# ASHRAE Task Force for Building Decarbonization

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## Carbon Sequestration

The world has a $CO_2$ problem and ASHRAE lives in that world. Approximately 40% of the $CO_2$ generated in the world is associated with the built environment. ASHRAE members, along with practitioners in allied fields, have made great strides in reducing the $CO_2$ generation footprint of the built environment. However, $CO_2$ has a "long tail," an extended life in the atmosphere, therefore reducing our future generation of it may not prove to be enough to minimize its impacts on the climate. Tools are needed which can reduce the current amount of $CO_2$ in the atmosphere to lessen its climate impacts. Carbon Sequestration is a term used to describe a fairly broad spectrum of processes—some natural, some human-made—which addresses this "in atmosphere" $CO_2$ issue.

The purpose of this document is to provide a brief overview of possible Carbon Sequestration processes and technologies. Strategies are identified that ASHRAE practitioners, building systems and equipment manufacturers, and other building professionals may be able to incorporate into their projects and products to sequester $CO_2$. This document is not intended to assess or opine on the technical or economic feasibility or viability of any given Carbon Sequestration approach.

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*Carbon Sequestration refers to both Carbon Dioxide Removal (CDR) and Carbon Capture with Storage (CCS). In CDR, the $CO_2$ is removed and converted or "reacted" with some other agent to become "something else." In CCS, a relatively pure stream of $CO_2$ is created from the flow of (typically) industrial and/or energy-related sources. The $CO_2$ is separated (removed and captured), conditioned, compressed and transported to a storage location intended to hold the $CO_2$ for long term isolation from the atmosphere.*

*The purpose of Carbon Sequestration is to keep and/or remove additional $CO_2$ from the atmosphere. $CO_2$ can remain in* the *atmosphere for a considerable length of time and, in so doing, continue to contribute to global climate change well beyond the date of its generation. With CDR, it is removed and converted into "something else." With CCS, it is removed and stored (or sequestered). The use of CCS does not preclude taking the sequestered $CO_2$ and processing it into something else later.*

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Some of the $CO_2$ in the atmosphere is naturally captured and stored in the earth's oceans, plants and soil with the remainder entering the atmosphere. Since the beginning of the industrial age, human activities have added $CO_2$ and other greenhouse gases to the atmosphere at rates which exceed the ability of the earth to handle the excess without considerably changing the climate. Carbon sequestration processes and technologies could offset the increasing $CO_2$ levels in the atmosphere and possibly reduce catastrophic climate change.

The main avenues of carbon sequestration and storage are:

- Oceanic—storage of atmospheric and aquatic carbon in water environments
- Terrestrial—storage of atmospheric carbon in vegetation, soils, and aquatic environments
- Geologic—storing $CO_2$ in underground or subsea geologic formations
- Manufactured Products—capture and/or conversion of $CO_2$ into other chemicals or materials

Table 1 lists sequestration processes and technologies in alphabetical order. Each is summarized following the table.

**Table 1. Carbon Sequestration Processes and Technologies**

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|---|---|---|
| 1. | Biochar | Capture and Storage |
| 2. | Bioenergy with Carbon Capture and Storage (BECCS) | Capture and Storage |
| 3. | Carbon Capture and Utilization (CCU) Concrete | Capture and Storage |
| 4. | Carbon Storage and Enhanced Oil Recovery | Capture and Storage |
| 5. | $CO_2$ to Chemicals, Fuels, and Other Products | Capture and Conversion |
| 6. | Enhanced Weathering Technology | Capture and Storage |
| 7. | HVAC Systems Capture | Capture |
| 8. | Vegetation and Soil Management | Capture and Storage |

# Biochar

Biochar is “pyrolyzed” biomass: **plant material that has been burnt at high temperatures under low oxygen levels**. Biochar application to agricultural soils has the potential to **increase crop yields**–but it is very hard to make a consistent product or predict soil reactions.[1]

# Bioenergy with Carbon Capture and Storage (BECCS)

BECCS is a carbon removal technique that depends on two technologies. Biomass (organic material, e.g., from planted trees) is converted into heat, electricity, or liquid or gas fuels (the “bioenergy” step), and the carbon emissions from this bioenergy conversion are captured and stored in geological formations or embedded in long-lasting products (the “carbon capture and storage” step).

