permanently, is anticipated to be necessary for achieving carbon neutrality. Carbon capture and use (CCU) consists of capturing CO_2 and using it (e.g. to produce fuels, chemicals, or materials) without requiring the extraction of fossil products. Its role is less clearly established, although it is a necessary piece of a fully fossil-fuel-free society, relying on carbon recycling (Figure 1, right) instead of carbon extraction and subsequent CO_2 emission (Figure 1, left). Figure 1 illustrates the different CCS and CCU pathways and their potential contributions to negative emissions (highlighted in green).

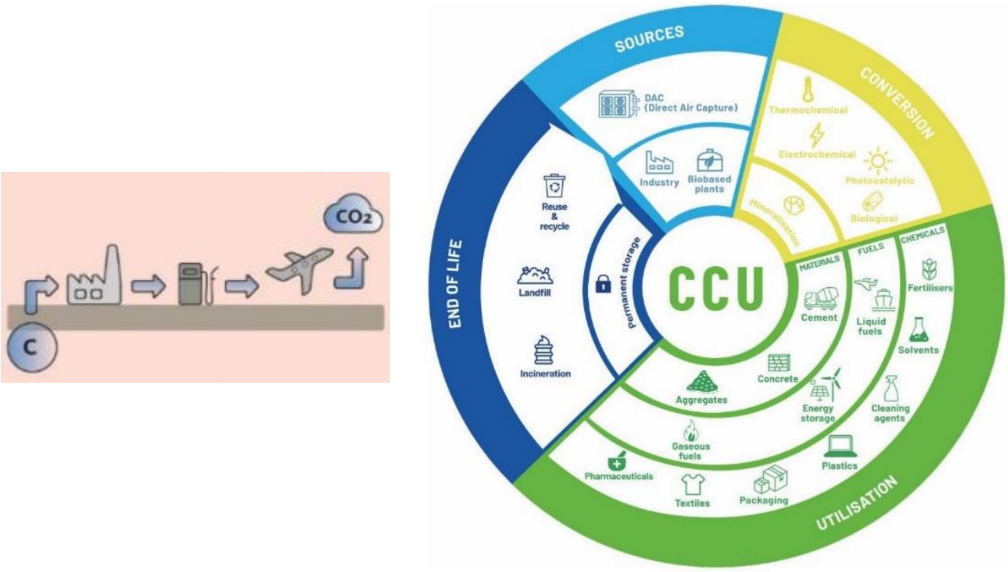

Figure 1 – Left: Linear carbon use relying on extraction of fossil C and leading to emission of fossil CO_2. Right: The cycle of CCU, with different sources conversion mechanisms, utilisations, and end of life[2].

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[1] Crippa, M., Guizzardi, D., Pagani, F., Banja, M., Muntean, M., Schaaf E., Becker, W., Monforti-Ferrario, F., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Köykkä, J., Grassi, G., Rossi, S., Brandao De Melo, J., Oom, D., Branco, A., San-Miguel, J., Vignati, E., GHG emissions of all world countries, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/953332, JRC134504

[2] CO_2 Value Europe: The contribution of carbon capture and utilisation towards climate neutrality in Europe

Specifically, Switzerland seeks to reduce its yearly CO_2-eq emissions from 42 Mt today to 12 Mt by 2050, excluding aviation emissions of 5 Mt in both cases. Of these 12 Mt/year of residual emissions, Switzerland plans to avoid 5 Mt through CCS technologies and remove 2 Mt of CO_2-eq domestically, with an additional 5 Mt removed abroad as represented in Figure 2.[3]

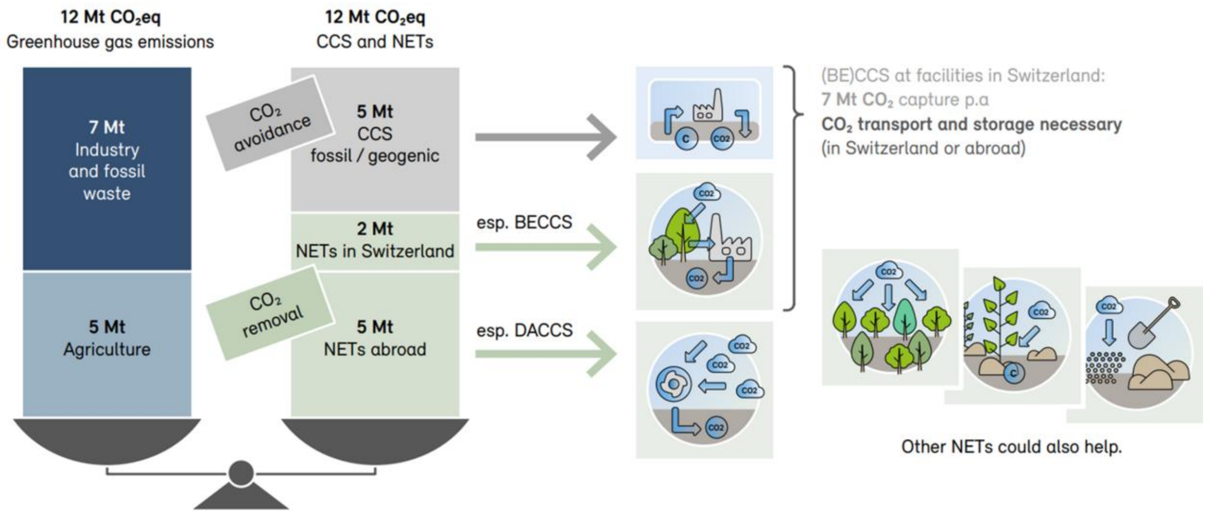

Figure 2 - Residual CO_2 emissions in 2050 and Switzerland long-term climate strategy

Capture and utilisation of CO_2 from biogas plants can contribute to Swiss climate goals in different ways. Deploying biogas enables substituting fossil natural gas with renewable energy. In addition to biomethane, biogas plants produce biogenic CO_2, which is currently usually not valorized. Given the economical challenges faced by biogas plants, valorizing this CO_2 could improve their financial viability while preventing its direct release into the atmosphere. Using CO_2 in long-duration applications can contribute to sequestration, whereas its use in short-duration applications (e.g. fuels, food and beverage, or plastic materials) enables to avoid some fossil CO_2 emissions. Consequently, it seems reasonable to state that CCU from biogas can contribute to Switzerland's climate goals. Yet the extent of this contribution depends on physical constraints (the amount of CO_2 that can be made available), on financial constraints (the economic viability of capturing and using biogenic CO_2), on regulatory constraints (which could foster CCU through e.g. obligations, incentives, or opposite hinder CCU through land-use restriction or other regulatory hurdles). Elucidating these aspects is the goal of this project, as well as quantifying the CO_2-eq benefits of the CCU pathways through a CO_2-eq analysis.

