How to establish a market for CCS with biochar in Denmark

February 2024

Preface

In this report, the CIP Foundation presents an action plan for market-driven production of biochar in Denmark that can help agriculture achieve its carbon reduction targets, and Denmark in achieving its national climate targets.

The point of departure is to exploit the technological opportunities for good climate solutions with huge potentials and possible co-benefits.

The plan has been prepared to promote the biochar market and increase interest from investors and other value chain participants, thus establishing a foundation for market-driven negative emissions based on feedstock.

Food production is today one of the largest sources of global anthropogenic climate change. In Denmark, agriculture accounts for almost one-quarter of Danish emissions, primarily through natural biological processes*. Danish agriculture and food production is trapped between requirements for reducing their climate footprint and investing more in the green transition, and consistent needs for increasing food production and exports.

With respect to the climate, the world needs to produce more climate-efficient food products on smaller areas. Development and use of new solutions can make Danish agriculture and food production a climate role model, showing how lower emissions can be compatible with continued growth and exports.

* Hvad er CO2? (lf.dk)

The Danish 2021 agreement on a green transition of the agricultural sector requires that the majority of carbon reductions in agriculture must be realised through new technologies, and not through decreasing total agricultural production. With the agreement, the Danish Parliament decided that pyrolysis and biochar production are to be key instruments in reducing emissions of green house gases from agriculture, with a potential of up to 2 million tonnes of carbon storage per year by 2030.

Pyrolysis is a flexible technology that can be adapted to changes in agriculture and can generate added value for a large number of crop residues and other agricultural residues. If carbon storage is sold as a service, i.e. through climate certificates, the technology can potentially be rolled out on market terms, thereby releasing resources for further investment in the green transition. With clear framework conditions, biochar could play a crucial role in this transition. Biochar has the potential to become the same benefit for agriculture as wind power has been for the energy sector.

Biochar is a climate measure and a stable type of carbon storage, similar to DACCS and BECCS. This is not about competing measures, but rather measures which supplement each other. Agriculture can benefit from a measure that offers long-term storage of the CO_2 absorbed by plants. Industry and the energy sector need measures which can capture carbon from production and store it.

Sometimes, carbon storage is criticised with the suggestion that it would be better to invest in real carbon reductions rather than storage technologies. It is true that substantial reductions must be made in the coming years, but one strategy does not rule out the other. If we are to meet the targets in the Paris Agreement, according to the UN Intergovernmental Panel on Climate Change (IPCC) we need to use negative emissions technologies. We must not only reduce carbon emissions; we must also take existing greenhouse gases out of the atmosphere.

The CIP Foundation's action plan for market-driven production of biochar should be seen in context with our vision for sustainable agriculture based on innovation and the use of new technologies. There is also the aim that Denmark should continue to be a front-runner and maintain its strong position on global markets.

The report can be read as a whole, or it can be used as a reference for specific interests. Some of the points appear several times – this is because they are important!

In 2024, the CIP Foundation will follow up on this report, with focus on the export opportunities in carbon storage using biochar.

We hope that the report is read in the light of the intention for which it was written.

Enjoy the read!

Anne Arhnung
Board Member at the CIP Foundation

Charlotte Jepsen
Managing Partner of the CIP Foundation

Summary

Biochar has the potential to play a major role in the transition of Danish agriculture. It is a mature technology that can store carbon effectively for many centuries. The socio-economic abatement costs of carbon sequestration with biochar are competitive amongst other climate measures.

The technology behind biochar can be rolled out on market terms, thereby releasing resources for further investment in the green transition. Market-driven CO_2 reductions in agriculture require that biochar sequestration be paid for through carbon credits, for example. An initial subsidy scheme can relieve some of the current uncertainty in the business case today. The absence of direct regulation around biochar is a source of uncertainty and is an obstacle to market development.

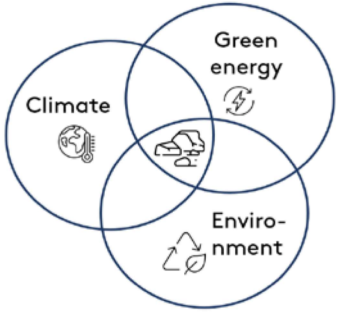
NEW CLIMATE MEASURE BASED ON WELL ESTABLISHED TECHNOLOGY

Biochar as a recognised and effective climate measure is relatively new both in Denmark and abroad. On the other hand, biochar production exploits nature's own CCS, and we have been making biochar for many years.

