Danish Ministry of Climate, Energy and Utilites
Ministry of Green Transition
Ministry of Food, Agriculture and Fisheries of Denmark
Danish Ministry of Environment and Gender Equality

Strategy and Work Program for Pyrolysis

1. Introduction and Summary

Denmark aims to reach climate neutrality by 2045 and to reduce greenhouse gas emissions by 110% by 2050 compared to the 1990 baseline. The government actively works to promote new technologies for carbon storage, a critical element in meeting these climate goals. Pyrolysis holds significant potential as a method of CO_2 storage. Through pyrolysis, various types of biomass can be converted into carbon-rich biochar, which can be stored in agricultural soils for centuries, thereby reducing emissions in the agricultural sector. Therefore, the government is committed to ensuring that pyrolysis can contribute as quickly as possible to achieving the 70% reduction target by 2030 relative to the 1990 baseline, including the sector-specific target for the forestry and agricultural sectors of 55-65% reduction, as well as the government's climate neutrality goal by 2045 and the 110% reduction by 2050.

Multiple companies in Denmark are currently developing pyrolysis technology, and a number of facilities have been established to test the technology. With this *Strategy and Work Program for Pyrolysis*, the government aims to accelerate ongoing developments. It is the government's vision that the technology should eventually deliver greenhouse gas reductions on market terms. Achieving this vision requires overcoming several existing barriers that hinder the scaling up of pyrolysis, so that pyrolysis technology can play a crucial role in the green transition in the coming years. To realize this vision, the government is launching a comprehensive strategy and work program with initiatives across three focus areas.

The Strategy and Work Program for Pyrolysis is a follow-up to the Agreement on the Green Transition of Danish Agriculture of October 4, 2021 (Landbrugsaftalen), which included an agreement to develop strategies for realizing the technical reduction potentials in agriculture, including biorefining (e.g., pyrolysis). The present strategy constitutes the final part of the agreements developmental track.

Box 1
Focus Areas in the Danish Pyrolysis Strategy and Work Program

Focus Area 1: Clear and Simple Regulation

- Establishment of clear and simple regulations under EU law for the application of biochar starting mid-2026.
- Greater clarity on site location options for pyrolysis plants through amendments to the Danish Planning Act effective January 1, 2025.
- Examination of the formation, content, and degradation of environmentally harmful substances during the pyrolysis process and the production of biochar by 2026.
- Assessment of potential environmental and agronomic effects through multi-year field experiments.
- Enhanced guidance for municipalities via advisory statements on § 19 permits by the end of 2024, along with guidance on environmental approvals.
- Creation of a Pyrolysis Task Force to coordinate the implementation of initiatives under the Danish pyrolysis strategy, involving a stakeholder group comprising relevant actors.

Focus Area 2: Strengthened Incentives for Adoption

- Establishment of a subsidy scheme for biochar stored in agricultural soil starting in 2027.
- Allocation of funds for research, development, and demonstration of pyrolysis technology in connection with an upcoming green research and innovation initiative in Denmark.
- Guidance on reduction factors for reporting pyrolysis-based fuels to meet the national Greenhouse gas reduction target.
- Support for the European Commission's work to implement an appropriate and credible EU-wide certification system for carbon removal.
- Analysis of opportunities to target CAP support for the use of biochar in agriculture in the next CAP reform period.

Focus Area 3: Climate Impact and Emissions inventory

- Development of an emission factor for biochar for inclusion in the Danish emissions inventory from 2027.
- Measurement of methane emissions in 2024 and determination of an emission factor for pyrolysis plants in 2025.
- Compilation of a knowledge synthesis on alternative biochar storage options by 2025.
- Contribution to the IPCC Methodology Report on Carbon Dioxide Removal Technologies and revision of IPCC guidelines to include more storage options in climate accounting.

Clear and Simple Regulation

A key barrier for further application of pyrolysis technology is that current regulations are not designed with biochar in mind. Today, the application of biochar to agricultural soil often requires a permit under § 19 of the Danish Environmental Protection Act (Miljøbeskyttelsesloven). This is because biochar contains substances that may harm the environment, such as those formed during the pyrolysis process or originating from the biomass used, and its use must currently be assessed on a case-by-case basis. Municipalities make local decisions regarding permits, and there is no standardized administrative process.

The lack of uniform administrative practices complicates the widespread adoption of pyrolysis technology and the large-scale use of biochar. The Danish government seeks to establish the foundation for clear and simple regulation and has allocated a total of DKK 101 million from the Research Reserve for 2023 and 2024. In the short term, environmental trials will be conducted to investigate the formation, content, and degradation of environmentally harmful substances in connection with biochar production. These trials will generate knowledge by mid-2025, forming the basis for establishing clear and simple legislative frameworks for the use of biochar from mid-2026, within the limits of existing EU regulation. The research funds will also be used to examine potential long-term agronomic and environmental side effects of storing biochar in agricultural soils under Danish conditions.

Additionally, the Danish government will amend the Danish Planning Act (Planloven), requiring municipalities to develop guidelines for the location siting of pyrolysis plants, thereby providing greater clarity on site location opportunities for such facilities. This is similar to the existing approach for biogas plants.

It is essential for the Danish government that regulatory frameworks are developed in collaboration with the industry and other relevant stakeholders, as effective cooperation will support the commercialization of the pyrolysis sector. To this end, the government will establish an inter-ministerial Pyrolysis Task Force tasked with coordinating and driving the implementation of the Danish government's roadmap for pyrolysis. The task force will involve a NEKST[1] implementation forum for pyrolysis, composed of relevant stakeholders.

Strengthened Incentives for Adoption

There is currently insufficient economic incentive to produce and store biochar in agricultural soil, and thereby reduce greenhouse gas emissions from agriculture. With the Agreement on a Green Denmark (Aftale om et Grønt Danmark) of June 24, 2024, the Danish government and the parties in the Green Tripartite Agreement propose establishing a subsidy scheme from 2027, amounting to approximately DKK 10 billion, for the storage of biochar produced through pyrolysis up to 2045.

Additionally, the government will prioritize funding for research, development, and demonstration of pyrolysis technology as part of an upcoming green research and innovation initiative to support the acceleration of pyrolysis technology by 2030.

Pyrolysis technology can become more competitive when the market for green energy products generated during biochar production exists. Pyrolysis gas and oil are by-products that can be processed into high-value products serving as alternatives to other high-value fuels. Green fuels based on pyrolysis gas and oil can contribute to meeting, for example, the greenhouse gas reduction target for road transportation. New pyrolysis-based fuels will need to be certified under one of the voluntary schemes approved by the European Commission. The Danish Energy Agency can provide guidance on current application possibilities.

[1] NEKST is the Danish National Energy Crisis Task Force

There are currently no clear guidelines for the certification of biochar or the potential for CO_2 storage with biochar. The Danish government will therefore support the European Commission's work to establish a robust and credible EU-wide certification system for carbon removal, as well as the subsequent development of methodologies.

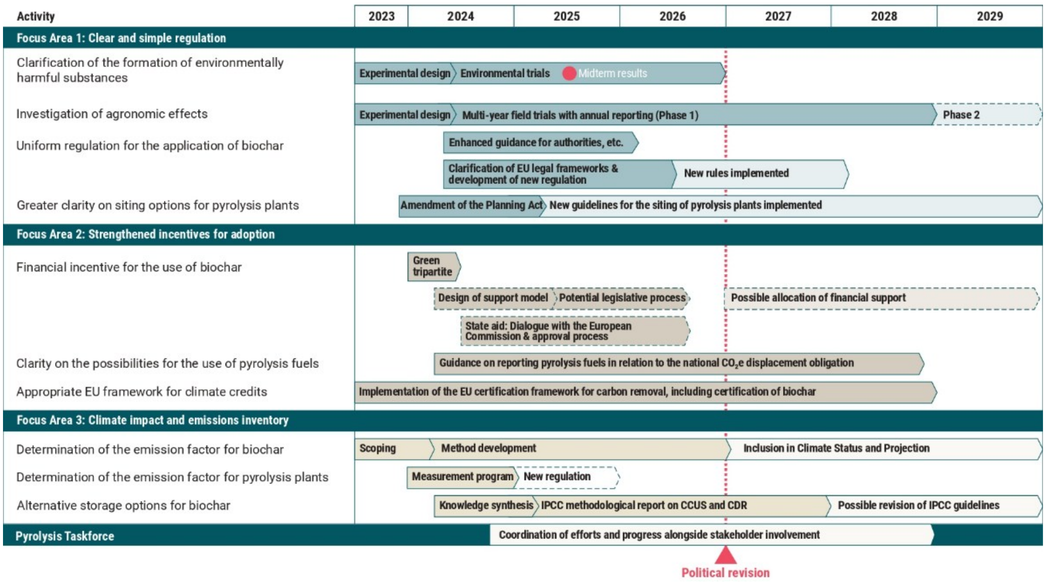
Climate Impact and Emissions Inventory

The overall climate impact of pyrolysis depends on several factors. Currently, there is no clarity on the climate effect of storing biochar in agricultural soil. Specifically, a Danish methodology to account for the climate impact associated with the use of biochar stored in agricultural soil is lacking. As a result, the climate effects from biochar storage cannot yet be included in the Danish emissions inventory. The Danish government has initiated work with the Geological Survey of Denmark and Greenland (GEUS) to develop a method for calculating the climate impact of biochar stored in agricultural soil. This method is expected to be developed by 2026 and conclude in the 2027 Climate Status and Projection (Klimastatus og -fremskrivning).