1.2 Project objectives

The main goal of this study is to assess the potential for biogenic CO_2 capture in biogas plants in Switzerland and evaluate the feasibility of utilizing this CO_2 in both current and emerging applications. This will involve a comprehensive market study to gauge the demand for biogenic CO_2. A second objective is to estimate the environmental relevance of various CO_2 capture and utilization pathways by quantifying their benefits in terms of CO_2-equivalent reductions.

[3] Stratégie climatique à long terme de la Suisse, Le Conseil Fédéral, 27.01.2021

The third goal is identifying the key barriers (regulatory, technical, economical, etc.) hindering the deployment of CO_2 capture and utilization (CCU) from biogas plants. This will enable providing actionable recommendations to address these challenges, including regulatory, technical, and economical considerations.

Research questions:

- What quantity of CO_2 could be captured from biogas plants throughout Switzerland?
- What is the current and projected demand for biogenic CO_2 in Switzerland?
- Where are suitable locations for CO_2 capture and utilization in Switzerland?
- What are the technical, economic, and regulatory hurdles affecting the implementation of CCU from biogas plants?
- What are the ecological benefits, in terms of CO_2-equivalent, of these different CCS and CCU pathways?

2 Approach, method, results and discussion

2.1 State-of-the-art

2.1.1.Literature review and technical framework

This task involves a literature review to assess the state-of-the-art of CCU from biogas plants. The primary goal is to define criteria for evaluating the technical feasibility of implementing CCU pathways at Swiss biogas plants, which will inform subsequent work packages. While Task 1.1 is largely complete, we will continue gathering references from ongoing research throughout the project.

To date, we have compiled a comprehensive collection of scientific studies, drawing from the broader research on CCUS. The key topics covered are listed in Table 1, along with selected references.

Table 1 - Overview of key topics covered in the literature review on CCU at biogas plants.

Topic	Preliminary key aspects	Selected References
CCUS Pathways → Overview of various routes with a focus on bioenergy CCUS (BECCUS).	Various pathways that produce synthetic methanol, methane (use for fuels chemicals) are dominating; context is PtX/PtG and a requirement is H_2 production. Possible pathways for direct CO_2 use include use as refrigerant, in biomass production (algae, greenhouses), for pH control, for beverages.	Chauvy et al., 2023 Cordova et al., 2022
Capture technologies → Assessments of specific, mature capture methods, some suitable for biogas facilities.	Post-combustion technologies are most mature; via absorption (amines), membranes, adsorption. Other technologies to mitigate emissions such as pre-combustion[4] or oxyfuel	Ganeshan et al., 2023

[4] Instead of direct combustion, the fuel undergoes a gasification process to produce syngas (CO and H_2). Through a water-gas shift with H_2O, more H_2 and CO_2 are formed. This increases the CO_2 fraction in the gas mixture compared to post-combustion pathways, increasing capturing efficiencies.

	combustion[5] are emerging and not directly relevant for biogas facilities.	
Life Cycle Assessments (LCA) → LCA or other environmental performance assessments on CCUS pathways. →Valuable results for WP5, where we assess the CO_2-eq balance for the CCUS pathways that are most relevant for Switzerland.	LCA case studies typically focus on a specific plant type or one CCU pathway. The emissions intensity of the electrical grid and heat source used are decisive for the overall impact in carbon capture. CCS assessments show that the type of transportation (road, rail, pipelines) strongly influences the overall impact.	Varling et al., 2023 Yang et al., 2020 Wang et al., 2024 Bargiacchi et al., 2020 CCS Swiss context: DemoUpCarma project
Biogenic Carbon Capture Potential →Studies that quantify the biogenic carbon capture potential for a country or region, some including spatial analysis. →Valuable comparison for WP2, where we assess this potential in detail for Switzerland.	Existing case studies vary in: Geographical scope (e.g. Switzerland, Sweden, Germany, Canada, Europe). Methodology (the potential is quantified based on biogenic CO_2 point source emissions or biomass availability). BECCUS pathway (e.g. using CO_2 for H_2 production vs. storage in concrete or geological mineralization). Time horizon (current potential and future scenarios). Inclusion of CO_2-eq balance quantification; quantifying carbon removal efficiencies.	CH/Europe: Rosa et al., 2022 Rosa et al., 2022 Rosa et al., 2021 Sweden: Cordova et al., 2022 Germany/Canada: Thrän et al., 2025

Building on this overview, we are now moving to a detailed analysis of the compiled literature, targeting specifically the aspects relevant for biogas plants in the Swiss context. This will allow us to derive the specific technical and operational criteria required for the following tasks.

2.1.2. State-of-the-art of international realizations

Carbon capture is nowadays dominated by fossil-fuel industry. It aims at storing the CO_2 emitted from fossil-fuel combustion and/or at extracting more oil from wells (enhanced oil recovery, EOR). North America is dominating this market, as seen in the figure below. The biogenic CO_2 projects are not as clearly identified although they are likely to be of much smaller capacity.

[5] In oxyfuel combustion, fuel is burned with pure oxygen instead of air, resulting in more complete combustion and a higher CO_2 concentration in the flue gas, which facilitates more efficient carbon capture.

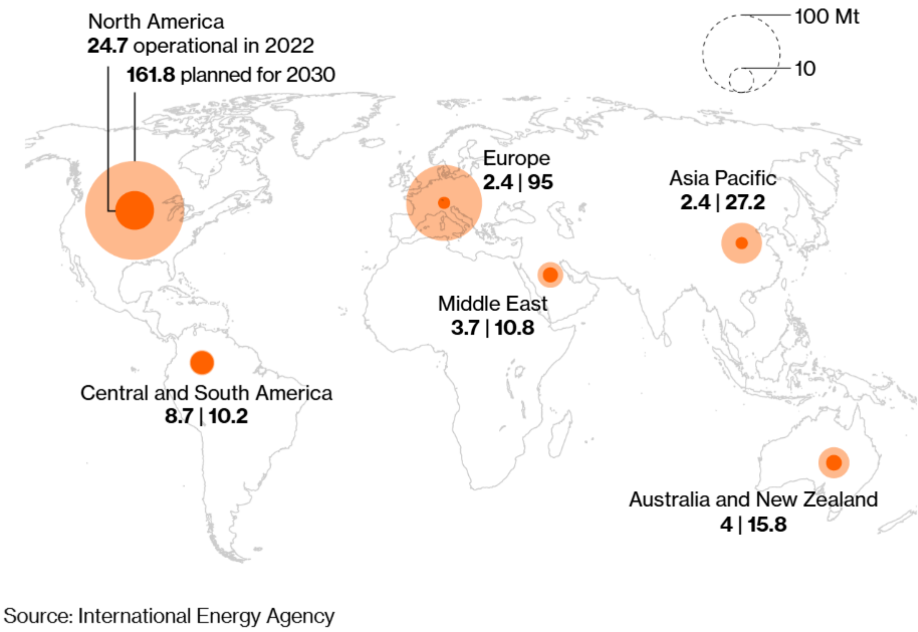

Figure 3 - Operational and planned (2030) carbon capture capacity, in million metric tons[6]

In Europe, among the 2.4 Mt captured annually, 1.17 Mt of captured CO_2 is biogenic, stemming from 125 plants. 75% of captured biogenic CO_2 is directed to CCU, used mostly in greenhouses (32%), food and beverages (21%), and e-fuels (10%). 2% of the captured biogenic CO_2 is used for CCS, specifically in concrete mineralisation. For the remaining 25%, the final application is unknown. Currently, the United Kingdom is leading the capture from biogas, accounting for 22% of the total captured volume. It is followed by Germany (15%), Denmark (14%), France (14%), the Netherlands (12%), and Italy (12%).[7]

In the following, a focus is laid on different European countries as well as on the American context.

