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Biochar market study

Analysis of the opportunity and risks of biochar through the assessment of the physical outlets and carbon markets trends

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Julia Artigas-Sancho, Léo Godard, Dorgeles Gomeu, Etienne Perrier, Matthieu Tiberghien

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1. Context and objectives of this study

This global market study was commissioned by the Belgian Development agency (ENABEL) as part of the VABICUI program which is focused on supporting initiatives for the valorization of agricultural residues in Ivory Coast. The objective was to provide a comprehensive overview of the biochar sector and specifically the market trends in order to inform potential investors and foster investments in biochar projects in Ivory Coast and West Africa in general. The results of this work were presented in 4 separate deliverables (in French), each targeting a specific aspect of the analysis:

1. Review of biochar production methods and technologies
2. Analysis of the global supply and demand of physical biochar
3. Analysis of the biochar carbon market
4. Focus on the opportunities and risks for the development of the biochar sector in Ivory Coast

This document is a translated summary of the deliverables 2 & 3 for industry actors and potential investors as an overview of the market opportunity and risks for the biochar sector.

2. Methodology of the market study

The methodology used for this study is based on extensive consultation with stakeholders in the global biochar sector. The different actors of the value chain were listed and categorized to set a consultation agenda, with a series of interviews organized with the main companies representing each category in the value chain. Particular attention was paid to the selection of stakeholders in order to cover as many different situations and models as possible and thus gather complementary perspectives on the evolution of the biochar industry.

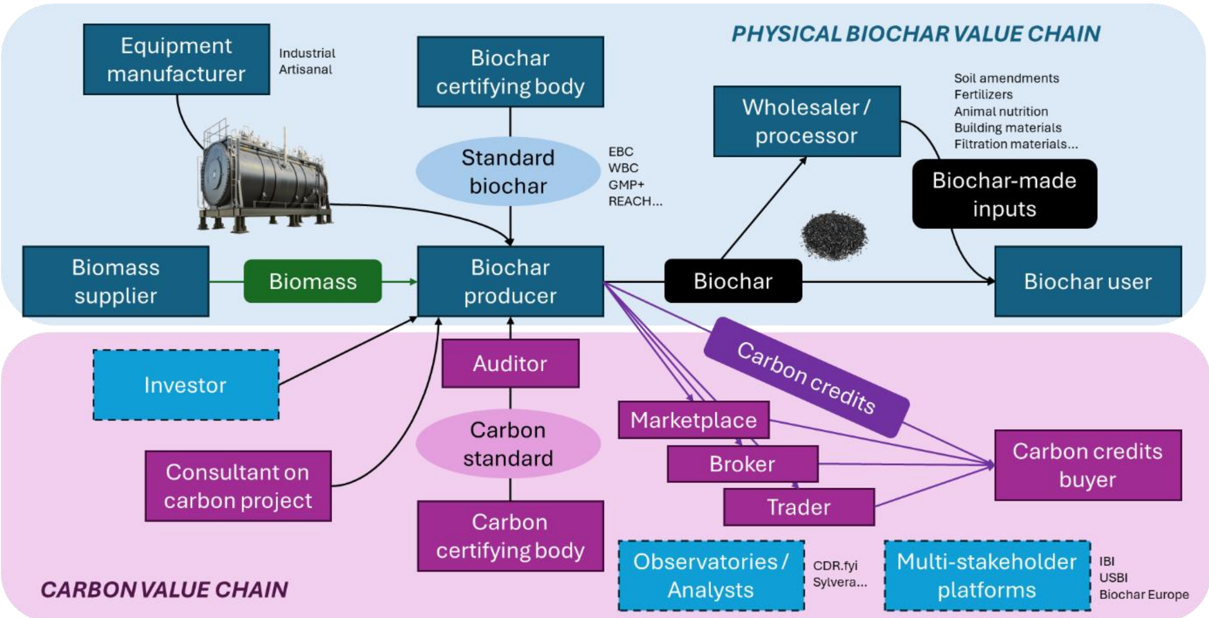

Figure 1: Mapping of the biochar sector stakeholders

One of the complexities of the biochar sector is that it overlaps two different value chains: physical biochar and carbon credits (Figure 1). This multiplies the number of categories of actors who all have a role to play in the successful development of the sector.

Table 1: List of the consulted stakeholders for this study

Category	Area	Company	Country
Biochar producers	Global South	WeAct (artisan)	India, Madagascar
		Planboo (artisan)	Thailand, Ghana, Namibia
		Recycoal (artisan)	Rwanda, Uganda
		PyroCCS (industrial & artisan PRO)	Namibia, India
		NetZero (industrial)	Cameroun, Brazil
		Interholco (industrial)	Congo
		HUSK (industrial)	Cambodia, Vietnam
		IED (industrial)	Senegal, Cambodia
	EU	Carbon Emergente (industrial)	Spain
		Athena recherche et innovation (industrial)	France
		Sonnenerde (industrial)	Austria
	USA	Circularity2 (industrial & wholesaler)	
Equipment manufacturer	EU	NGE	Austria
		Stiesdal	Denmark
Certication	Global	Puro	
		CSI	
Fertilizers and inputs suppliers	Global	Elephant vert	
		Bayer	
Consultants	Global South	DSS+	
		Koko networks	
	USA	Ithaka Institute	
	Global	Cula	
Insurance	Global	Artio	
Investors	Global	ISF	
Platforms	Global	International Biochar Initiative (IBI)	
	USA	US Biochar Initiative (USBI)	

To conduct this market study, 26 stakeholders were consulted between February 2025 and April 2025 (Table 1), covering different geographical areas. A non-exhaustive list of all biochar sector actors has been referenced and can be found in Appendix 1: Non-exhaustive list of biochar actors.

In addition to this consultation, scientific and sector-specific bibliographic research was carried out in order to collect the latest available information (the list of the most relevant documents is presented in the BibliographyBibliograph).

3. Global overview of the biochar industry

3.1 Types of stakeholders in biochar industry

The biochar sector is complex because it overlaps two different value chains: that of physical biochar and that of carbon credits (Figure 1).

Physical biochar value chain

- Biomass supplier: Owns biomass that can be converted into biochar. These may include family farmers, large plantations, processing plants, forest concessions or community sanitation networks, for example. The supplier may either sell the biomass, make it available free of charge, or pay for it to be removed. The arrangement depends on the type of biomass and any perceived benefits to the supplier (energy production, biochar donation, share of carbon credits, etc.). It is common for biomass suppliers to have their own biochar production projects.
- Equipment manufacturer: *Examples: Stiesdal, NGE, PyroCCS, NetZero, etc*. Manufactures and distributes pyrolysis equipment or other technologies. In a number of projects, the equipment manufacturer itself owns the biochar production project, often in order to demonstrate the feasibility of its technological solution. Artisanal equipment (e.g. Kon-Tiki furnaces) is often produced by artisans or small local companies.
- Biochar producer = project developer: *Examples: NetZero, Planboo, Interholco, Exomad Green, HUSK, etc.* In charge of the biochar production project. It is responsible for collecting biomass and transforming it into biochar via pyrolysis or gasification, for example, using appropriate equipment. This company is also responsible for marketing the biochar, as well as obtaining certifications to generate CCs and selling them.
- Certifying body: *Examples: Puro.earth, CSI, Verra, Riverse, Isometric, etc.* Establishes standards, either for 'quality' or for carbon credits. To do this, they publish methodologies setting out the requirements that must be met, as well as the guidelines followed by auditors.
- Auditor: *Examples: CERES-CERT, etc.* Audits biochar projects according to specifications and guidelines published by certifying bodies. In most cases, certifying bodies use third parties for the audit part to ensure a neutral judgement.
- Biochar distributor and/or processor: *Examples: Circularity2, HUSK, etc.* Purchases raw biochar either to resell it (wholesaler) or to transform it into a new, marketable product.
- Biochar user: Applies the biochar in a 'matrix'. The most obvious option is the application of biochar to agricultural soil by a farmer, but it can also involve the incorporation of biochar into a fertilizer product by an input producer, or into a planting substrate, animal feed product or certain construction materials (see section 5.1).

Carbon value chain

- Carbon project consultant: *Examples: DSS+, Artio (insurance company specializing in biochar CC), Grain Ecosystem, Plant Village, CULA, PyroCCS, NetZero (can offer a 'franchise' type project structure).* Responsible for setting up the entire biochar project model, from A to Z for some. They have expertise in technology, operations, life cycle analysis, carbon certification schemes, dMRV systems, and sometimes even marketing (physical and carbon credits) and raising capital. These companies can also be called upon to carry out due diligence for carbon credit buyers and investors.

- Marketplace / broker / carbon trader: *Examples include Carbonfuture, Supercritical, Patch, Ceezer, Cloverly, etc.* Marketplaces are platforms that connect CC producers and buyers. Sometimes, CCs can even be purchased directly on the platform. These companies have experts who analyze a buyer's needs and recommend a specific project. Brokers are players who connect CC projects with buyers. Traders purchase CCs directly in order to resell them to buyers. Many companies fall into all three categories.

- Carbon credit buyer: A company or group that wishes to offset its carbon footprint by purchasing CCs. Buyers of biochar CC are currently mainly large companies in the technology sector (see section 7.2) *Examples: Microsoft, Google…* However, it should also be noted that large trading groups may be interested in financing biochar projects in their value chains, either to offset their Scope 3 carbon footprint or to increase the added value of their products by communicating their net zero aspect *(e.g. ECOM for coffee and cocoa)*.

- Observatory/analyst: Responsible for analyzing the carbon market and developments in biochar projects. Some publish databases *(e.g. CDR.fyi)* and others offer assessment methodologies similar to rating agencies *(e.g. Sylvera)*. This category includes marketplace/broker/trader-type players who also regularly publish analysis bulletins and host conferences *(e.g. Supercritical, Carbonfuture, etc.)*.

- Multi-stakeholder platforms: Associations that bring together all stakeholders in the biochar sector, such as inter-professional organizations, and are responsible for providing information, advocacy and coordinating the network. They are organized at the national level and then brought together at the international level *(e.g. IBI, USBI, Biochar Europe, ANZBIG, etc.)*.

- Investors: Investors interested in biochar projects have a variety of profiles. They may be funds or private investors specializing in the energy or infrastructure sector *(e.g. the STOA fund, which invested in NetZero)*, ESG (Environmental Social Governance) funds focused on climate solutions and/or agriculture *(e.g. Carbon Removal Partners and Oikocredit)*, or DFIs (Development Finance Institutions, *e.g. Bio-invest, Proparco, etc.*).

3.2 Biochar production in the world

Biochar is an emerging niche sector that is attracting a great deal of interest and has therefore profited from significant momentum in recent years thanks to the booming carbon credit market. This momentum began in 2020, and we are now starting to see the first industrial biochar production projects come to fruition, as well as a large number of new projects.

Global production has been estimated by IBI[1] at **350,000 tons in 2023**, compared to **less than 100,000 tons in 2021**. Production is therefore growing very rapidly (+100%/year) and is expected to reach more than **2.5 million tons in 2025**. Supercritical, one of the top carbon marketplaces, estimates production of **4.4 million tons in 2028** (11 million carbon credits, applying a ratio of 1 ton of physical biochar = 2.5 carbon credits).

[1] This estimate may be well under reality since it lacks information from big players such as China

It should also be noted that tracking global production is quite complex: the figures announced by IBI are the most reliable source of information, based on their large network of members, but a significant amount of biochar is probably not included, coming from players who do not yet have a carbon certification scheme (absolute traceability of quantities) or who do not report their volumes.

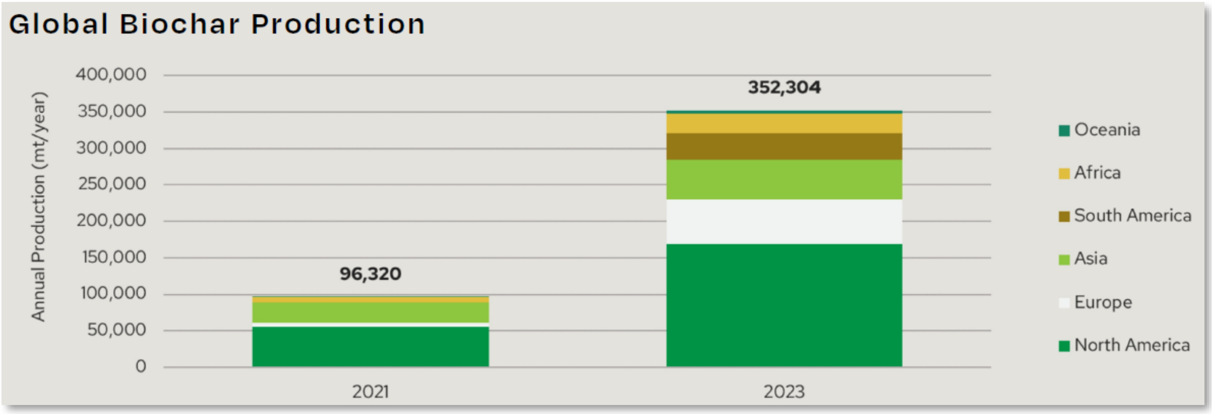

Figure 2 : Global biochar production per continent (Source: IBI 2023 – now obsolete)

Globally, the US and the EU remain the leaders in biochar production, accounting for 45% and 20% of global production in 2023, respectively (Figure 2).

