



White Paper

Building-Integrated Carbon Capture (BICC)

How the built environment can become carbon-negative

June 2024

Contents

1 **Introduction**

Notice 03

Abbreviations and acronyms 04

Editorial 05

Executive summary 06

2 **Climate Crisis, Buildings, and Carbon Capture**

The urgent climate crisis and the built environment 07

Carbon capture – an additional carbon mitigation strategy 09

Different direct air carbon capture technologies 10

3 **Integrating Carbon Capture in Buildings**

BICC technology – example by Soletair Power 11

Different BICC integration strategies 12

Building system integration and energy cascade potential 13

4 **The Danish Built Environment**

Danish legislation and other initiatives regarding carbon emissions 14

An example of a BICC facility in Aarhus, Denmark 17

Assessing potential environmental impacts through LCA 19

Similar installation cases 21

Storage and utilization avenues for captured CO_2 22

5 **Way Forward for the Real Estate Industry**

Real estate as a driver for carbon capture technologies 23

Carbon neutral commercial buildings using BICC 24

Financial perspectives regarding carbon economy 25

6 **Disclaimer** 26

REGENERATIVT BYGGERI

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Revision 2: Updated LCA calculations, page 18+19

Notice

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Abbreviations and acronyms

BECCS	Bioenergy carbon capture and storage
BICC	Building Integrated Carbon Capture
CAPEX	Capital expenditure
CC	Carbon capture
CCS	Carbon Capture and Storage
CCU	Carbon capture and utilization
CDR	Carbon dioxide removal
CO_2	Carbon dioxide
DAC	Direct Air Capture
DACCS	Direct air carbon capture and sequestration
EU	European Union
ETS	Emissions Trading Scheme
FT	Fischer–Tropsch
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
IPCC AR6	IPCC Sixth Assessment Report
ITC	Investment tax credit
PTC	Production tax credit
PTX	Power-to-X
R&D	Research and development

Editorial

Frank Jensen
Owner, Board Chair, Søren Jensen Engineering

Petri Laakso
Co-Founder, CEO, Soletair Power

In this white paper, Soletair Power and Søren Jensen Engineering present the case for an additional, affordable, low-risk strategy for the hard-to-abate parts of the built environment, which account for 38% of global CO_2 emissions. When we use "additionality" to describe the strategy, we mean to say that the presented strategy cannot stand alone but must be supported by additional measures such as emission reductions like change to renewable energy, use of biogenic materials like wood, straws and other grasses, material optimization and reuse.

The United Nations Intergovernmental Panel on Climate Change (IPCC) has consistently warned humanity of the dangers and costs of continuing on the path of exceeding planetary boundaries. We are now at a point where humanity has to rely on capturing carbon from the atmosphere if we are to keep the warming of the Earth within 1.5-2 degrees Celsius. Of course, we must maximize emission reductions and avoid emissions in the short and medium term. However, the scope for further emission reductions will decrease as we approach the net zero target date, and we must shift towards carbon removals, which remove carbon from the atmosphere to counterbalance residual emissions and achieve net zero. Again, to supplement afforestation, biochar, and similar approaches, the technology of Direct Air Carbon Capture (DACC) will play a role.

Real estate is a dominant contributor to all these human overuses and emissions. Real estate accounts for roughly two-thirds of all human wealth. Buildings are constructed not only for occupation and production but also for wealth preservation and growth, particularly in urban areas. Hence, any successful green transition towards a sustainable future will have to engage the built environment and present compelling financial futures for the real estate sector, both commercial and private.

Over the last few years, we have worked together to understand the sustainability, technical, and financial aspects of Building Integrated Carbon Capture (BICC). We have come to believe that such systems have a role to play on both a global level and at the asset level in initially reaching net zero goals and thereafter accelerating the regeneration of the atmosphere.

To supplement the global push for large-scale, often one-off DACC projects, real estate offers an ideal platform for a modular, less risky approach to carbon capture.

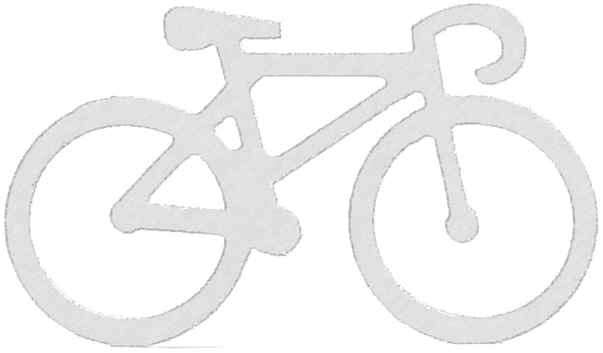
Real estate offers existing mechanical air-handling units and infrastructure. This infrastructure provides a major platform for capturing significant amounts of CO_2 on a global scale. In buildings, there is also available energy, and one needs different levels of heat, which means that it can be used several times to maximize total consumption.

Integrating BICC technology in new construction and existing real estate, there are few, if any, codes and legislation hindering a rapid deployment of BICC, unlike that for many new building materials. Instead, regulations and legislation are gradually shifting to require low- or zero-emission buildings, and an increasing number of tenants are looking for leases that support their own ESG goals, including emission reduction goals. We believe that the future economical mechanism within the carbon economy like carbon credits and green financing as well as the already seen user demand for sustainable real estate alternatives will push the market for BICC.

Within this white paper, we will document that BICC is rapidly becoming sustainable technically, environmentally, and financially, while being significantly lower risk than many alternative ways of emission abatement. If BICC were to over time become as universally adopted in real estate as photovoltaics, then real estate would transition from being a dominant emission source to a dominant contributor to atmospheric regeneration while enabling the preservation of the financial value of new and existing real estate.

Executive summary

This white paper explores the concept of regenerative buildings and discusses a specific case study of a Building Integrated Carbon Capture (BICC) technology installation in a building located in Denmark. The paper provides an overview of BICC technology and its integration process within the building. It showcases the project's targeted performance, highlighting the captured carbon dioxide tonnage and its utilization potential. Furthermore, the paper explores the various benefits of BICC technology for achieving regenerative building goals. The concluding remarks discuss the future trajectory of BICC technology and its role in advancing regenerative design principles.



Key takeaways:

- The urgency of addressing climate change necessities exploring all available solutions, including carbon capture technologies like BICC.
- BICC offers a unique opportunity for the real estate sector to reduce its carbon footprint and achieve carbon neutral or even net-negative emissions.
- Denmark serves as a valuable example of a country actively promoting carbon capture implementation through ambitious goals, supportive regulations, and a thriving innovation ecosystem.
- The Søren Jensen Engineering own office project demonstrates the viability of BICC in a real-world application, achieving significant CO_2 reductions. A life-cycle-analysis (LCA) of the BICC unit shows that the amount of carbon captured surpasses significantly the emitted CO_2 from producing the BICC unit and for the operation of the BICC unit.
- Beyond environmental benefits, BICC presents financial advantages through improved ESG compliance, potential carbon credit revenue, and future tax incentives.
- Net-zero buildings can command rent premiums as tenants seek to reduce their Scope 3 emissions, can increase property resale value by mitigating price depreciation risks, and can lead to green financing with lower interest rates due to regulations favoring green buildings, accelerating payback periods for building owners.

The urgent climate crisis and the built environment

The IPCC's Sixth Assessment Report (AR6) paints a stark picture: we are facing a climate crisis, and immediate action is required to limit global warming to 1.5 degrees Celsius. There is an urgency to reduce greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), the most abundant anthropogenic GHG. Current estimates suggest that global CO_2 emissions need to reach net zero by 2050 to achieve the 1.5°C target.

New data from 2023 from the European Copernicus Climate Change Service indicates that we are already very close to the 1.5°C target and therefore likely are looking into the below 2°C scenarios (RPC 2.6) described in the IPCC AR6 report.