We all know that plants absorb CO_2 from the atmosphere through nature's own photosynthesis process. When you heat plant residues, for example grass, straw or wood, in a pyrolytic oven to around 500-600 °C in an oxygen-limited environment, the carbon from the biomass is distributed fairly evenly between gasses (green energy) and a stable residual product (biochar), which can store the carbon stably for a very long time.

Making biochar from biomass residues, in this way capturing and removing CO_2 from the atmosphere, and then storing it, is a negative emissions technology.

Figure A: *Biochar is beneficial on several parameters*



Source: The CIP Foundation's own graphic

TECHNOLOGY WITH THREE CLEAR BENEFITS

Pyrolysis of biomass residues can benefit in three important areas simultaneously:
The pyrolysis process generates green energy in the form of pyrolysis gas and bio-oils that can be used as green fuels, and the process also generates surplus heat that can be used for district heating or to heat installations or buildings. This type of green energy does not depend on the wind blowing or the sun shining, and is therefore a good supplement in future energy systems.
The climate benefits because biomass residues are used in a pyrolysis plant instead of, for example being spread on a field to decay. Processing prevents emissions of powerful greenhouse gasses from the biomass residues, and the green energy from this process can be used to displace other climate-impacting alternatives. Finally, it has been documented that biochar in itself can serve as a CCS technology. This is new.

"Biochar has a number of positive side-effects when it used on agricultural land. The soil becomes better at retaining water and this benefits crops, and it is possible to recirculate important nutrients such as phosphorus and potassium to nutrient-poor areas."
- The CIP Foundation

On the other hand, there is nothing new about the possible environmental benefits of using biochar in the soil. In fact, this is why biochar has been made for many years. In other countries, biochar has been used as a natural means of enriching the soil for many years. People in the Amazon region started using biochar to enrich the soil more than 2,500 years ago. The soil in the rain forest is often sandy and infertile below the first, thin soil layer. Adding biochar made it possible to transform the soil and make it richer and more fertile to cultivate food.

In Europe and a number of other countries, biochar is today used especially to improve the soil on farms and as a fertiliser for gardens and parks.

Biochar makes the soil more resistant to drought, it reduces emissions of potent climate gasses from the soil, and can also reduce nitrogen leaching from the soil to water bodies.

Biochar can also be used in other places, for example as a feed supplement, in building materials and insulation, in soil remediation and filtration, or even in health products.

EFFECTIVE CARBON STORAGE AND ADDITIONAL CLIMATE IMPACTS

Even though the biochar is used as fertiliser, for example, it still stores the carbon stably and for a long time.

80 % of the carbon in biochar will still be there after 100 years and...

75 % will be there after 1,000

"There is scientific consensus that biochar is a reliable mitigation measure against climate change with long-term sequestration effects."
- The CIP Foundation

After only a few years, biochar stores more carbon net compared with the alternative of spreading residue straw or biogas fibres on fields.

"Besides the direct carbon storage, which removes CO_2 from the atmosphere, there are further positive climate impacts in the form of emissions avoided and fuel displacement."
- The CIP Foundation

The climate impacts of Danish-produced biochar are encouraging. In general, one tonne of dry matter of biomass residues can

1 tonne of biochar ~ 2 tonnes of stored carbon

be converted to a minimum of one tonne of climate benefits. Straw and residual fibres from biogas have the largest total climate impacts long-term, while processing sewage sludge into biochar, for example, has more short-term positive climate impacts in the form of emissions prevented.

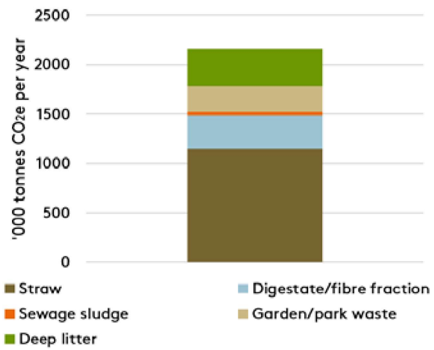
ENOUGH BIOMASS RESIDUALS TO MEET POLITICAL OBJECTIVES

Biochar is the last phase in a circular use of biomass, and it is based on residues with no appreciable alternative use. These residues include straw and other crop residues, residual biogas fibres, and sewage sludge, and can have added commercial value if it is used in the pyrolysis process and converted to green energy and biochar that can store CO_2.