The countries of the Global South (Africa, Asia, Latin America) account for the rest of production. It can be predicted that production in the US will grow more slowly, while in the EU it will continue to increase in the short term. The potential of the countries of the Global South is very significant, particularly through artisanal production projects (see section 4.3), and will probably account for a much larger share of production in the near future (Supercritical predicts 80% in 2028). It is important to note that the context and drivers of biochar project development vary depending on the geographical area:

In North America:

The biochar industry is one of the oldest (along with China). It is there that the first large-scale biochar projects were developed. The cost of biomass is high, while the cost of energy is low (compared to the EU), so pyrolysis projects do not make good use of the energy produced; only the sale of physical biochar can supplement the income from carbon credits. This is why the USA is home to the most research and innovation (China is nonetheless well advanced in academic research), as well as knowledge and experience regarding the physical outlets for biochar. Many biochar projects are not yet benefitting from carbon market, but rely on wildfire mitigation and waste management

In EU countries:

The context is different from North America, with high biomass costs, but also high energy costs and significant environmental expectations regarding the decarbonization of the energy sector. Biochar projects are therefore driven by the valorization of this 'decarbonized' energy. Biochar can be considered more as a co-product of energy production and/or waste treatment. This puts less pressure on the need to sell the physical biochar.

In the Global South:

The contexts vary greatly, as this category includes countries on three different continents. However, some contextual elements are common: some types of biomasses are more abundant and cheaper, and labor costs are lower. Energy costs are also low, but there are challenges related to the overuse of electricity grids, leading to malfunctions that are damaging to industries. Decentralized electricity production is therefore an attractive solution. Furthermore, the business environment and low levels of banking support reduce investment capacity. In this context, biochar projects are less expensive (thanks to the low price of biomass) but are less likely to receive large-scale funding. Furthermore, selling the physical biochar will be more challenging, since agriculture is generally realized with a low-input / low-investment model. This is why there are many small-scale projects that rely solely on carbon credits and distribute biochar free of charge. Asia, and India in particular, are areas where the biochar sector is booming, mainly due to the high energy demand of various industries, coupled with the wide availability of biomass and low labor costs.

With regard to the number and distribution of biochar production projects, a non-exhaustive survey was conducted as part of this market study to supplement the data obtained from the literature. This census was conducted in March 2025 and is probably already obsolete given the growth of the sector (the complete list can be found in Appendix 1: Non-exhaustive list of biochar actors):

- Europe: 125 projects of which 34 already emitted carbon credits (CC)
- North America: 84 projects of which 19 already emitted CC
- Africa: 23 projects (15 artisans et 8 industrials) of which 9 already emitted CC
- Asia: 22 projects (10 artisans et 12 industrials) of which 10 already emitted CC
- South America: 9 projects of which 6 already emitted CC
- Oceania: 4 projects of which 3 already emitted CC

The biochar value chain is complex and comprises many different actors, specifically since it includes the carbon market ecosystem as well. It is, however, still an emerging industry (only 350,000 tons produced in 2023) with few mature projects and many recent initiatives. The growth rate is impressive (production is expected to be around 2.5 M tons in 2025), boosted by the profitability offered by the current prices of the carbon market (see section 6.4).

4. The different biochar production models

Biochar is a product of thermo-industrial processes that have been known for some time (pyrolysis, gasification). So, before attracting media and financial attention for its carbon sequestration potential, biochar was primarily a by-product of energy generation. Since the promotion of the carbon removal credit market, which provides a significant source of income through the sale of biochar carbon removal credits (BCR – see section 6.3), we have seen the emergence of industrial models with biochar as their main product, as well as programs aimed at organizing a network of small-scale biochar producers (artisans).

Biochar production models can be classified into three main categories.

4.1 Industrial production: biochar as co-product of energy

The oldest biochar projects are those in this category, i.e. producing biochar as a by-product of their main objective: energy. Pyrolysis and gasification are processes used to produce heat and/or electricity. Most of these projects are found in Europe, given that the cost of energy and biomass is high there. As a result, the use of agricultural and forestry residues or sewage sludge to produce energy has developed rapidly.

The largest biochar projects also fall into this model because energy production facilities must reach a certain scale to be profitable, and the quantities of biochar generated as co-products are proportionally significant. There are three scenarios:

1. The collection of biomasses around a power plant that produces energy and sells it to local industries, either via a heating network or the electricity grid.
2. A circular or 'self-production' model where an industry uses its own residues to produce energy used in its own processes (heat for drying or heating operations, electricity for the factory, etc.).
3. Collection of waste of factories or urban hubs as a paying service and process it in biochar and/or energy/ heat.

This type of financial model is usually balanced in such a way that the income from energy production (and possibly sanitation) covers operational expenses, allowing the project to break even, while the income from the sale of CCs repays the investment and generates long-term profits. These projects may also receive European funding as they contribute to the decarbonization of industry.

Physical biochar is rarely sold (at least in the beginning); in some cases, biochar is given away. Marketing biochar requires investment and expertise that are not included in the project. Indeed, the core business of these projects remains energy, biomass management and CC recovery.

<u>Case study 1</u>: Agri Energy Vraa – Denmark

This is a methane digester plant that collects around 200,000 tons of biomass from agricultural residues in the surrounding area and produces 13 million m^3 of biogas. The sludge from the anaerobic digestion process is dried and converted into pyrolyzed fiber pellets using Stiesdal reactors. The syngas generated are used in the biogas plant process and the biochar is redistributed to farmers. The facility will be able to convert 40,000 tons of fiber into 14,000 tons of biochar per year, equivalent to 30,000 potential carbon credits.

Aerial view of the project

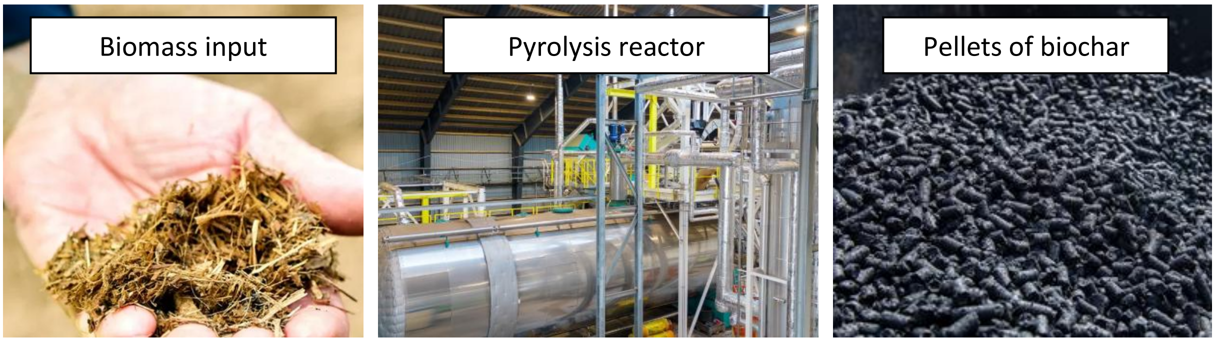

Figure 3: Photos of the Agri Energy Vraa biochar project - Stiesdal SkyClean

The biochar project offers numerous advantages for the biogas plant: savings are made thanks to the energy produced by syngas, and biochar is easier for farmers to distribute and spread than sludge – especially since biochar is produced directly in pellet form, which is very easy to distribute using agricultural machinery. However, this model relies on the pyrolysis of biomass that is very wet and difficult to process before pyrolysis. This is the main technical challenge of the project, which has so far limited biochar production to 1,200 tons per year.

But the teams are confident that they will reach the plant's full capacity in the near future. Another challenge will be to convince a large enough number of farmers to use biochar, but this does not seem to be too difficult a challenge according to the project team.

Observations on the industrial energy/biochar model

This model for producing biochar as a co-product of energy offers the following advantages:

- ✓ Financial balance is achieved thanks to energy generation / waste evacuation fee.
- ✓ Biomass collection is guaranteed (if factory waste is used).
- ✓ May be eligible for public subsidies depending on the country.

However, it also has the following limitations:

- ❖ Dependence on a partnership with a factory/secondary activity.
- ❖ Potential lack of expertise in the marketing of physical biochar (as it is not necessary for the economic viability of the project).
- ❖ Significant investment required for customized pyrolysis facilities.
- ❖ Depending on the biomass, complex pre-treatment steps are required before pyrolysis.

4.2 Industrial production: biochar as main product

As mentioned in the introduction to this section, the revenue generated by CCs has made it possible to develop viable business models based mainly on biochar production. Projects following this model focus their efforts on producing maximum quantities of biochar, most stable possible, while optimizing logistics to increase the number of CCs generated. Companies interviewed that use this model reported that sales of CCs represent between 20 up to 80% of their revenues.

Calculation of CCs by biochar carbon standards are based on a Life Cycle Assessment (LCA) of the biochar project to calculate the number of credits generated: greenhouse gas (GHG) emissions associated with the logistics of collecting and pre-treating biomass, biochar production and distribution logistics are subtracted (purpose-grown biomass production as well).

Therefore, a key element of projects focused entirely on biochar production is to minimize their carbon footprint in order to generate as many CCs as possible. It is achieved as follows:

- Supply / distribution logistics:
    - Limit the biomass collection and biochar distribution area to a 60-200km maximum radius around the pyrolysis unit to avoid long journeys.
    - Optimize the vehicle fleet to transport the maximum amount of biomass and/or biochar with the minimum number of vehicles.
    - Set up a circular economy system in which the biomass supplier (e.g. a network of farmers) is also the biochar user, to avoid empty runs: trucks bring biochar and return with biomass.
- Biochar production:
    - Use advanced technologies to limit GHG emissions and increase stability of biochar.
    - Use syngas from pyrolysis to supply the energy needs of the biomass drying and pyrolysis processes, to limit energy consumption.

The keys to success for this production model are to **ensure the marketing of physical biochar** by investing in the creation/penetration of consumer markets and the **marketing of CCs**. Another key to success is to **make the best possible use of the by-products of biochar production**: syngas (heat recovery) and bio-oil (biofuel production or use in the chemical industry).

However, these elements are debated amongst the carbon standards since the basis of the concept of carbon finance is additionality (biochar projects selling CCs must prove that they cannot be economically viable without this revenue stream). Hence additional revenues such as sales of physical biochar or by-products can be seen as taking advantage of the carbon finance.

<u>Case study 2</u>: NetZero – Cameroon, Brazil (+ other projects in process in the Global South)

NetZero is a company that develops biochar production projects, specifically in developing countries. To date, it has set up a unit in Cameroon, as well as 2 units in Brazil. 2 other units are planned in Brazil, and projects are under development in other countries such as Côte d'Ivoire. NetZero's business model is designed to be as circular as possible: it involves collecting residual biomass from a value chain and distributing the biochar produced within that same value chain, via strategic partnerships.

Their 1st and 2nd units in Brazil are fueled by coffee parchment, a by-product of coffee processing which is normally burnt or left to decompose in the open air by producers. This biomass is recovered free of charge and then resold in the form of biochar to the same coffee growers at an affordable price. To secure its supply and distribution, NetZero has formed a partnership with the area's largest coffee cooperative, signing a contract with each farmer stipulating the terms of the partnership. In addition to this, the company has invested in a scheme of field experiments to obtain robust data capable of convincing coffee growers.

Figure 4 : Photos of the NetZero biochar project in Brazil

NetZero's 1st plant in Brazil aims to produce 4,000 t of biochar per year and has already sold over 1,000 CCs. The 2nd plant will have roughly the same capacity. The Cameroon plant is more of a pilot project. NetZero's ambition is to multiply the number of units in the Global South, in various relevant value chains. The strength of NetZero's model lies in its expertise in analyzing value chains to (i) identify in which value chain biochar provides a relevant solution (ii) with which partner to set up the project (iii) under which conditions to contract the biomass supplier and biochar users.

Case study 3: HUSK – Cambodia and Vietnam

HUSK is following the same circular economy logic as NetZero, producing biochar in SE Asia since 2019 with operations in Cambodia and Vietnam. In Cambodia the company recovers rice husks as biomass at $40/t and transforms it into biochar in their 2 industrial pyrolysis units, each producing 1000 tons per year and increasing capacity. A 3rd unit is to be installed in 2025.

HUSK also produces compost (although not a composting business) so as to be able to design and sell formulated biochar-based fertilizers for specific crops and specific crop stages (approx. 3,000 t per year), which have a greater agronomic impact than pure biochar. These products are targeted at rice farmers, high value crops (coffee, cashew and horticulture) and row crops (sugarcane, cassava) improving yields and the overall net revenue per hectare for farmers whilst reducing chemical fertilizers.

Figure 5 : Photos of the HUSK biochar project

HUSK's business model is still based more on the sale of biochar-based fertilizers than carbon credit (only 10-20% of revenues). The company's strategy is therefore strongly oriented towards the commercialization of their fertilizer products, with considerable investment in R&D and distribution.

This is a model that requires more investment and time to reach profitability, as the success of the project relies on the development of the sales network. However, it is more resilient than models relying largely on the sale of carbon credits, since it relies on a "physical" fertilizer market rather than the highly volatile carbon market.

Observations on the industrial biochar-focused model

The advantages of this model are:

- ✓ A more flexible model than the previous one, since it does not rely on the need for a partnership with an industrial or network operator to valorize the energy.
- ✓ All the project's efforts are concentrated on the biochar, so the teams are less dispersed and more specialized.
- ✓ A model that can be applied to any value chain and geography, easily replicable project and technology = high scalability potential, especially with mobile or containerized equipment
- ✓ If the project strategy is more focused on the commercialization of physical biochar, greater resilience compared to carbon market volatility.

This model has also its challenges:

- ❖ Biomass sources are not guaranteed (in the case when biomass source are not owned by the project), so they need to be carefully analyzed; relevant partnerships must be closed with strategic actors.
- ❖ The logistics of collection and distribution are crucial (see explanations on LCA).
- ❖ For projects whose financial equilibrium relies heavily on CCs, mastery of the carbon market is required, as is anticipation of price volatility (potential price drop in the coming years – see 7.4).
- ❖ Outlets for physical biochar are varied, but no market is yet mature, i.e. demand has to be created and buyers lack knowledge and confidence. A substantial budget is therefore needed to create and penetrate these markets (R&D, sales, communication, etc.).