In order to rapidly "bend-the-curve" and stay below 2°C further global warming potential two overall mitigation pathways are described in AR6:

1. Carbon mitigation – replacing with fossil carbon-free technologies.
2. Carbon removal technologies – to compensate for carbon-emitting technologies and to accelerate the general reduction of carbon emissions, carbon removal technologies are essential.

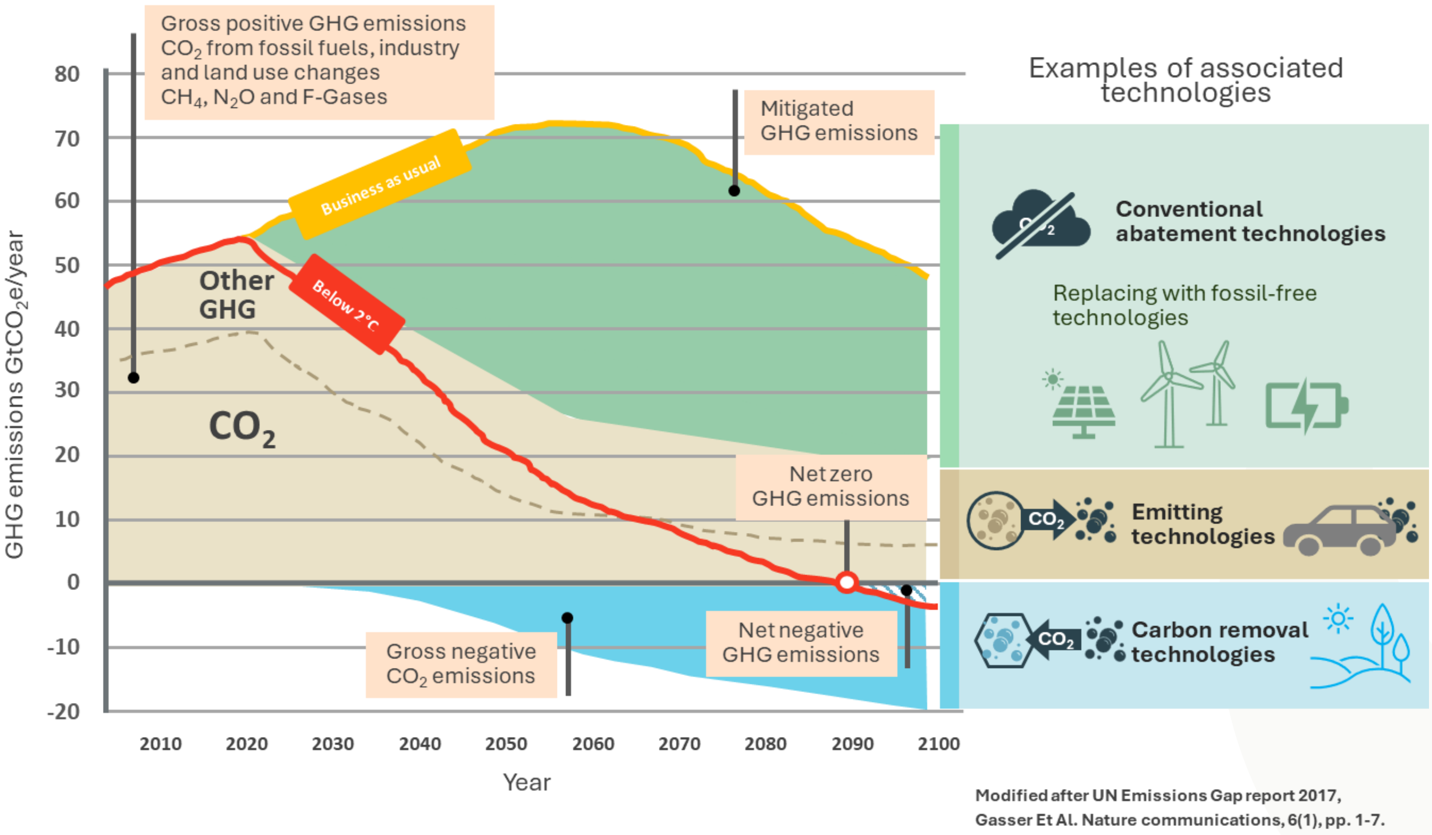


Figure: The mitigation of greenhouse gas emissions can be achieved by avoiding emissions (e.g., through technologies and changes in human behavior) and carbon dioxide removal (CDR) from the atmosphere. Gross negative emissions are the result of CDR from the atmosphere and "... durably storing it in geological, terrestrial, or ocean reservoirs, or products" (IPCC, 2018). Net-negative GHG emissions are achieved when negative emissions are larger than GHG emissions at a global scale. Net-zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period. Net-zero CO_2 emissions are also referred to as carbon neutrality. Source of figure: UNEP Emission Gap Report (2017), borrowed from The Novo Nordisk Foundation CO_2 Research Center, Aarhus University.

Carbon mitigation strategies like energy efficiency and renewable energy are crucial, but according to IPCC and other scientific papers like Gasser et al. (2015) carbon removal technologies will be necessary to achieve net negative CO_2 emissions.

"In addition to deep, rapid, and sustained emission reductions, CDR can fulfill three complementary roles: lowering net CO_2 or net GHG emissions in the near term; counterbalancing 'hard-to-abate' residual emissions (e.g., some emissions from agriculture, aviation, shipping, industrial processes) to help reach net zero CO_2 or GHG emissions and achieving net negative CO_2 or GHG emissions if deployed at levels exceeding annual residual emissions."

IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

It is estimated that 1 Gt CO_2e per year from 2030 to 20 Gt CO_2e per year in 2100 needs to be removed from the atmosphere (negative CO_2 emissions).

Capturing such vast quantities surely presents a challenge. Because the concentration of CO_2 in the atmosphere is relatively low, this requires an enormous throughput of ambient air to capture significant amounts of CO_2.

Approximately 400 m^3/hour air flow needed to capture 1 ton of CO_2 per year

However, there is an opportunity to leverage existing infrastructure in buildings. Modern commercial buildings already ventilate a significant amount of air due to human occupancy (typically above 1000 ppm CO_2-concentration in the exhaust air) and due to regulations. While the exact volume of air exchanged varies, it still represents a substantial amount. This existing airflow could be utilized by integrating carbon capture technologies into building ventilation systems.

This approach offers a potential solution by utilizing existing infrastructure to contribute to negative emissions strategies.

The built environment

The built environment sector is one of the largest contributors to global greenhouse gas (GHG) emissions. According to a recent publication from the UN Environment Program (UNEP) the built environment contributes to more than a third (37%) of the global GHG emissions. Combined with the fact that the total built floor area is predicted to increase by 75% from 2020 to 2050 the decarbonization of the building sector is crucial (IEA, 2022). This white paper explores the potential of *Building Integrated Carbon Capture* technology as one of the many essential tools to address the climate crisis, especially in the built environment.

Gasser, T., Guivarch, C., Tachiiri, K. *et al.* Negative emissions physically needed to keep global warming below 2 °C. *Nat Commun* **6**, 7958 (2015). https://doi.org/10.1038/ncomms8958
United Nations Environment Programme, & Yale Center for Ecosystems + Architecture (2023). Building Materials and the Climate: Constructing a New Future. https://wedocs.unep.org/20.500.11822/43293.
IEA, Technology and Innovation Pathways for Zero-carbon-ready Buildings by 2030, IEA, (2022), Paris https://www.iea.org/reports/technology-and-innovation-pathways-for-zero-carbon-ready-buildings-by-2030, License: CC BY 4.0

Carbon capture – an additional carbon mitigation strategy

As stated in the IPCC AR6 report, we need several solutions to solve the climate change problem. Carbon capture should not be used as an alternative to other carbon mitigation strategies, it should be used as an addition to other carbon mitigation strategies like use of biogenic materials, material optimization, and waste reduction which remain essential strategies. However, Carbon capture offers a way to address existing emissions and potentially achieve net-negative emissions.