Overview of Danish context

Denmark's CO_2 demand is estimated at around 65'000 t/year.[8]

The demand for biogenic CO_2 in Denmark is driven by new e-fuel plants and CO_2 capture projects funded by the NECCS fund, which aims to reduce CO_2 emissions by 0.5 million tonnes annually from 2025. A tender was issued, with contracts awarded to biomethane producers, and the necessary investment was supported by revenue from biogenic CO_2 removal credits. This initiative shows how targeted support can promote biogenic CO_2 capture and storage.

Overview of French context

In France, the commercial CO_2 market currently represents around 80 million euros (500 million euros at the European level).[9] Total demand is not clearly established. It is estimated at around 400'000 tonnes per year, although up to 1 Mt/year was evoked by actors of the field. Out of this demand, 70% comes from the food and beverage industry,[10] typically for preservation in packaging or for soda carbonation.

Concerning production, one large ethanol production facility (the largest in Europe) produces 400'000 t of CO_2 per year, of which 100'000 t are liquefied by Air Liquide for further commercialization, while the

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[6] US Bets Big on Carbon Capture Technology to Reach Climate Goals

[7] Biogenic CO_2 from biomethane : the key to Europe's Carbon Strategy, EBA, 2025

[8] Biogenic CO_2 from the biogas industry, EBA, 2022

[9] Note de veille - Marche & Nouveaux usages à fort potentiel du CO_2 en France | Mécathèque Cetim

[10] Personal communications during the event Journée Technique Valorisation du BioCO2 | ATEE

remaining fraction is emitted. Such large point sources enable economies of scale for production, but require potentially long transportation to valorize all the collected CO_2. France is the main European producer of bioethanol (used as a fuel for cars), generating about 1 Mt per year, resulting in the production of the same amount of biogenic CO_2 yearly directly in the plants ($C_6H_{12}O_6 \rightarrow\ 2\ C_2H_5OH + 2\ CO_2$).

A study by Club CO_2 in 2025 estimated the availability of biogenic CO_2 in France at 22 Mt/year, from about 2000 sites.[11] The largest contributors are incinerators, paper production, and ethanol production. The 50 largest suppliers (2.5% of sites) account for more than half of the total available quantity. While supply from these large emitters is expected to remain relatively stable, significant growth is expected from new methanation installations and other small sources, resulting in potential supplies of 40 Mt/year by 2040 and 55 Mt/year by 2050.

To match demand and supply, a merit-order was conducted (Figure 4), indicating a potential supply of up to 32 Mt/year, with half of it available at prices below 170 €/t. The lowest cost source is from bioethanol production, whereas the "other" category is the most expensive. CO_2 recovery from biomethane is estimated to be the next cheapest sources, overlapping in cost with cement production, waste incineration, and heat production.

Concerning demand, current usage is expected to remain relatively stable, but new demand is expected for methanation, mineralisation, e-Fuels and BECCS, with the latter two representing the largest potential shares. Overall, market projections vary widely depending on assumptions (Figure 5). White and dark grey in the figure represent demand from BECCS and e-Fuels production, respectively, while other uses are comparatively minor, except for mineralization in one scenario by 2050. Despite variability, the market is expected to grow significantly by 2050, reaching 10 to 50 Mt/year of CO_2, compared to 1 Mt today - a 10- to 100-fold increase. For biogas-derived CO_2, market uptake could range from near zero (if demand is fully met by large, less expensive suppliers) to over 20 Mt/year, depending on the scenario, highlighting both market uncertainty and the critical role of policy and regulation.

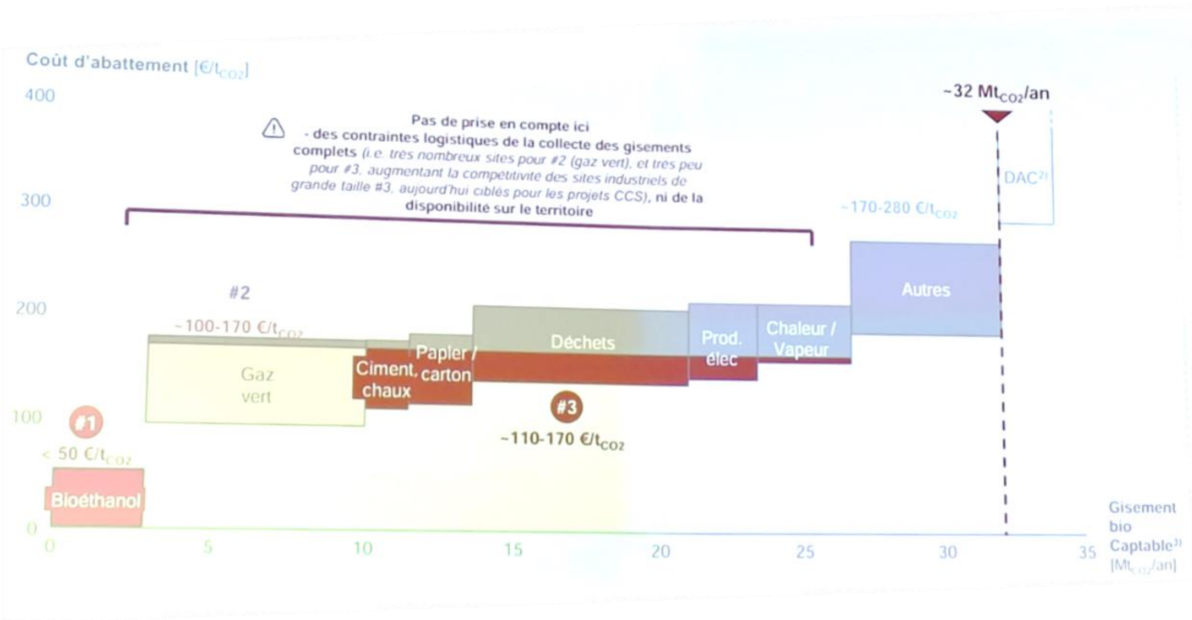

Figure 4 - volume of CO_2 available classified as a function of production cost

[11] "Captage, stockage et utilisation du CO_2 biogénique en France", Club CO_2, 2025