There is a risk that pyrolysis plants may release methane during the production process. Therefore, the Danish government initiated a measurement program in 2024 to examine and document any methane emissions from pyrolysis plants. Based on the findings, a decision will be made regarding the need to establish threshold values for methane emissions.

The Danish government's initiatives will be implemented over the coming years, as illustrated in *Figure 1*. A political revision will be conducted in 2026/2027 to follow up on the implementation progress.

Figure 2
Timeline for the implementation of initiatives



Reductions Potential for Biochar from Pyrolysis

The Agreement on the Green Transition of Danish Agriculture from 2021 estimated a technical reduction potential for biochar via pyrolysis of 2 million tons of CO_2 in 2030. This estimate is based on an assessment by the Danish Council on Climate Change, which in turn relied on a technical report from the Technical University of Denmark (DTU)[2]. This report estimated the CO_2 effect of converting one-third of Denmark's total biomass resources into biochar. The technical reduction potential has been revised in connection with the Danish government's Pyrolysis Strategy and Action Plan, based on the view that the primary technical limitations for long-term potential are likely to be the availability of land for biochar application and existing Danish environmental regulations. Based on this reassessment, there is estimated to be a large technical potential for biochar via pyrolysis ranging from 0.8 to 38 million tons of CO_2, depending on the type of biomass used cf. section 3.2.

As highlighted in the Agreement on the Green Transition of Danish Agriculture, realizing this potential in the short term will require the widespread adoption of the technology. Similar to other emerging technologies, the expansion of pyrolysis plants is expected to occur gradually as commercial experience with the technology increases. Therefore, the adoption of the technology is considered a limiting factor for realizing the potential effects by 2030 cf. section 3.3. With significant uncertainty, it is estimated that support for biochar storage could lead to an expansion of pyrolysis plant capacity from approximately 30 MW of production capacity in 2024 to between 120 and 680 MW by 2030, and to between 320 and 3,400 MW by 2035. This estimated capacity expansion corresponds to greenhouse gas reduction effects of 0.1–0.7 million tons in 2030, with an average estimate of 0.3 million tons. Further capacity expansion by 2035 is estimated to

[2] The technical report in question refers to DTU's technical potential in its report *Known Pathways and New Tracks to a 70 Percent Reduction* from 2020.

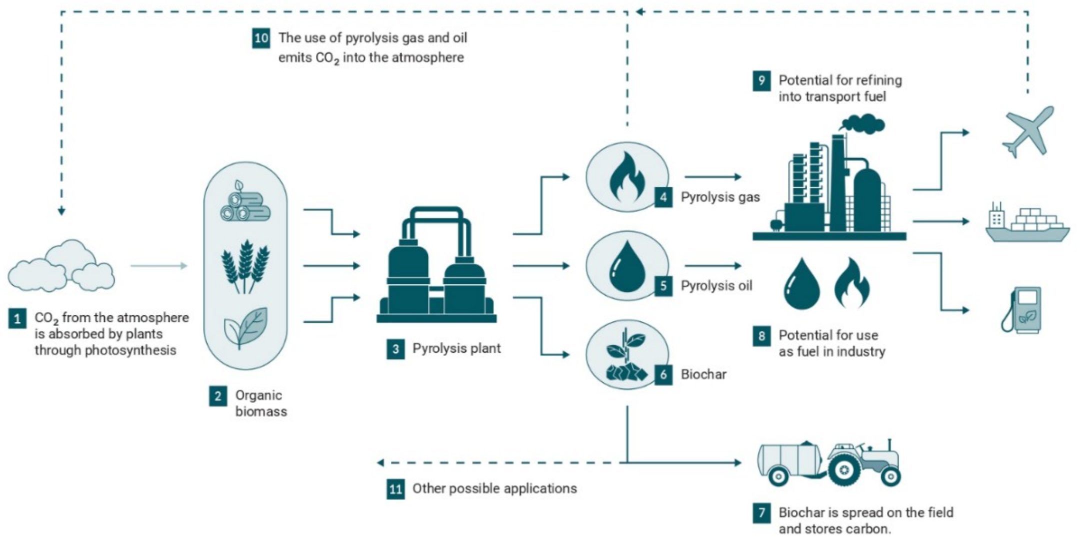
achieve greenhouse gas reduction effects of 0.3–3.5 million tons, with an average estimate of 1.2 million tons of CO_2 by 2035.

2. Description of the Pyrolysis Technology

Pyrolysis refers to the decomposition of material through heating under oxygen-free conditions. When organic material is treated at sufficiently high temperatures, part of the biomass is converted into biochar, a solid material with a high carbon content. Additionally, an energy-rich gas known as pyrolysis gas is produced. The gas can condense into pyrolysis oil when cooled. Both pyrolysis gas and oil can be classified as green energy products and have the potential to replace fossil fuels.

Biochar can be stored for centuries with minimal release of CO_2, unlike the original biomass, which decomposes more rapidly. When biochar is applied to agricultural soil, the carbon is stored in the soil, thereby reducing CO_2 emissions to the atmosphere, as illustrated in Figure 2.

Figure 2
Illustration of the value chain for pyrolysis



Pyrolysis is a flexible technology, meaning that virtually all types of biomass can, in principle, be used as raw material for pyrolysis. Potential raw materials include straw, degassed biomass from biogas production, the wood fraction from garden and park waste, sewage sludge, and the fiber fraction from biorefining of grass. Common to these types of input materials is that they can be considered waste, residuals, or by-products, some of which are already applied to agricultural soil today.

2.1. Application of Biochar in Agricultural Soil

The pyrolysis process varies depending on the specific technology used for biochar production. In so-called slow pyrolysis, approximately 30–60 percent of the biomass carbon content is estimated to be retained in the biochar. A small portion of the carbon in the biochar decomposes relatively quickly and is released back into the atmosphere, but the majority decomposes slowly over centuries. The properties of biochar depend on various factors, such as the type of biomass used, the temperature, and the residence time in the pyrolysis plant.

When applied to agricultural soil, biochar can be incorporated into the upper soil layers, where its carbon content is stored long-term. If residual biomass is used for biochar production, it can potentially contribute to recycling nutrients (such as phosphorus) when the biochar is applied to fields. Additionally, some studies have shown that adding biochar can, for instance, improve the soil's water retention capacity and increase nutrient availability in the soil. However, biochar also contains substances that are harmful to the environment and human health, which may limit its application if concentrations are too high. These may include heavy metals derived from the biomass used or substances formed during the pyrolysis process. It is therefore crucial that biochar complies with relevant environmental standards.

2.2. Application of Pyrolysis Gas and Oil

Pyrolysis gas and oil produced from sustainable biomass are classified as green energy products according to IPCC guidelines. If the use of pyrolysis gas and oil replaces the combustion of fossil fuels, it results in CO_2 reductions due to displacement effects.

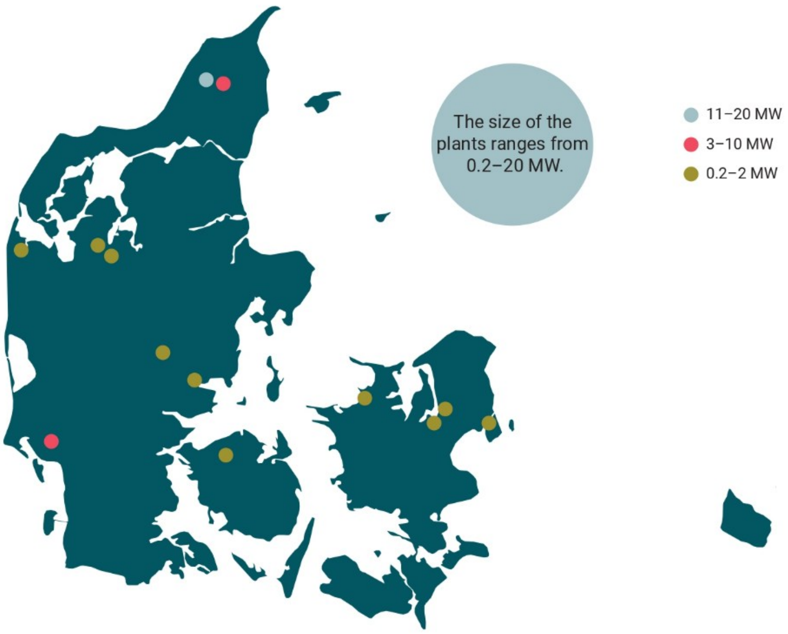
Green fuels are exempt from CO_2 taxes, increasing the incentive to use renewable fuels instead of fossil fuels - including pyrolysis-based fuels. Pyrolysis gas and oil can be used for various purposes, although upgrading is often necessary to replace fossil alternatives. Part of the pyrolysis gas can be utilized within the pyrolysis plant itself to produce the process heat needed for drying and heating the biomass. Surplus gas or oil can then be used for other purposes, such as producing heat for district heating networks serving households or process heat for industrial use.