Carbon capture technologies enable the removal of carbon dioxide from the atmosphere or from processes that emit CO_2 in high concentrations, such as industrial flue gases or biogenic processes like fermentation. Carbon capture technologies can be categorized according to the end-use of CO_2. Carbon capture and storage (CCS) stores CO_2 in geological formations, where it mineralizes to solid carbonate minerals. Carbon capture and utilization (CCU) uses the captured CO_2, for example, as a potential feedstock to produce e-fuels. It's important to understand that Carbon capture is not a replacement for reducing emissions at the source. However, it can be a valuable tool in addressing existing emissions and potentially achieving net-negative emissions profiles, particularly when combined with other sustainability strategies.

There are several different carbon capture technologies. Some are more market-ready than others. In Babiker et al. (2022), twelve different carbon dioxide removal (CDR) technologies are listed. The ones with the highest technology readiness level (TRL) and highest mitigation potential are listed below.

Technology	Status (TRL)	Mitigation Potential (Gt/year)	Permanence (years)	Cost (USD per ton CO_2)
Direct air carbon capture and sequestration (DACCS)	6	5–40	1000+	100–300
Bioenergy with carbon capture and storage (BECCS)	5-6	0.5–11	1000+	15–400
Afforestation/reforestation	8-9	0.5–10	20-50	0–240
Enhanced rock weathering	3-4	2–4	1000+	50–200
Biochar	6-7	0.3–6.6	100-500	10–345

Babiker, M., G. Berndes, K. Blok, B. Cohen, A. Cowie, O. Geden, V. Ginzburg, A. Leip, P. Smith, M. Sugiyama, F. Yamba, 2022: Cross-sectoral perspectives. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.005

Different direct air carbon capture technologies

Direct air carbon capture (DACC) is the technology to remove CO_2 from the atmosphere. There are two main DACC technologies, which can be distinguished according to their modes of operation, solid and liquid direct air capture (S-DACC and L-DACC, respectively).

- S-DACC: uses a solid material that acts as an absorber of atmospheric CO_2. The CO_2 is then released by heating the material with medium-elevated process heat at around 100°C. Current research focuses on the electrical or pressure-based recovery of the absorbing material to increase the process efficiency (McQueen et al., 2021).
- L-DACC: uses an alkaline liquid to capture CO_2 and requires much higher temperatures to release the CO_2 (300-900°C).

In DACC, around 80% of the total energy needed to capture atmospheric CO_2 must be supplied by process heat. The high-temperature process heat required for L-DACC is still supplied by the combustion of natural gas, which also releases CO_2. This CO_2 can be directly captured within the process to avoid being emitted into the atmosphere. However, this lowers the efficiency of CO_2 capture (the ratio of emitted to captured CO_2).

Therefore, S-DACC technology, which does not require high-temperature heat, is more efficient. The advantage of S-DACC over L-DACC is that the low-temperature heat can be more easily recovered from the waste heat of other processes, like the Fischer-Tropsch process. This can reduce costs and enhance system integration if the processes are combined. Low-temperature heat can also be supplied using heat pumps, which can be powered by renewable electricity.

Different carbon capture technologies are suited for various applications. Here's a breakdown of the two main carbon capture systems:

1. **Building-Integrated Carbon Capture (BICC):** Seamlessly integrates with existing building ventilation systems, capturing CO_2 directly at the source through chemical or physical absorption processes. Ideal for the built environment as it minimizes additional infrastructure needs.
   Example: Soletair Power's BICC system captures CO_2 from a building's ventilation air and can potentially reduce a building's CO_2 footprint by 40-60%. If the building uses renewables, 100% carbon sink buildings can be made.
2. **Centralized Direct Air Carbon Capture:** Captures CO_2 from a centralized plant and at larger volumes than BICC. It also uses direct air carbon capture technologies. The placement of the facility is often far away from cities.
   Example: The Climeworks ORCA project in Iceland, the world’s first large-scale DAC plant, captures a total of 4000 tons of CO_2 per year. The process is DACCS where CO_2 is captured and injected into nearby basaltic rock formations to be permanently turned into stone.

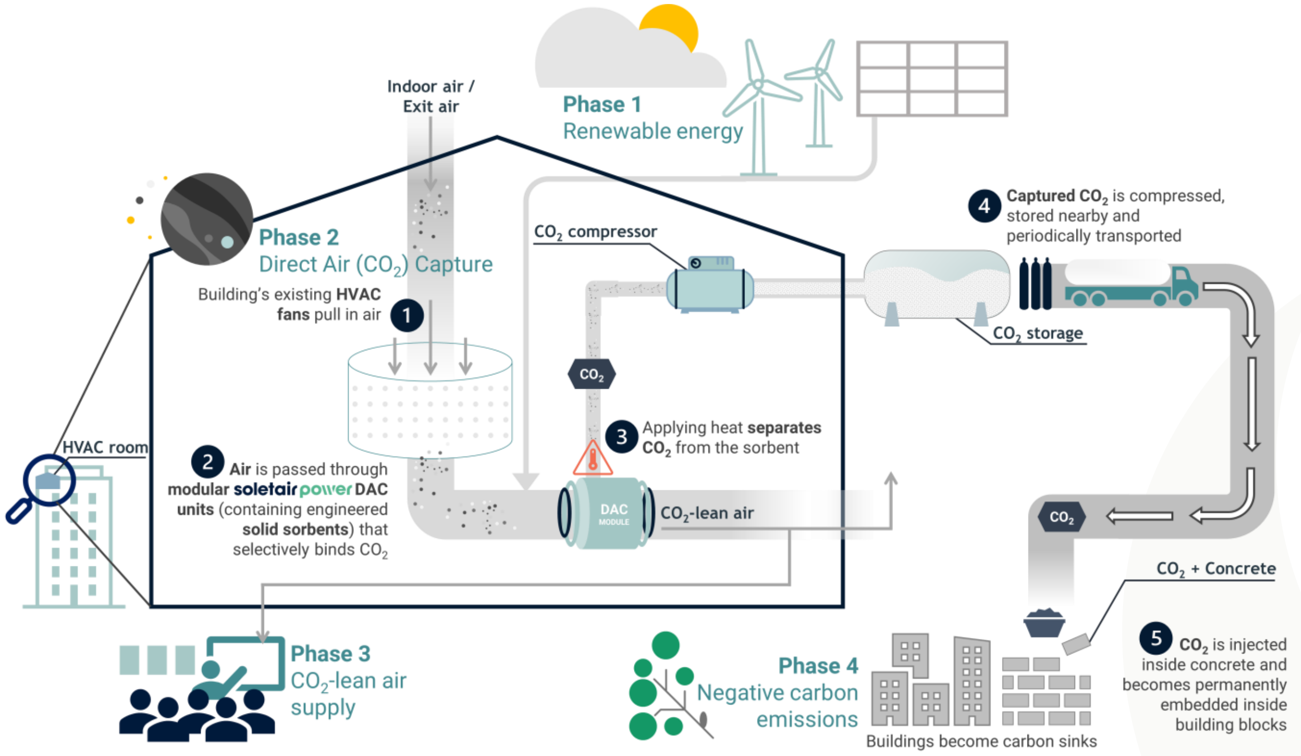
BICC technology – example by the Soletair Power's system

Soletair Power's HVAC Integrated CO_2 Capturing Unit is a modular carbon capture system that operates plug-and-play. Each unit can capture up to 20 tons of CO_2 per year, equivalent to 3 hectares of Nordic forest aged 30 years and can be integrated into the building's HVAC (heating, ventilation, and air conditioning) system.