4.3 Artisan projects

Biochar production is described as "artisan" depending on the type of technology used (small kon-tiki type kiln - Figure 6), the profile of the biochar producer (an individual or farmer, not a company) and the volume of biochar produced: varies widely, but the maximum imposed by CSI (the only certifying body for artisan projects) is $100m^3 \approx 40$ t/year per artisan.

Figure 6 : Photos of Kon Tiki kilns in Namibia (Source: Omiti Biochar)

Artisan production projects are differentiated from others by their specific type of carbon credit certification "Artisan C-sink" - a standard held by Carbon Standard International (CSI - the same company that holds the EBC, EBC C-sink and Global C-sink standards, the leading certifier in terms of carbon credit volume, but behind Puro in terms of value).

This certification is less stringent than the CC standards for industrial projects (Puro, Isometric…), and this is fueling a debate about the "quality" of these carbon credits and therefore their future prices.

The model for artisan projects is quite different from that for industrial projects: it consists of distributing low-cost, low-tech pyrolysis equipment and training the users of this equipment. The project leader also sets up a monitoring system (dMRV = digital Monitoring Reporting and Verification) to ensure traceability of the volumes of biochar produced by the artisans, and their application. In most cases, these users are farmers who will use the biochar directly in their fields.

<u>Case study 4</u>: Recycoal – Rwanda

Recycoal is a German company setting up artisan biochar projects in Africa, notably in Rwanda, Tanzania and Senegal. The project in Rwanda supports 250 producers in the production of artisanal biochar from crop residues in their fields. They are provided with a Kon-Tiki type kiln and training in production management. Recycoal uses a dMRV called PlantVillage where all the information declared by the artisan producers is recorded (volumes of biochar produced, location of plots where biochar is applied, photos of the application, etc.). According to the Recycoal team, each individual producer has the potential to produce between 0.5 and 20 tons of biochar per year (for the largest) with his crop residues. On average, these farmers cultivate around 5 ha and produce 1 to 2 t of biochar per year.

Figure 7 : Photos of the artisan biochar project of RecyCoal in Rwanda

Recycoal then generates CCs using the Artisan C-sink standard. The model involves sharing 50% of the value of the CCs with the producers and paying them in advance. The team estimates that it can sell its CCs for around €150/credit, enabling farmers to earn between €100 and €700 a year, which is a significant contribution to their household income. The remainder of the value of the CCs is kept by Recycoal to pay for the construction of the Kon-Tiki (200-400€ per locally produced kiln), as well as for their technical team who provide support.

The project is recent, but the team already estimates that the quantity of biochar produced is around 1,000 tons per year. So far, only 40 tons have generated CCs. Recycoal notes that demand for this type of carbon credit remains low, and marketing them is a challenge.

Other, older artisan projects have already sold and issued a large number of CCs, such as Carboneers in India (120,000 CC sold and 50,000 issued), Varaha in India (122,000 CC sold and 15,000 issued) or Planboo projects in Ghana, Thailand or Namibia. It's worth noting that 20% of credits sold to date are artisan credits, and that this figure could rise to over 60% by 2026.

4.4 Comments about biomass sources for biochar production

The logistics of collecting and pre-processing available biomass is a key criterion in the design of a biochar production project. This will have a major influence on (i) production costs: biomass purchase and collection logistics are a major factor in business plans; (ii) the technology to be employed: which practices, which size, which investment; (iii) the quality of the biochar produced, and therefore its marketability; (iv) the quantity of CCs generated: the GHG emissions produced by the collection, production and distribution of biochar are taken into account in the project's LCA.

It is therefore important to know which sources are viable and represent an interesting opportunity for biochar production. Prior to project design, a biomass study must be carried out, covering:

1. Availability and price: is the biomass valued/used by other actors? Does the biomass supplier want to sell it (and at what price), or would he be willing to pay to dispose of it?
2. What biomass deposits are available within 100km of the biochar plant site?
3. Is this biomass scattered in fields (agricultural or forest biomass), concentrated in processing units (industrial biomass) or in sewage treatment units (sewage sludge)?
4. Quantifying: what volumes according to seasonality, how will these volumes evolve over the next few years?
5. Qualification: what type of biomass (moisture content, granulometry, contaminants, etc.)?
6. What is the most optimized logistical scheme for collecting this biomass?

All these questions need to be addressed, and the study needs to go into as much detail as possible about the biomass, and potential other sources if the project can be fed with secondary biomass. Some keys to success can be drawn from the biochar projects interviewed in this study:

- Always give preference to industrial biomass (i.e. concentrated in a processing unit, such as cashew nut shells / sawmill residues / coffee parchment) over agricultural biomass (scattered in farmers' fields, e.g. cocoa pods). Indeed, as mentioned above, collection logistics are crucial, and collecting biomass from smallholders' fields is a challenge that makes projects unviable. This is not necessarily the case with large commercial plantations. What's more, industrial biomass is often regarded as waste by factories, so they are prepared to dispose of it free of charge or even pay to have it disposed of. This is not the case for farmers, who can always use crop residues to improve the fertility of their land.

- Be sure to find out whether any other projects are under development to collect this biomass, particularly for energy purposes. Very large sources (>50,000 tons/year) are often captured by biomass power plant projects, which are often subsidized and can therefore create competition that is difficult to match.

- If possible, secure your biomass supply by entering into a contractual partnership with the biomass supplier (if it's a legal entity) or by setting up contracts with a network of farmers. The contract must provide highly satisfactory conditions to ensure resilience (biomass purchase price, conditions of exchange for biochar, other advantages, etc.).

- Set up biomass pre-treatment stages to facilitate and optimize pyrolysis/gasification processes (drying, cutting, pelletizing, etc.).

Depending on geography and production model, certain deposits are predominantly used in biochar projects:

- In Europe and North America, where biomass are more expensive and other uses are more developed, the sources used by biochar projects are:
    - Forestry residues, notably sawmill off-cuts. This type of biomass is fairly abundant and difficult to value in other ways (small quantities for biomass power plants, for example) - or there are projects that combine energy production and biochar.
    - Municipal waste. Most often incinerated, it can be converted into biochar, but it is a mixed and sometimes contaminated biomass that needs to be sorted and pre-treated.
    - Sewage sludge, abundant but high moisture content and not easy to pre-treat.
    - By-products from specific industries: vine stocks in France, olive stones in Spain, fruit trees pruning, etc.
- In the Global South, biomass sources are more diversified:
    - Rice husks, especially in Asia, where rice hulling is carried out in large rice mills.
    - Coffee parchment, especially in Latin America, where coffee is processed either in commercial plantations with large volumes, or in cooperatives.
    - Cashew nutshells, in Côte d'Ivoire, but also potentially in Vietnam and India.
    - Crop residues (corn cobs) are mainly for artisan projects.
    - In very specific areas, invasive species represent valuable biomass sources, for example bamboo in Asia or the encroaching bush in Namibia and Republic of South Africa.

5. Physical biochar commercialization

One of the main challenges for the industry is the sale of the physical biochars. Whatever the project model (sale or donation of the biochar), the biochar must be introduced into a "matrix" (soil, agricultural input, non-combustible building material) to justify the generation of carbon credits. All projects must therefore find an outlet for their biochar. The term "physical biochar" is used here to distinguish it from the market for biochar carbon credits.

It's important to identify the various possible outlets for biochar, which is fairly versatile material with uses in a number of sectors. These outlets are presented below, along with their advantages, limitations, obstacles and potential for future development.

In their study of the biochar sector in 2023, IBI and USBI consulted biochar producers in relation to their target market, highlighting the main areas of demand for biochar (Figure 8). Soil applications through agriculture (fertilizers, amendment), forestry and soil remediation are vastly considered as the main outlets. The other ones (animal nutrition, water filtration, building materials) are seen as secondary, if not marginal.

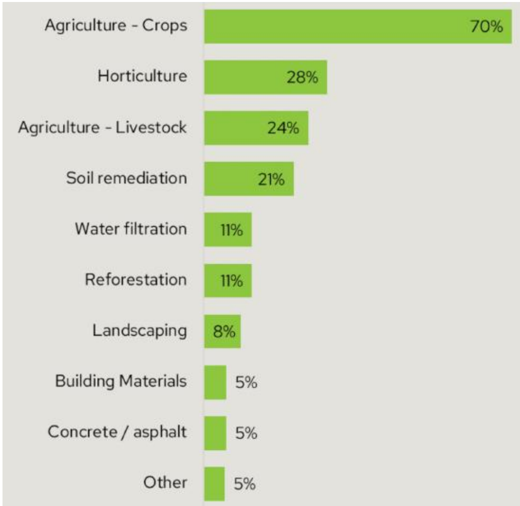

Figure 8: Biochar producer outlets reported by respondents to the IBI 2023 study

5.1 The different biochar outlets

5.1.1 Agriculture, forestry and horticulture

The primary market for biochar remains agriculture in the broadest sense (including livestock farming and horticulture). As can be seen on Figure 8, agricultural crops, horticulture (nursery, gardening) and livestock are the main outlets for 70%, 28% and 24% of biochar producers respectively.

Whether used as a soil amendment, a substrate or as an input combined with mineral fertilizers or organic inputs, biochar makes the most of its properties when introduced into cultivated and degraded soils, as it meets key challenges (improving soil porosity, increasing soil pH, adsorbing nutrients, increasing soil water retention capacity, stimulating microbial life...). Soil is also the most stable destination ("matrix") for biochar in terms of carbon sink.

Soil amendment

The properties of biochar, as accepted by the current scientific consensus, as a soil improver are multiple. In particular, we can cite 4 biochar actions that respond to strong agricultural issues:

- Increasing soil water retention capacity, making production systems more resilient to drought episodes and reducing irrigation costs. These are two major concerns for many farmers around the world facing the impacts of climate change.
- Increasing soil pH, allowing better nutrient availability and generally improving plant nutrition and health processes.
- Nutrient adsorption, i.e. the ability to "secure" nutrients against leaching and release them slowly in the long term, making them more accessible to crop plants. This action is particularly appreciated in production systems using fertilizers, most of which are lost during rainy episodes. In this way, biochar helps to optimize the nutrients supplied and thus reduce fertilizer purchase costs, which is particularly relevant in the current and future context of rising fertilizer prices.

- Stimulation of microbial life via a number of mechanisms, improving natural soil fertility, crop vitality and immunity to pathogens. This action is appreciated by agricultural production systems based on a natural approach (organic, conservation, agroecology, etc.).

It must be stressed, however, that these actions of biochar, although accepted by the majority of the scientific community, depend enormously on the characteristics of the biochar (its "quality"), its mode and dose of application, the type of soil and the farming system (type of crop and agricultural technical itinerary). It can be misleading to make claims about the benefits of biochar in specific contexts, without a robust protocol for testing under real conditions (in the field, in the long term).

It's worth noting that biochar remains an unknown input for farmers worldwide (although it's better known in the USA). The success of any attempt to market biochar as a "raw" amendment therefore depends on investment in R&D, communication and technical support. The same applies to all types of input: see the strategies of the major distributors of agricultural inputs: extensive network of sales representatives, financing of tests, etc. Today's producers are finding it difficult to sell this type of product, which means they need to make major marketing efforts (Figure 9).

Figure 9: Biochar promotion deals

For the time being, the agricultural sectors for which biochar-based products are most attractive are those with the highest added value (vineyards, fruit trees, horticulture in the USA and Europe, and coffee, for example, in Latin America); and the ones that are the most sensitive to climate change: take the example of coffee growers in Brazil, who are experiencing major difficulties due to increasingly frequent and prolonged periods of drought (see Case Study 2: NetZero).

Other potential markets include forest plantation projects (which use inputs to condition the soil for tree seedlings), reforestation projects (which could enhance their sustainability image by using biochar) and agroforestry projects.

Given the quantities required to be applied per hectare (often quoted as between 5 and 20 tons per hectare, ideally every 3-5 years), the best packaging for selling biochar as a soil improver is in 1 ton big bag or in bulk, depending on transport (Figure 10).

Figure 10 : Advertisement for biochar

Combined fertilizer

Although biochar has a positive agronomic impact when applied raw to the soil, particularly in very acidic and dry soils (depending on the case), its characteristics also make it an excellent component for combined fertilizers. Indeed, several projects valorize their biochar directly associated with organic inputs such as compost (see Case Study 3: HUSK - Figure 11). It should be noted that these projects must therefore develop expertise and a parallel compost production activity in addition to the biochar production activity.

Figure 11: HUSK product range

Formulated as a fertilizer, biochar is easier to sell to farmers because it meets a number of issues, including the short-term nutritional needs of plants (whereas soil amendments have a more long-term effect). This is why combined fertilizers are seen as the best commercial opportunity in the future (Figure 12Figure 11).

As far as pricing is concerned, producers of this type of biochar-based product said they had to match the prices charged for other fertilizers, for the same effect (often assessed according to the dose of NPK nutrients supplied). Since biochar also reduces fertilizer inputs, the price can be set according to the % savings achieved by farmers. This method needs to be backed up by test results.

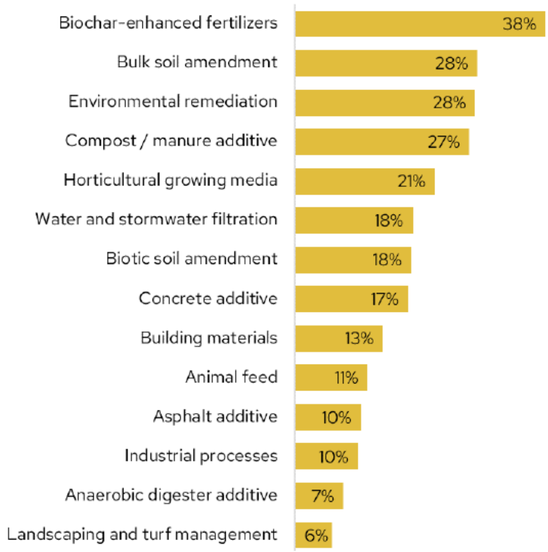

Figure 12: The most interesting products to explore for biochar sales, according to industry players

Another marketing model could be to sell biochar directly to input producers and distributors, so that they can use it themselves by mixing it with their products. This would be an ideal opportunity, as these players already have expertise in marketing agricultural inputs, enabling the biochar producer to avoid allocating resources to distribution and concentrate on biochar production.