In theory, pyrolysis gas and oil can also be upgraded into green fuels for use in the transport sector. However, further refinement of pyrolysis products still requires development, demonstration, and commercialization. The conversion costs and technical barriers to using pyrolysis oil are likely lowest in shipping or as industrial fuel. The market for using pyrolysis gas and oil is expected to develop as commercial pyrolysis plants are established and the technology is more widely adopted.

2.3. Existing Facilities in Denmark and Abroad

Several companies in Denmark are developing and utilizing pyrolysis technology, and a number of test and demonstration facilities have been established, as illustrated in Figure 3 and Table 1. Different technical concepts and process designs are in focus among the companies. Alongside other factors this influences the type of biomass used at individual pyrolysis facilities.

Figure 3
Overview of Selected Pyrolysis Projects in Denmark



Tabel 1
Overview of selected pyrolysis projects in Denmark

Developer	Size	Location	Commisioned/ Established	CO_2 Storage (tons per year)
Aquagreen ApS	0,5 MW	Fårevejle	Yes	500
Aquagreen ApS	0,5 MW	Søndersø	Yes	500
Aquagreen ApS	0,7 MW	Lemvig	No (2024)	500
Aquagreen ApS	1,4 MW	Tårnby	No (2025)	1.000
Stiesdal A/S	0,2 MW	Risø	Yes	275
Stiesdal A/S	0,2 MW	Brædstrup	Yes	275
Stiesdal A/S	2 MW	Skive	Yes	2.750
Stiesdal A/S	20 MW	Vrå	Yes	25.500
Dall Energy ApS	8 MW	Esbjerg	No (2026)	4.000
Frichs ApS	2 MW	Horsens	No (2024)	2.000
Frichs ApS	6 MW	Vrejlev	No (2024)	6.000
Mash Makes A/S	-	Risø	Yes	-
Organic Fuel Technology	2 MW	Skive	No (2025)	1.500

In Europe, more than 170 smaller biochar-producing facilities are currently operational, with a total production capacity of approximately 75,000 tons of biochar per year, despite the market for biochar sales remaining limited. Biochar is not necessarily produced with the primary purpose of carbon storage but is instead used as a fertilizer product and for other applications. The market is developing, and production capacity in the EU increased by approximately 50 percent from 2020 to 2023[3].

2.4. Technological Maturity

New technologies typically go through a series of maturity levels as part of their overall development. The Danish Energy Agency's Technology Catalogue and the Climate Program use four levels to assess a technology's maturity. Pyrolysis technology is currently assessed to be in the transition phase from the pioneer to the pre-commercial level, as outlined in Box 2. Technological maturity can also be assessed using the IEA's Technology Readiness Level (TRL) scale, which comprises a total of 11 levels for evaluating the maturity of a technology. Pyrolysis technology is currently considered to be at levels 7–9 on the TRL scale.

Box 2
Maturity Levels

1. **Demonstration:** Larger prototypes have been developed, and the technology has been demonstrated in a relevant environment. The greenhouse gas reduction factors are not necessarily documentable. Costs and efficiency are associated with significant uncertainty.

2. **Pioneer:** Technologies have been demonstrated on a limited scale. Greenhouse gas reduction factors are not necessarily documentable. Costs and efficiency involve some uncertainty due to the limited dissemination of the technology and its ongoing development and adaptation.

3. **Pre-commercial:** Technologies have some level of dissemination and scale, and greenhouse gas reduction factors are known and documentable. There remains significant development potential, and costs are expected to decrease further with upscaling. There is typically uncertainty about future price and efficiency developments.

4. **Mature:** Technologies are widely disseminated, and greenhouse gas reduction factors are known and documentable. Technological improvements from further upscaling are marginal.

Source: The Danish Climate Program 2022 and Technology Catalougue of 2022 from The Danish Energy Agency

[3] Source: European Biochar Market Report 2023/2024.

2.5. Measures taken to promote pyrolysis technology

Significant efforts to support the expansion of pyrolysis in Denmark has already been initiated, as described in Box 3.

Box 3
Measures already initiated to promote pyrolysis and biochar

Funding for technologies in the agricultural sector with high greenhouse gas reduction potential
The 2021 Finance Act allocated DKK 194 million to a fund for the development and demonstration of technologies with high greenhouse gas reduction potential in the agricultural sector. The fund is administered by the Danish Energy Agency and has been allocated to three pyrolysis projects focusing on the entire pyrolysis value chain, including energy products in the form of pyrolysis oil and gas, as well as biochar. Environmental impacts and fertilizer value of biochar will also be studied. The funding is financed by the European Union under NextGenerationEU.

EU funds for promoting brown biorefining
The parties behind the Agricultural Agreement have allocated DKK 196 million in 2023-24 for the pyrolysis sector, provided through the EU fund the *'Just Transition Fund'*, which is administered by the Danish Business Authority. Approximately DKK 38 million is designated for establishing a project in North Jutland. Through this project, two companies and one university are expected to receive support for consultancy and the development of test and demonstration facilities for brown biorefining. The remaining funds were re-announced in August 2024.

Fund for innovative green energy technologies
The 2023 Finance Act allocated DKK 50 million under the Energy Technology Development and Demonstration Program (EUDP) for pyrolysis technology projects aimed at reducing greenhouse gas emissions in agriculture. These funds were partially disbursed in December 2023 for a project demonstrating and optimizing microwave cracking of biomass into bio-oil and biochar at full scale. Additionally, another project received support to develop concrete with a lower carbon footprint by utilizing biochar from pyrolysis.

Subsidies for biochar projects through GUDP with various objectives:

- The Green Development and Demonstration Programme (GUDP) has provided funding of DKK 6 million for the project Grass Biochar. The purpose of the project is to extract energy from grass pulp from grass protein production through a combined Steam Drying and Pyrolysis process (DTP), as well as to produce activated carbon as a high-value product. The project was completed in December 2023.
- By applying biochar produced from straw and wood, the aim is to improve the ability of sandy fields to retain water for plants, enable plant roots to penetrate deeper, and build up a CO_2 reservoir in the soil (BioAdapt, DKK 7.9 million, to be completed in 2024).
- Production of biochar from pig slurry followed by incorporation into the soil and demonstration of its application, including determination of the reduction potential for climate emissions (STABIL, DKK 10.5 million, to be completed in 2025).
- Develop technological synergy between the company's biogas plant and pyrolysis with the aim of improving energy efficiency, and develop an understanding of which types of biomass are best suited for pyrolysis (Development of synergy between biogas and pyrolysis = Doubling gas extraction from agricultural residues, DKK 14.5 million, to be completed in 2025).
- Use of biochar produced from livestock manure as a phosphorus fertilizer. In this way, the aim is to balance the phosphorus surplus between Eastern and Western Denmark, as biochar is cheaper to transport than slurry, while also achieving CO_2 reductions (PiBalance, DKK 4.2 million, to be completed in 2026).

Subsidies through EUDP for upgrading pyrolysis oil and gas
The goal of the project is to increase the maturity of pyrolysis technology by bringing it to TRL 7 (Technology Readiness Level) and reducing the risks associated with pyrolysis technology. Direct use and upgrading of pyrolysis oil and gas will be investigated and tested in the project. DKK 23 million have been allocated, and the project is expected to be completed in 2024.

Source: The Danish Climate Program 2022 and Technology Catalougue of 2022 from The Danish Energy Agency

3. Greenhouse gas reduction effects and cost estimates

3.1. Greenhouse gas reduction effects of biochar

Biochar can result in greenhouse gas reductions if it is permanently stored. Biochar can, in principle, be produced from all types of biomass, but in particular straw, biogas digestate, wood residues, and the wood-containing part of garden waste are relevant biomasses for biochar production. Other biomasses, such as manure or sewage sludge, could also be included in the pyrolysis process, but these biomasses have a lower potential for carbon storage due to their lower carbon content. The Greenhouse gas reduction calculations for Danish biomass are based on biomass currently used for combustion or applied to agricultural land.

Danish biomass already has a current use that is included in the national emissions inventory under the LULUCF sector. Straw and biogas digestate, which are currently applied to Danish agricultural land, result in a temporary carbon storage effect in the soil. If the same biomass is instead used for pyrolysis, the current carbon storage effect of the biomass will be canceled out and replaced by the carbon storage effect of the biochar. Therefore, when calculating the net reduction effect of biochar, the effects of its alternative use, where the biomass is applied to the field, are deducted.

Biomass currently used for combustion, such as wood waste, garden waste, and straw for combustion, is accounted for as CO_2-neutral, as CO_2 emissions are already calculated when the biomass leaves the field or forest. Therefore, biomass for combustion neither has an emissions nor a carbon storage effect initially, and there will be no need to offset effects from its alternative use.

Imported biomass is not included in the Danish emissions inventory but is accounted for in the emissions inventory of the country from which the biomass is imported. Therefore, when calculating the effects of imported biomass, there will be no need to offset the effects of the biomass's alternative use.

Biochar has a significantly longer decomposition time in the soil compared to biomass that has not undergone pyrolysis, as shown in *Box 4*. The precise decomposition time of biochar is subject to ongoing research. Models of the decomposition time range from several hundred years to, according to certain models, up to several million years. Some research findings suggest that about 80% of the carbon in biochar remains bound in the biochar after 100 years. In comparison, about 80% of the carbon is released within the first year for straw left on the field.