For example, from a 10,000 sqm office space, with 5 Soletair Power units, total capture will be 5 x 20 = 100 tons of CO_2 per year.

This is a rough estimate where the system operates 8 hours per day, 365 days a year, with an airflow of 3 m^3/s. More units can be added to increase the capture capacity.

The unique selling points of the system are its building retrofitability, easy installation, modular design, weatherproof capture, and low water/ heat/ electricity/ material/ carbon footprint.



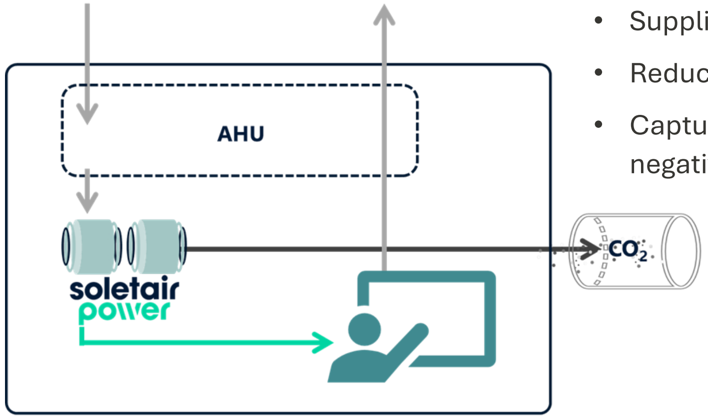
How it works

1. The building's HVAC system pulls in air and ventilates it. The polluted air exiting from the building is delivered to the carbon capture system.
2. The air is pushed through the proprietary sorbents. They selectively adsorb carbon dioxide.
3. When the filter is saturated, the machine is closed and regenerated via vacuum & heating to collect the captured CO_2.
4. The captured CO_2 is stored in a separate container near or inside the building.
5. CO_2 is stored and e.g., can later be supplied for making concrete.

Different BICC integration strategies

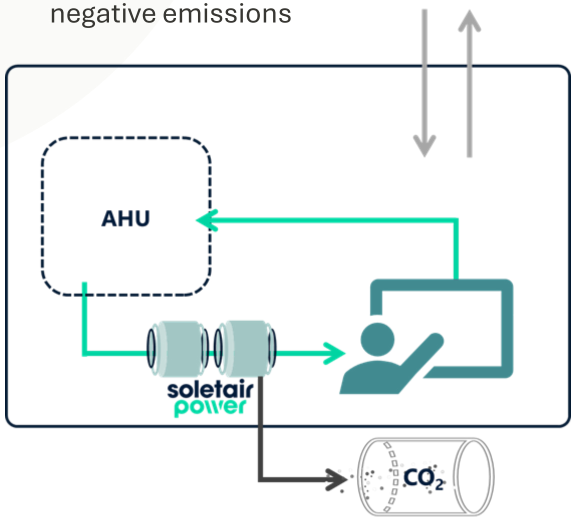
Intake Air CO_2 Capture

- Captures CO_2 from the supply air passing through inlet
- Supplies CO_2 lean air to people
- Reduces HVAC energy costs
- Captured CO_2 can be stored and create negative emissions



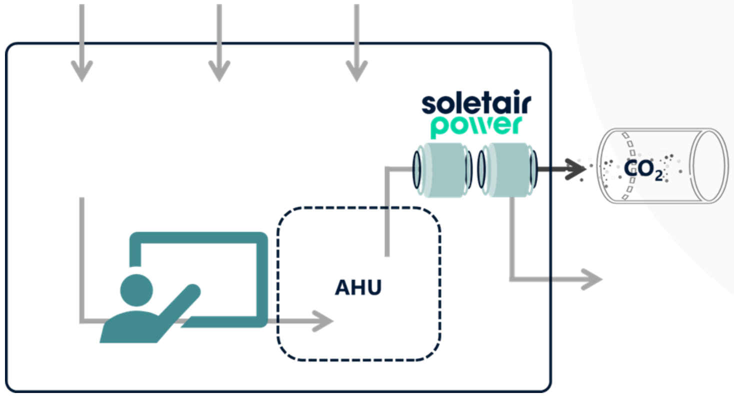
Circulating Air CO_2 Capture

- Captures CO_2 from the circulating air by AHU
- Supplies CO_2 lean air to people but CO_2 capture volume might be less than inlet or outlet if airflow is low
- Reduces HVAC energy costs
- Captured CO_2 can be stored and create negative emissions



Exhaust Air CO_2 Capture

- Operates in building with multiple small air vents
- Captures CO_2 from the return air going through outlet
- Does not supply CO_2 lean air to people
- Does not reduce HVAC energy costs
- Captured CO_2 can be stored and create negative emissions



Building-system integration and energy cascade potential

Modern buildings are complex ecosystems with various technical installations working in tandem to ensure occupant comfort, functionality, and energy efficiency. Building system integration focuses on optimizing the interaction between these systems, leading to significant benefits such as reduced energy consumption, improved operational efficiency, and a smaller environmental footprint. Energy cascade potential refers to the opportunity to utilize waste/surplus heat or excess energy generated by one system within the building to power another system requiring a lower temperature. This creates a cascading effect, maximizing energy use and minimizing reliance on primary energy sources.

Potential avenues for using surplus heat from the DACC system:

75%

Estimated heat recovery potential from the carbon capture unit which is enough to heat up an energy-efficient commercial building

Proposal	Use
Floor heating	Low-temperature system that can reuse surplus heat from the DACC. When embedded in concrete, the system can benefit from heat storage.
Radiators	Low-temperature system that can reuse surplus heat from the DACC.
Frost-free greenhouse, shed, conservatory etc.	The surplus heat from the DACC can be reused to keep the space frost-free using underfloor heating or radiators.
Tracing of ex. roof water	Instead of a solution with electric tracing, tracing could be done with surplus heat
Selling surplus heat to the distribution	If it is possible to sell surplus heat back to the utility, there can be an advantage.

Danish national legislation and initiatives in Denmark regarding carbon emissions from the built environment

National Legislation in Denmark

Denmark is at the forefront of implementing carbon-reducing initiatives in the built environment.

Denmark has been an early leader in decarbonization and in 2022 the government announced a net zero by 2050 target. Denmark's technology leadership is important in the areas of offshore wind, biomethane and district heating.

On 1 January 2023, new climate requirements were added to the Danish Building Regulations. Now, the majority of newly constructed heated buildings must be accompanied by a Life Cycle Assessment (LCA). An LCA is a methodology that evaluates the environmental impact of buildings concerning processes, materials and energy use over a period of time (50 years in the methodology adopted in the Danish Building Regulations).

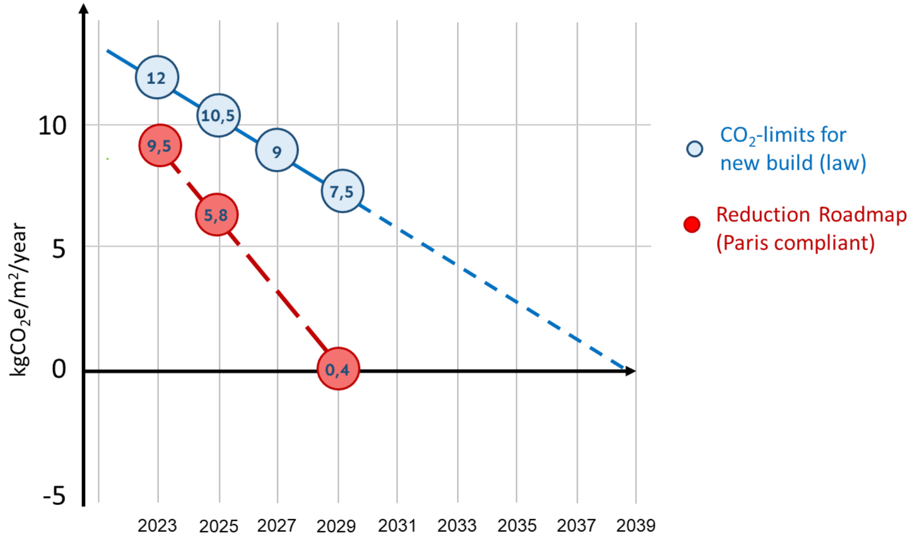
The existence of an LCA is thus a prerequisite for obtaining an occupancy permit for newly constructed buildings falling within the scope of the regulation. Additionally, if the building has an area of more than 1,000 square meters it must (also) adhere to a predefined threshold limit value of 12 kg CO_2eq/m^2 per year.