However, several international input producers were contacted as part of this market study, and all expressed little interest in biochar. The arguments put forward were often the lack of hindsight and scientific literature. It can also be assumed that the reduced fertilization requirements brought about by biochar do not fit in with the business model of these players.

Nonetheless, this type of partnership seems to remain one of the ideal opportunities for biochar commercialization. Biochar projects should continue to explore this possibility, particularly in the light of the decarbonization/sustainability angle that may appeal to the input sector. Indeed, especially since the Nairobi Declaration, fertilizer producers are under increasing pressure to find solutions to reduce their carbon footprint and improve the nutrient efficiency of their products. What's more, it would seem that companies focusing on fertilizer blending are facing difficulties in obtaining the inert materials they need for their blends. Here too, biochar could be an interesting solution.

Substrate

Biochar can be used in mixtures to produce growing substrates, mainly used by nurseries, for ornamental plants and gardening (Figure 13). The qualities required of a good substrate are (i) porosity (ii) water retention capacity (iii) stability over time (iv) nutrient supply and (v) harmlessness - i.e. absence of toxicity or pathogenic elements: all are fitting with biochar.

Figure 13: Advertisement for biochar as substrate

These sectors, although much smaller than the agricultural sector, are all showing significant growth rates in the USA or the EU, driven by an increase in post-COVID gardening activities and urban and soilless agriculture (especially in containers).

In the case of nurseries, biochar is a serious candidate as a substitute for peat, a highly controversial component due to the very negative impact its extraction has on the environment and biodiversity[2].

As substrate, biochar is also a lighter material than clay or soil and can be cheaper than imported coconut fibers. It should be noted, however, that when it comes to carbon sequestration, biochar used as substrate cannot generate CCs in countries where most waste is incinerated. Indeed, standards consider that ornamental plants are burnt and that the carbon contained in the biochar is therefore released back into the atmosphere.

Animal feed

The characteristics of biochar also make it an excellent additive for animal feed (improved digestion, binding and elimination of toxins). It can be added at a rate of 0.5% to 2% to the feed ration. This use is still little known but is beginning to gain visibility in countries where livestock farming is important (EU, Australia, New Zealand). It should be noted that the potential benefits of biochar used in animal feed are most pronounced in animals suffering from disease or malnutrition, often in developing countries. The growth of this use of biochar also depends on regulations, as in some countries what can be added to animal feed is strictly regulated. There are also certifications such as GMP+ or EBC-Feed, which guarantee the safety and quality of the product as animal feed.

Figure 14 : Advertisement for biochar as an animal feed in Switzerland

5.1.2 Landscaping and soil remediation/regeneration

Biochar is also used as a substrate or soil amendment in non-agricultural sectors such as urban landscaping (as a substrate for trees, lawns and ornamental plants), waste burial (as a layer to cover

[2] Avoid using peat in gardening - Office Français de la Biodiversité (link)

waste), mining backfills (filling holes left after mining operations), soil decontamination[3] (following industrial operations) or soil regeneration (compensation for large-scale projects such as mining).

Some of the EU-based biochar projects interviewed in this study testified that the market for landscaping substrates is where their main demand comes from. In particular, the planting method known as the Stockholm Trench, which improves the development and survival of urban trees, as well as water management with biochar, is gaining ground.

5.1.3 Building materials

A great deal of research is conducted for the use of biochar in construction materials such as cement, plaster and asphalt. This is a sector which represents a very significant demand in quantitative terms, but for which the prices paid to components are very low (except for specific niche materials). The market in which biochar is the most advanced is concrete. The building sector is interested because of its significant carbon footprint (11% of global GHG emissions). There is talk of using 1% to 3% biochar in concrete, and potentially up to 5% without any major drop in quality.

Asphalt is also a construction material for which biochar could substitute certain components. Scientific research on the subject is more recent, so applications are rarer, but we're talking about using 3% biochar, and I'd go as high as 10%.

As in the case of animal feed, regulations in some countries require new components to be registered for use in construction materials. One example is the EU's REACH regulation. In terms of quality certification, CSI has published several EBC standards for biochars not applied to soil: EBC-BasicMaterial, EBC-ConsumerMaterial and EBC-Urban.


Figure 15: Building materials with biochar: concrete (left - University of California), asphalt (right - Hansa Asphalt Germany)

5.1.4 Water and air filtration

This sector is probably the one that could offer the highest prices for its components, particularly the PFAS (Per- and polyfluoroalkyl Substances) filtration market. However, regulations in these sectors are extremely strict, due to the major health issues involved. The use of a new component such as biochar could therefore take a long time to come into force. What's more, the characteristics demanded of biochars will be extremely stringent, requiring processes that are precisely adapted to filtration applications. As a result, some projects will have to specialize and will find it difficult to diversify their outlets.

[3] Find out more about the use of biochar for soil decontamination on the biochar-zero website.

5.1.5 Substitute components in the chemical and metallurgy industries

Metallurgy could become a major outlet for carbon-rich components, given that fossil coal is a frequent component of this sector. However, CCs cannot be generated by selling biochar for metallurgy, so we're talking about bio-carbon instead. This makes this outlet much less attractive. As far as the chemical industry is concerned, several applications for biochar have been identified, but the state of research is still in its infancy. These include the substitution of so-called carbon black in rubber mixtures, notably in the tire industry.[4]

5.1.6 Nutraceuticals and cosmetics

This market is ultra-niche and will only involve very small volumes. The characteristics of activated carbon used in nutraceuticals and cosmetics are difficult for biochar to match. This sector is therefore considered irrelevant.

5.2 Physical biochar prices

5.2.1 Current prices for biochar sales

Physical biochar can find demand in various sectors, depending on the type of outlet. Hence the selling price of "raw" biochar must be differentiated from biochar-based products, which require more processing and other inputs.

It is difficult to give an estimate of the prices charged for the sale of raw biochar, given the low volumes marketed, and the fact that a large proportion is donated/distributed free of charge by projects based on the valorization of energy and the sale of CCs. Prices are currently in the range $70-300 per ton, with lower prices in countries where supply is greater and there are very large industrial plants (economies of scale), such as the USA.

For biochar-based products, it will depend on the benefits derived from their use in the sector. In the agricultural sector, the price of biochar will be closely linked to the price of NPK fertilizers, meaning the value of the product will be assessed mainly by the amount of NPK and the prices of the competing other products.

In the case of building materials, the substitute components competing with biochar are particularly inexpensive, so the price paid for biochar in this sector is likely to be low, at $150 per ton maximum.

The sectors offering the highest prices will probably be the filtration and chemical/metallurgy industries, with prices of up to $600-1500/t. But these prices will only apply to biochars with very specific characteristics adapted to this kind of niche use.

5.2.2 The main limits to demand for biochar

Demand for biochar is limited today, and although the supply of biochar is still very low, most biochar producers consider that the lack of demand remains the main challenge on the development of the sector, and this is due in particular to a lack of knowledge among potential consumers.

[4] More information on the biochar-zero website: Steel and Metal Industry / Polymers

Indeed, the potential applications of biochar (soil improver, fertilizer, animal feed, construction, filtration) all have major impacts for consumers: crop yields, soil decontamination, animal health, building solidity, health of water and air users... The integration of a new input like biochar needs to be scientifically demonstrated in a robust, specific way, with the necessary historical hindsight on potential long-term impacts.

We can see from Figure 16Figure 16 that the number of scientific publications on biochar has increased exponentially since 2018, so this gap in scientific knowledge is being filled, but it is still very inadequate. Surprisingly, the subject seems to have slowed down since 2022.

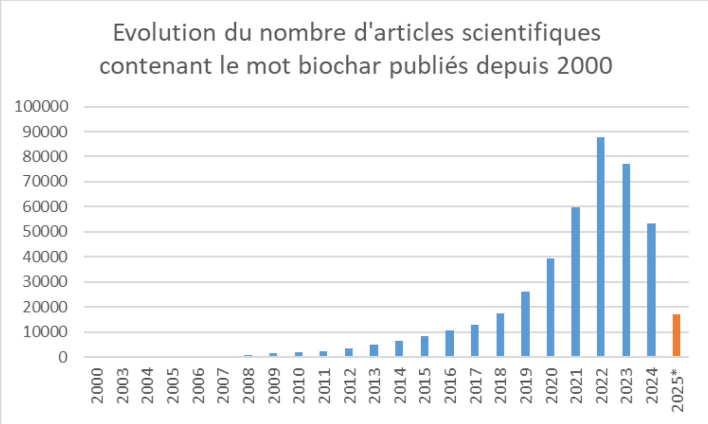

Figure 16 : Evolution of scientific articles containing the word "biochar" since 2020until March 2025 – Source: Google scholar

Probably even more significantly, the major obstacle to the development of biochar demand remains the competitiveness of biochar in terms of production costs compared with its competitors (compost, fertilizers, cement, etc.). Indeed, these products come from sectors that are already well structured and have achieved significant economies of scale.

Another limitation is the current low level of biochar production. Some sectors are dominated by large industrial groups (fertilizers, construction, chemical industry, etc.) who need large quantities to start up a partnership. Finally, the lack of regulations for certain markets and strict countries (filtration, building materials) is also hindering their developments.

In conclusion, current biochar prices of around $100-300/ton are considered high and are probably due to low supply and the innovative nature of biochar. Demand is likely to grow only at a slow pace compared with supply, which is boosted by the carbon market. As a result, physical biochar prices are likely to drop over the next few years.

This trend will also be reinforced by the economies of scale achieved by ever-larger biochar production plants. We are likely to see a race to lower the price of biochar in the near future, as biochar needs to be competitive with other substitution products. This will only be possible by increasing the production capacity of industrial projects (economies of scale). This trend is becoming increasingly apparent in projects whose model is energy production + biochar, with the design of new, high-capacity, custom-built equipment, fully integrated into the plant's industrial system. As a result, price declines will first happen in countries such as the EU and the USA.

This drop in price is also linked to the carbon market, since the sale of credits is supposed to mitigate the cost of production. If the prices of CCs are high, then the projects can sell physical biochar at lower prices. However, trends of the carbon market are very difficult to analyze and anticipate due to its volatile nature, and even more so when it comes to new CCs such as those from biochar.

5.3 Marketing strategies

The analysis of biochar outlets shows that markets for this product are still emerging and that demand is limited and will remain so until the product receives greater scientific, operational and public recognition. Today, selling physical biochar is a real challenge that should not be underestimated, and which requires the implementation of appropriate and relevant marketing strategies. Below is a list of some of the strategies observed in existing projects:

Agricultural research and development

Given that the main market for biochar is agriculture, and that consumers in this sector (farmers) are characterized by their conservative approach (low risk-taking) and a certain skepticism about changing practices (since this entails significant risk), it is necessary to be able to provide concrete scientific evidence of the benefits of a new input is to be sold to them. This strategy is used by NetZero (Case study 2) and HUSK (Case Study 3).

With this in mind, it's essential to set up an ambitious and rigorous R&D program as soon as possible, with field tests based on a robust scientific protocol involving controls, repetitions and variations, and preferably over the long term (>5 years). Key points to bear in mind when setting up a successful agricultural R&D project:

- Ambitious sizing: multiplying the number of tests under varying conditions (soil type, farmer profile, technical itinerary, etc.) to cover as many different scenarios as possible.
- Tests in real-life situations: setting up as many tests as possible in the plots of typical consumers, i.e. directly with the producers targeted for the sale of biochar. These testers can also become ambassadors, as word-of-mouth is the most efficient method for spreading innovation in the agricultural sector.
- Scientific protocol: designing the protocol and its follow-up in collaboration with a research institution or have an in-house manager with solid scientific experience. If possible, publish results in scientific articles.
- Operational partnerships: it's a good idea to sign partnerships with key players in the targeted value chain or landscape, either to share the costs of the R&D program, or to benefit from their expertise, network and credibility with farmers (cooperatives, interprofessions, processing plants, etc.).

Communication and technical support

As for all agricultural input sellers, it's important to have an extensive network of technical sales staff responsible for prospection, as well as agricultural advice to consumers (how to apply biochar, what dosage, what equipment, what season, etc.). What's more, the marketing effort should be important, with communications tailored to the target audience (for example advertising on social networks).

Product development

Along the same lines as agricultural R&D, R&D for biochar-based products is very important. Selling "raw" (bulk) biochar is more difficult than selling biochar-based products, and this is particularly true for the agricultural sector. This means investing in the development of differentiated products that offer more benefits than biochar alone. This strategy is employed by companies such as HUSK (Case study 3), PyroCCS or Carbon Gold, as well as a growing number of start-ups developing specific uses for biochar in building materials (Castorcon, Durra Panel).

Setting up partnerships

This key to success is fairly general and could be applied to all marketing strategies (whether for agricultural R&D, communication/distribution or new product development). However, it is important to understand its relevance: a biochar production company needs to focus first and foremost on the complete mastery of its production model, which faces many challenges. As a result, it is difficult to dedicate resources and know-how to other activities such as R&D or marketing (of both physical biochar and carbon credits), at the risk of dispersing the resources of the company.