As an alternative to application on agricultural land, biochar could theoretically also be stored in other underground or above-ground reservoirs, such as certain building materials, and thus act as a carbon reservoir. However, the current guidelines from the United Nations for the accounting of national greenhouse gas emissions do not support the inclusion of climate effects from storing biochar in anything other than agricultural land.

Biochar can also be burned to produce renewable energy, where it would not act as a carbon reservoir. However, burning biochar could displace fossil fuels and thereby have a climate effect. The disadvantage of burning the biochar is twofold. Firstly, the biochar no longer functions as a permanent carbon reservoir, thus eliminating that part of the climate effect. Secondly, nutrients typically get lost instead of being recirculated.

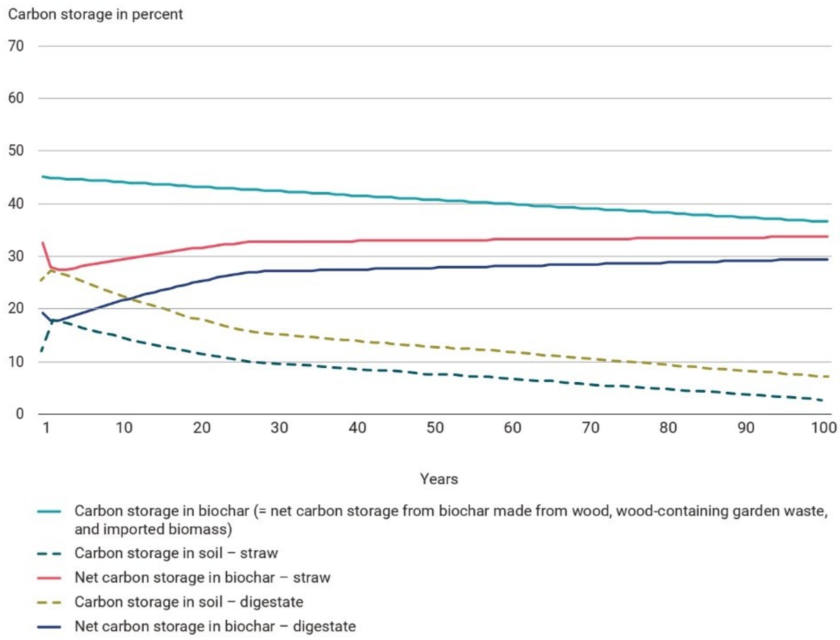
Currently, biochar cannot be included in the national emissions inventory. As mentioned in Section 4.3 an emission factor that accounts for and documents the climate effect of applying biochar to agricultural land has not yet been developed. Current calculations are therefore based on preliminary estimates of CO_2 effects based on existing knowledge of the decomposition rates of biochar and biomass, as well as the accounting principles currently used for Denmark's emissions inventory, as explained in *Box 4*.

Box 4
Carbon Storage in Biochar Depending on Biomass Type

It is assumed that 45% of the carbon from the biomass is bound in the biochar. The remaining amount of carbon is converted into energy products from pyrolysis, with a small portion being wasted. When comparing the amount of carbon stored in biochar to the biomass's alternative use, net carbon binding is highest over time for wood, wood-containing garden waste and imported biomass, as these are currently used for combustion and therefore have no storage effect in the LULUCF sector, as shown in Figure 4.

The net carbon binding of biochar from the use of straw is somewhat lower than from wood and garden waste, as about 60% of the biomass is currently applied to agricultural land, where it contributes to carbon storage. Digestate has the lowest net effect, as all digestate is currently applied to agricultural land and therefore already contributes to some degree of carbon storage. The final CO_2 effect will also depend on the carbon content of the biomass used.

Figure 4
Carbon storage in biochar over time depending on biomass type (percent)



Note: It is assumed that 45 percent of the carbon in the biomass is retained in the biochar in year 1. When calculating net carbon sequestration, adjustments are made for the current use of the biomass—biomass applied to agricultural land contributes to carbon storage today, whereas biomass used for combustion does not contribute to storage. Variations in the early years are due to transitions between carbon pools in the C-TOOL model, which is the model used for soil carbon pools in Denmark's emissions inventory, cf. *Note on the inclusion of the effect of biomass in C-TOOL/the national greenhouse gas inventory*, Steen Gyldenkærne, 2023.
Source: Ministry of Climate, Energy and Utilities

3.2. Technical Reduction Potential

The technical reduction potential is an estimate of the upper technical limits for greenhouse gas reductions, disregarding economic and legal barriers. The technical potential for greenhouse gas reductions from biochar is estimated to be limited by the amount of biochar that can be applied to Danish agricultural land in accordance with existing environmental regulations. The greenhouse gas reduction effects per ton of biochar especially depends on the current use of the biomass and the carbon content in the original biomass, as described in *Section 3.1*. The estimate of the technical reduction potential for biochar is based on the assumption that biochar is produced and applied in compliance with the applicable environmental regulations.

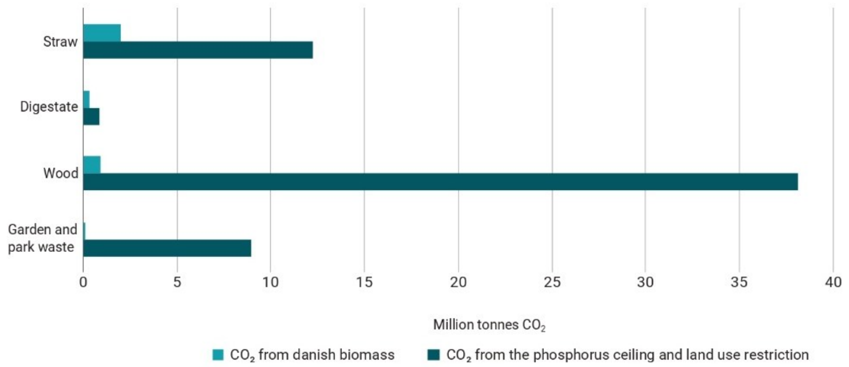
Under current environmental regulations, phosphorus application to fields is controlled through the so-called phosphorus ceiling, which sets an upper limit on the amount of phosphorus that can be applied on average per hectare for a given farm. Since biochar contains phosphorus, the phosphorus ceiling also applies to biochar that is applied to agricultural land[4]. Therefore, it is assumed that the phosphorus ceiling will eventually set the upper limit for the total amount of biochar that can be applied to Danish agricultural land. The assessment is based on the amount of phosphorus that can be applied nationwide, which assumes that biochar is applied where there is excess land available for phosphorus application.

Within the national phosphorus ceiling, it is estimated that a total of 12 million tons of biochar can be applied annually, provided the biochar is produced from wood that would otherwise be used for incineration, corresponding to an annual CO_2 effect of 38 million tons. It is highly uncertain whether this level can be reached, considering environmental and agronomic conditions. If the biochar is produced from straw, it is estimated that 6 million tons can be applied annually, corresponding to an annual greenhouse gas reduction effect of 12 million tons, as shown in *Figure 5*. For biochar produced from digestate, it is estimated that 0.8 million tons could be applied annually, corresponding to an annual greenhouse gas reduction effect of 0.9 million tons. The technical reduction potential thus depends heavily on the type of biomass used to produce biochar, which affects the carbon and phosphorus content of the biochar. These are annual CO_2 effects, as long as the biochar is applied annually. No consideration has been given to the possibility that, over time, there may be a limit to the physical accumulation of biochar on the land due to the application of very large amounts of biochar.

The technical potential for biochar application is therefore very large, assuming that phosphorus regulation is the limiting factor and that no distinction is made between Danish and imported biomass. If the potential is limited to biochar produced from Danish biomass resources, which is already either applied to agricultural land or used for combustion, this would result in a significantly lower amount of biochar and lower greenhouse gas reduction effect, ranging from 0.1 million tons CO_2 for garden waste up to 2 million tons CO_2 for straw, as shown in *Figure 5*. If the potential is further limited to reflect only the biomass applied to Danish agricultural land, the potential would be reduced to about 1 million tons of biochar per year and a CO_2 effect of 1.6 million tons per year.

[4] Further research into the properties of biochar when applied to agricultural soil may lead to environmental regulations that are more restrictive than the phosphorus ceiling, and the phosphorus ceiling itself may become more restrictive over time.

Figure 5
Technical potential for annual CO_2 reductions from biochar within the phosphorus cap (million tons of CO_2)



Note: The phosphorus ceiling is 30 kg of phosphorus per hectare. Phosphorus from the application of straw is not currently counted towards the phosphorus ceiling, and therefore phosphorus from biochar made from straw will count as an additional phosphorus input. Phosphorus that is already applied to the field in the form of digestate will not count as an additional phosphorus input if the same phosphorus is applied as biochar.

Source: Danish Ministry of Climate, Energy and Utilities

Considerations regarding the optimal use of biomass are not included. It is not possible to estimate what proportion of Danish biomass could be allocated to pyrolysis, as biomass can also be used for other purposes, such as biorefining or the production of feed or materials like bioplastics, or for processing the biomass for the construction sector. There may be economic, supply-related, or regulatory limitations in allocating all biomass from agricultural land and combustion plants to pyrolysis. For instance, there may be limitations in allocating biomass applied to agricultural land, as there could be a risk of soil depletion if all biomass is removed. Additionally, there could be restrictions concerning the import of biomass. Thus, there are significant uncertainties associated with estimating the potential for biochar application and the resulting CO_2 effects.

