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Carbonated demolition concrete in tunnelling

Demolition concrete is the largest waste material stream in the world in terms of volume [1]. Having developed a solution to permanently store CO_2 from the air in recycled mineral waste streams, Neustark, based in Bern, is a leading provider in the rapidly growing field of carbon dioxide removal (CDR).

1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), net zero emissions must be achieved by 2050 in order to limit the rise in global temperatures to 1.5 °C. In addition to considerable emission reductions, this goal will only be possible through the global use of CO_2 removal solutions – to the tune of billions of tonnes [2]. Neustark is a leading supplier in this fast-growing market – with its solutions to permanently store CO_2 from the air in mineral by-product and waste streams.

Neustark's commercial solutions are used in Switzerland and Europe and store CO_2 from the atmosphere on a daily basis. With a large-scale plant in Berlin-Marzahn, Neustark and its partners commissioned 14 such plants in Switzerland and Germany last year. These plants have a cumulative CO_2 storage capacity of around 5,000 tonnes per year. The company is currently working on rolling out its activities globally in order to significantly increase storage performance. By 2030, one million tonnes of CO_2 per year will be permanently removed from the atmosphere and stored.

Founded in 2019, Neustark AG is a spin-off of ETH Zurich, is based in Bern, Switzerland, and comprises a team of around 55 people (as of the first quarter of 2024).

2 The mineralisation process

Carbon dioxide mineralisation is a process in which CO_2 reacts with freed lime and other reactive metal oxides to form carbonate minerals. Calcium oxide mainly reacts to form calcium carbonate.

Demolition concrete aggregates contain cement hydrate phases. These come into contact with the pore water in a solid-liquid equilibrium. Part of the hydrated cement (Fig. 1 before treatment) is dissolved in water and is present as an ionic species. When the water absorbs CO_2, its new composition changes the chemical equilibrium in such a way that the precipitation of calcium carbonate ($CaCO_3$; Fig. 1 after treatment) is favoured.

The CO_2 and the hydrated cement undergo a chemical reaction and form limestone, which binds to the concrete granulate. While this carbonation process also takes place in nature, Neustark technology accelerates it a thousand-fold. This is due to the high CO_2 concentration in the reaction silos (> 98% instead of the 0.04% in the ambient air).

Demolition concrete can permanently store an average of 10 kg of CO_2 per tonne, while the absorption potential of slag and ash is significantly higher. Within the first two hours of storage, the demolition material typically reaches around 80% of its CO_2 absorption capacity (Fig. 2). Particularly fine-grained material has a greater absorption capacity because it offers the CO_2 a larger reaction surface. In addition, mineralisation releases so much heat per kilogram of CO_2 that the temperature of 1,000 kg of concrete aggregate increases by around 2.5 °C.

$CaCO_3$ is considered to be one of the most durable ways of binding carbon, with a storage period of thousands of years. Only temperatures above 600 °C or very strong acids can release the bound CO_2 once again [3, 4]. This ensures that the CO_2 remains stored in the concrete, even if it is demolished again after reuse. Permanence plays an important role in assessing CO_2 storage technologies.

3 Value chain

Neustark's entire value chain is summarised in Figure 3.

Béton de démolition minéralisé au service des constructeurs de tunnel

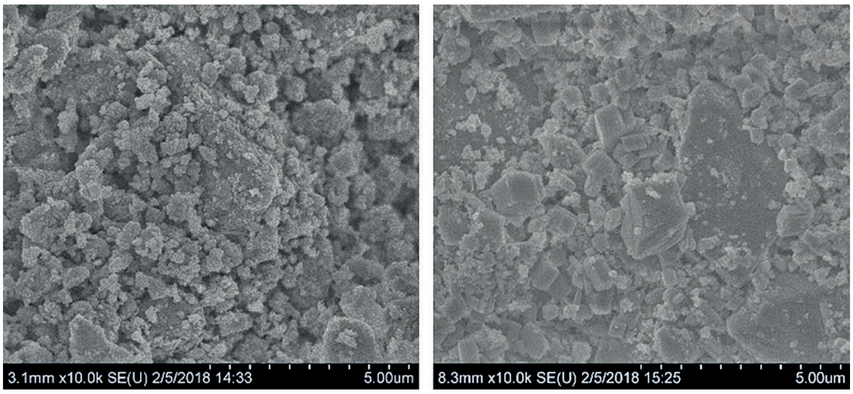
Le CO_2 provient de sources biogènes, telles que les usines de biogaz. Il est ensuite liquéfié afin de favoriser son acheminement vers des sites de stockage. Puis il est injecté dans des produits minéraux et des déchets (ex. : béton démoli, scories et cendres). Ces matériaux minéralisés sont ensuite recyclés ou détruits.
L'industrie du creusement de tunnels a ainsi l'opportunité de recycler le béton démoli issu des travaux de rénovation des tunnels, l'enrichir en CO_2 et exploiter ledit béton recylcé pour ses infrastructures.