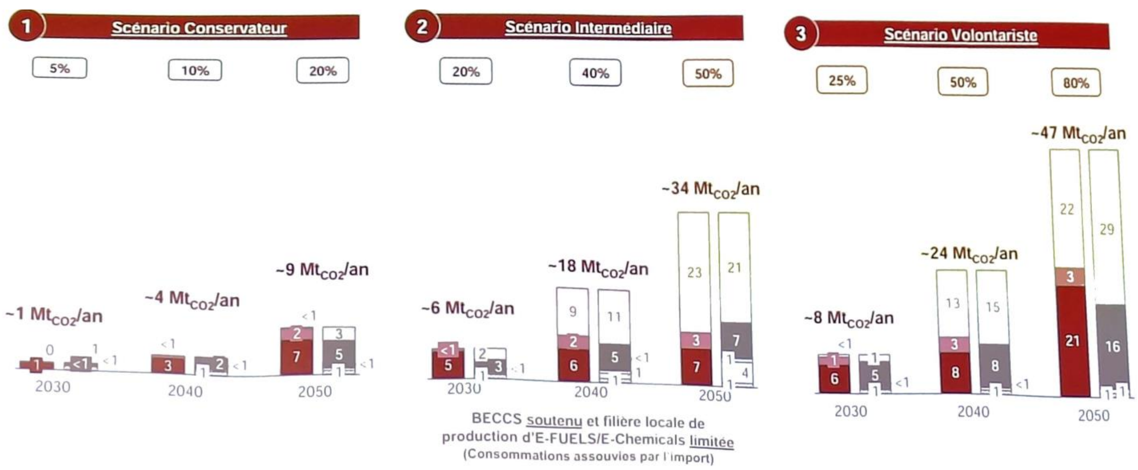

Figure 5 - Market volume for biogenic CO_2 in 2030, 2040 and 2050 according to three scenarios.

In terms of market projections, a study by CO_2 Value Europe[12] rovides another outlook for CO_2 capture and utilization. Similar to the previous analysis, direct air capture (DAC) is considered a last-resort source of biogenic CO_2 due to its high costs. The study forecasts a total market of 57 Mt/year, with 41 Mt/year coming from sources other than DAC, which is comparable to the most ambitious scenario presented before. In terms of demand, CCS represents the largest share, followed by e-Fuels. Initiatives also exist to aggregate "small" biogas producers through the company CAPCOO[13], which currently has 77'000 t/year of available CO_2 though only 20'000 t/year is currently commercialised.

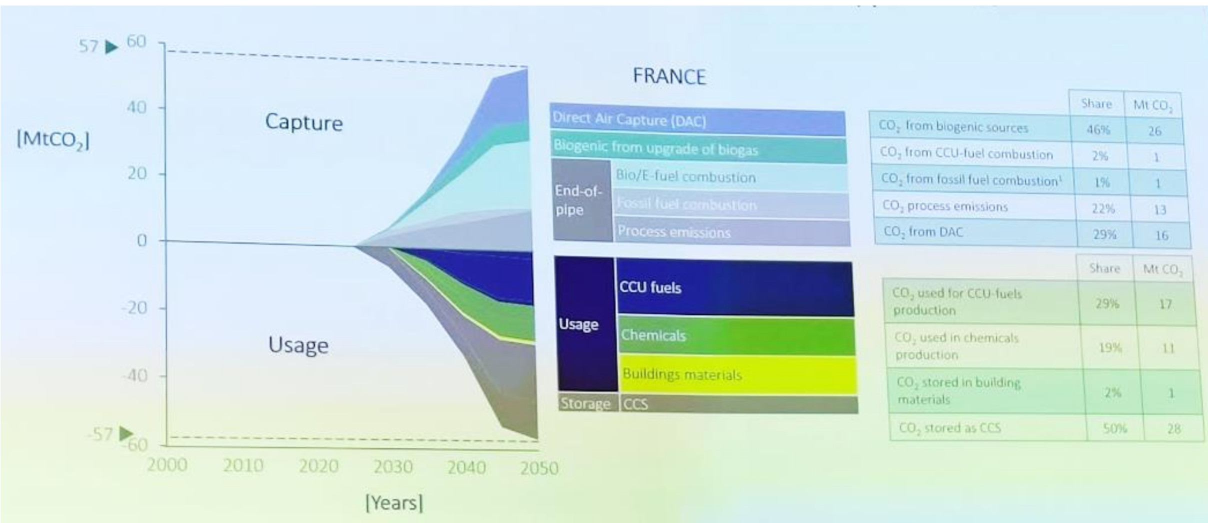

Figure 6 - projection of biogenic CO_2 production and demand volumes from 2025 to 2050, according to CO_2 Value Europe[12]

[12] CO_2 Value Europe: The contribution of carbon capture and utilisation towards climate neutrality in Europe

[13] CAPCOO | Collectif d'agriculteurs méthaniseurs : www.capcoo.fr

Overview of German context

In Germany, CO_2 demand is estimated at around 1 Mt/year for urea synthesis and around 2.5 Mt/year for methanol synthesis, with both expected to increase in the future. For the production of methanol, urea, and high-value chemicals (HVCs, including olefins and aromatics), total CO_2 demand could reach 44’000–52’000 kt by 2045.

According to the German trade association Fachverband Biogas, there were around 9’800 biogas plants in Germany in 2022. About 90 % of these plants had on-site electricity generation via combined heat and power (CHP) systems, while 242 biogas plants upgraded biogas into biomethane for injection into the grid. Overall, biogas plants emitted approximately 13.7 Mt of CO_2, with 1.7 Mt attributed to the 242 biomethane plants. Most of this CO_2 is currently released into the atmosphere.[14]

Several biogenic CCU projects have already emerged in Germany. At a liqueur distillery in Helmstedt, organic waste is digested to produce biogas, which is upgraded to biomethane, while the CO_2 stream is recovered and liquefied into food-grade biogenic CO_2.[15] This system upgrades 350 Nm^3/h and liquefies roughly 700 kg of CO_2 per hour (≈ 17 t per day, thus ~5’000 t/year).

On a larger scale, the BioEnergie Park in Güstrow produces up to 25’000 kg of bio-liquefied natural gas (LNG) per day and co-produces up to 18’000 t/year of food-grade liquid CO_2, entirely purchased by Carbo Kohlensäurewerke GmbH & Co.[16] In Apensen, the Bioenergie Geest/Hitachi Zosen Inova joint venture plans to use ~32 GWh of sustainable biogas to generate around 2’100 t of bio-LNG per year while recovering over 4’000 t of liquid CO_2 to replace fossil CO_2 in industry. The project expects to sell more than 20’000 t/year of CO_2-reduction credits[17].