# Carbon Capture and Utilization (CCU) Concrete

Concrete contributes 8% of total annual $CO_2$ emissions worldwide, primarily associated with the production of cement.[2] The volume of concrete used in building projects should be minimized to

[1] This definition is a direct quotation from E. Adlen and C. Hepburn, 10 Carbon Capture Methods Compared: Costs, Scalability, Permanence, Cleanness, https://energypost.eu/10-carbon-capture-methods-compared-costs-scalability-permanence-cleanness/.
[2] https://e360.yale.edu/digest/the-cement-industry-one-of-the-worlds-largest-co2-emitters-pledges-to-cut-greenhouse-gases

reduce embodied energy. Concrete can be subjected to two distinct types of carbonation to sequester carbon. The first is weathering carbonation, which concerns mature concrete reacting over an extended period when it is exposed to carbon dioxide in the atmosphere. The second is early age carbonation, which involves utilizing carbon dioxide in the production of concrete wherein the reaction occurs at early ages of fresh concrete. The carbonation can take place as early as concrete mixing stage and can end prior to, or in line with, the conclusion of accelerated curing (as much as 48 hours later).

# Carbon Storage and Enhanced Oil Recovery Technologies

Called *carbon dioxide enhanced oil recovery*, $CO_2$ emissions are captured from fossil fuel-fired power plants and other major industrial $CO_2$ sources, then transported to old oil fields where production peaked long ago. By injecting the captured $CO_2$ into existing oil wells that have been producing diminishing amounts of crude oil, hard-to-get crude oil expands after mixing with $CO_2$, boosting oil recovery.[3] The oil becomes thinner, allowing it to flow more freely into an old oil well thus reviving production in an old oil field. Alternatively, captured $CO_2$ can be injected one to two kilometers deep into porous rock formations where it is sealed and monitored by experts to ensure there is no leakage or impact on public safety or the environment.

# $CO_2$ to Chemicals, Fuels, and Other Products

$CO_2$ to chemicals technology involves catalytic conversion of $CO_2$ to build products, such as methanol, urea (to use as fertilizer) or polymers (for use in durable products, e.g., buildings or cars).

$CO_2$ to fuels approach centers on the concept of the large-scale re-use of $CO_2$ released by human activity to produce synthetic fuels. There are three types of fuels which could be produced by different strategies involving $CO_2$ conversion by physicochemical approaches (viz. photo and/or electro and/or thermal catalytic conversion):

- sustainable (or renewable) synthetic methanol
- syngas production derived from flue gases from coal-, gas-, or oil-fired electric power stations
- photochemical production of other synthetic fuels

Although these three prototypical areas differ in their ultimate applications, the underpinning thermodynamic considerations center on the conversion and hence the utilization of $CO_2$.

Another approach to converting $CO_2$ to other products involves microalgae. Microalgae can be grown in wastewater and exposed to sunlight for photosynthesis. It can then be used to fix $CO_2$ at high efficiencies and then process the biomass to make products, such as fuels and high-value chemicals.

# Enhanced Weathering Technology

Enhanced weathering is a method that involves storing carbon in the ocean through a chemical reaction that removes $CO_2$ from the atmosphere. Weathering is a natural process whereby rocks are

[3] www.netl.doe.gov/sites/default/files/netl-file/co2_eor_primer.pdf

broken down by rainwater, extreme temperatures or human activity. This process normally takes place over millions of years, constituting an important carbon sink. Enhanced mineral weathering is the speeding up of this natural process, whereby rocks are ground into fine particles and spread across large spans of land or the ocean. Rock particles (dust or powder) could be applied on open ocean regions or combined with agriculture with the additional benefit of enhancing crop yields and preventing soil erosion. Best climates for weathering are hot and humid climates.