Utilizzo di calcestruzzo riciclato e carbonizzato

Per la costruzione e il risanamento di gallerie si presentano occasioni per l'impiego del calcestruzzo riciclato, ossia ricavato da demolizioni, e trattato con CO_2.
Nello specifico, la CO_2 viene recuperata da fonti biogeniche, come impianti di biometano che di solito la liberano nell'atmosfera, e liquefatta per un efficiente trasporto. Viene poi immessa nel calcestruzzo di recupero tritato e prepararato per la lavorazione tramite un impianto di Neustark, ad esempio nelle gallerie.

3.1 CO_2 capture at biogas source points

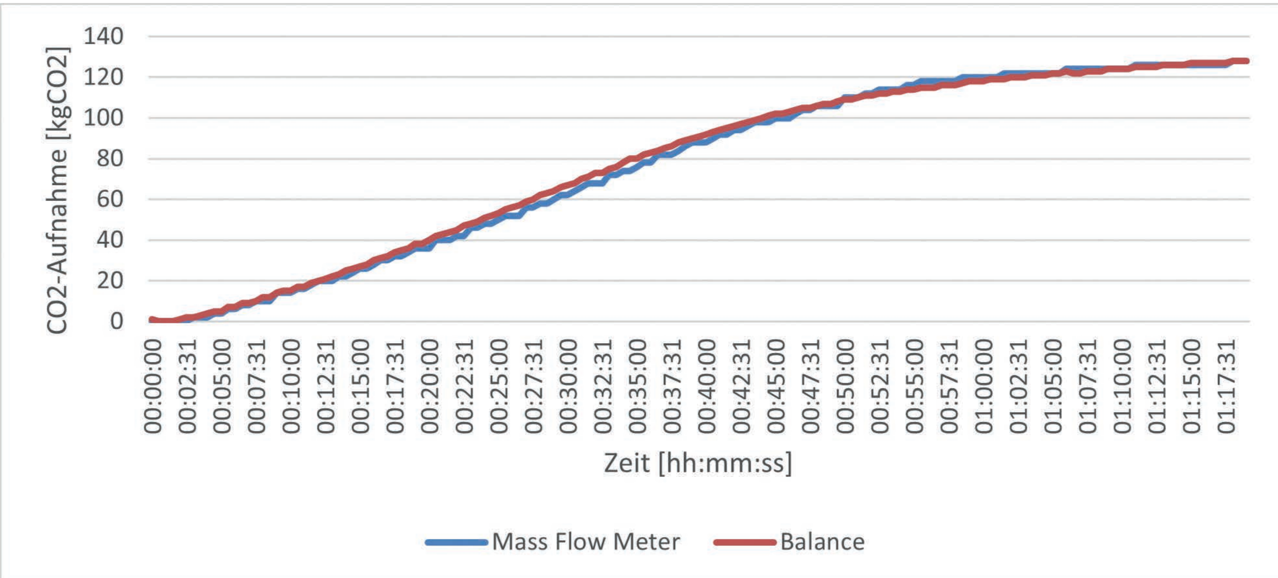
Biogenic CO_2 is primarily used for storage in mineral waste streams. Biogenic CO_2 emissions come from processing organic materials such as plants and trees (e.g., through incineration or fermentation). Burning biomass releases CO_2, which is part of the biogenic carbon cycle. This is in contrast to burning fossil fuels, which releases CO_2 that has been trapped in the ground for millions of years. In other words: When biomass is burned, the CO_2 that was absorbed during plants' growth is simply released back into the atmosphere. The process is CO_2-neutral in itself.



Credit: Neustark AG

1 Electron microscope image of demolition concrete granulate before carbonation (hydrated cement phases) and after carbonation (limestone, $CaCO_3$)

The CO_2 content in the atmosphere is around 0.04%. Filtering out CO_2, for example through direct air capture (DAC), is a complex and cost-intensive process. In contrast, the capture of CO_2 during the conversion of biogas into biomethane is much simpler and more effective.