3.3. Estimated Greenhouse Gas Effects for 2030 and 2035

The Danish government expects that, based on results from ongoing research initiatives, national regulation for the use of biochar in agricultural soils can be implemented starting mid-2026. Consequently, it is estimated that biochar could be applied on a larger scale from 2027, once the regulatory framework is clarified.

As with other technologies, the expansion of pyrolysis plants is expected to occur gradually, in line with gaining commercial experience with the technology. Projections for capacity development towards 2030 and 2035 are based on the development of production capacity for renewable energy technologies such as biogas and large-scale solar heating plants for district heating, which are comparable in terms of technical characteristics. Biogas and solar heating resemble pyrolysis plants in terms of physical scale, and as with pyrolysis, each new facility represents a relatively specific installation. Comparing biogas plants to pyrolysis plants is particularly relevant, as both involve large-scale biomass processing and refining a desired end product.

Historically, biogas and solar heating have required a maturity period of 20 years before significant capacity expansion was observed. However, it is assumed that pyrolysis technology will not need such an extended maturity phase, as both international and national climate focus are expected to accelerate its development. Therefore, it is assumed that biochar production will accelerate starting in 2027, based on current demonstration projects and research. If this acceleration begins later, the expected production capacity for 2030 will be proportionally lower.

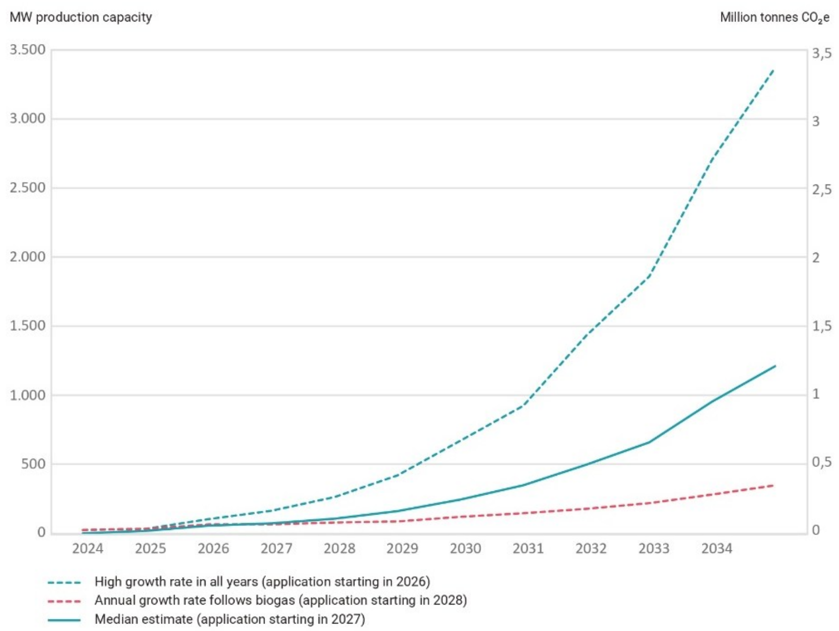
Estimating acceleration for new technologies is highly uncertain. For projections of pyrolysis plant expansion, historical acceleration and growth rates for comparable technologies have been used. For biogas, an average annual growth rate of approximately 25% has been observed during its acceleration phase. The highest observed annual growth rate across comparable technologies is 60%, seen in solar heating plants. It is assumed that the acceleration of capacity expansion for pyrolysis will fall within this range, as illustrated in *Figure 6*.

It is assumed that there will be market readiness to expand pyrolysis plants and confidence that identified barriers will be resolved before 2027, including clarity on the scientific basis for environmental impact, related environmental regulations, support schemes, and emission factors. On this basis, it is estimated, with significant uncertainty, that biochar storage could begin in 2027. This assumes that the first facilities (beyond current demonstration projects) will be completed and producing biochar by 2027, with capacity expansion starting in 2025. This assumes that it takes two years from the initiation of a facility to full-scale biochar production.

Several factors could influence the expansion of pyrolysis plants, either increasing or decreasing the acceleration and growth rate towards 2030. Calculations are thus based on a moderate estimate, with deviations particularly likely in the short term. Furthermore, it should be noted that inclusion in the emissions inventory and projections requires that ongoing research projects document the reduction effects, which are expected to be available for the 2027 Climate Status and Projection. The potential and effects will be revised in connection with the inclusion in the 2027 Climate Status and Projection (Klimastatus og -fremskrivning).

Based on this, it is estimated, with significant uncertainty, that the capacity of pyrolysis plants could increase from just under 30 MW in 2024 to 120-680 MW by 2030 and 320-3400 MW by 2035. This projected expansion corresponds to greenhouse gas effects of 0.1-0.7 million tons in 2030 and 0.3-3.4 million tons in 2035, as shown in *Figure 6*. This corresponds to an average estimate of greenhouse gas effects from biochar storage of 0.3 million tons of CO_2 in 2030 and 1.2 million tons of CO_2 in 2035.

Figure 6
Development in CO_2 effects based on estimated production capacity



Note: Estimating the development of production capacity for immature technologies is associated with considerable uncertainty
Source: Danish Ministry of Climate, Energy and Utilities

3.4. Costs and Shadow Carbon Price

The production and application of biochar are currently estimated to involve a net cost that must be covered before biochar from pyrolysis can be rolled out on a larger scale. This section outlines the cost estimates and shadow carbon price for biochar through pyrolysis.

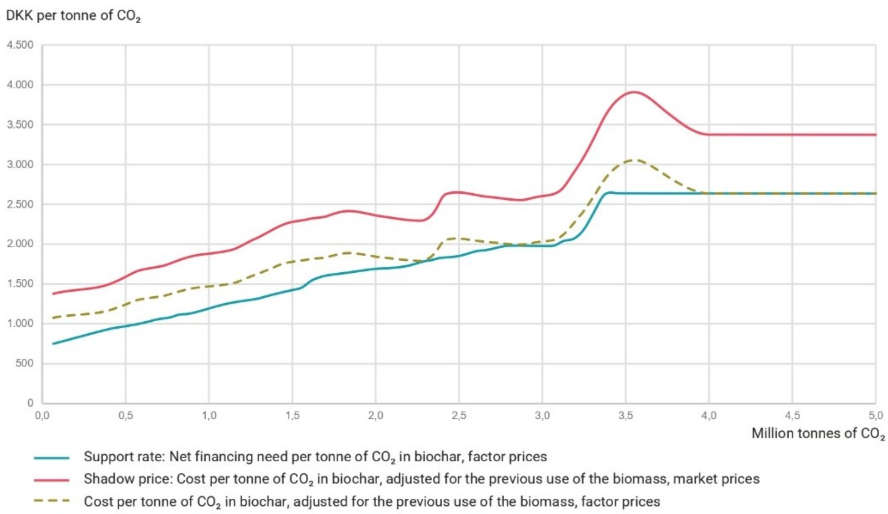
There is currently no significant market for selling biochar or economic incentives for its application and use in agricultural soil. Therefore, it is assumed that biochar currently has no inherent value. However, biochar could potentially have soil-enhancing and fertilization effects, which have not yet been established and may vary depending on input biomass and production conditions.

The net financing requirement for the production and application of biochar is estimated based on the Danish Energy Agency's Technology Catalogue for renewable fuels, including assumptions related to pyrolysis plant size, production characteristics, energy balance, and a range of other assumptions regarding biomass and energy product prices, as described in *Box 5*.

The production and application of biochar are currently estimated with significant uncertainty, based on the prices used for biomass, investment and operating costs of the pyrolysis plant, costs for applying biochar, and revenues associated with selling energy products. The marginal shadow carbon price is estimated to range between approximately 1,400 and 4,000 DKK per ton of CO_2 (2025 prices), as shown in *Figure 7*. The shadow carbon price represents the societal cost per ton of CO_2 stored within Denmark's borders, considering the alternative CO_2 storage effect of the biomass's current use. The shadow carbon price therefore varies along the curve, depending on the type of biomass assumed, as determined by biomass price estimates. The average shadow carbon price across the curve is estimated to be approximately 2,500 DKK per ton of CO_2 (2025 prices).

The cost curve is estimated under the assumption that biochar is produced from the biomass that yields the lowest cost per ton of CO_2 reduction in the biochar itself, meaning that the alternative carbon storage effect of the biomass is not included. Costs vary due to transport costs for biomass, which is why it is estimated to be most expensive to produce biochar from imported biomass. After using approximately 8 million tons of biomass, corresponding to just under 4 million tons of CO_2, it is estimated that biochar will be produced from imported biomass, which causes a drop in the shadow carbon price, as biochar from imported biomass does not require a deduction for the carbon storage effect of the biomass's current use.

Figur 7
Marginal cost per ton of CO_2 for biochar from pyrolysis (DKK per ton CO_2, 2025 prices)



Note: The figure indicates the marginal shadow carbon price and net cost per ton of CO_2. The costs increase depending on the amount of biochar, as biomass expenses are expected to rise due to the need to allocate more biomass of potentially higher quality and from greater distances. Different types of biomass are introduced for pyrolysis along the curve, which causes jumps in the cost per ton of CO_2. The curve has been smoothed to reduce these fluctuations. When correcting for the previous use of the biomass, an average of its current use has been applied.