Certain strategic partnerships are therefore necessary in order to avoid exhausting efforts in too many different directions (especially for new companies, or start-ups, the majority profile of biochar projects). Examples include potential partnerships with compost or fertilizer producers to formulate composite fertilizers, or with companies producing building materials.

Limit your distribution area

The number of carbon credits that a biochar project can generate is calculated by considering the GHG emissions associated with biomass collection and pre-processing, biochar production and distribution (LCA method). In this way, every kilometer covered by the biochar before its introduction into its final "matrix" will be deducted from the carbon credit total and has a strong impact on the project's revenues. The aim is to ensure outlets are as close as possible to the production site. This also decreases the relevance of exporting biochar, beyond the fact that it's a raw material with a very low density and therefore requires more container volume.

Targeting relevant value chains

In order to facilitate the commercial sale of biochar, it makes sense to target agricultural value chains that are currently facing severe climatic and agronomic constraints. The most interesting effects of biochar according to producers are mainly its ability to increase soil pH and water retention, as well as the possibility of optimizing the action of fertilizers and therefore buying less of them (reducing fertilization costs). It is therefore necessary to carry out value chain analyses to identify which are the most relevant, and in which territories.

The criteria used for such analysis can be: (i) crops are increasingly suffering from drought; (ii) farmers are buying fertilizers; (iii) the soil is facing fertility/acidity/salinity problems; (iv) farmers are trying to comply with natural agricultural production specifications such as Organic Farming. Last but not least, to implement a circular model, a value chain with a lot of residues/waste that is not very well valorized will also be a potentially interesting biomass source.

6. Carbon market trends

6.1 The 2 carbon markets: compliance and voluntary

Carbon certification began to emerge in the 1990s, in response to growing environmental concerns and the need to measure and reduce greenhouse gas (GHG) emissions. The first carbon certification was introduced in 1997 as a "flexibility mechanism" under the Kyoto Protocol, with the launch of the

Clean Development Mechanism (CDM), which allowed industrialized countries (subject to binding commitments) to use carbon credits[5] - in other words, GHG emission reductions, or carbon sequestration, generated by the implementation of a project - in place of limitations on their own GHG emissions.

This first carbon market was based on the respect of regulations and hence called the compliance markets. Created as a result of a national, regional and/or international policy or regulatory requirement. Companies or governments are required to reduce their GHG emissions to a certain predetermined level. If they cannot meet this target by reducing their emissions, they can purchase CCs from other companies that have reduced their emissions beyond their quota, or from the government. These transactions are carried out through national trading systems called *Regional Emissions Trading Systems* (ETS), based on carbon taxes and cap-and-trade systems. Of these ETS we can mention for example the European Union System (ETS-EU), the RGGI (Northeastern USA), the Western Climate Initiative (Canada) or the China Emissions Trading Scheme. Today, only 16% of CO_{2e}emissions are covered by this type of binding measure[6].

The voluntary market, on the other hand, is a system in which companies or individuals can choose to voluntarily offset their GHG emissions by purchasing CCs. This voluntary market is governed by private certifications/labels (VCS, Gold Standard, Plan Vivo, etc.), whose methodological frameworks are inspired by the CDM, and by international standards (GHG Protocol, Carbon Disclosure Project, Science Based Targets Initiative, etc.).

It is important to make a clear distinction between CCs traded on compliance markets, which in fact only represent compliance with national quotas, and those traded on the voluntary market, which come from various types of carbon projects developed by third parties.

In the last years, the CCs from compliance and voluntary markets were not interchangeable, there was little "**fungibility**" between the 2 markets. However, recently, there were initiatives to increase the fungibility, for example the *Carbon Offsetting and Reduction Scheme for International Aviation* (CORSIA), a global scheme designed to offset the fraction of CO_{2e} emissions from international flights. Also, the compliance markets are planned to be changed with the revision of the Article 6 of the Paris Agreement, that would allow some project typologies of the voluntary market to be allowed in the compliance market. It would seem that biochar is well placed to be included, which would be a major opportunity (see section 7.4).

6.2 Types of carbon projects

Carbon projects are divided into 2 main categories: those that *avoid* emissions and those that *remove* CO_2 from the atmosphere, also known as CDR (*Carbon Dioxide Removal)*. Projects are also classified according to whether their carbon avoidance/ removal methods are based on natural processes (*Nature-based Solutions = NbS*), or on the use of technologies (Table 2).

[5] Carbon credit is an exchange unit representing the avoidance or sequestration of 1 metric ton of CO_2 or equivalent GHG (=CO_{2e}). 1 tCO2erepresents the emissions of 5 full tanks (350L of diesel), the combustion of 2 barrels of oil or 1 Paris-New York round plane trip per passenger.

[6] ICAP (2023). Emissions Trading Worldwide: Status Report 2023, UNFCCC

Table 2: Matrix of carbon project types

Carbon projects typology	Avoided emissions *AVOIDANCE*	Removal of CO2 from the atmosphere *REMOVAL or CDR*
Nature-based solutions (NBS)	Avoided deforestation (REDD+) Peatland conservation Mangrove and grassland protection Low-carbon agriculture	Afforestation / reforestation / agroforestry Wetland restoration Regenerative agriculture
Technology-based solutions	Energy efficiency: improved cookstoves or upgraded industrial equipment Renewable energies Coal substitution --> gas (hydrogen)	*-- Also known as stable CDR --* DACCS (direct air capture & carbon storage) BECCS (bioenergy & carbon storage) ERW (enhanced rock weathering) **BCR (Biochar carbon removal)**

It should be noted that certain types of projects are at the frontier between several categories, such as biochar, which can be considered as either *nature-based* or *tech-based* CDR, depending on the point of view, and can also be considered as *avoidance* (Pirard 2024).

Projects are also classified by sector: AFOLU (Agriculture, Forestry and Land Use), renewable energy, chemical and industrial processes, household/community devices (improved cookstoves), energy efficiency/fuel switching, waste disposal and transportation.

6.3 Biochar's place in the carbon markets

In this landscape of carbon markets, biochar represents a very small niche segment, but one that is gaining momentum for reasons explained below. According to CDR.fyi, 473,000 biochar CCs have been issued since 2019, when Puro began issuing this type of credit. This is very little compared with the total of 4.1 billion CCs that have been issued, most of which have been generated by Agriculture, Forestry and Land Use (AFOLU) projects like REDD+ or reforestation, and renewable energy projects. Hence, **in 2025 biochar accounted for just 0.001% of all the carbon credits issued.**

However, various sources predict that this sector will grow intensively over the next few years. For example, Supercritical gives an estimate of 2.86 million biochar CCs for 2026, and 11 million for 2028[7]. **The number of CCs generated by biochar projects could increase 12-fold by the end of 2025** and thus represent 0.8% of the voluntary market.

Biochar is considered to be a durable CDR method

Biochar projects (shortened by the acronym BCR - Biochar Carbon Removal) are considered by the carbon market as part of the typology of projects that remove carbon from the atmosphere (CDR). CDRs accounted for 35% of all CCs issued on the voluntary market in 2023.

CDRs fall into 2 categories: "nature-based solutions" (mainly sequestration in trees) and technological solutions (of which biochar is one). **These technological solutions have the advantage of being considered more durable over time, unlike carbon sequestered in trees, which runs the risk of being re-emitted into the atmosphere.** Carbon sequestered in biochar is considered to be a stable/irreversible sequestration: when biochar is applied in a stable matrix (soil or concrete, for example), it cannot be incinerated and degrades very slowly in the soil.

[7] Boom or bust, 2024 Biochar Market Outlook, Supercritical 2024

Among durable CDRs, biochar is the most mature technology

Apart from biochar, stable CDRs include technologies such as CO_2 capture directly from the air - DACCS, enhanced rock weathering - ERW, bioenergy with carbon dioxide capture and storage - BECCS, long-term biomass burial, ocean alkalinization capture, and others. Biochar is the only one of these technologies that is today considered "mature"[8] (Figure 17), i.e. operational and can be implemented in viable commercial projects generating CCs. **To date, 76% of durable CDR carbon credits issued and sold ("delivered") have come from biochar projects.**[9]

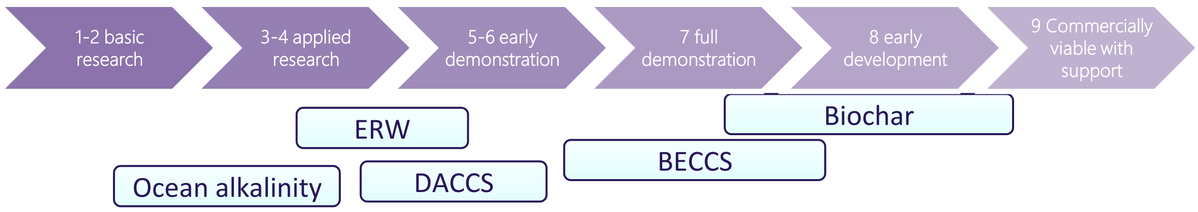

Figure 17: TRL levels of the different CDR methods Source: carboncredits.com

Demand for durable CDR is increasing from private groups

The demand for CDR projects is increasing from CC buyers, as they represent a more tangible impact on climate change (compared with avoided emissions). Large companies are even starting to include separate targets for *avoidance* and CDR purchases in their offset strategies.

Indeed, the promise of becoming *net zero* has become a key element of corporate communications in recent years. We need to differentiate between the terms "net zero" and "carbon neutral": to claim *net zero*, once a company has reduced its emissions as much as possible, it can only offset the remainder by purchasing credits that have effectively removed carbon from the atmosphere, i.e. CDRs[10], whereas to be carbon neutral, you can purchase any type of CC. This means that CDRs become a complementary and differentiated market in relation to other credits.

Complementary arguments (co-benefits) for biochar carbon credits

In addition to the arguments mentioned above, biochar offers other co-benefits:

- Environmentally speaking, in addition to carbon sequestration, depending on how it is used, biochar can be used to address major issues such as declining soil fertility and the adaptation of cultivated systems to climate change; bioremediation (soil decontamination, water or air filtration); replacement of polluting materials (substrate industry, fertilizers, construction materials, etc.).
- On a social level, some biochar production models, mainly artisan projects, require the value of the sale of CCs to be shared with small producers and rural households, providing significant additional income for the local population. What's more, where the agronomic impact of biochar is significant, it can improve the performance, and therefore the agricultural income, of households.

[8] An important concept in climate technologies is the TRL (*Technology readiness level*) scale. It assesses the level of maturity of a technology up to the point of industrialization. It has 9 levels.
[9] Data from CDR.fyi, sum of credits whose status is *Delivered*, and *Retired*

[10] Understanding the Use of Carbon Credits by Companies: A Review of the Defining Elements of Corporate Climate Claims, D. Trouwloon et al., 2023

- From an economic point of view, it can make sense to recover energy from the carbonization process to power an industrial process (drying, water/air heating) or the generation of electricity, which benefits not only the energy balance of the carbonization operation but also that of other complementary activities. This is especially true in sectors where the biomass to be carbonized is normally generated by an agro-industrial unit (e.g. coffee hulling, sawmills).

Biochar provides sustainable solutions to several key issues at once (regenerative agriculture, renewable energy production, AgTech, circular economy…), making it an attractive solution for certain players such as international funders and impact investors.

6.4 Prices of carbon credits

The selling prices of CCs are highly heterogeneous (from a few euros to around ten euros on average, to over 500€ for certain micro-niches such as durable CDRs).

Firstly, there are several markets with different prices: compliance markets, with fixed credit value known to all, and voluntary markets, where prices are not fixed and depend on negotiation between seller and buyer. Several factors influence these prices, which are different for compliance or voluntary markets.

For the compliance markets

Economic paradigm (2011 debt crisis, COVID-19), international crises (war in Ukraine), political decisions (lowering of emissions caps, carbon tax) and changes in the mechanisms/rules governing this market (introduction of the Market Stability Reserve - MSR to prevent oversupply) have a strong impact, as can be seen on Figure 18.

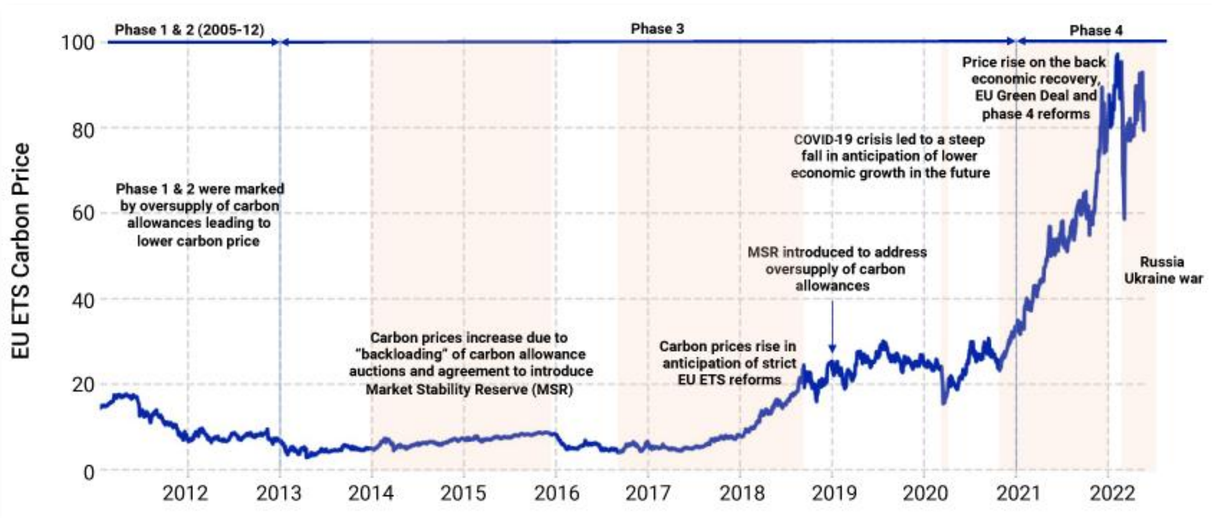

Figure 18: Price trends on the EU-ETS European compliance market. Source: MSCI 2022

Prices depend on the country/region of the compliance market: in 2024, the price on the European market was $61, $58 in Canada, $45 in the UK-ETS, $38 in California, $25 in Washington and $12 in China. However, the global trend is upwards.