Overview of the USA context

As part of its net-zero strategy, the United States relies heavily on CCUS technologies, including the management of biogenic CO_2 from renewable sources. Existing infrastructure, such as CO_2 pipelines and oil wells, is being repurposed to enable faster and more cost-effective geological storage.

[14] Final report «Systemauswahl zur biotechnologischen Verwertung von CO_2 aus Biogasanlagen (BiogasanlagePLUS)», DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V., financed by the German Parliament, 2025

[15] Bright Renewables, https://www.bright-renewables.com

[16] BioEnergie Park Güstrow | EnviTec Biogas

[17] https://bioenergyinternational.com/bioenergie-geest-a

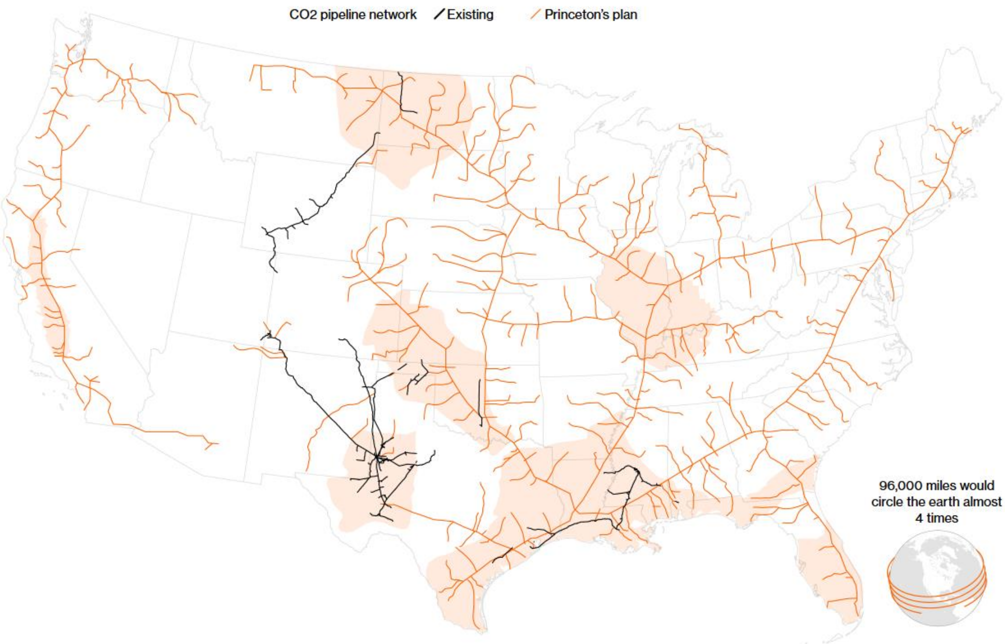

Figure 7 – Existing CO_2 pipelines and necessary ones according to Princeton's plan.[10]

The United States currently has over 5'000 miles (8'000 km) of pipelines dedicated to CO_2 transport, primarily used for Enhanced Oil Recovery (EOR). Some natural gas pipelines are also being adapted for CO_2 transport.[18] These networks are now being adapted to carry captured CO_2, whether fossil or biogenic, to underground storage sites.[19] This infrastructure supports the competitiveness of ethanol production, a major source of biogenic CO_2 in the U.S., similarly to France.[20]

For example, the Midwest Carbon Express pipeline project aims to collect biogenic CO_2 from ethanol refineries in Iowa and transport it to deep geological formations in Illinois for permanent storage. Capturing and storing biogenic CO_2 in this way generates net-negative emissions, enabling companies to sell high-value carbon credits. While such large-scale infrastructure is not directly applicable to Switzerland, these projects illustrate the technological maturity of CCUS. U.S. projects benefit from tax incentives such as Section 45Q, which provides $85 per tonne for permanently stored CO_2. Recent U.S. legislation, including the Inflation Reduction Act (IRA), offers substantial tax incentives for CCUS initiatives. Federal agencies such as the department of energy (DOE) and environmental protection agency (EPA) support permitting and storage well development.[21] However, the future of these initiatives is uncertain in the current political landscape. The Net Zero America study from Princeton university gives clues on the USA broad context of energy transition, and notably the role of CCU and CCS, and their projected deployment for various scenarios.[22]

2.1.3. Swiss situation

Examples of realisations

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[18] Trailblazer - When farmers and ranchers do well, we all do well

[19] Summit Carbon Solutions | Carbon Capture and Transport in the Midwest

[20] Biogenic CO_2 Removal in the US Takes Shape with Immense Potential

[21] U.S. Department of Energy (2021). ' CO_2 Pipeline Infrastructure in the United States.' www.energy.gov

[22] The Report | Net-Zero America Project

Several biogenic CCU projects are currently operational in Switzerland, although at a small scale. Notably, the plant in Nesselnbach (AG), operated by CO_2 Energie AG, captures CO_2 during biogas processing. The plant produces up to 4 kt of food-grade liquid CO_2 per year, which is sold to the industrial gas company Messer Schweiz AG for applications such as dry ice or carbonated beverages.

To support the plant's economics, CO_2 Energie AG also generates further revenue through the sale of CO_2 compensation certificates via the Swiss climate protection foundation KliK (https://www.klik.ch/fr/suisse/), although this subsidy mechanism is no longer available. The sale of certificates is an essential aspect, as income from CO_2 sales alone is insufficient to cover production costs. Producing food-grade liquid CO_2 requires relatively expensive equipment, making additional revenue streams critical for financial viability.[23]

Another example is the wastewater treatment plant ARA region Bern, which captures and liquefies biogenic CO_2 from its biogas plant. Currently, 4 kt of CO_2 per year are captured and liquefied, with plans to increase this to 5.2 kt/year. The CO_2 is sold to Neustark, a company that permanently stores CO_2 in demolition concrete. The selling price is partly indexed on electricity prices. No subsidies were received for construction or operation; the project's revenue is solely generated through CO_2 sales. Here, the value of CO_2 lies primarily in its the climate impact through atmospheric removal, in contrast to food applications, where CO_2 is valued for its chemical properties.

The Lenzburg region wastewater association (AVRL) is an example of a local, circular CCU application. Instead of purchasing chemical additives, AVRL uses CO_2 produced during the conversion of biogas into biomethane to stabilize the pH in the water treatment process. This approach allows AVRL to save significant quantities of inorganic acids annually, along with the associated CO_2 emissions.[24]

The Swiss company, Airfix, strives to activate the European bioenergy with carbon capture and storage market by using private and public climate finance. They provide advisory services to biogenic CO_2 emitters, develop projects from financing to transport and permanent storage, and offer carbon removal certificates for buyers. Projects will remove over 20'000 tonnes of CO_2 annually from 2026 and 50'000 tonnes of CO_2 per year across Europe by 2027.