Source: Danish Ministry of Climate, Energy and Utilities

For the support requirement, the return on investment for biochar per ton of CO_2 in the biochar itself is used, as it is not considered feasible to differentiate support based on the biomass's previous use. This results in a support requirement lower than the societal cost per ton of CO_2 (shadow price).

Box 5
Assumptions behind Cost Estimates (2025 Prices)

Based on the Danish Energy Agency's Technology Catalogue, a 20 MW pyrolysis plant with a capital cost of approximately 160 million DKK is assumed. A required return of 7 percent is applied to the capital investment, based on an estimate of the structural equity return.

Pyrolysis oil is assumed to be used for international shipping, where it can result in a global CO_2 displacement effect by replacing fossil oil. It is assumed in the calculations that pyrolysis oil is directly substitutable with fossil fuel oil. From 2025, shipping in the EU is regulated by the EU's CO_2 displacement requirements under the FuelEU Maritime Regulation, which mandates 2% displacement in 2025, 6% in 2030, and 80% in 2050. Furthermore, CO_2 emissions from maritime shipping over 5,000 gross tons are subject to quotas from January 1, 2024, provided the ship sails to or from an EU port.

In the calculations, it is therefore assumed that pyrolysis oil can be priced as fuel oil plus the CO_2 quota price as the substitutable price. From this, 10% of the price is deducted to account for conversion costs, as well as costs for transporting and storing the oil. This results in a pyrolysis oil pricing of approximately 420 DKK per MWh in 2030, increasing to 620 DKK per MWh in 2050.

For pyrolysis gas, it is assumed to replace grid gas. It is estimated that biogas production is expected to exceed Danish grid gas consumption from 2030, according to the Climate Status and Projections 2024. This means that there is no displacement effect for pyrolysis gas. The valuation of pyrolysis gas is assumed to follow the price of grid gas minus 10%, which is assumed to cover the costs of establishing separate pipelines and boilers. This results in a pyrolysis gas price of approximately 190 DKK per MWh.

Excess heat is assumed to replace heat production from other renewable energy sources and is therefore priced based on heat price estimates from the Danish Energy Agency, with 10% deducted for conversion costs. This results in a price estimate for excess heat of approximately 180 DKK per MWh. In the pyrolysis process, methane can be formed. However, it is assumed that there are not significant methane emissions resulting from the utilization of pyrolysis gas at Danish pyrolysis plants. Finally, the pyrolysis plant has an electricity consumption for operation, which is priced according to projections for electricity prices based on Climate Status and Projections 2024, at 530 DKK per MWh in 2027, decreasing to 430 DKK per MWh in 2035.

Average biomass prices follow the assumptions for Climate Status and Projections 2024 and average 980 DKK per ton of biomass for straw, 170 DKK per ton for digestate, 1,070 DKK per ton for wood, and 700 DKK per ton for garden waste. However, prices vary to reflect transport costs depending on the distance to the pyrolysis plant and previous use. For the lower estimates, price estimates for decentralized plants, exclusive of transport costs, are used. For the upper estimates, price estimates for imported wood pellets converted to DKK per MWh for the relevant biomass are used, which are considered an upper estimate for biomass transport costs.

For straw, the lower estimate is 550 DKK per ton, while the upper estimate is 1,690 DKK per ton. For digestate, the lower estimate is set at 0 DKK per ton, while the upper estimate is 330 DKK per ton. For wood, the lower estimate is assessed at 950 DKK per ton, while the upper estimate is set at 1,300 DKK per ton. For garden waste, the lower estimate is 560 DKK per ton, while the upper estimate is assessed at 1,000 DKK per ton.

Source: Danish Ministry of Climate, Energy and Utilities

4. Addressing Barriers and Risks, and Efforts to Promote Technology

Currently, several barriers hinder the large-scale implementation of pyrolysis technology, which need to be addressed through the following areas of focus:

I. **Focus Area 1 – Clear and simple regulation:** Clear and straightforward regulatory frameworks must be developed, aligned with EU law, to enable environmentally and agronomically sound large-scale use of biochar on agricultural land.

II. **Focus Area 2 – Strengthened Incentives for Adoption:** Framework conditions should provide the right incentives for greenhouse gas reductions in the agricultural and forestry sectors, where pyrolysis can play an important role.

III. **Focus Area 3 – Climate Impact and Emissions inventory:** A Danish methodology must be developed to ensure the climate impact of biochar storage can be included in Denmark's emissions inventory.

The strategy and work program for pyrolysis initiates measures across these three focus areas to remove the barriers to the adoption of pyrolysis technology and the use of biochar on agricultural land.

4.1. Focus Area 1: Clear and Simple Regulation

Biochar's Environmental and Agronomic Effects

In other countries, biochar is sometimes used as a fertilizer and soil amendment. However, the long-term effects of widespread use of biochar as a climate mitigation tool in the agricultural sector are not well understood. In Denmark, biochar is currently produced primarily for demonstration and research purposes, with limited commercial sales.

Biochar can be produced from various types of biomass and exhibit different properties depending on the input biomass and production conditions, such as pyrolysis temperature and residence time in the facility. Both the physical characteristics and the biological activity of soil are affected when biochar is applied. Some studies have suggested that biochar can improve soil properties, such as its ability to retain water and nutrients. However, further knowledge and documentation are needed on the long-term environmental and agronomic effects of biochar under practical cultivation conditions in Denmark. New insights into these aspects could also enhance understanding of biochar's climate benefits and influence farmers' incentives to use biochar on their fields.

The potential fertilizer value of biochar could be significant for its adoption in agriculture. Particularly, the phosphorus content is important, as phosphorus is a limited resource and an essential nutrient for plant growth. Applying biochar to fields might positively impact crop growth. However, regulations on phosphorus application to agricultural land could locally limit its use. There is also a lack of clarity on how available the phosphorus in biochar is for plant uptake and whether there is a risk of phosphorus leaking into water systems. In contrast, much of the nitrogen content is either lost or converted into plant-unavailable forms during the pyrolysis process. Currently, the entire phosphorus content is accounted for in nutrient management plans, while nitrogen in biochar is considered unavailable and is therefore excluded.

Biochar contains substances harmful to the environment and health, which, in high concentrations, risk leaking into groundwater, marine environments, or surface water, or accumulating in the soil where they might be taken up by plants or microorganisms. These substances include heavy metals, which may originate from the input biomass, or persistent chemicals formed during pyrolysis. To mitigate these risks, regulations must ensure that biochar meets appropriate quality standards or equivalent requirements. On the other hand, certain contaminants present in the input material, such as pharmaceutical residues and microplastics, may be entirely or partially eliminated through pyrolysis.

If initiatives are launched to promote biochar storage outside of agricultural applications, prior assessment of environmental impacts will be required. Current regulations prohibit placing biochar in landfills, as it is not deemed suitable for landfill disposal. Similarly, it cannot be used in land rehabilitation projects, such as restoring areas previously used for raw material extraction, due to potential risks of leaking substances from the biochar into surface and groundwater, leading to contamination that would be challenging to address later.

Site location and Environmental Approval of Pyrolysis Plants

Pyrolysis plants are typically proposed for rural site locations as being close to biomass resources will minimize transportation costs for biomass. Constructing such facilities in rural zones requires a zoning permit from the municipal council, and if the facility is subject to local planning requirements, the necessary planning framework, including a local development plan, must be established. The Danish Planning Act stipulates that municipal plans must include guidelines for the location of technical facilities, such as shared biogas plants. However, unlike biogas plants, the Planning Act does not explicitly require guidelines for the location of pyrolysis facilities. This can make the application process more complex, as project developers lack predefined siting guidelines for pyrolysis plants.

The construction of a pyrolysis plant usually requires an environmental permit, which may be issued by either the municipality or the Danish Environmental Protection Agency. Depending on the plant’s size and other environmental factors, an Environmental Impact Assessment (EIA) may be required, providing a detailed evaluation of environmental considerations related to the facility and its surroundings. Whether an EIA is necessary depends on factors such as the plant's size and specific environmental conditions. If required, the EIA forms part of the overall environmental approval process. The time taken to process applications for construction and operation approval varies by project and responsible authority.

Regulations on Biochar Application

Currently, spreading biochar on agricultural fields is generally prohibited. This is because biochar is covered by the pollution concept under the Environmental Protection Act, as its constituents could contaminate groundwater, soil, and the subsurface if present in high concentrations. However, certain types of biochar can be applied to farmland under a permit granted pursuant to Section 19 of the Environmental Protection Act, with local municipalities making such decisions. Biochar classified as waste may be applied under the Waste to Soil Regulation (affald til jord-bekendtgørelsen) if it originates from biomass specified in the regulation. This requires notification to the municipality before application. If the municipality does not prohibit the application it can proceed eight days after the application.

Although current regulations allow biochar application to agricultural land if its production, marketing, and use comply with applicable rules, navigating the relevant regulations can be challenging for both producers and users. Danish pyrolysis companies emphasize the need for clear and straightforward rules to quickly address regulatory barriers and avoid unnecessary delays in the market development for pyrolysis and biochar.