For the voluntary market

The law of supply and demand prevails. Carbon credits will behave like any other product on this market, with differentiating factors characterizing the "quality" of the credits, and therefore their price: type of project (clean cooking, renewable energy, forestry), type of standard (VCS, Gold Standard, CDM, Puro...), vintage (year in which the credit was generated), liquidity (eligibility on several markets - e.g. CORSIA), geography, organizations involved, risks, co-benefits...

	2023			2024			Percent Change		
CATEGORY	Volume ($MtCO_2e$)	Value (USD)	Price (USD)	Volume ($MtCO_2e$)	Value (USD)	Price (USD)	Volume	Value	Price
Forestry and Land Use	37.1	$372.3M	10.04	37.0	$342.5M	9.27	0%	-8%	-8%
Renewable Energy	29.0	$113.5M	3.92	22.3	$59.5M	2.67	-23%	-48%	-32%
Chemical Processes / Industrial Manufacturing	12.2	$50.2M	4.10	5.7	$20.8M	3.66	-53%	-58%	-11%
Household / Community Devices	10.2	$78.3M	7.71	5.1	$37.4M	7.30	-50%	-52%	-5%
Waste Disposal	1.5	$10.9M	7.46	4.8	$32.0M	6.72	226%	193%	-10%
Agriculture	4.7	$30.7M	6.51	0.6	$4.7M	7.66	-87%	-85%	18%
Energy Efficiency / Fuel Switching	9.4	$34.4M	3.65	0.6	$1.9M	3.05	-93%	-95%	-16%
Transportation	-	-	-	0.2	$0.6M	3.24	-	-	-

Figure 19: Volume, value and price of CCs traded on the voluntary market, by type. Source: Ecosystem Marketplace 2025

Although market prices are published by observatories, the price of each transaction is the result of a commercial negotiation and can be confidential. A carbon project will therefore try to sell its CCs at the best possible price, using every possible argument, including credibility (rigorous certification methodology) and differentiation (*storytelling* that makes the project unique). Prices in 2023 ranged from an average of $3.65 to $10.04 and fluctuate from one year to the next (Figure 19).

The carbon markets (compliance and voluntary) have experienced significant volatility over the past 15 years, influenced by a variety of economic, social, political and regulatory factors. Recent volatility factors include scandals and loss of confidence in REDD+ methodologies which have tarnished the image of CCs in general, and the change of government in the USA. Other developments may positively affect the market, such as the fungibility between compliance and voluntary markets. Carbon markets are extremely volatile by nature, and their prices are complex and difficult to anticipate, especially over the long term.

Prices of the biochar carbon credits

Durable CDRs are methods of extracting CO_2 from the atmosphere using advanced technologies requiring costly and time-consuming R&D, CAPEX investments and high operating costs. This has an impact on the sale prices of CCs, which vary enormously depending on the method, but are generally much higher than the prices of CCs for other project types (between $4 and $10 per credit, and $27 for NBS-type CDRs e.g. reforestation). Indeed, the prices of CCs from durable CDRs are all well above $100 per credit, even reaching over $500 for some very high-tech methods (Figure 20). Biochar is the most competitive type of durable CDR project, with prices between $100 and $300.

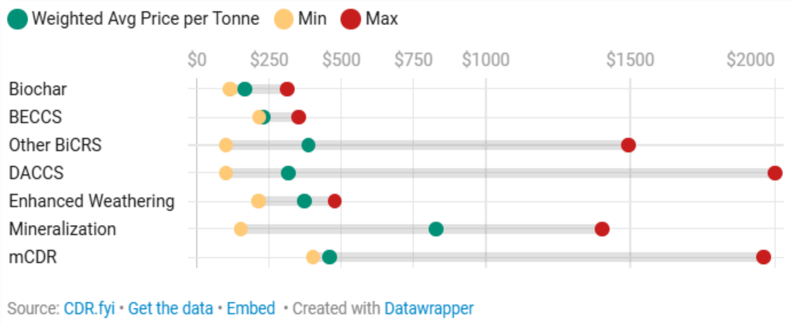

Figure 20: Price range for durable CDR credits - Source: CDR.fyi

Although biochar is a niche in the voluntary carbon market, it has significant potential in terms of demand compared to other methods of generating CCs, for several reasons:

- it is a CDR, i.e. it removes carbon from the atmosphere, and is therefore considered to have a greater impact on climate change than emissions reductions.
- it can store carbon over very long periods (> 1000 years), which is not the case for forestry projects that are sensitive to fire and timber harvesting: it is a "durable" CDR.
- it is the most mature, operational, and competitive durable CDR method to date.
- its use generates social, economic and environmental co-benefits.

These various arguments therefore support the thesis that demand for biochar carbon credits will grow in the future. However, while these arguments are effective, if prices for biochar CCs remain high, there is a risk of hindering this demand.

7. Outlooks for the biochar carbon credit market

7.1 Demand for biochar carbon credits (from BCR projects)

To date, according to the CDR.fyi database, around 1.77M biochar CCs have been sold. This represents only 6% of all durable CDRs sold, making biochar the 3rd method in terms of CC sales, far behind BECCS with 21.8 M CCs sold and DACCS with 2.5 M.

However, since biochar is the most mature technology, CCs purchased for other methods are "investments for the future" rather than CCs already generated. Almost all (76%) of the "delivered" CCs (credits that have been purchased and generated) from durable CDRs comes from biochar.

In terms of development, purchases of biochar CCs are growing rapidly, multiplying by 4 over the past 2 years, reaching almost 1 million in 2024 (Figure 21).

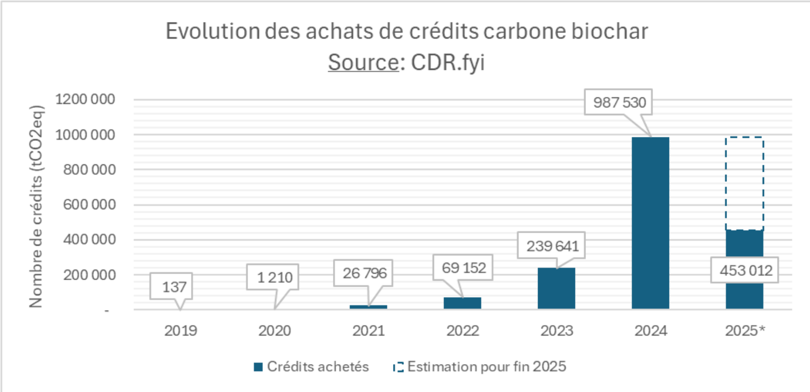

Figure 21: Purchases of biochar carbon credits

One of the reasons boosting demand for durable CDRs (and therefore biochar CCs) in 2023 and 2024, in addition to the arguments put forward in the section 6.3, is the declining confidence of buyers in credits from REDD+ (deforestation reduction) programs, which account for a significant proportion of credits on the voluntary carbon market. Scandals linked to carbon accounting errors have been reported in the media and have tarnished the reputation of these programs, partly redirecting demand towards CDRs.

7.2 Profiles and expectations of biochar credit buyers

Although demand looks promising, only a handful of large private groups centralize all the demand. The top 5 buyers account for 40% of total purchases, and potentially more since a large part of the transactions is confidential (Figure 22).

These companies, which overwhelmingly dominate biochar CCs orders, are mainly Tech groups (Microsoft, Google, Shopify, Stripe, Autodesk) that have large carbon footprints but rely on a climate-aware employee base that pushes their environmental targets. Other sectors that make up the demand for CC biochar include consulting groups (JP Morgan Chase, TD Securities, Morgan Stanley, BCG, McKinsey).

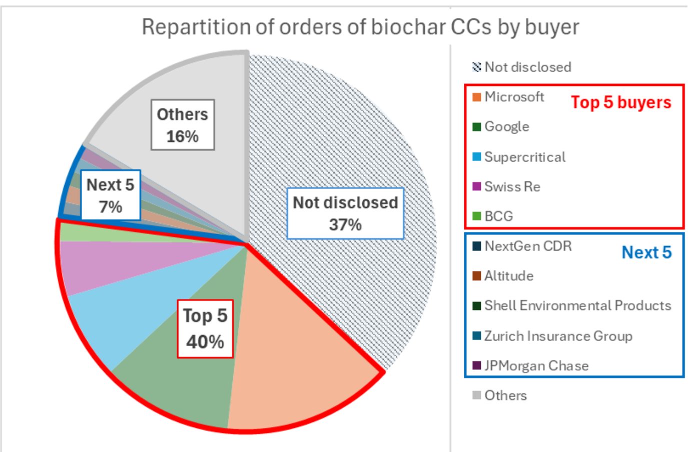

Figure 22: Repartition of the orders of biochar CCs per buyer
Source: CDR.fyi 02/05/2025

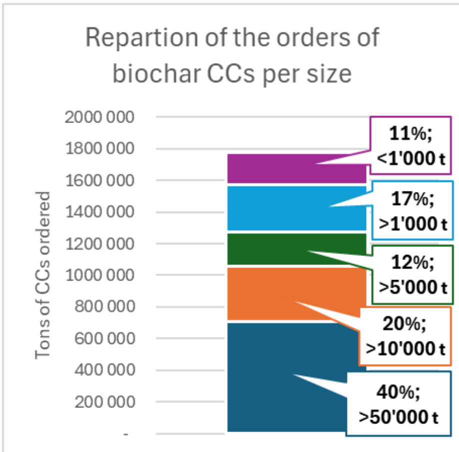

Figure 23: Repartition of orders per size
Source: CDR.fyi 02/05/2025

Given that the supply of CCs from durable CDRs is still very low, and that there are few projects, almost all of which are in the development phase, buyers tend to secure their carbon offsets in the form of **very large-scale offtake contracts: often >50,000 credits** – 40% of the CC orders (see Figure 23). From this angle, buyers of durable CDR can be seen as investors in their own right. This strategy entails risk-taking, which encourages these buyers/investors to bet on the **most exemplary and ambitious projects**, and those that can demonstrate **scalability potential**. It also means carrying out pre-investment due diligence to analyze projects and assess the risk of failing to meet carbon credit generation targets. Insurance is even beginning to emerge for biochar carbon credit offtake.

Other sectors likely to purchase biochar CCs / or finance a project against a share of the carbon credits generated could be:

- **Impact funds and DFIs** with sustainable development goals (SDGs). This type of buyer is more sensitive to storytelling and the project's environmental and social co-benefits.
- **Commodity traders** seeking to offset the carbon footprint of their suppliers (scope 3) and whose value chains generate agricultural residues such as cashew nutshells, cotton stems, coffee husk and cocoa pods (ECOM, ETG, OFI…). These players are already implementing carbon offset programs within their value chains (insetting), using other levers such as agroforestry. Biochar can be added as an additional lever to reinforce the program.
- Sectors whose carbon footprint is difficult to reduce (hard-to-abate sectors), such as **shipping and aviation**, thanks in particular to the fungibility of certain biochar standards with the CORSIA system.
- Potential biochar users with large carbon footprints, such as **fertilizer or building materials producers**. These players can finance biochar projects to secure their biochar supplies.

Given the complexity of the biochar CC market (highly technical subject, multiple project types and standards, etc.), buyers find it difficult to analyze the risk of each project on their own, and to compare them with one another. This is why intermediaries such as brokers and marketplaces are becoming increasingly important, acting as "filters" or "rating agencies" to guarantee the quality of projects and their suitability for each buyer's requirements.

7.3 Price evolution for biochar carbon credits

As explained in the section 6.4, prices for biochar CCs today range from $100 to $300. These prices are negotiated freely between buyer and seller for each contract and vary widely depending on the project and the quantity of credits to be sold. The factors influencing the price are as follows:

- Project type: Industrial projects are considered more reliable than artisan ones, and therefore have higher prices for their CCs, especially if the buyer does not value co-benefits.
- Rigorous monitoring: buyers of carbon credits fear that the project in which they have invested will be the subject of a scandal or a revision of the number of CCs generated due to poor carbon accounting methodology. A project with a rigorous and easily accessible monitoring system (dMRV) is at an advantage.
- Type of pyrolysis technology: Beyond the fact that the most advanced technologies emit less CH_4 from biochar production, and generate more credits, there is a "premium for innovation"

and modernity in pyrolysis reactors. Some standards do not allow the use of certain pyrolysis technologies, forcing operators to select one from their "positive list of technologies".

- Credibility of the standard: The carbon certification standard is the guarantor of all the elements mentioned above, the choice of standard plays an important role in the price of CCs.
- Narrative and co-benefits: The more positive the project's impacts and circular economy logic (use of biochar in short circuits), the more credits can be valorized.
- Geography: Countries with a large number of carbon projects are valued more highly. Credit buyers tend to choose projects located in the same country as their own.
- Type of purchase contract: One of the most important factors influencing price is whether the credit is purchased upfront, i.e. in offtake format, or issued. In this way, the buyer can obtain a better price if he pays in advance, but he also takes a risk that the project will not be completed.

Since the recent beginnings of the biochar carbon credit market, the average price has risen steadily and seems to be stabilizing between \$100 and \$150, as can be seen from the Puro biochar CC price tracking index, which does not track all biochar projects but remains a good indication (Figure 24). In March 2025, Puro reported an index of \$148 per biochar CC.