The requirement originates from the Danish National Strategy for Sustainable Construction (2021), which is a long-term political framework for an ambitious transition of the Danish construction sector towards lower sector-wide CO_2 emissions.

The Reduction Roadmap

The Reduction Roadmap is an Earth-shot project which – for the first time ever - works to translate the Paris Agreement and the Planetary Boundary for Climate Change into industry-specific reduction targets for new Danish housing projects. The Reduction Roadmap identifies where we are today, where we need to go, and the speed at which we must reduce our carbon emissions to reach Earth's safe operating space. The result is a science-based transformation tool and a call to action for the Danish building sector, working to align all building industry actors with commitment to the Paris Agreement.

The Reduction Roadmap is expressed in a stepped, linear reduction pathway and assumes a constant rate of construction. The vertical, y-axis represents the embodied carbon footprint of building materials, expressed in CO_2eq/m^2 per year. The horizontal x-axis represents time, beginning in 2020 and extending until the target level is reached. Today's median emission level is 9,63 kg CO_2eq/m^2 per year and is the starting point. The target emission level 0,4 kg CO_2eq/m^2 per year is the ending point.



24x

Reduction is necessary to reach target.

Reduction Roadmap in Denmark (signed by 600+ companies) toward a target for reducing carbon emissions

Today's national emissions

Denmark emitted 44,9 million tons of CO_2eq in 2020 (EES, 2022) exceeding the budget of 1.882.500 tons of CO_2eq per year nearly 24 times.

Reduction Roadmap emissions target

Denmark is allotted 0,075% of the global carbon budget (Paris Agreement, 2015). This equates to 1.882.500 tons CO_2eq per year for all carbon-producing activity in Denmark.

Source: Reduction Roadmap

Frameworks, laws & emission standards around the world

Local Law 97

LL97 (New York City Local Law 97): A regulation enacted in 2019 as part of the Climate Mobilization Act. It mandates large buildings in New York City to significantly reduce their greenhouse gas emissions.

Carbon pricing

Regulators may implement a carbon price as an **Emissions Trading System (ETS)** or a carbon tax. An ETS sets an annual decreasing emissions target and issues emissions allowances to regulated entities. Entities receive or buy credits through auctions and trade allowances with one another to comply with the target. Companies emitting below their allowance can sell surplus allowances to companies overshooting their budget. An ETS thus creates a market for carbon credits with a market price approximating industry-wide marginal abatement costs.

Carbon taxes are set on the CO_2 emissions produced from energy consumption and can also address other negative externalities (e.g., air pollution) and concerns (e.g., energy security). Contrary to ETSs, the carbon price under a carbon tax does not result from market forces but is administratively set.

CSRD

CSRD, short for Corporate Sustainability Reporting Directive, is an EU law requiring large companies to report on their environmental and social impact, alongside financials. This standardized reporting on ESG (environmental, social, and governance) factors aims to boost transparency and empower investors and consumers to make informed choices.

Section 45Q (US)

Tax credits introduced in 2018 to incentivize carbon capture, utilization, and storage (CCUS) technologies that capture and store CO_2 emissions from power plants and industrial facilities.

The Inflation Reduction Act United States 2022 (IRA)

The comprehensive policy package embraces several sectors of the economy. It offers tax credits to incentivize renewable electricity and hydrogen production from green (renewables with electrolysis), pink (nuclear power with electrolysis) and blue (natural gas with CCS) pathways. The IRA proposes investment tax credits (ITC) and production tax credits (PTC). ITC accrues as a one-time incentive, and PTC accrues over ten years.

EPBD

EPBD or Energy Performance of Buildings Directive is An EU directive (2002) that sets minimum energy efficiency requirements for new and existing buildings. It promotes energy-saving measures in construction.

SBTI

Established in 2015, SBTI (Science Based Targets initiative) helps companies set ambitious emissions reduction targets aligned with the latest climate science and the goals of the Paris Agreement. It's a collaborative effort by CDP, UN Global Compact, WRI and WWF. Over 4,000 businesses have already joined SBTI and set science-based emissions reduction targets. SBTi states to achieve net-zero with the SBTi, emissions that are not possible to cut, the final 5-10% may be neutralized through offsetting or carbon removals.

Retrofitting

real estate will be critical to meet the demand for net-zero carbon space and incoming regulations.

World Economic Forum

SBTI: If the company's initial carbon footprint is 100 tonnes of CO_2eq, they are allowed by SBTi to use external carbon credits to neutralize a maximum of 5-10 tonnes of CO_2eq.

Source: sciencebasedtargets.org/news/sbti-launches-world-first-net-zero-corporate-standard

Learn about more regulations:

NY Carbon City Property Tax Abatement Act, LNET, CDRLA, LECCLA, CAIP, MEES, GEG Buildings Energy Act, Montreal's Building Emissions Bylaw, Dubai's Green Building Regulations.

www.soletairpower.fi/12-global-building-emissions-regulations/

Søren Jensen Engineering's approach to regenerative construction in relation to carbon capture

Regenerative Buildings

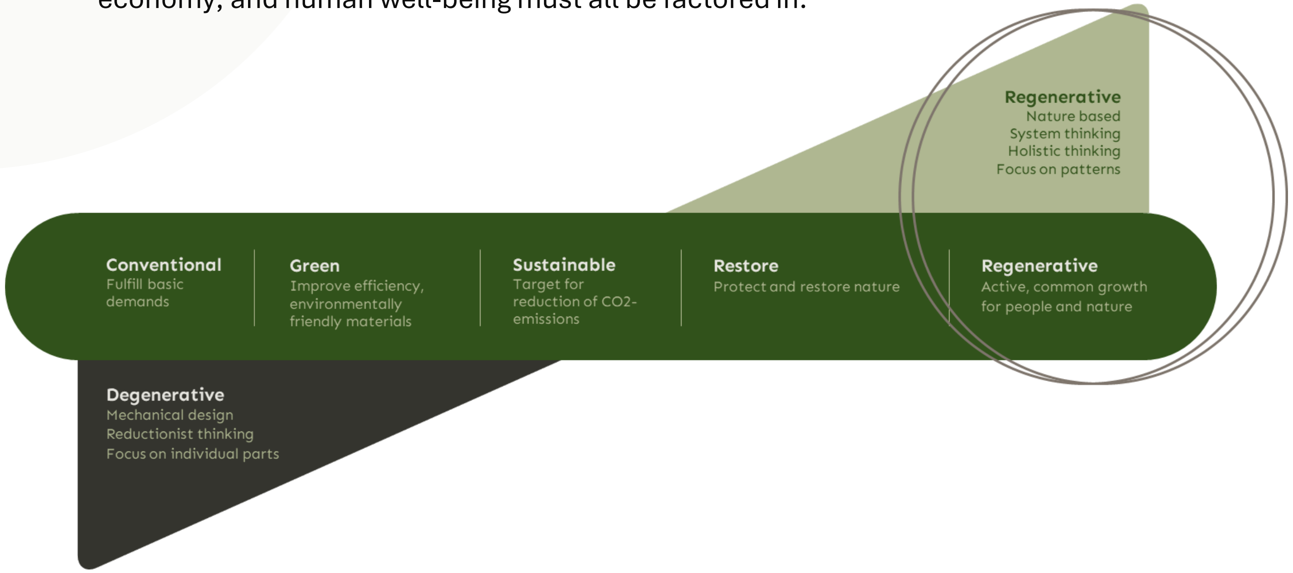
"Imagine if one could create buildings that did not burden the environment, but actually contributed to restoring it."