Additionally, the existing regulations risk increasing the administrative burden on municipalities if biochar is used on a larger scale, as each application requires an individual assessment by the municipality. Currently, this process often takes several weeks. In comparison, applying sewage sludge to fields can be notified to municipalities and spread without prior approval unless the municipality raises objections. Clear regulatory frameworks would therefore support administrative practices in municipalities and provide secure guidelines for both producers and users of biochar.

Box 6
Screening of Applicable Law for the Use of Biochar in Agriculture in Denmark

In connection with the preparation of the strategy, a screening of the applicable law regarding the use of biochar on agricultural land has been conducted. The screening highlights the following challenges:

- The use of biochar on agricultural land often requires a permit under Section 19 of the Danish Environmental Protection Act, where municipalities make local decisions regarding the specific use based on the biochar's composition and the specific area. Section 19 permits can be revoked, meaning producers and buyers of biochar do not have certainty that they can sell the biochar.

- The type of biomass used to produce biochar is currently decisive for the rules that apply to it. Specifically, the choice of biomass determines whether the biochar is classified as a product or as waste, which affects its use in agriculture. Therefore, some types of biochar can be applied to agricultural land according to the rules in the Waste to Soil Regulation, while other types of biochar are not covered, which is undesirable.

- Biochar that is fully or partially produced from animal manure falls under the definition of solid animal manure according to The Livestock Manure Regulation (husdyrgødningsbekendtgørelsen). This means that, when stored, it must be covered with a tight, waterproof material immediately after application during storage. This can complicate the handling of biochar in practice.

- Environmental and health risk thresholds and national requirements for harmful substances are not collected in one place but are set out in different legislation, which has not been specifically drafted with biochar in mind. This can complicate the development of consistent administrative practices regarding biochar.

Legislation that may be relevant to the production and use of biochar	
Legislation that may be relevant to the production and use of biochar	The Waste Incineration Regulation (Affaldsforbrændingsbekendtgørelsen)
	Waste to Soil Regulation (Affald til jord-bekendtgørelsen)
	Regulation on the content of cadmium in phosphorus-containing fertilizer (Bekendtgørelse om indhold af cadmium i fosforholdig gødning)
	The EU Animal By-Products Regulation (Biproduktforordningen)
	The EU Implementing Regulation (Gennemførselsforordningen)
	The Approval Regulation (Godkendelsesbekendtgørelsen)
	The Fertilization Regulation (Gødskningsbekendtgørelsen)
	The Fertilizer Application Regulation (Gødningsanvendelsesbekendtgørelsen)
	The EU Fertilizing Products Regulation (Gødningsforordningen)
	The Fertilizer Act (Gødningsloven (Lov om gødning og jordforbedringsmidler m.v.))
	The Fertilizer Regulation (Gødningsbekendtgørelsen)
	The Livestock Holdings Act (Husdyrbrugloven)
	The Livestock Manure Regulation (Husdyrgødningsbekendtgørelsen)
	The Mercury Regulation (Kviksølvbekendtgørelsen)
	The Environmental Assesment Act og Plans and Programmes and of Specific Projects (Lov om miljøvurdering af planer og programmer og af konkrete projekter (VVM))
	The Environmental Protection Act (Miljøbeskyttelsesloven)
	The Regulation on Organic Fertilizers and Soil Improvers with Animal Content (OGJ-bekendtgørelsen)
	The EU POPs regulation (POP-forordningen)
	The EU REACH regulation (REACH-forordningen)
	The EU Organic Regulation (Økologiforordningen)

Source: Danish Ministry of Climate, Energy and Utilities

Both the Fertilizer Application Regulation (gødningsanvendelsesbekendtgørelsen) and the Fertilizer Regulation (gødskningsbekendtgørelsen) have been adjusted in 2023 as a result of the conducted screening and stakeholder consultation. This has, among other things, led to biochar now being explicitly defined as a type of fertilizer in terms of the scope of application of these two regulations. However, the changes to these two regulations are considered insufficient to support the scaling up of a market for carbon storage via biochar.

The Danish Government's Initiatives

The Danish government proposes to clarify where pyrolysis plants can be established by amending the Danish Planning Act. This amendment will require municipalities to include guidelines for the location of pyrolysis plants when preparing municipal plans. The government aims for the proposed amendment to the Planning Act to take effect on January 1, 2025.

Furthermore, it is important to the Danish government to establish clear and straightforward regulatory frameworks for the use of biochar on agricultural land as soon as possible, grounded in robust scientific evidence.

To support this, the government has allocated funds for environmental studies to investigate the formation, content, and degradation of environmentally harmful substances during the pyrolysis process and biochar production. The studies will also assess the risks of leaking nitrogen, phosphorus, and harmful substances from biochar. The results will form the basis for government regulations on the use of biochar, expected to be implemented by mid-2026. A total of DKK 15 million from the Danish Research Reserve for 2023 and DKK 7 million from the 2024 Research Reserve have been allocated for these studies.

Preliminary results to inform environmental regulations for applying biochar on agricultural land are expected in 2025. The government is working toward establishing clear and simple regulations by mid-2026. This requires a dual-track approach over the coming years. The EU legal framework must be clarified, and the regulatory basis must be further developed and simplified, while the regulation should be established based on the results of the research trials that will be generated in the coming years. Consequently, new biochar regulations, such as a ministerial order on biochar with thresholds for substances in biochar applied to agricultural soil, are expected to take effect by mid-2026. The regulations must comply with EU law.

Until general national rules are established, enhanced guidance for municipalities and stakeholders will be provided from late 2024 to streamline administrative processing across municipalities.

The government emphasizes that regulatory frameworks must be developed in collaboration with the industry and other relevant stakeholders, as effective cooperation will support the commercialization of the pyrolysis sector. To this end, the government will establish a pyrolysis task force to coordinate implementation and address practical barriers.

Additionally, the government has initiated multi-year field trials to determine the long-term effects of using biochar on Danish agricultural soil. Contracts were signed with Aarhus University and the University of Copenhagen in early 2024. The aim is to investigate biochar's properties under Danish cultivation conditions, ensuring that soil quality and agronomic properties are not compromised. Assessing biochar's impact on nutrient supply and cultivation potential is also crucial to provide farmers with the best possible decision-making basis for adopting biochar. These trials, funded with DKK 63 million from the 2023 Research Reserve and DKK 14 million from the 2024 Research Reserve, will run from 2024 to 2028. Annual reports will be produced, allowing for adjustments to regulations if research results warrant it.

Box 7
Focus Area 1

The Danish government will:

- **Amend the Planning Act** so that, as of 1 January 2025, it will be mandatory for municipalities to establish guidelines for the site location of pyrolysis plants when revising and preparing municipal plans.

- **Investigate the formation, content, and degradation** of harmful substances related to biochar production as a basis for **establishing scientifically grounded environmental regulations**. This work began in December 2023 and is expected to be completed by mid-2026, with DKK 15 million allocated from the 2023 Research Reserve and DKK 7 million from the 2024 Research Reserve.

- Conduct **multi-year field experiments** to explore the scale at which biochar can be used in agriculture without unacceptable risks to the environment, nature, or agronomic conditions such as soil biology, nutrient availability, and crop yields. These studies will also evaluate biochar's **fertilization potential**. The studies will be initiated in 2024, and partial results will be reported annually. Funding includes DKK 63 million from the 2023 Research Reserve and DKK 14 million from the 2024 Research Reserve.

- Establish **clear and simple legal frameworks** for using biochar based on ongoing research. The government expects that the regulation can **be implemented from mid-2026**, insofar as it is possible within the framework of EU law. The regulation can be adjusted as needed based on subsequent research results.

- **Strengthen guidance** for municipalities with an advisory statement on § 19 permits from the Environmental Protection Agency to **streamline administrative processing across** municipalities, complemented by **information meetings** and/or **workshops** for stakeholders, environmental authorities, and other relevant actors.

- **Address practical barriers** by creating an **inter-ministerial pyrolysis task force** to coordinate the implementation of government initiatives and support the development of a future market for carbon storage via biochar. This task force will establish a NEKST implementation forum involving relevant external stakeholders and pyrolysis market actors.

- **Develop guidance materials** for environmental authorities **to facilitate approval processes** for establishing pyrolysis plants, including relevant listing points for pyrolysis plants related to the approval regulation, collection of emissions data from existing plants, and adjustments to the revised air guidance.

- Evaluate by late 2026, based on ongoing environmental studies, whether current **requirements for covering biochar stack piles in fields** produced from livestock manure can be eased.

The government's efforts to assess the environmental and agronomic effects of biochar application on Danish agricultural soil and to establish clear and simple regulations will consider existing research projects in the biochar sector.

4.2. Focus Area 2: Strengthened Incentives for Adoption

Under current regulations and expected market prices for pyrolysis oil, gas, and biochar, pyrolysis technology is not considered profitable enough to compete on market terms.

Carbon quotas and taxes on CO_2e emissions from the combustion of fossil fuels significantly impact the competitiveness of green pyrolysis oil and gas. The Agreement on a Green Tax Reform for Industry (Grøn Skattereform for Industri mv.) of June 24, 2022, introduced new frameworks for industries, incentivizing businesses to switch to non-fossil fuels such as pyrolysis oil and gas. This is because the overall tax level for energy products will increasingly comprise a CO_2 tax, from which pure biofuels and bio-based fuels derived from pyrolysis are exempt.