While on-site utilization is feasible for some CO_2, transportation remains a major challenge, both within Switzerland and internationally. Currently, CO_2 is transported by truck. However, with the Swiss climate goal of capturing and transporting 7 Mt of CO_2 (biogenic and fossil), transportation becomes a significant challenge. Transporting 1 Mt of CO_2 would require either a single pipeline, 50 marine vessels, 600 trains with 30 wagons each, or 50'000 tank trucks. Compared to the current heavy transalpine traffic of 860'000 trucks/year crossing the Alps[25], CO_2 transport would require an addition of 350'00 tank trucks, which may strain Switzerland's transport infrastructure. In response, Pipeline Schweiz AG is developing the first pipeline section connecting Basel and Zurich, where the largest CO_2 cluster is located (estimated at 2 Mt of CO_2 per year in this corridor). The formalization of financing is currently underway, but several critical system parameters still need to be addressed, including CO_2 quality, pressure, availability, security, and the overall regulatory framework.[26]

Swiss regulatory and political framework

Switzerland's climate policy is based on the Climate and Innovation Act (CIA) and the CO_2 Act (RS 641.71), along with their respective ordinances (Climate Protection Ordinance (RS 814.310.1) and CO_2 Ordinance (RS 641.711)).

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[23] www.ieabioenergy.com/wp-content/uploads/2024/10/IEA-Bioenergy-Task-37-case-story_CO2-092024.pdf

[24] www.aquaetgas.ch/38260

[25] Trafic lourd transalpin: www.astra.admin.ch/astra/fr/home/themes/trafic-lourd-et-transport-de-marchandises-dangereuses/trafic-transalpin-de-marchandises.html

[26] Notes from CO_2 Congress 2025

The CIA, effective since 2025, outlines Switzerland's medium- to long-term climate policy framework. It sets emission reduction targets and provides guiding principles for various sectors to achieve net-zero emissions by 2050. The Act also includes two temporary measures to promote carbon reduction in the industrial and building sectors: the CO_2 tax which applies mainly to fossil fuels used for heating and process purposes and the Swiss emissions trading system (CH-ETS) where companies can buy or sell emission allowances depending on their performance relative to their reduction objectives.

The CO_2 Act operationalizes the reduction targets set in the CIA, specifying tools for cutting harmful greenhouse gas emissions and mandating the federal government to oversee climate adaptation efforts. In particular, it defines the CO_2 tax (RS 641.71, Art. 29), as well as the Swiss emissions trading system (RS 641.71, Art 15-21). Additionally, Switzerland recognizes carbon credits from certified projects that reduce or avoid emissions, which can be used for partial compensation of obligations. The Federal Office for the Environment (FOEN) supervises the certification and validation of these credits, ensuring compliance with Swiss and international standards (RS 641.711, Art. 5, 6, 15, 16, 17).

In this context, biogenic CO_2 emissions (e.g. from biomethane combustion) are considered climate-neutral and are therefore exempt from the levy according to Art. 29 para. 2 of the CO_2 Act and Annex 10 of the CO_2 Ordinance (RS 641.711). In fact, the CO_2 tax applies exclusively to fossil fuels. Injecting CO_2 in deep geological formations or sequestrating it in building materials like concrete for example enable the generation of CO_2 certificates, which can then be sold and thus give value to the sequestrated CO_2. In this case, the CO_2 is considered permanently removed from the atmosphere. This mechanism supports thus CCS, but not really CCU. Moreover, mandatory compensation is only applied to the activity of placing fuels on the market. Other sources of CO_2 emissions such as cement production are not subject to this tax. Also, the value of the tax can be recovered when committing to reduce emissions.

Despite clear climate policy, adequate regulations are lacking to ensure safe transport, industrial use, and storage of CO_2. While there is no national basis for CCUS, cantons have enforcement powers. Regulatory drivers are required, for example carbon tax, emissions performance, and carbon intensity standards. At the annual Swiss CO_2 Congress, the Swiss Gas Industry Association (ASIG) showed its involvement in these various areas and informed about its participation in the development of the Swiss regulatory framework: Indeed, the Confederation is currently working on developing a legal basis that should, among others, allow for the construction and operation of pipelines. While the importance of CCU was highlighted at the national CO_2 congress, focus was primarily laid on CCS as CCU itself is not enough to reach net zero.[27]

Potential regulatory restrictions for CCU

Biogenic CO_2 capture facilities are subject to construction permit applications, and potentially environmental impact assessment (EIA). The methane gas concentration is not high enough to be classified as an ATEX zone, so the regulations are relatively limited. However, CCU projects requiring significant land use and employing few people may face land-use restrictions, due to competition for land from agriculture, urban development, and regulations in industrial areas.

Incentives

An allocation of 1.2 billion CHF has been approved to support innovative processes and technologies (Articles 6 and 7 of the Climate Law, effective until 2030). Subsidies can cover up to 50% of investment and/or operational costs (for a maximum duration of 7 years) for decarbonization measures. However, when investment contributions exceed 20 million CHF, financial assistance is limited to the additional costs incurred compared to using conventional technologies. Operating subsidies are also reduced in a similar manner. To apply for subsidies, companies can either submit a direct application or participate in thematic calls for tenders, where they must present a clear decarbonization roadmap.

Under Article 6 of the CIA directive, the amount of subsidy is based on the scope of emission reductions. For scope 1 and 2, financial assistance is available for measures that reduce both direct and indirect

[27] Note from the CO_2 Congress 2025

greenhouse gas emissions at the company or operating site. For scope 3, assistance is available if the company can directly influence the emissions of its upstream suppliers or downstream buyers. Eligibility for financial support across the different scopes also depends on the amount of CO_2 captured and the maturity of the project, as summarized in Figure 8.

	A des fins de démonstration	**Autorisation de mise sur le marché et lancement**	**Diffusion du marché**
Mesure Scope 1 et 2	*Ne concerne pas KIG.*	1'000 tonnes de CO2eq	5'000 tonnes de CO2eq
Mesure Scope 3	100 tonnes de CO2eq	500 tonnes de CO2eq	500 tonnes de CO2eq
Mesure d'élimination du CO2	5'000 tonnes de CO2eq	5'000 tonnes de CO2eq	5'000 tonnes de CO2eq

Figure 8 - Eligibility criteria for subsidies according to Article 6 of the Climate and Innovation Act (CIA)

Although biogenic CCU technology is a reliable pathway to reduce or neutralize CO_2 emissions, biogenic CCU is not enough to reach the net zero by 2050. From a strategic level, CCS projects have thus on average more chance to get funding as their business case are easier to build in comparison to CCU projects. Additionally, the CIA promotes only innovative solutions rather than established technologies, which may complicate the process of securing financial support for CCU technologies and hinder their deployment. The construction of the incentives renders application more straightforward for companies emitting large quantities of fossil CO_2, than for small installations providing renewable energy or CO_2 capture. Thus a lot of installations from which biogenic CO_2 could be captured cannot get funded individually because of their small size and their very small CO_2 emissions.