Credit: Neustark AG

2 CO_2 absorption of demolition concrete aggregate during carbonation over time

For this reason, Neustark works together with biomethane plants to capture their CO_2 directly on site. This type of separation does not interfere with the ongoing operation of the systems. On the contrary, it creates added value by offering the possibility of further utilising the CO_2 that is actually produced as a by-product.

The CO_2 is compacted to make it transportable. The first step is to cool down and compress the CO_2 so that it can then be transported in liquid form in tankers to the storage facilities. Here, the CO_2 is converted back into a gaseous state by means of a vaporiser, brought together with the mineral material flow in a reactor and permanently removed from the atmosphere through storage. This is how decisive negative emissions are created together.

3.2 CO_2 storage on building material recycling sites

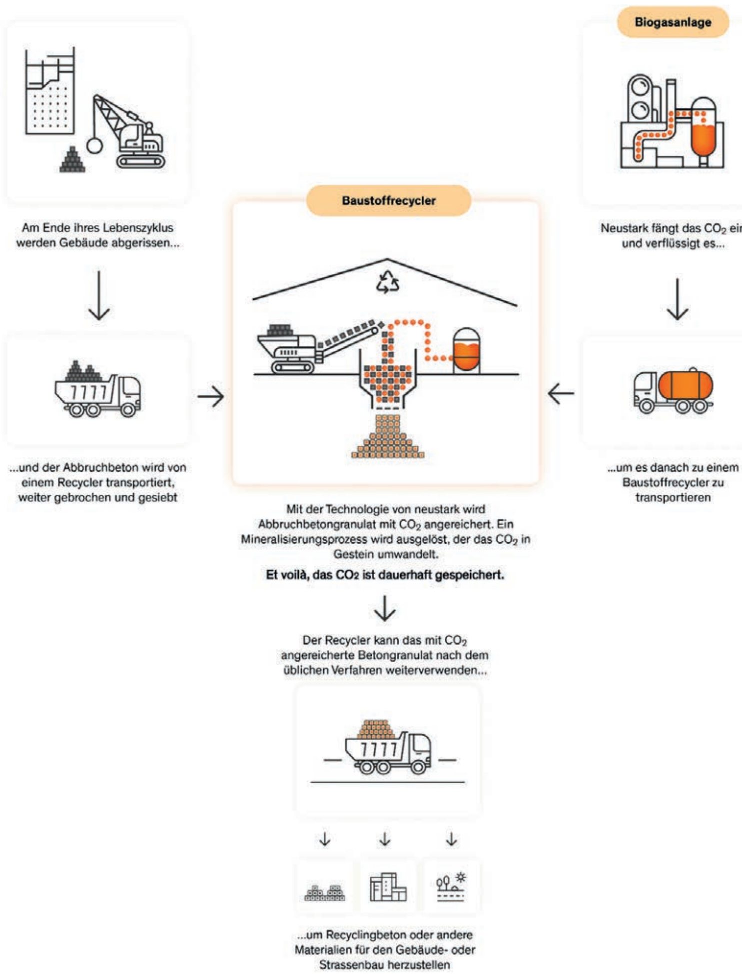
Construction material recyclers collect demolition concrete and other mineral waste and crush and sieve the material in their plants in order to prepare it for further use. In the storage facility, the mineral material flow is gasified with the CO_2 captured at the biogas plant before the material is reused or disposed of.

All of this takes place alongside the existing process of the recycler without affecting the operation of the plant. The storage system is set up on site at the recycling plant and the treatment process is supplemented by a work process.

The granulate mixed with CO_2 can then be reused normally, for example, for the construction of roads or other infrastructure or for the production of fresh, recycled concrete. It is in no way inferior to conventional concrete in terms of quality.

3.3 Sale of CDR certificates on the voluntary market

There is one final and important step at the end of the value chain: The storage services provided generate climate certificates that Neustark sells to companies with ambitious climate targets. In addition to their own reduction measures, companies can offset emissions that are difficult to avoid and thus achieve their net zero targets.



Credit: Neustark AG

3 Neustark value chain

4 Life Cycle Assessment

In a life cycle analysis, losses (leakages and losses during handling) and grey emissions (electricity consumption for liquefaction, fuels for transport, etc.) are deducted as CO_2 equivalents from the stored quantities in order to only show the net stored CO_2 quantities as CDR certificates.