To achieve the ambition of making pyrolysis and carbon storage from biochar competitive under market conditions, several challenges must be addressed.

First, farmers currently lack sufficient incentives to apply biochar to their fields, as the revenue opportunities do not outweigh the associated costs.

Second, the EU's Renewable Energy Directive II (RED II) sets standardized CO_2e displacement values for various renewable fuels as part of its goals for renewable energy use in the transport sector. However, the directive does not establish specific displacement values for pyrolysis gas or oil used as biofuels. These values must be calculated for a given quantity of pyrolysis gas or oil, which among other parameters can significantly influence their market value.

EU Framework for Carbon Removal Certification

A common EU framework for carbon capture and storage could potentially support Denmark's climate targets in the short and long term.

Currently, EU regulatory frameworks are not adequately designed to promote technologies like pyrolysis for carbon capture and storage. Common certification standards could build credibility around the quality of carbon removal methods and facilitate private financing. In November 2022, the European Commission proposed a regulation for an EU certification framework for carbon removal, aiming to develop an appropriate certification tool to promote CO_2 capture and storage initiatives. A provisional agreement on this proposal was reached between the European Parliament and the Council in February 2024, and it was subsequently adopted by the Parliament on April 10, 2024. The Council is now set to formally approve the text, after which it will take effect.

Government Initiatives

The government and stakeholders in the Green Tripartite Agreement agree that Denmark should lead the way in addressing climate challenges in the agriculture and food sector. Accordingly, the parties also agree that the government should establish economic frameworks to accelerate the scaling-up of pyrolysis technology. This includes implementing a subsidy scheme starting in 2027 for the storage of biochar produced through pyrolysis. The scheme will focus on biochar stored in Danish agricultural soil, with support provided per ton of stored CO_2, subject to approval under EU state aid rules.

In line with the green tripartite agreement, the government will prioritize funding for further demonstration and development of pyrolysis technology leading up to 2030 through upcoming green innovation and research initiatives.

Additionally, the government will explore opportunities to use funds from the EU's Common Agricultural Policy (CAP) in the next reform period to support Danish farmers in adopting new technological measures, such as biochar via pyrolysis, thereby promoting the green transition in agriculture.

The Danish Energy Agency will provide guidance to fuel suppliers seeking to report the use of pyrolysis-based renewable fuels towards meeting the national CO_2 displacement requirements, provided the product meets the sustainability criteria outlined in RED II. In this context, fuel suppliers can utilize EU-approved voluntary schemes. For determining displacement values for pyrolysis gas and oil, producers can engage with EU-approved voluntary schemes and the producers' certification bodies to establish these values and achieve certification.

The Danish government advocates for an ambitious, credible, and cost-effective climate effort in the EU that supports both the government's goal of climate neutrality in Denmark by 2045 and the EU's goal of climate neutrality by 2050. Accordingly, the government is also working at the EU level to establish regulatory frameworks that support the sustainable expansion of carbon removal activities.

During negotiations on an EU certification framework for carbon removal, the government has worked to secure clearer guidelines for certifying biochar, including making it explicitly clear in the regulation that storing biochar could potentially be considered permanent carbon storage. The government generally supports the provisional agreement, which is expected to enhance the credibility and transparency of carbon removal certifications and potentially secure increased financing from private actors. This could contribute to Denmark's and the EU's climate efforts, for instance, by accelerating the adoption of pyrolysis technology.

Box 8
Focus Area 2

The government will:

- Work towards establishing a **subsidy scheme from 2027 for the storage of biochar** produced through pyrolysis. The subsidy will be granted for biochar stored in agricultural soil, based on the amount of CO_2 stored per ton.
  - Specifically work towards allocating DKK 0.2 billion in 2027, DKK 0.3 billion in 2028, DKK 0.4 billion in 2029, and DKK 0.6 billion from 2030 onwards, corresponding to a **total pool of approximately DKK 10 billion** towards 2045.

- Prioritize **funding for the demonstration and development** of pyrolysis technology leading up to 2030 in upcoming green innovation and research initiatives.

- Explore opportunities to use funds from the Common Agricultural Policy (CAP) in the next reform period to support the use of biochar for carbon storage in agricultural soil, thereby **promoting technological transition through EU agricultural subsidies**.

- **Provide guidance on displacement factors** for reporting pyrolysis gas or oil usage towards fulfilling national CO_2 displacement requirements.

- Support the European Commission's work on implementing a credible and appropriate **EU-wide certification system for carbon removal**.

- Make a proactive effort to establish **clear guidelines for the certification of biochar**.

4.3. Focus Area 3: Climate Impact and Emissions Inventory

In a climate context, changes in soil carbon content are accounted for as part of the overall Land Use, Land Use Change and Forestry (LULUCF) inventory, which covers soils, land areas, and forests. The LULUCF inventory is included in Denmark's annual reporting of greenhouse gas emissions to the UN in accordance with IPCC guidelines.

Currently, there are three challenges related to incorporating the climate impact of biochar from pyrolysis into the Danish emmisions inventory, which the government aims to address through this strategy and work program.

First, biochar cannot yet be included in the national emissions inventory, as there is no existing calculation method capable of accounting for the addition of biochar to agricultural soil. This is because the IPCC has not yet established standardized methods for calculating the climate effect of incorporating biochar into soil, leaving the responsibility for developing such methods to individual countries.

Second, the IPCC assumes a high level of greenhouse gas emissions, particularly methane, during biochar production, based on a simplified production process. However, it is currently believed that modern pyrolysis plants operating under Danish conditions will emit negligible amounts of methane. In the absence of a national emission factor and plant-specific data on methane emissions, the default assumption would be based on the IPCC's standard emission factor, which underestimates the overall climate effect of carbon sequestration through biochar. Therefore, there is a need to investigate and document whether, and to what extent, biochar production under Danish conditions emits greenhouse gases.

Third, other forms of aboveground or subsurface storage of biochar—such as in storage facilities, building materials, or similar applications—are currently not covered by IPCC guidelines. Therefore, these uses of biochar cannot contribute to achieving Denmark's climate targets.

Government Initiatives

The Danish Ministry of Climate, Energy, and Utilities has initiated preparatory work to develop a method for including the climate effect of biochar in the national emissions inventory. This work began in 2024 and is expected to be completed by 2026. Once completed, the climate effect of applying biochar to agricultural soils can be included in Denmark's emissions inventory. To document the climate effect, a system for measurement, reporting, and verification (MRV) will be established, where farmers and/or pyrolysis producers can report relevant activity data related to biochar application. Additionally, it is expected that the climate effect will contribute to meeting Denmark's reduction targets under the LULUCF regulation.

Emissions associated with the use of pyrolysis oil and gas for energy purposes are currently accounted for at the point source where the oil or gas is utilized. However, aboveground storage of biochar—for example, in building materials—cannot be included in the fulfillment of Denmark's climate targets.

The IPCC can regularly update or refine its guidelines for emissions inventories. It has recently started the seventh cycle (2023–2030). In the work program, member states have tasked the IPCC with producing a methodological report on emissions inventories for negative emissions (Carbon Dioxide Removal Technologies), scheduled for completion in 2027. This marks an important first step in Denmark's efforts to ensure that the IPCC develops methods for accounting negative emissions. Denmark is actively advocating for the inclusion of pyrolysis and biochar storage in the report. As part of this effort, the government will launch a knowledge synthesis in 2024 to examine the advantages and disadvantages of alternative uses of biochar beyond soil application.

To investigate and document whether and to what extent biochar production under Danish conditions emits greenhouse gases, the government has allocated DKK 1 million from the 2023 Research Reserve. This work is expected to be completed by 2025. As long as there are only a few facilities, it is anticipated that direct emissions measurements from individual pyrolysis plants can be incorporated into Denmark's emissions inventory. As pyrolysis production scales up, developing a Danish emission factor for methane emissions from biochar production is expected to be the most practical approach. Based on the findings of these studies, the government will decide whether to introduce regulations on greenhouse gas emissions from pyrolysis plants. This need will be assessed in 2025. Should regulation of methane emissions from pyrolysis plants be deemed necessary, such regulation could take effect in 2027.

Box 9
Focus Area 3

The government will:

- Initiate the development of a method to ensure that the **climate effect of biochar when stored in agricultural soil can be included in the Danish** emissions **inventory starting in 2027**. The method must be approved by the Danish Centre for Environment and Energy (DCE), which is responsible for reporting Denmark's emissions inventory to the UN. This will be part of the method development process. Once approved, the climate effect can be included in the inventory if accepted by the UN review panel.

- Conduct measurements of greenhouse gas emissions during biochar production, including methane emissions, to **investigate and document emission levels.** The project, financed by DKK 1 million from the Research Reserve, began in 2023 with a contract awarded to a company responsible for the measurements. The initiative is expected to be completed in 2025, after which the need for methane emission regulation from pyrolysis plants will be assessed.

- Actively work to ensure that **the IPCC develops an accounting method for alternative biochar storage options**. The first step was the decision to prepare a methodological report on negative emissions, expected in 2027. Subsequently, Denmark will work to secure member state agreement that the report should include pyrolysis and biochar storage.

- Produce a knowledge synthesis in 2024 to **examine the advantages and disadvantages of alternative uses of biochar** beyond soil application.