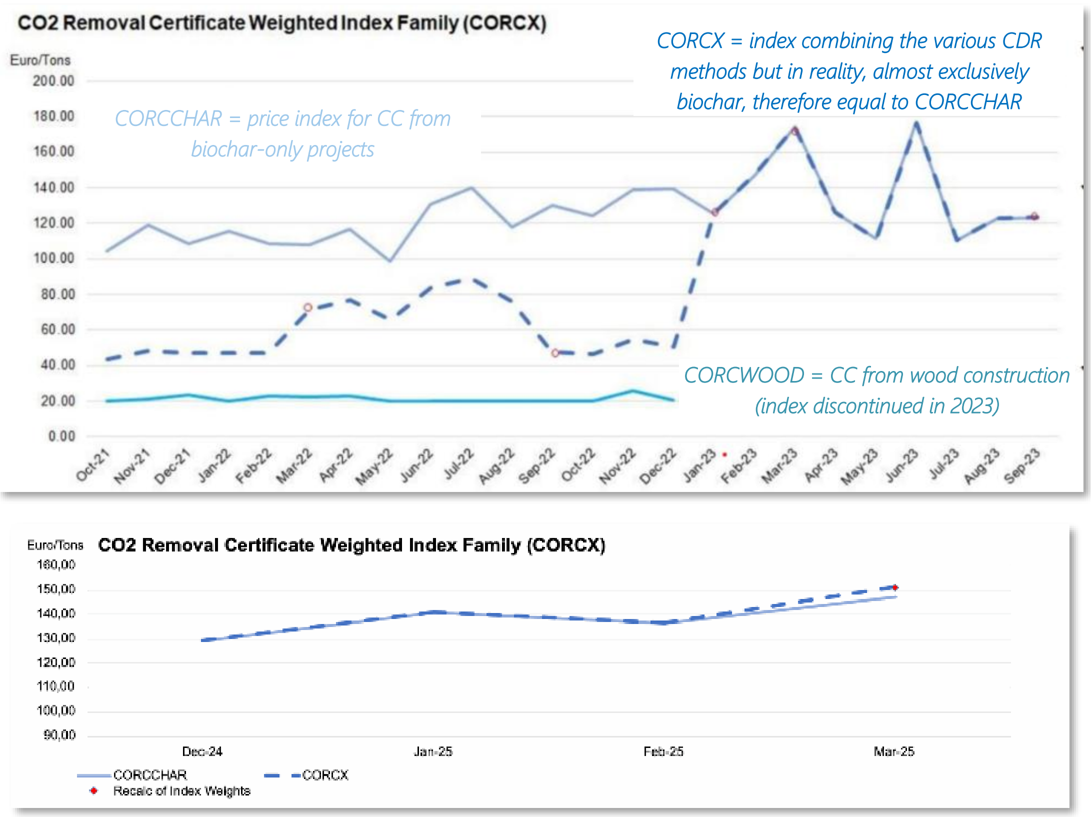

Figure 24: Price trend for Puro Standard biochar carbon credits since 2021

7.4 Potential risks and opportunities influencing price trends

The risks that could have a negative impact on the price of biochar CC are as follows:

❖ Reduced international pressure on companies to meet climate targets. As with the arrival in power of climate-skeptic governments (e.g. the USA).

❖ Media scandal/questioning of carbon accounting methods and carbon certification for certain biochar projects, tainting the entire sector. This was the case for REDD+ projects. This risk is heightened by the arrival on the market of many new biochar projects, driven by promoters attracted by the profitability opportunities offered by the price of CCs. This type of project could be less qualitative in terms of dMRV rigor, and lead to abuses that would discredit biochar projects.

❖ Questioning whether biochar credits should be considered as CDRs (*removals*) but rather as a method of avoided emissions (*avoidance*): according to Pirard (2024) (see Bibliography), if the biomass used comes from a waste (e.g. agricultural) that would have degraded in the open air without being transformed into biochar, then biochar should be classified as a method of avoided emissions rather than of CO_2removal. If this argument were to be accepted, it would call into question the attractiveness of biochar credits to customers.

Opportunities that would positively impact on the price of biochar CCs are:

➢ Loss of confidence in other project types and associated methodologies in the voluntary market has been the case over the past 2 years following scandals involving REDD+ projects.

➢ The mandatory application of airline compensation by phase 3 of the CORSIA mechanism (from 2027) may have a significant effect on demand for biochar CC: there is a strong chance that CDRs will be accepted, and some biochar standards have already applied for this, such as Puro or Verra for phase 2 (2024-2026). Such demand would overwhelm the limited supply of CDRs, driving prices upward (see Table 3).

Table 3 : Estimated demand for carbon credits generated by the different phases of the CORSIA mechanism. Sources: estimates based on aggregated forecasts from S&P, MSCI, Reuters

Etapes CORSIA	Période	Participation	Demande en M de CC	Offre	Offre / Demande	Prix
Phase 1	2021 - 2023	volontaire	10 M de CC	7 M	faible déficit	11 - 23
Phase 2	2024 - 2026	volontaire	100 M de CC	90 M	déficit	18 - 50
Phase 3	2027 - 2035	obligatoire	>500 M de CC	*variable*	fort déficit	25 - 90

➢ Integration of durable CDRs (and biochar in particular) into compliance markets thanks to the application of article 6.4 of the Paris Agreement[11]. Companies in certain countries (see *Puro.earth's CDR meta-map*) could comply with their regulations and offset their emissions by purchasing CCs from biochar projects. Other types of projects could also be approved under article 6.4. This change in the rules of the carbon markets could drastically alter the situation, making it difficult to estimate the real impact on biochar CC prices, even if we can assume that it would create more demand. According to expert opinion, the deadline for implementing article 6.4 would be around 2030. What's more, when it comes to buying credits for compliance (regulatory market), most buyers are not looking for differentiated projects, but simply the cheapest options.

The concentration of demand for biochar carbon credits among a few large buyers with a specific profile (such as GAFAM) blurs visibility of the real potential for growth in demand and price levels. Indeed, the volume of credits demanded and financed is greater than supply today, but this depends too heavily on a few leading buyers who can decide overnight to change their carbon offset strategy (the change of administration in the USA is an example of this risk). Many players also anticipate a

[11] Find out more in this document from The Nature Conservancy: Article 6 explainer

(slight) drop in biochar CC prices due to the fact that many projects are currently being financed/constructed, which will significantly increase supply in the near future.

On the other hand, certain events, such as the inclusion of biochar as a method of carbon offsetting in the regulatory market via article 6.4 of the Paris agreements, or the mandatory implementation of the CORSIA mechanism, will have a significant effect, boosting demand tenfold.

It is very difficult to predict price trends for biochar CCs in a historically volatile market with over-concentrated demand and hypothetical regulatory developments. The strategy of some biochar project developers is to try to lower their production costs as much as possible to achieve unit prices of around $100/CC, which would be a conservative estimate in the short term but is also subject to quality issues.

8. Challenges and key success points

For this section it is important to differentiate the cases of industrial and artisan biochar production:

For industrial projects

1. It is difficult to find sufficient quantities of biomass (>5,000 t/year), within a not too large radius of the biochar production unit (generally under 100km) and with practicable access routes (to lower the cost of the logistical scheme).

- ➔ Carry out in-depth upstream studies to identify the best biomass deposits (abundant, not widely scattered over the territory, concentrated at the level of processing units, easy to access, not or little valorized).
- ➔ Favor circular economy models, identifying value chains / regions where residues are available, not valorized and represent a waste to evacuate; and where farmers are facing climate resilience and fertility issues to put in place a system where farmers provide biomass and receive biochar to be applied in their plots.

2. Maintaining a constant "quality" (criteria analyzed by standards and evaluated by buyers) of biochar is a challenge, especially in a frequent situation where biomass varies according to suppliers and time of year.

- ➔ Sizing and choosing the right equipment, as well as the right equipment manufacturer (capable of supporting the project through design and installation) and technical support (from a skilled consultant, for example), is an important key to success.
- ➔ Include in the budget one or more employees trained to monitor production processes and capable of modifying equipment parameters to adapt to variations in biomass.

3. Markets for biochar are still emerging, demand is limited, and biochar prices vary significantly.

- ➔ Promote models based on multiple sources of revenue outside biochar (energy production electricity/heat, waste management = sanitation, by-products = bio-oils and syngas).
- ➔ Plan to invest significant resources (financial and HR) in the marketing of physical biochar
- ➔ Increase sales opportunities through diversification of markets / consumers.

4. As the sale of physical biochar does not enable production models to be profitable, the sale of carbon credits is still vital for biochar projects. However, the market for these carbon credits is highly volatile and difficult to control and anticipate.

- ➔ As with the marketing of physical biochar, significant resources must be allocated to invest in a carbon credit marketing strategy.
- ➔ Carefully analyze the advantages and disadvantages of each carbon certification (today there are only 2 major players, Puro and CSI, but new players are emerging in the near future) to choose the most appropriate one (credibility, market penetration, audit efficiency, eligibility for markets other than voluntary, reactivity of the standard team...).
- ➔ Optimize your LCA as much as possible, i.e. your biomass collection and pre-processing logistics, biochar production (most recent technology) and distribution logistics.
- ➔ Propose a convincing "storytelling" about the project's carbon credits (social and environmental benefits, circular economy, scientific rigor and traceability...).
- ➔ Have a varied prospecting strategy (seek out customers directly, go through a marketplace/broker/trader, take part in conferences and trade shows, etc.).

5. The sale and payment of carbon credits can take place a long time after biochar production (minimum 6 months, sometimes 2 years), creating a significant time lag between costs and revenues in the financial model, and therefore a significant working capital requirement.

- ➔ Don't underestimate the need for working capital and ensure that your financial reserves allow you to get through the first 2 years without income.
- ➔ Be very conservative in the design of financial models, given the high level of uncertainty in the selling prices of physical biochar and CCs.
- ➔ Imagine innovative financing models: pre-financing the project by a large CC buyer in the form of an offtake contract, using carbon credits as a currency to raise debt or equity, etc.

For artisan projects

Advantages of this model:

- ✓ Equipment is very inexpensive and easy to produce in any country, resulting in very low investment requirements.
- ✓ The cost structure is limited and the potential for scalability (multiplication of artisans and therefore of CCs) is very high, generating rapid cash flow.
- ✓ The model relies solely on the sale of CCs, which eliminates the challenges associated with marketing physical biochar.
- ✓ This type of model does not require large, geographically concentrated biomass deposits like the industrial models, but instead valorizes producers' crop residues.
- ✓ This type of model emphasizes the sharing of the value of CCs with artisans, and therefore a very significant social impact in areas where income sources are scarce for farmers. This may attract certain "impact-oriented" financiers/buyers of CCs.

Disadvantages of this model:

- The rigor of carbon certification methodologies for artisan projects is being criticized by some players, leaving the door open to possible abuses and scandals that could damage the image of artisan carbon credits and biochar in general.
- Some CC buyers consider these projects less credible than industrial projects (because biochar production is less controlled, with pyrolysis technologies emitting more GHGs), thus lowering the estimated price of artisan CCs compared with those from industrial projects.
- The quality of the biochars produced by artisans is less controlled and may entail risks of soil pollution if pyrolysis processes are not controlled. Although this risk is often pointed out, it is unlikely since the biomass used must be "clean" (no sewage sludge, urban waste, etc.) and the pyrolysis temperature in Kon-Tiki furnaces reaches 600°C.

The keys to success are:

- Invest in a network of technical advisors who train and support artisans in their biochar production activities.
- Prefer pyrolysis technologies that, while low-tech, still ensure acceptable biochar quality and the lowest possible emissions.
- Centralize pyrolysis units as much as possible for better supervision.
- Select and implement the most robust dMRV system possible.

Promote a system of "biomass purchase" from producers, with a price based on the sale of carbon credits, rather than sharing the value of the credits. This will provide greater security and simplicity of payment for artisans.

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Appendix 1: Non-exhaustive list of biochar actors

#	EUROPE (123)	Zone	Country	Certification
1	3R-BioPhosphate	EU	Hungary	
2	A Healthier Earth	EU	UK	
3	Abfallwirtschaft und Stadtreinigung Freiburg GmbH	EU	Germany	EBC sink certificate
4	AFE Ferrara	EU	Italy	
5	Agri Energy Vraa	EU	Denmark	
6	agriCARBON (Microchar)	EU	Czech Republic	
7	Amata green	EU	Spain	
8	Arigna Fuels	EU	Ireland	
9	Athena	EU	France	
10	Auen care service APD	EU	Switzerland	
11	Auen Pflegedienst AG	EU	Switzerland	
12	AWN Abfallwirtschaftsgesellschaft des Neckar-Odenwald-Kreises mbH	EU	Germany	
13	BASNA d.o.o.	EU	Serbia	Puro.earth
14	Bcircle	EU	Portugal	
15	BIATEX GmbH	EU	Germany	
16	BioCarbo GmbH	EU	Italy	
17	Biochar GmbH & Co. KG	EU	Germany	
18	Biochar Latium	EU	Italy	
19	Biochar Rendsburg GmbH	EU	Germany	
20	Bioenergie Ahlintel GmbH & Co. KG	EU	Germany	
21	Bioenergie Frauenfeld AG	EU	Switzerland	Carbonfuture
22	Biokolprodukter	EU	Sweden	
23	bionero GmbH	EU	Germany	Carbonfuture, EBC si
24	Bionika AG	EU	Switzerland	Carbonfuture
25	BLOCK Bio Innovationen GmbH & Co. KG	EU	Germany	EBC sink certificate
26	Bordet	EU	France	Puro.earth
27	Brodie Biomass	EU	UK	
28	Bussme Biochar	EU	Sweden	Puro.earth
29	Carbex GmbH	EU	Germany	
30	Carbo Culture	EU	Finland	Puro.earth
31	Carbofex (SOLER)	EU	Finland	Puro.earth
32	CARBOLIVA	EU	Spain	EBC sink certificate
33	Carbon Collectors	EU	Germany	
34	Carbon Cycle GmbH & Co. KG	EU	Germany	Puro.earth
35	Carbon Emergente	EU	Spain	
36	Carbon Hill	EU	UK	Puro.earth
37	carbonauten GmbH	EU	Germany	Puro.earth
38	CarbonCentric	EU	France	
39	Carbonex	EU	France	Carbonfuture
40	Carbon Gold	EU	UK	
41	Carbonis GmbH & Co. KG	EU	Germany	
42	Carbons Finland Oy	EU	Finland	
43	CarboVerte GmbH	EU	Germany	
44	Carbuna AG	EU	Germany	
45	CharLine GmbH	EU	Austria	Carbonfuture, Puro.e
46	Christoph Fischer GmbH	EU	Germany	
47	Circular Carbon GmbH	EU	Germany	
48	Cycles Verts	EU	Belgium	EBC sink certificate
49	Dad's Farm Biochar	EU	Scotland	
50	Demio Normandie	EU	France	
51	Ecoera	EU	Sweden	Puro.earth
52	EGoS GmbH	EU	Germany	