# HVAC Systems Capture

Within the buildings context, two primary sources of $CO_2$ are: return air and flue gas from fuel-based thermal systems. Air quality within a building plays an important role in the well-being of its occupants whether it be a residential or an office space. Some of the critical contaminants include chemicals such as volatile organic compounds (VOCs), aldehydes, ozone, carbon monoxide in addition to high concentrations of carbon dioxide and low oxygen concentration. Numerous research studies have shown the negative impact of some of these contaminants on the general health and cognitive abilities of the residents.[4] Typical $CO_2$ concentrations in return air vary from 400 ppm to 2000 ppm.[5] Gas-solid contactors such as packed and fluidized beds, membranes, monoliths, fibers are potential candidates for integration with air handling systems in buildings to capture the $CO_2$. Commercial application of materials and processes is now being explored by several organizations, with a target cost of much less than $100/ton of $CO_2$. Hydroxides, Amines packed into granules, or porous honeycomb, among others are some of the approaches being utilized for large scale direct air capture (DAC) applications.

Flue gas from fuel-fired thermal equipment on the other hand produces $CO_2$ at concentrations of 4% to 7%, depending on the fuel type.[6] Sorbents are considered to be the most suitable materials for such applications and must possess high selectivity towards $CO_2$ since flue gas contains oxygen depleted air along with criterion pollutants and water. Other desirable characteristics include high capacity, long-term stability, fast reaction kinetics, low regeneration energy demand.

Different sorbent materials utilized in DAC and CCS technologies are potentially suitable for applications in HVAC-related $CO_2$ sequestration. These include carbon-based materials, zeolites, porous organic polymers, ionic liquids, resins, metal-organic-frameworks, solid amine hybrids, and carbonates.

These technologies are methods of capturing $CO_2$ and are currently in the research phase to early product cycle. Additional development is needed to identify viable technologies and opportunities for storage, reuse, or conversion.

# Vegetation and Soil Management

Vegetation and soil management can enhance natural carbon sequestration—the process by which atmospheric carbon dioxide is taken up by trees, grasses, and other plants through photosynthesis and

[4] Allen, J.G., et al. (2016), Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments. *Environ Health Perspect*, 124(6): 805–12.
[5] Taylor, S.T. (2006). $CO_2$-based DCV Using 62.1-2004. *ASHRAE Journal* 48(5):67–75.
[6] https://netl.doe.gov/coal/carbon-capture/post-combustion#:~:text=However%2C%20flue%20gases%20from%20natural,therefore%2C%20requires%20greater%20energy%20input

stored as carbon in biomass (trunks, branches, foliage, and roots) and soils. This approach includes multiple processes.

Restoring soil enhances agricultural yields while increasing soil carbon retention. The technique seeks opportunities to increase soil carbon in all ecosystems—from tropical forests to pasture to wetlands—by planting trees in areas not presently treed (afforestation), by replanting degraded areas (reforestation), replanting native species or engineering the landscape to enhance carbon sequestration (rewilding), increased mulching of biomass instead of burning, large-scale use of biochar, improved pasture management, effective erosion control, and restoration of wetlands, mangroves, salt marshes, and sea grasses.

An additional approach is to literally "green" buildings and perhaps, some associated impervious man-made surfaces using plants. This includes adding green roofs, vegetated berms, vegetated walls, and parking areas constructed of permeable pavers.

The enhanced nature-based carbon sequestration helps to directly reduce atmospheric $CO_2$ concentrations whilst also creating a series of other benefits such as biodiversity, and improved air and water quality.

# Applicability

The following questions can be used as a framework to identify the applicability of each technology to ASHRAE member interests:

- Is the technology scalable to a building, typical building site, or campus where it would be deployed?
- What is the permanence and/or stability of the capture and sequestration, and the cleanness of the future energy mix used to power the method?
- Is it a technology that a typical ASHRAE practitioner would (or should) contribute technical or design expertise as part of their scope as a design team member?
- Is detailed knowledge, design skills and metrics of the technology at the building level required for the ASHRAE practitioner to possess, and if so, what are those skills and metrics?
- Will using this process or technology have a net reduction in $CO_2$, when considering the end-to-end carbon emissions and reductions to implement any given solution

It is acknowledged that some ASHRAE practitioners will be valuable to a project team by taking a lead in calculating a project's carbon footprint. These practitioners should be familiar with the contribution of sequestration to the carbon content of a project, but this acknowledgment stops short of advocating that the practitioner should be the designer of the process details, unless it is noted otherwise.

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