"....and there are enough biomass residues to achieve the goal in the political agreement on a green transition of the agricultural sector to store 2 million tonnes of CO_2e annually."
- The CIP Foundation

Straw residues, residual fibres from biogas production and deep litter are particularly important in production of biochar because

***Figure B:** Available biomass residues can support the storage of 2 million tonnes carbon*



Source: NIRAS (2023)

they contain relatively high amounts of carbon. The good news is that there are enough biomass residues to achieve the goal in the political agreement on a green transition of the agricultural sector to store 2 million tonnes of CO_2e annually. And there is great potential for more biomass residues from Danish agriculture, with up to 10 million tonnes of bioresources in 2030, see Det Nationale Bioøkonomipanel (2022). Primarily more residual straw and hay, which are very suitable for making biochar.

Biochar is also a good opportunity to reuse phosphorus from the biomass and redistribute it, thereby avoiding imports of phosphorus, which is otherwise a scarce resource. In practice, phosphorus caps for agricultural land put a limit on the amount of biochar that can be spread on fields.

PAYMENT FOR CARBON STORAGE CAN ENABLE PYROLYSIS TECHNOLOGY ON MARKET TERMS

Building pyrolysis plants requires major initial investments, and this means that the regulatory framework and future long-term revenue flows must be clear. There must be clear agreements between parties for biomass residues as input and biochar as output, and there must be payment for the costs of CO_2 storage.

"The costs of CCS using biochar can be covered through climate credits, CCS subsidies for a period, or through a higher willingness to pay from consumers for the products made within the value chain."
- The CIP Foundation

Analyses of the value chain and the potential revenue flows show that the technology behind biochar could be rolled out on market terms, thereby releasing further resources for investment in green transition.

".. pyrolysis and biochar are at a technological stage with potential for deployment on market terms and with contributions to CCS in the agricultural sector, where there are no other alternatives at this scale."
- The CIP Foundation

Commercialisation of carbon storage with biochar requires collaboration across sectors and stakeholders that do not necessarily work together normally, and it requires that everyone involved profits from participating in the value chain.

In simple terms, the value chain will consist of 1) a supplier of biomass (e.g. agriculture or biogas plants), 2) a pyrolysis plant, 3) receivers of biochar (e.g. agriculture) 4) receivers of energy products (e.g. shipping companies) and 5) receivers of surplus heat from the pyrolysis plant (e.g. a heating plant).

WHAT AFFECTS PROFITABILITY?

The business case depends on the biomass used, the need for pre-processing, the energy and carbon content in the biomass, and the sales prices of energy in the form of heat and green petroleum products. Some biomass residues are almost free, such as residual fibres from biogas, while other biomass costs money, such as straw residues. Moreover, there is payment for receiving some residues, such as sewage sludge. The different types of biomass also differ according to the required amount of dehydration and separation prior to the pyrolysis treatment.

Profitability is increased by symbioses and combining locations, i.e. if the pyrolysis plant is located close to an input supplier. This could be a biogas plant, a wastewater treatment plant, or close to an output receiver, for example an energy utility, or close to infrastructure such as the district heating grid.

"If the value chain is to be financially sustainable, agriculture has to benefit from supplying feedstock and subsequently using the biochar on fields."
- The CIP Foundation

If biochar production and use in agriculture is to be profitable, there must be revenues for carbon storage in biochar which, together with the revenues from energy, can reward both the farm supplying feedstock, the pyrolysis plant producing biochar, and the farm receiving biochar and storing it.

In other words, someone has to pay for the biochar's positive impact on the climate!

The CIP Foundation has examined the profitability of CCS with biochar for the whole value chain. The conclusion is that, today, producing biochar from residual fibres from biogas is profitable in a simple set-up where pyrolysis gas is also produced. It is also profitable with biochar made from residual straw, provided that bio-oil is also produced. However, the business cases are dependent on co-financing of around DKK 400-700 per tonne for carbon storage.