In addition to the CIA, the CO_2 Act, which will come into effect after 2030, also proposes the introduction of new financing mechanisms. A consultation is planned for summer 2026, with the law set to be enforced in 2031. Its implementation will occur in two phases: an initial pilot phase spanning from now until 2030, using the existing legal setting followed by a scaling-up phase which relies on the new law with a period until 2050.[28] The new law will cover a broader range of projects, which will make biogenic CCU more favourable to get funding also for smaller plants.

In the context of biogas plants, strong incentives are available to produce electricity from biogas through the RS 730.03 (OEneR), whereas the incentives to produce biomethane are very limited. This favours thus electricity production for the biogas plants or projects, over biomethane production. This indirectly hinders biogenic CO_2 capture, since biomethane production includes CO_2 separation.

Finally, according to the CO_2 Ordinance (RS 641.711), projects eligible for emission reduction certificates ("CO_2 certificates") must either generate negative emissions or increase CO_2 storage capacities. In this context, CCU is not considered as storage unless the carbon remains effectively sequestrated in a sustainable manner, meaning the CO_2 does not return to the atmosphere during the product's lifecycle. This is typically not the case when CO_2 is used in greenhouses for producing synthetic fuels, but could be the case if the CO_2 is mineralized or incorporated into construction materials concrete, carbonates etc) or transformed into durable materials (e.g. polymers) in a permanent way, above 30 years (RS 641.711, al.2).

2.1.4. Interviews of actors in the field

Various stakeholders in the CO_2 sector, including water treatment facilities, suppliers, and end users, were interviewed to gather their feedback and perspectives on the biogenic CO_2 market. A high percentage of these players responded positively to our request, demonstrating a high interest in the sector. This section presents a summary of the main discussions and conclusions drawn from these exchanges.

[28] Annual CCUS conference in Bern, 2025

Current and future CO_2 needs

The CO_2 market in Switzerland is estimated by the different experts between 70'000 and 100'000 t CO_2/year, showing the lack of public data on the topic. It is forecasted to increase by 10% over the next 10 years, according to Messer group. This demand is mainly driven by the food industry, particularly for applications in beverages and food packaging, but also for the production of sustainable fuels. However, although demand is increasing, it is also facing growing competition from CO_2 capture from other sources, which could put pressure on biogenic CO_2 prices in the future.

Economic challenges related to production and transport costs

The cost of producing biogenic CO_2 remains a major challenge. On average, it is 50% higher than that of fossil CO_2. The production price depends on several factors, such as the quality of the CO_2 (industrial or food grade). For example, food-grade CO_2 requires specific analysis equipment, resulting in a production cost of up to CHF 200/t CO_2 for biogenic CO_2, well above the market price of CHF 150/t CO_2. This difference must be made up by government subsidies. Currently, subsidies are lacking, making it more difficult for projects to be profitable.

The size of the facilities is also a key factor in ensuring profitability. According to Messer group, a minimum volume of 10'000 t CO_2/year is required for the facility to be economically viable. According to Prodeval, some end consumers, such as greenhouses, are willing to pay more for biogenic CO_2 if they can guarantee year-round supply. In this case, production of 3'000 t CO_2/year may be sufficient to ensure economic profitability. According to Verdemobil, a minimum installation size of 1'000 t CO_2/year is sufficient for industrial quality, while for food quality, the minimum size is 5'000 t CO_2/year. For food quality, Prodeval suggests combining the analysis systems of several installations, which would allow for a production of 2'500 t CO_2/year.

The transport of CO_2 is also a determining factor. Transport costs represent a significant portion of overall expenses. Companies recommend that the maximum transport distance be 150 km, ideally less than 100 km. For example, the wastewater association of Lenzburg (AVRL) uses captured biogenic CO_2 to stabilize the pH of wastewater, minimizing transport costs by using it on site as seen before.

Finally, the cost of electricity, which accounts for around 30% of production costs, also largely influences the profitability of projects.

Market opportunities and competition

The increase in CO_2 demand for food industry and sustainable fuel, as well as the companies' desire to reduce their carbon footprint are creating a favourable environment for the biogenic CO_2 market. In Switzerland, initiatives such as CO_2 sequestration in concrete by Neustark could also boost demand for biogenic CO_2.

However, competition is increasing as various actors will enter the market, notably for the production of sustainable fuels. For example, waste incinerators, which may capture CO_2 at a larger scale, thus at a lower cost, represent a competition for biogenic CO_2 producers as discussed around Figure 4.

In addition, volumes of biogenic CO_2 remain limited by the capacity of existing anaerobic digestion facilities, which are heavily dependent on raw materials such as organic waste. Growing demand could therefore be hampered by this supply constraint.

Conclusion

The biogenic CO_2 market is increasing driven by growing demand for decarbonization. However, challenges such as higher production costs, transport expenses, and increasing competition from fossil CO_2 sources persist. To succeed, biogenic CO_2 producers must focus on securing long-term contracts and optimise cost to maintain competitiveness in an evolving market.

2.2 Biogenic CO_2 potential from biogas plants in Switzerland

2.2.1. Evaluation of current potential

The objective of this task is to quantify the current biogenic CO_2 capture potential from agricultural, industrial, and sewage sludge biogas plants in Switzerland.

Method

In a first step, we compiled a comprehensive bottom-up database on Swiss biogas plants using the following sources:

Feed-in Remuneration at Cost (KEV): The 2024 list of recipients provided power production data for CHP plants, serving as our primary data source for agricultural biogas plants.

Swiss Gas Industry Association: The 2024 annual report contains production data for plants that upgrade biogas to biomethane for grid injection.

Swiss Water Association (VSA): The 2019/2020 Kennzahlenerhebung was our main source for public sewage sludge biogas plants.

These primary data sources were complemented with a desktop research and direct exchanges with representatives of specific plant types (e.g. ökostrom Schweiz, biomasse Suisse). For each plant, the most recent available data was used.

The focus of this database is to collect information on the plants' annual biogas production volume. Where this was not directly reported, the volume (V_{bg}) is calculated from other production data available, such as the plant's reported energy output, maximum capacity or biomethane volume (equations in Table 2). Other information collected in the database includes the plant's location, contact details, substrate type, plant size, type of output (CHP or upgrading to biomethane) and technology specifications, where available.