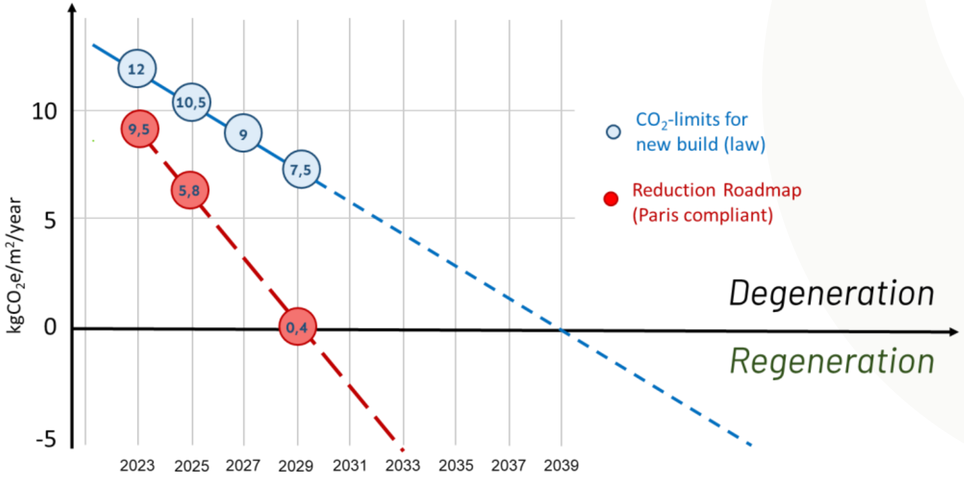
Regenerative building is about building in a way that makes a positive impact; built environments should not only be sustainable in the traditional sense; they should actively contribute to restoring the surrounding ecosystems. In this equation, considerations for climate, environment, nature, economy, and human well-being must all be factored in.

Carbon Emission and Regenerative Buildings

In relation to the present climate challenges addressed by the IPCC and many scientists around the world, a regenerative approach would be to create buildings with a negative CO_2 footprint, meaning that carbon removal technologies need to be implemented in our current building design.

Using building-integrated-carbon-capture (BICC) we make it possible to create buildings not only with a zero-emission impact, but we make it possible to create buildings with negative carbon emissions. So, every new building is better for the climate in relation to carbon emissions than no building.





An example of a BICC facility in Søren Jensen office, Aarhus, Denmark

Since BICC is still an emerging technology with many “first times” Søren Jensen Engineering has decided to install a BICC unit in the company office in Aarhus, Denmark. This is going to be the sixth unit installed by Soletair Power in the world, the first one in Denmark, and the first in the world in an office building.

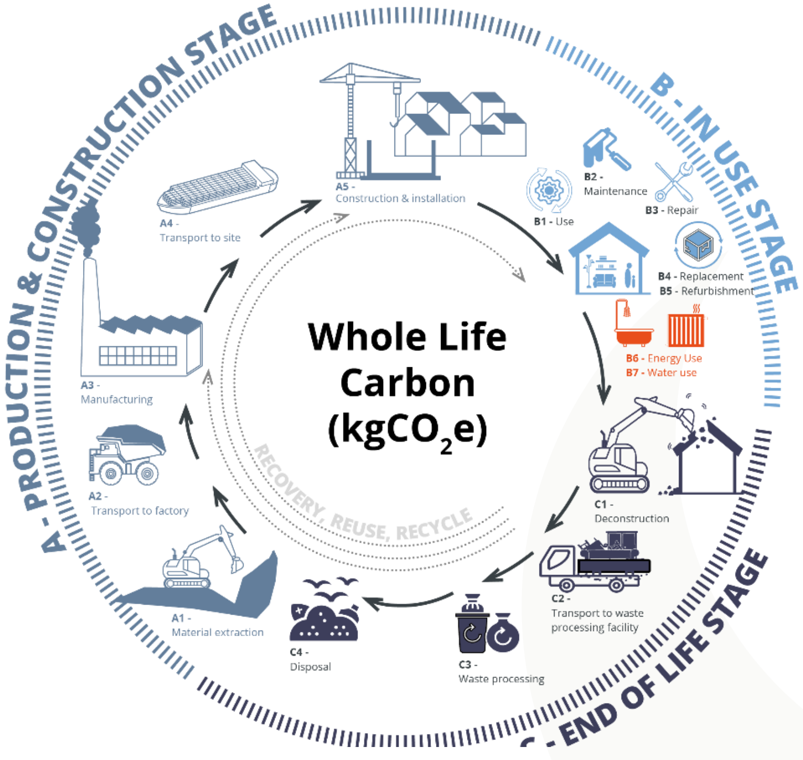
A life cycle assessment (LCA) evaluates the environmental impact of a product or system throughout its lifecycle. A key concern regarding BICC is the energy consumption associated with its operation. However, LCA studies demonstrate that the CO_2 captured by BICC systems outweighs the emissions generated from their energy use. We will show this using our own planned BICC unit at the Søren Jensen office in Aarhus, Denmark.

LCA on BICC at Søren Jensen office

The LCA calculation has been made to assess the total CO_2 emissions of the BICC system and thus evaluate the system's net capture. The calculation has been made with a 50-year consideration period, with the construction year being 2025.

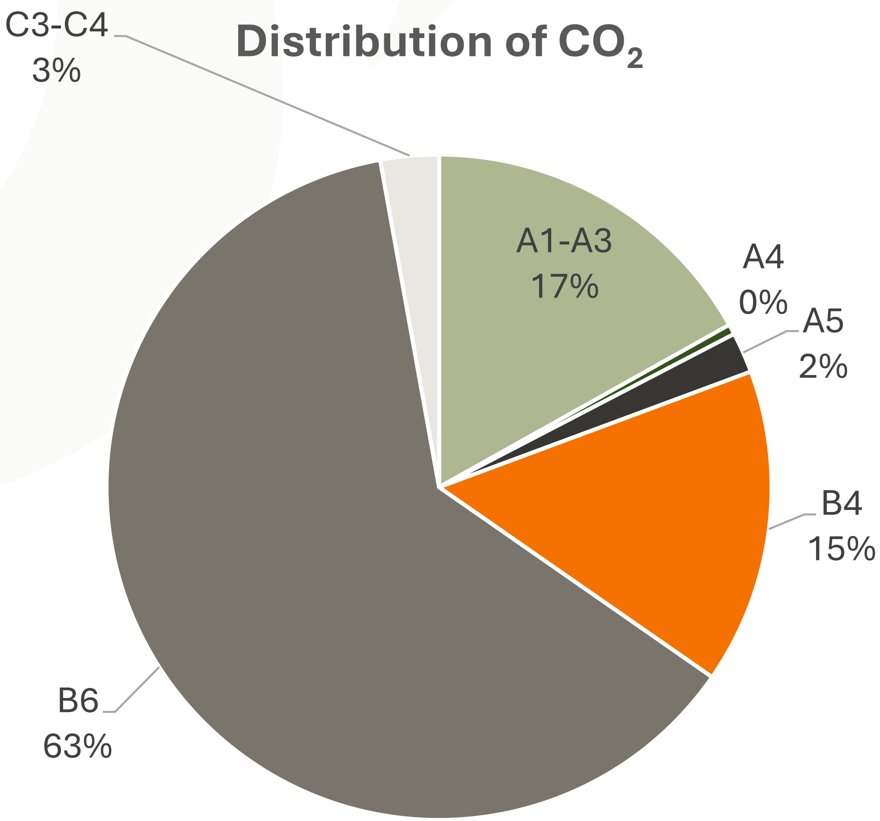
In the LCA calculation, the following phases are included:

- **A1-A3:** Following materials are included; walls, roof, deck doors, lightning and reinforcement to new technical room, technical equipment am. valves, pipes (gas, heat, water , drain), buffer tanks, heat pumps, electrical cabinets, chillers, cables, compressors, filters, ducts, insulation. Refri gerant (phase B1) is included in A1-A3.
- **A4:** Transport is included. Building components purchased in Denmark are set to a distance of 500 km with a Lorry >26 tons, and building components purchased in Finland are set to a distance of 1000km with a Lorry >26 tons and 500 km with a container ship.
- **A5:** Site waste is currently set at 10% of all used building materials.
- **B1:** Impacts related to the characteristics of the products in their application. Here CO_2-capture.
- **B4:** Replacements are calculated according to BUILD's lifetime table. Building components beyond the lifetime table are assessed in collaboration with the supplier.
- **B6:** Energy consumption where emission factors are according to the Social- og Boligstyrelsen new projection emission factors from 2025 and forward.
- **C3-C4:** Waste phases are included according to the environmental product declarations of materials.



BUILD levetidstabel: Version 2021 — Aalborg Universitets forskningsportal (aau.dk)
Emissionsfaktorer for el, fjernvarme og ledningsgas for 2025-2075 | Social- og Boligstyrelsen (sbst.dk)

Assessing potential environmental impacts through LCA (energy and materials)



The energy calculation is made with an air-to-water heat pump and is calculated to be 7,0-9,0 kWh electric/kg CO_2e. As the BICC system is designed to capture 50 kgCO_2e per day, energy calculations show that the system uses 164.250 kWh annually. The calculation currently does not include solar power, although there is an expectation that solar panels will be installed for the system or other forms of green electricity.

The annual CO_2 account for the BICC system at Europaplads is as follows:

- **A1-A3:** 1240 kg CO_2e/yr
- **A4:** 37 kg CO_2e/yr
- **A5:** 145 kg CO_2e/yr
- **B4:** 1126 kg CO_2e/yr
- **B6:** 4591 kg CO_2e/yr
- **C3-C4:** 209 kg CO_2e/yr
- **Capture (B1):** -18250 kg CO_2e/yr

The annual CO_2 emission over a consideration period of 50 years thus becomes 7.4 tons of CO_2, and with an annual capture of 18.2 tons of CO_2, the net capture is 10.9 tons of CO_2. Over a 50-year period, the BICC system will reduce the building's CO_2 emissions by 545 tons.

It is also seen by the LCA calculation that converting the electricity production to 100% renewable energy will increase the net captured CO_2 from 10.9 tons per year to approximately 15.5 tons per year.

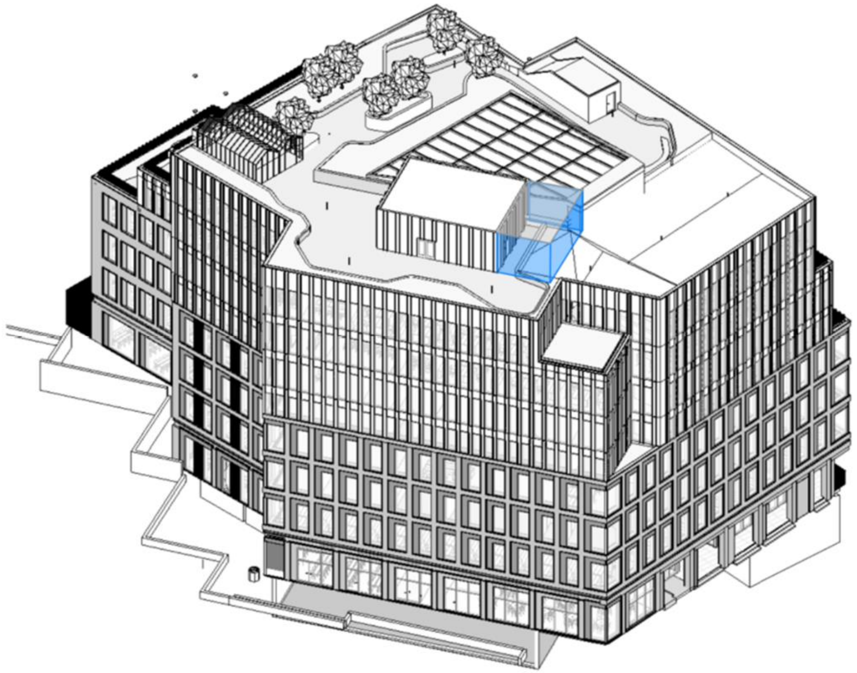
In the Søren Jensen office in Aarhus is ~2700 m^2. So, the CO_2e-capture per floor area is 4 CO_2eq/m^2 per year. This is a third of the allowed CO_2 emissions in Denmark (see 'Danish National Legislation and Initiatives' above). The LCA calculation for the CO_2 capture of the BICC system will be continuously updated as we become more energy- and material-specific and will finally be calculated as built.

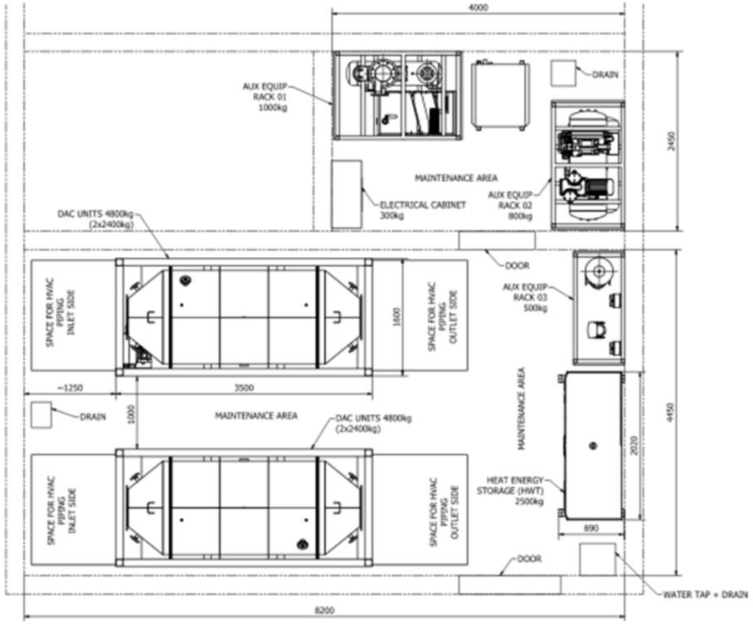
Materials included in the LCA calculation

The environmental impact of materials is according to product-specific or generic environmental product declarations. Since there are refrigerants in the BICC system and heat pump, the GWP of the refrigerants upon emission is also included.

Due to the installation of the BICC unit, several building-related materials and installations are included in the LCA calculation, among those are:

- *Expansion of the technical room on the roof*
- *Reinforcement of existing technical room*
- *Complete BICC system (e.g., equipment* including buffer tanks, compressors, heat exchangers, vacuum pump, condenser, etc. consisting mainly of stainless steel, but also aluminum, brass, copper, and technical insulation, etc.)
- *Expansion of the ventilation system*

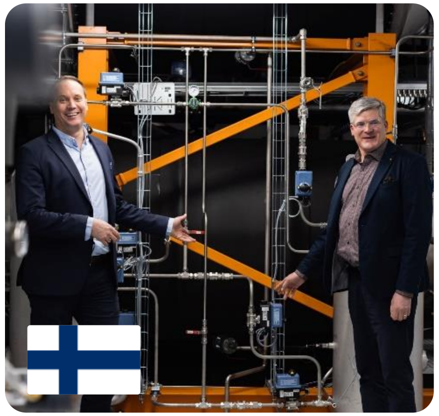




Similar installation cases

Two similar systems have been installed by Soletair Power in Vaasa and Vantaa, Finland in 2022 and 2023, respectively. Both systems utilize HVAC-integrated direct air capture technology to capture CO_2 from the air.