Biochar from sewage sludge will also be profitable if the willingness of to pay for the processing of the sludge from the waste water plants gets slightly higher than the current payment to farmers for directly applying the sludge to their fields

CLIMATE CREDITS CAN CO-FINANCE CARBON STORAGE IN BIOCHAR

A carbon removal certificate is proof that one tonne of CO_2 has been removed from the atmosphere. When a certificate is then traded, it is called a climate credit.

There are good prospects for co-financing carbon storage in biochar through the growing global market for climate credits. This is because the technology supplies stable and long-term storage which cannot be reversed, and as it constitutes a readily communicated solution with several co-benefits.
The market for climate credits is in rapid development, driven by increasing demand for products with a lower climate footprint, and by companies with ambitious climate targets (e.g. net-zero emissions), that cannot necessarily reduce all emissions among themselves and their closest cooperation partners. Climate credits can be used as set-off in companies' climate accounts.

"Willingness to pay for climate credits primarily depends on the duration of the climate impact, the documentation, and certainty of the project."
- The CIP Foundation

A climate credit based on CCS with biochar costs around EUR 130 per tonne CO_2e. In the summer of 2023, the first climate credits based on Danish biochar were sold by SkyClean for EUR 160 per tonne CO_2e.

NEED FOR A STANDARDISED FRAMEWORK

The market for climate credits, including biochar credits, can be strengthened by establishing a uniform, standardised certification framework with clear guidelines for how climate impacts are calculated, used and communicated, and with clear verification from an independent third party. A fixed system for Monitoring, Reporting and Verification (MRV) is also required.
There are currently several standards globally on the voluntary market for climate credits. Even though they also have MRV systems, it can be difficult to navigate between the various standards. The EU is working on a standardised certification framework for carbon removal, and this is expected to be in place around 2028. This framework could become the norm for future carbon removal certification.

"A European standard for certification of carbon removal is on the way, and it could strengthen the market for purchases and sales of carbon removal certificates."
- The CIP Foundation

If, in the current negotiations, the EU can classify biochar as a climate measure with long-term and stable storage effects similar to other CO_2 storage technologies, such as DACCS and BECCS, this will give an important signal to the market.

CLEAR SIGNALS FROM INTERNATIONAL REGULATION

In 2018, the UN Intergovernmental Panel on Climate Change (IPCC) decided to recognise biochar as a Net Zero Emissions technology, and the panel has subsequently estimated a global reduction potential of 2.6 bn. tonnes CO_2e annually. In other words, there is a need for a broad range of CCS technologies, if we are to limit the rise of global temperatures. A need to both capture emissions from hard-to-abate industries, but also to capture previous CO_2 emissions from the atmosphere.

In 2022, the EU allowed biochar based on plant residues to be used in the EU as fertiliser for the first time, and later also biochar based on livestock manure via the revised Fertilising Products Regulation. Now biochar fertilisers may be sold within the EU if they are CE labelled and meet certain content requirements.

BIOCHAR IS ALMOST NON-EXISTENT IN DANISH REGULATION

In the summer of 2023, biochar made from agricultural residues was incorporated as a fertiliser product in Danish regulations for the first time. But only in regulations around how to use it, not a general permission to spread biochar on fields.

Broadly speaking, is the use of biochar based on agricultural residues not legally allowed in Denmark. A special environmental permit is required. More specifically, a section 19 approval ("§19 tilladelse") from the municipality. The permit is temporary and only applies for specific fields and specific amounts of biochar. This type of permit is used when there is no other regulation. It is impossible to base market deployment on this.

Regulations on biochar in Denmark have to be derived indirectly through other regulations. Because of that, paradoxically, Danish regulation allows biochar based on waste such as sewage sludge to be spread on fields. This is one of the feedstock types that might contain the highest amount of substances of concern. Therefore, only some biochar can currently be used in Denmark.

Paradox: biochar based on waste is allowed in Denmark, while biochar based on cleaner feedstock such as straw residues or grass requires a special environmental permit.

NEED FOR CLEAR FRAMEWORK CONDITIONS

The absence of direct regulation of biochar is a source of uncertainty and an obstacle to market development.

The same applies for rules on locating pyrolysis plants, as these often require time-consuming changes to local development plans, etc. In this context, the experiences from the construction of the biogas market serves as an example to be studied, and pyrolysis plants should be allowed to be sited in rural zones as well.