Table 2 - Calculation pathways to derive a plant's produced biogas volume V_{bg} based on production data available. Uncertainty ranges for the parameters will be introduced as part of the sensitivity analysis.

Type of plant and production data	**Equation**	**Parameters**			
CHP					
Power production $\mathbf{P_{el}}$	$V_{bg}=\frac{P_{el}}{ec_{eff}*frac_{CH4}*l\_hv_{CH4}}$	$\mathbf{ec_{eff}}$	energy conversion efficiency of plant	0.43	VSE, 2015[29]
		$\mathbf{frac_{CH4}}$	fraction of CH_4 in raw biogas	0.64	VSA, 2022[30]
Plant capacity **CF**	$V_{bg}=\frac{CF*frac_{CF}}{ec_{eff}*frac_{CH4}*l\_hv_{CH4}}$	$\mathbf{frac_{CF}}$	capacity utilization	0.55	analysis of KEV data, preliminary
		$\mathbf{l\_hv_{CH4}}$	lower heating value of CH_4	9.97 kWh/Nm^3	SVGW, 2024[31]
Upgrading plant					

[29] VSE (2015). Verband Schweizerischer Elektrizitätsunternehmen: Strom aus Biomasse. Accessed on 25.09.2025. https://www.infothek-biomasse.ch/images/311_2015_VSE_StromAusBiomasse.pdf
[30] VSA (2022). Handbuch Gasproduktion und -verwertung auf ARAs.
[31] SVGW (2024). Biogas – Umrechnungen kg und kWh. Accessed on 25.09.2025. https://gazenergie.ch/fileadmin/user_upload/ErneuerbareGase/20240115-Biogas-Umrechnungen-kg-und-kWh-DE.pdf

Biomethane volume V_{CH4}	$V_{bg}=\frac{V_{CH4}*purity_{bm}}{\text{frac}_{CH4}}$	$purity_{bm}$	fraction of methane in biomethane fed into grid	0.96	VSG, 2023[32]
Power equivalent PE_{el}	$V_{bg}=\frac{PE_{el}*purity_{bm}}{u\_hv_{CH4}*frac_{CH4}}$	$frac_{CH4}$	fraction of CH_4 in raw biogas	0.64	VSA, 2022
Plant capacity CF	$V_{bg}=\frac{CF*purity_{bm}}{u\_hv_{CH4}*frac_{CH4}}$	u_hv_{CH4}	upper heating value of CH_4	11.1 kWh/Nm^3	SVGW, 2024

Based on the raw biogas volume, we estimated the on-site CO_2 emissions of each plant per year (Table 3). Here, we distinguished between CHP and upgrading plants: at CHP plants, the total CO_2 emissions are the sum of the CO_2 in the raw biogas plus the CO_2 produced during combustion of the biomethane contained in the raw biogas. In biogas upgrading plants, the CO_2 emissions are the CO_2 fraction that is contained in the raw biogas which is sequestered during upgrading.

Table 2 - Equation to calculate the biogas plant's CO_2 emissions from the biogas volume V_{bg} produced.

Type of plant	Parameters			
CHP	$frac_{CO2}$	fraction of CO_2 in raw biogas	0.35	VSA, 2022[33]
$m_{CO2}=\rho_{CO2}*\text{frac}_{CO2}*V_{bg}$	$frac_{CH4}$	fraction of CH_4 in raw biogas	0.64	VSA, 2022
Upgrading plant	EF_{CH4}	CO_2 emission factor of burning CH_4	2.744 t CO_2/t CH_4	BAFU, 2025[34]
$m_{CO2}=m_{CO2\text{-}bg}+m_{CO2\text{-}burn}$	ρ_{CO2}	density of CO_2 (norm conditions)	1.98 kg/Nm^3	BAFU, 2025
$m_{CO2\text{-}bg}=\rho_{CO2}*\text{frac}_{CO2}*V_{bg}$ $m_{CO2\text{-}burn}=EF_{CH4}*\rho_{CH4}*\text{frac}_{CH4}*V_{bg}$	ρ_{CH4}	density of CH_4 (norm conditions)	0.72 kg/Nm^3	BAFU, 2025

Next steps

Our next steps focus on finalizing the database. We will fill remaining data gaps (e.g. on industrial sewage sludge biogas plants) and refine key calculation parameters – either through a sensitivity analysis or by adjusting them to characteristics of individual plants. These parameters include the biogas composition and the CHP's energy conversion efficiency. Also, we will validate the data against statistics (Swiss gas association, Swiss Statistics on Renewable Energy) and by contacting plant operators directly. These steps will improve the accuracy of the data and allow us to establish uncertainty ranges.

The steps so far result in the total CO_2 emissions at Swiss biogas plants, i.e. the *maximum theoretical* potential for carbon capture. Building on this, we will the evaluate the *feasible* capture potential by applying the criteria that will be defined in WP1. The criteria will focus on technical aspects, such as the size of the biogas plant, the size requirements for the sequestration unit, the demand for heat and

[32] VSG (2023). Neue Gasbeschaffenheiten im Schweizer Gasnetz. Accessed on 25.09.2025. https://gazenergie.ch/fileadmin/user_upload/e-paper/GE-Gasette/2023/Gazette-2023-01-DE.pdf
[33] VSA (2022). *Handbuch Gasproduktion und -verwertung auf ARAs.*
[34] BAFU (2025). *Faktenblatt: CO_2-Emissionsfaktoren des Treibhausgasinventars der Schweiz.*

electricity, and the minimum CO_2 concentration in the flue gas. In accordance with the other work packages, we are considering including economic aspects as well.

3 Conclusions

The global market for biogenic CO_2 is expected to grow, driven by the increasing demand for decarbonization. In Europe, over half of captured CO_2 is biogenic, with 75% directed towards Carbon Capture and Utilization (CCU), primarily in greenhouses (32%), food and beverages (21%), and e-fuels (10%). In Switzerland, the biogenic CO_2 market is estimated at 70'000-100'000 t CO_2/year and is expected to grow by 10% over the next decade, primarily driven by the food industry, including beverage production, packaging, and sustainable fuel and chemical production. Sequestration is expected to be the dominant future market.

Several biogenic CCU projects are already operational in Switzerland, including a plant in Nesselnbach producing 4'000 t of food-grade liquid CO_2 annually, and the ARA Bern wastewater treatment plant, which captures and stores 4'000 t per year in demolition concrete. Additionally, the Lenzburg wastewater treatment plant uses captured CO_2 on-site to stabilize pH levels during water treatment.

According to interviews with different actors in the field, the main challenge remains the high cost of producing biogenic CO_2 (around 200 CHF/t), influenced by factors such as quality, facility size, electricity prices, and transport distance. However, increasing CO_2 demand and the drive for reduced carbon footprints are creating a favorable environment for the biogenic CO_2 market.