#	EUROPE (123)	Zone	Country	Certification
53	Eigenbetrieb für kommunale Aufgaben und Dienstleistungen (EAD)	EU	Germany	
54	Ekovilla	EU	Sweden	
55	EM Technologie Zentrum Süd GmbH	EU	Germany	
56	EnergieWerk	EU	Austria	Carbonfuture
57	Energy Ocean GmbH	EU	Switzerland	
58	Envigas	EU	Suede	
59	eoc energy ocean GmbH	EU	Switzerland	
60	Euthenia Energy	EU	Spain	Puro.earth
61	Explocom (+Gekka)	EU	Romania	Puro.earth
62	F. Ehrich GmbH & Co. KG	EU	Germany	
63	FETZER Rohstoffe + Recycling GmbH	EU	Germany	Carbonfuture, EBC si
64	Grassroots Biochar AB	EU	Sweden	
65	Green Carbon GmbH	EU	Germany	
66	Greene	EU	Spain	
67	GRK	EU	Finland	
68	Grossenbacher Grüngut	EU	Switzerland	
69	Bordet Group	EU	France	
70	Hjelmsäters Egendom	EU	Sweden	Puro.earth
71	Holtzenergie Gut	EU	Switzerland	
72	INEGA AG	EU	Switzerland	
73	Inkoh	EU	Switzerland	
74	Innsbrucker IKB	EU	Austria	
75	IWB Industrielle Werke Basel	EU	Switzerland	
76	Klimafarmer	EU	Denmark	Carbonfuture
77	KohleHelden GmbH & Co. KG	EU	Germany	Carbonfuture, EBC si
78	Kompostbau Wagner	EU	Germany	
79	KRIŽEVCI-PRODUKT	EU	Croatia	
80	KWS Ökokraft	EU	Austria	
81	LignoCarbon Schweiz AG	EU	Switzerland	
82	Lucrat GmbH	EU	Germany	Puro.earth
83	Macrocarbon	EU	Spain (canaries)	
84	Made of Air	EU	Germany	
85	Mash Makes	EU	Denmark	EBC sink certificate
86	Moola - Fetzer Rohstoffe + Recycling	EU	Germany	
87	Nawaro	EU	Austria	
88	Nevel AB	EU	Sweden	
89	Nordgau	EU	Germany	Puro.earth
90	NORDGAU CARBON GmbH & Co. KG	EU	Germany	Puro.earth
91	Nordvästra Skånes Renhållnings AB (NSR)	EU	Sweden	
92	Novaris Energy Ltd.	EU	Turkey	Other
93	Novocarbo GmbH	EU	Germany	Carbonfuture, Puro.e
94	OBIO	EU	Norway	Puro.earth
95	Ökologische Klärschlammtrocknung Offenhausen	EU	Denmark	
96	Oplandske Bioenergi AS	EU	Norway	Puro.earth
97	Origin Biochar	EU	Ireland	
98	Oxford Charcoal Biochar Ltd	EU	UK	Other
99	Ozen	EU	Poland	
100	Premier Forest	EU	UK	Puro.earth
101	ProE Bioenergie GmbH	EU	Germany	
102	PUHI	EU	Finland	
103	Restord	EU	UK	
104	SCS GmbH	EU	Germany	
105	SIOTUU GmbH	EU	Austria	
106	Skanefro	EU	Sweden	Puro.earth
107	Skanska	EU	Sweden	
108	Skelleftea Carbon AB/ Envigas AB	EU	Sweden	
109	SOLER (Carbon Centric)	EU	France	
110	Sonnenerde	EU	Austria	Carbonfuture, Puro.e

#	EUROPE (123)	Zone	Country	Certification
111	Stiesdal	EU	Denmark	
112	Stiesdal SkyClean A/S	EU		
113	Sustainable Century	EU	Germany	
114	Swiss Biochar Sàrl	EU	Switzerland	
115	Telge Återvinning AB	EU	Sweden	
116	Terra fertilis	EU	France	Puro.earth
117	Terrawatt	EU	Spain	Riverse
118	Timo Ferdinand und Andreas Scherer HerbaCarbo GbR	EU	Germany	
119	TORRCoal	EU	Belgium	
120	Unyte Biochar	EU	UK	Riverse
121	Verora	EU	Switzerland	Carbonfuture
122	Vow Green Metals	EU	Norway	
123	Woodtek Biochar	EU	Scotland	Puro.earth

#	NORTH AMERICA (84)	Zone	Country	Certification
1	Again & Again Farmstead	USA	New Hampshire	
2	AgraMarketing Solutions	USA	California	
3	All Power Labs	USA	California	
4	American BioCarbon	USA	Louisiana	Puro.earth
5	American Biochar Company	USA	Michigan	
6	Applied Carbon	USA	Texas	
7	Aries Clean Energy	USA	Tennessee	
8	ARTi	USA	Iowa	
9	Bartlett Tree Experts	USA	North Carolina	
10	BC Biocarbon	Canada	Brit Columbia	
11	Bella biochar corporation	Canada		Puro.earth
12	Bio365	USA	California	
13	Biochar Solutions	USA	Colorado	
14	Biochar Supreme	USA	Washington	
15	BiocharCentral	USA	Georgia	
16	BiocharNow	USA	Colorado	
17	Biological Carbon LLC	USA	Oregon	
18	BioSphere Carbon Group	USA	Washington	
19	Black Bison Organics LLC	USA	North Dakota	
20	Blackwood Solutions	USA	Indiana	
21	Blue Sky Biochar	USA	California	
22	Blusky Carbon	USA	Arkansas	
23	Brimac Char	USA	Texas	
24	Canadian Agrichar	Canada	Brit Columbia	
25	Carbo Culture	USA	California	
26	Carbonity (SUEZ, AIREX)	Canada	Quebec	
27	Char Technologies	Canada	Ontario	
28	Chargrow	USA	North Carolina	
29	CharTerra	Canada	Alberta	
30	Circularity2	USA		
31	Clean Main Carbon	USA	Maine	
32	Corigin	USA	California	Puro.earth
33	Davey Tree Expert Company	USA		
34	Douglas County Forest Products	USA	Oregon	Puro.earth
35	Earthcare	USA	Indiana	Puro.earth
36	Ecochar	USA	Indiana	
37	Ecotone Inc.	USA	Maryland	
38	enviraPAC Monticello LLC	USA	Arizona	
39	Freres biochar	USA	Colorado	Puro.earth
40	Genesis Biochar	USA	Montana	

#	NORTH AMERICA (84)	Zone	Country	Certification
41	Glanris LLC	USA	Tennessee	Puro.earth
42	GoBiochar	USA	Utah	
43	Green State Biochar	USA	Vermont	
44	GreenQuest	USA	Wisconsin	
45	Groundup Soil	USA	Oregon	
46	High Plains Biochar	USA	Wyoming	
47	Joanna	USA		Puro.earth
48	Kellogg Garden Products	USA	California	
49	LESCO/SiteOne	USA		
50	Lewis Bamboo	USA	Alabama	
51	Locoal	USA		
52	Metzler Biochar	USA	Pennsylvania	
53	Miller Soils LLC	USA	Colorado	
54	Mirimichi Green	USA		
55	Missouri Organic Recycling	USA	Missouri	
56	New England Biochar	USA	Massachussets	
57	NextChar	USA	Massachussets	
58	Olympic Biochar	USA	Washington	
59	Oregon Biochar Solutions	USA	Oregon	
60	Organic Mechanics	USA	Pennsylvania	
61	Organilock	USA	Kentucky	
62	Pacific Biochar	USA	California	Puro.earth
63	Phoenix Energy	USA	California	
64	Purelife Carbon	Canada	Alberta	
65	Qualterra	USA	Washington	
66	Real Montana Charcoal	USA	Montana	
67	ReGenerate Livermore Falls	USA		Puro.earth
68	Restoration Bioproducts, LLC	USA	Virginia	
69	Restoration Fuels	USA	Oregon	Puro.earth
70	Rexius Forest Byproducts Inc.	USA	Oregon	
71	Seneca Farms Biochar	USA	New York	
72	Sequest Wood Waste Solutions	USA	Kansas	
73	Sitos Group	USA	California	
74	Soil Reef LLC	USA	Pennsylvania	
75	Standard Biocarbon LLC	USA	Maine	
76	Stormwater Biochar.com	USA	Oregon	
77	Symsoil	USA	California	
78	TerraChar	USA	Missouri	
79	The Andersons	USA	Ohio	
80	Titan Carbon Smart Technologies	Canada	Saskatchewan	
81	Vermont Biochar	USA	Vermont	
82	Vermont Natural Ag Products	USA	Vermont	
83	V-Grid Energy Systems	USA	California	Puro.earth
84	Wakefield Biochar	USA	Missouri	Puro.earth

#	SOUTH AMERICA (9)	Zone	Country	Certification
1	Aperam	Amsud	Brazil	Puro.earth
2	Bio Restorative Ideas	Amsud	Puerto Rico	
3	Biodiversal (w/ planboo)	Amsud	Colombia	
4	Cotierra	Amsud	Colombia	Artisan C-sink
5	Exomad Green	Amsud	Bolivia	Puro.earth
6	General biochar systems	Amsud	Mexico	Puro.earth
7	NetZero	Amsud	Brazil	Puro.earth
8	Tectocarbon	Amsud	Ecuador	
9	The Next 150	Amsud	Mexico	

#	OCEANIA (5)	Zone	Country	Certification
1	Echo2 = Rainbow bee eater	Oceania	Australia	Puro.earth
2	Fasera	Oceania	Australia	Puro.earth
3	Jeffries Group	Oceania	Australia	Puro.earth
4	Kangaroo Island = Biocare projects	Oceania	Australia	
5	Pyrocal	Oceania	Australia	Puro.earth

#	ASIA (22)	Zone	Country	Certification
1	Alcom Carbon Markets	Asia	Philippines	Puro.earth
2	Atmosfair	Asia	India	Artisan C-sink
3	Bamboo King Vina	Asia	Vietnam	Verra - under validat
4	Biochar Life	Asia	Thailand	Artisan C-sink
5	Biochar Life	Asia	Indonesia	Artisan C-sink
6	Bukit Selar	Asia	Malaysia	
7	Carboneers	Asia	India	Artisan C-sink
8	Circonomy	Asia	India	Artisan C-sink
9	EKI Energy	Asia	India	Verra - under validat
10	Formosan Salamander	Asia	Taiwan	
11	Halmahera / Dewacoco	Asia	Indonesia	Verra - under validat
12	HUSK	Asia	Cambodia	EBC C-sink
13	MASH Makes	Asia	India	EBC C-sink
14	Planboo	Asia	Sri lanka	Artisan C-sink TRANS
15	Reclimate	Asia	Malaysia	
16	SRCNatura Sure	Asia	India	Verra
17	Takachar	Asia	India	
18	Varaha	Asia	India	Artisan C-sink
19	Varhad	Asia	India	
20	WasteX	Asia	Indonesia	
21	WeAct	Asia	India	Verra
22	Wongphai (w/ planboo)	Asia	Thailand	Artisan C-sink

#	AFRICA (24)	Zone	Country	Certification
1	Airsmat	Africa	Nigeria	Artisan C-sink
2	Biochar Life	Africa	Kenya	Artisan C-sink
3	Biochar Life	Africa	Malawi	Artisan C-sink
4	Biochar Life	Africa	Tanzania	
5	Bio-logical	Africa	Kenya	
6	Biosorra	Africa	Kenya	
7	CarbonConnect	Africa	Nigeria	Artisan C-sink
8	CarbonConnect	Africa	Zimbabwe	Artisan C-sink TRANS
9	Carboneers	Africa	Ghana	
10	Dark Earth Carbon	Africa	Tanzania	Global C-sink
11	Farm gai kaisa (planboo)	Africa	Namibia	Puro.earth
12	INTERHOLCO (Tropi'coal)	Africa	GROUND FLC	EBC C-sink
13	Kohero Farming CC	Africa	Namibia	Artisan C-sink
14	Mirae Green Chemicals	Africa	Tanzania	
15	NetZero	Africa	Cameroon	Puro.earth
16	Omiti biochar	Africa	Namibia	Artisan C-sink
17	Namibia Savannah Restoration (planboo)	Africa	Namibia	Artisan C-sink
18	PyroCCS	Africa	Namibia	EBC C-sink TRANSITIC
19	Pyrogen	Africa	Kenya	
20	RecyCoal	Africa	Rwanda	Artisan C-sink
21	Tachibana (planboo)	Africa	Ghana	Artisan C-sink
22	Truecoco	Africa	Ghana	
23	Sinkit	Africa	Cameroon	Artisan C-sink
24	WeAct	Africa	Madagascar	Verra - under validat