Major investment decisions on market deployment are unlikely to be made, when permitting and local approvals are associated with much uncertainty and with the risk of local variations.

"There is a need for clear framework conditions and particularly for a clear legal basis on the use of biochar on Danish fields, provided compliance with the limit values for the biochar's content."
- The CIP Foundation

As biochar can be produced from different types of feedstock residues, legal permission to use biochar on Danish fields should be independent of the type of biomass used in production. Instead, there should be regulation on the final content of the biochar. This will ensure that regulation is simple and unambiguous.

Socio-economic costs of storing one tonne of CO_2e:

Biochar from straw	DKK 250
Biochar from biogas fibres	DKK 700
BECCS	DKK 1,450
DACCS	DKK 1,500

If potential environmental impacts and income from climate credits are also taken into account, biochar has a socio-economic gain, while BECCS remains a cost.

Source: EA Energy analyses (2024)

RISK OF NEGATIVE IMPACTS CAN BE PREVENTED

Since biochar is new to agriculture, extra effort should be put into preventing potential adverse environmental and sustainability impacts. For example, this could be when setting limits for the content of different substances in the biochar. It is important to apply a prudence principle based on the most restrictive existing limit values across fertiliser products, EU regulation, and requirements for different carbon removal certificates.
This is not because any negative impacts have been demonstrated from biochar use in agriculture, but so there is confidence in its use. Regulation for biochar should not necessarily be less restrictive than for other fertilisers, yet nothing indicates a need for tightened restrictions on the use of biochar as a fertiliser.

Continued research and knowledge-building from practice is required. The knowledge should systematised and form the basis for guidelines on the use of biochar.
Then a market can be established and followed by research experiments and measurements that can guide future development of regulations.

COMPETITIVE CO_2 STORAGE WITH BIOCHAR

From a macro-economic perspective, the cost of storing one tonne of CO_2 from the atmosphere using biochar is competitive with other CCS technologies such as DACCS and BECCS.

Biochar is therefore an effective and relatively inexpensive way for society to achieve climate improvements compared with other climate measures.

"From a socio-economic perspective, using biochar as a climate measure is associated with a relatively low displacement cost."
- The CIP Foundation

Taking into account some of the adverse environmental side-effects of the different methods, the net result in macro-economic terms is improved for biochar based on digestate, whereas it is worse for BECCS and largely neutral for biochar based on straw residues.

Taking the possibility of payment for the service derived from CO_2 storage into account, for example through climate credits, further changes the picture. The use of biochar ends up as a small gain for society, while BECCS remains a net socio-economic cost, although this method can also obtain financing through climate credits.

Including potential revenues from climate credits in the socio-economic calculation gives an impression of the extent government funded support required for this type of CCS. This may be required in a start-up period for the market, and while the international market for climate credits is under development, standardisation, and consolidation. However, in the longer term, there are prospects that carbon storage with biochar will be financially sustainable for society.

Biochar as a climate measure is a socio-economically good investment. And one of the few climate measures with such potential, particularly in agriculture. Therefore, promoting the market should be considered through clear regulation, effective approval processes, and through CCS subsidies during market start-up. This is to cover some of the costs of CO_2 storage, which potentially could be met by the market for climate credits once it is less uncertain.

RECOMMENDATIONS AND A PLAN FOR LARGE-SCALE PRODUCTION OF BIOCHAR

Biochar could potentially play a major role in the green transition of Danish agriculture. It is based on a mature technology, and biochar can store large amounts of carbon effectively for up to 1,000 years. Furthermore, the socio-economic abatement costs of carbon sequestration with biochar are very competitive amongst other climate measures. In contrast to the large carbon-capture installations at CHP plants and large industrial enterprises, this type of carbon capture and storage can be decentral and close to where feedstock residues exist.

For agriculture as a whole, all the biochar stored in agricultural land will contribute to the total emission reduction requirement for agriculture. Even though climate credits are sold off to third-party companies, the net storage will still count in national and sector-based emission inventories.

"All reductions from using biochar in agriculture will reduce the collective requirements for agriculture as a whole – even if climate credits are sold, for example."
- The CIP Foundation

The collective gains in the form of reduced net emissions from agriculture therefore entail a corresponding reduction in the need for a carbon tax or other instruments aimed at agriculture.