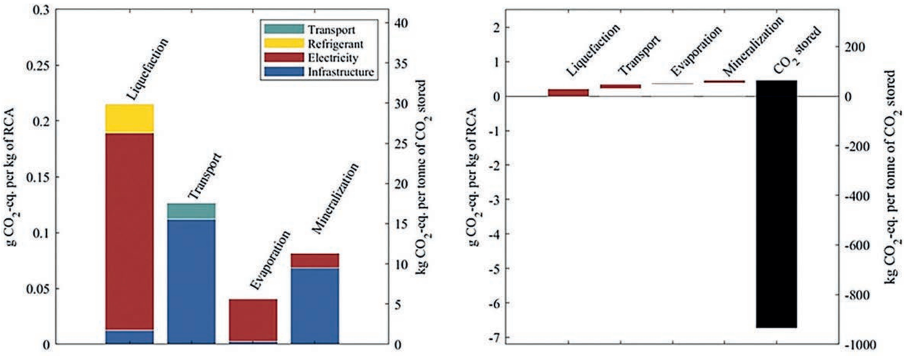
The CO_2 footprint of the country in which the CO_2 source is located is considered, which is heavily dependent on the electricity mix. In addition to the clear cost optimisation, a short transport route between the CO_2 source and the storage facility also pays off in the quantity of CDR certificates that can be sold.

Neustark's CO_2 removal technology achieves an efficiency of 94% in the life cycle analysis for Switzerland [5]. This means that storing 1,000 tonnes of CO_2 produces around 64 tonnes of process emissions (Fig. 4).

5 Applying Neustark technology in tunnelling

There are various possibilities for tunnelling in terms of material input and output.

Material input for new construction projects: According to the Swiss company Lombardi, the use of CO_2-loaded recycled concrete in the input for tunnel construction projects is permitted under the current legal situation, particularly as a base concrete and filler concrete. Other applications also seem possible. However, there is little clarity on this issue, as there is still no precedent for its use as an input material in tunnelling. See Table 1 for more info.



Credit: Technological Demonstration and Life Cycle Assessment of a Negative Emission Value Chain in the Swiss Concrete Sector (2021)

4 Life Cycle Assessment: 94% CO_2 permanently removed

Other possible input streams for tunnelling sites are base layers or frost protection layers within the construction site infrastructure.

Material output from demolition/renovation projects: During tunnel refurbishment or in the initial construction processes, significant quantities of concrete and therefore cement-containing mineral by-product streams are produced, all of which are suitable for carbonation. This material can be treated with CO_2 both on site and at the building materials recycler.

		Components or areas of application*															
	Sprayed concrete and other concrete types	Backfills, fissures and cavities	Immediate support	Excavation support	Lining, single-shell finish	Base concrete	Filling concrete	Base lining (unreinforced, not in the portal area)	Vault lining (unreinforced, not in the portal area)	Suspended ceiling	Segments	Utility duct	Hard shoulder portal area	Inner hard shoulder	Cable conduit block	In-situ concrete shaft	Lining and interior fittings for underground control centres
Sprayed concrete according to SIA 198	SC 1	x															
	SC 2		x														
	SC 3			x													
	SC 4			x													
	SC 5			x													
	SC 6				x												
	SC 7				x												
In-situ concrete according to SN EN 206	NPK 0					x	x										
	NPK A																
	NPK B													x			x
	NPK C							x	x								x
	NPK D														x	x	
	Other							x	x	x	x	x	x				

Credit: Lombardi AG

Table 1 *Possible applications for recycled concrete in tunnelling*

- (red) *Inadmissible because the required exposure or compressive strength classes cannot be achieved*
- (orange) *Theoretically possible. Further clarification required, as not conclusively dealt with in the standards*
- (yellow) *According to SIA 2030, only permitted after appropriate preliminary investigations*
- (green) *Admissible*

** This table is only valid for RC-C25 (25 wt.-% ≤ 50 wt.-%, in mass per cent, according to SIA data sheet 2030). The application possibilities for other RC concretes are more limited.*

6 Conclusion

CO_2 removal technologies are essential for achieving net zero emissions by 2050. Neustark's mineralisation process is one of these technologies and also offers many starting points in tunnelling, both in terms of material input and for the use and recycling of waste streams.

In the market, there is currently a generally high level of interest in approaches to reducing CO_2 emissions in contrast to a small selection of market-ready technical solutions. An increasing demand for carbonated recycling (RC) material is to be expected in the interests of the circular economy and emission reduction.

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