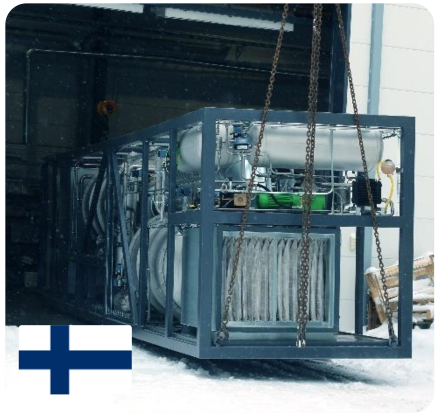
In Vaasa, there is a 3.6 cubic meter stationary CO_2 storage tank outside the building whereas captured CO_2 is stored in a 12-bottle bundle storage system in the Vantaa installation.



HVAC integrated CO_2 capture unit at Wärtsilä STH in Vaasa, Finland

2022

Delivers better air to meeting rooms, enables energy savings and net zero building



HVAC integrated CO_2 capture unit in a factory in Vantaa, Finland

2023

HVAC-exit air connected DAC for CO_2 for novel synthetic product manufacturing

Storage and utilization avenues for captured CO_2

Once captured, CO_2 needs a safe and permanent storage solution. For the installation at the Søren Jensen office, here are the main CO_2 storage options:

1. **Geological Storage:** Injecting captured CO_2 deep underground into suitable geological formations for permanent storage.
2. **Mineralization:** Converting captured CO_2 into stable carbonate minerals that can be safely stored. Mineralization can be done by utilization companies, for example, Neustark, Carbon Cure or Carbonaide.
3. **Utilization:** There is a scope to utilize the captured CO_2 in various utilization applications, such as synthetic fuel production (although considered a form of utilization, since it's not a permanent storage solution due to the eventual release of CO_2)

The choice of storage method depends on various factors, including geological conditions, technological feasibility, and economic viability.

Building materials	Chemicals
Ready Mix Concrete	Carbonates
Precast Concrete	Sulfuric acid
Aggregate (Ash, Slag, Brines)	Fertilizer
	Silica
	Baking Soda
	Methanol
	Ethanol

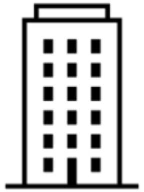
Carbon materials	Other use / End product
Polyols	Fuels
Ethylene carbonate	Beverage Fizz
Ethylene glycol	Fertilizers
Lactic acid	Proteins
Carbon nanotubes	Soap and Foams
Polymers	Plastics and container
	Furnitures
	Shatterproof glass
	Fire extinguisher
	Greenhouse stimulants

Real estate as a driver for carbon capture technologies

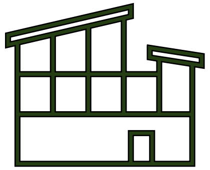
Combining direct air carbon capture with a building and the finances involved in developing, investing in, and using a building has several advantages.

1. Most modern buildings have existing HVAC systems and a technical infrastructure that can be integrated with a carbon capture facility.
2. Building integrated carbon capture makes it possible to include carbon capture technologies within a real estate cadastre and the financial setup of the whole building. Real estate loans are often divided over many years and the total cost of a building is many times larger than the price of a BICC unit.
3. The construction and building sector contributes to approximately 40% of the total global carbon emissions. National legislations, regional initiatives, and the market in general evoke an ambitious reduction in carbon emissions in the near future in the built environment. Low-carbon emitting buildings, carbon-neutral buildings, and even carbon-negative buildings will be a competition factor for many investors and developers.

In order to illustrate the potential of including a carbon capture in a real state financial case, an example explores two different design strategies of a 10.000 m^2 commercial new building and a 10.000 m^2 existing building retrofitted building. The prediction of innovation in the carbon capture field is estimated to be substantial within a few years. A today scenario (2024) and a new future scenario (2028) is investigated. In all examples, technologies like BICC and photovoltaics are calculated as a part of the building construction economy with corresponding financial prerequisites.



10.000 m^2 new building



10.000 m^2 retrofitted existing building

Carbon neutral commercial buildings using BICC

For 10.000 m^2 commercial buildings	2024		2028		2024		2028	
Type	Low Energy & CO_2 construction		Future low energy & CO_2 construction		Retrofitted existing real estate		Future retrofitted existing real estate	
Emissions before CO_2 capture	8 $kgCO_2e/m^2/year$		5 $kgCO_2e/m^2/year$		3 $kgCO_2e/m^2/year$		<2 $kgCO_2e/m^2/year$	
Units for CO_2 capture	5		3		2		1	
Self-sufficient through photovoltaics & batteries	Yes	No	Yes	No	Yes	No	Yes	No
Share of rent + O&M	6-8%	11-14%	2%	3-4%	4-5%	5-6%	1%	1-2%

The above analysis shows that when including Building-Integrated Carbon Capture in the total finance of a real estate economy, the share of the rent, operation, and maintenance expenses is between 0-14% for installing a BICC system, that will make a building carbon neutral. Especially for the scenarios of new buildings planned to be built in 2028 and retrofitting existing buildings are economically feasible with a share of rent, operation, and maintenance expenses between 1-6%. The most economical feasible scenarios for making buildings carbon neutral is then existing buildings or new buildings with a low carbon footprint . This relatively low economical share of the cost of renting an office, makes it possible to prioritize carbon capture compared over other economic decisions of an office building. The color of the "Self-sufficient through photovoltaics & batteries" indicates if the area of photovoltaics is estimated too critical large or realistic according to building size (red = critical, green = realistic).

Other financial perspectives regarding carbon economy

Below are some examples of other financial perspectives regarding carbon economy that could be relevant when introducing BICC.

ESG Compliance: Implementing BICC technologies can enhance a company's Environmental, Social, and Governance (ESG) profile. This can attract environmentally conscious investors and improve access to green financing.

Carbon Credits: Emerging carbon credit markets could provide financial rewards for companies that capture and store CO_2. While these markets are still evolving, they offer a potential future revenue stream for Carbon Capture projects.

Tax Incentives: Governments might introduce tax breaks or subsidies to incentivize the adoption of Carbon Capture technologies. This could significantly improve the financial viability of Carbon Capture projects.

Increased Rental Income: There is a possibility of a 1-7% rental increase for providing net zero building to tenant companies in a commercial building as most environmentally conscious tenant companies want to reduce scope 3 emissions and they can achieve it by operating in a net zero building. 2021 JLL report: https://www.jll.com.au/en/newsroom/seven-in-10-companies-in-asia-pacific-willing-to-pay-higher-rent

Mitigating Price Depreciation Risks: As the real estate market is increasingly valuing sustainability, buildings with outdated environmental profiles may face challenges in attracting tenants and buyers. BICC helps ensure a building remains competitive and aligns with future market trends.

Green Financing Opportunities: Green financing, also known as sustainable finance, aims to channel financial resources towards projects and initiatives that have positive environmental and social impacts. Green loans may offer more favorable terms, such as lower interest rates or longer repayment periods, as an incentive to support environmentally sustainable initiatives like BICC as buildings with lower carbon footprints are seen as less risky investments, as they are less likely to face regulatory challenges or become stranded assets due to changing environmental expectations. For building owners, securing green financing translates to significant cost savings.

63%

of leading investors strongly agree that green buildings can drive higher occupancy, higher rents, higher tenant retention and overall higher value.

Source: JLL's 2021 "Decarbonizing the Built Environment" report

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