Biochar has the potential to contribute to Denmark's 2030 targets, and the later goals of climate neutrality in 2045, and net negative emissions in 2050. Biochar cannot meet the political objective of 2 million tonnes of carbon storage by 2030 from the agreement on a green transition of the agricultural sector, as it is impossible to build such production capacity so rapidly. But it is likely within relatively few years after 2030, depending on the framework conditions.

Even though other countries have been making biochar for some time, they have not had climate impacts as their primary focus. Denmark has potential to develop a biochar industry in light of existing logistical opportunities for various types of biomass residues, possibilities to sell green energy and surplus heat through well-developed infrastructure, and possibilities for co/localisations.
Technologically, Denmark is also up to speed, and at the beginning of 2024, Denmark will have one of the largest biochar-production facilities in Europe. Other Danish producers are also underway with large, commercial installations.

So, there is a basis for biochar, the supporting technology, and effective documentation of the climate impacts to be a new Danish export stronghold. Export opportunities, competence building, and learning-effects are themes for the next initiatives by the CIP Foundation within this area.

The most important challenges right now in order to use this promising technology in Denmark are linked to the absence of direct regulation of biochar in Danish legislation, to new value chain collaborations where income must be obtained to cover the costs of carbon storage, and for an increased knowledge and practice of how biochar can be used.

On this basis, the CIP Foundation recommends the following:

The CIP Foundation's main recommendations

- **Establish a legal framework for the use of biochar made of agricultural residues**
- **Allow access to CCS subsidies on a competitive basis with other CDR technologies during the initial phase**
- **Develop guidelines for the use of biochar in agriculture**

***Tabel A:** Recommendations from the CIP Foundation to promote biochar as a means of carbon storage in agriculture*

	Regulator	Market players	Researchers and experts
Central recommendations	Establish a legal basis for biochar made of agricultural residues.	Support the start-up with CCS subsidies; to be replaced by the market for climate credits.	Develop guidelines for the use of biochar in agriculture.
General recommendations	• Start with **framework regulation** and **limit values** for the biochar contents, based on the strictest current limits across different regulation and by applying a prudence principle, which can be tightened or relaxed in line with new knowledge. • **Inter-ministerial task force** with focus on authorisation and process simplification for quicker establishment of biochar production. • Develop **method to calculate net CO_2 storage** with biochar in the national emission inventories, so that storage can also be recognised and included in political objectives. • **Identify relevant areas for pyrolysis plants** in combination with current municipal projects to identify suitable areas for biogas production and energy parks for quicker establishment.	• Spread **awareness among potential investors** to accelerate interest in the technology. • Establish logistics chains with the possibility of **long-term agreements** (PPPs) for biomass and biochar. • Accelerate **scaling and learning processes** to develop the pyrolysis technology to large-scale. • Start **development of energy products for high-value use** and prepare possible upgrading, methanation and future coordination with PtX.	• **Categorisation of research results** according to evidence, biomass, pyrolysis process and area of application to make insights more practicable. • Initiate **long-term field studies** and gain an overview of the long-term environmental and agronomic impacts of use on agricultural land. • Develop **practical knowledge** for optimal use of biochar and exchange experience. • Extend **competence development**, training activities and learning tools for the people who are to develop, operate and administrate/supervise etc. biochar processes.
Specific recommendations	• **Equate pyrolysis plants with biogas plants** in the Planning Act to support possible location close to residual biomass. • Support quicker **environmental classification** of pyrolysis plants and thus the process for environmental assessments with outset in standard examples. • Adjust **phosphorus caps** with regard to biochar-release over time. • Work to get carbon storage with biochar **in other sectors**, for example the construction sector, recognised in national emission inventories (via the IPCC). • Develop **standard processes** for municipal assessments and section 19 permits, until central regulation is in place. • Establish a "**compliance assessment body**" to approve biochar with CE labelling as a fertilizer product.	• Develop **field management methods** for biochar (agriculture and materials suppliers). • Develop **combination of biochar and other fertilizer products** to achieve the best effects.	• Investigate the impact of biochar on **nitrogen leaching** from soil to the aquatic environment. • Examine the **interplay** between biochar, soil type, and the effect of different types of living organisms in the soil under Danish conditions.

Source: The CIP Foundation