Danish Energy Agency

Technology Brief

New chapters on fast pyrolysis, slow pyrolysis and bio-oil upgrading (February 2026)

The Danish Energy Agency has published updated Technology Catalogue chapters on pyrolysis. The revision was necessary because large differences in the assumptions for pyrolysis were identified between the old chapter and other studies. Moreover, a scoping analysis done for the DEA identified that all the pyrolysis chapters require an update and restructuring, particularly slow, fast and catalytic pyrolysis.

The update of the pyrolysis chapters involves the removal of the old chapters, namely the Pyrolysis Oils, Slow Pyrolysis, Catalytic Hydropyrolysis and Methane Pyrolysis and the replacement with the following chapters:

- Pyrolysis Overview
- Fast and Catalytic Pyrolysis
- Slow Pyrolysis
- Upgrading of biocrudes

Across the package of updates, the new version of the chapters brings updated cost and technical data, more technology data sheets split between biomass inputs and plant sizes and information on energy usage for the preconditioning of biomass (drying and palletisation) previously not assessed.

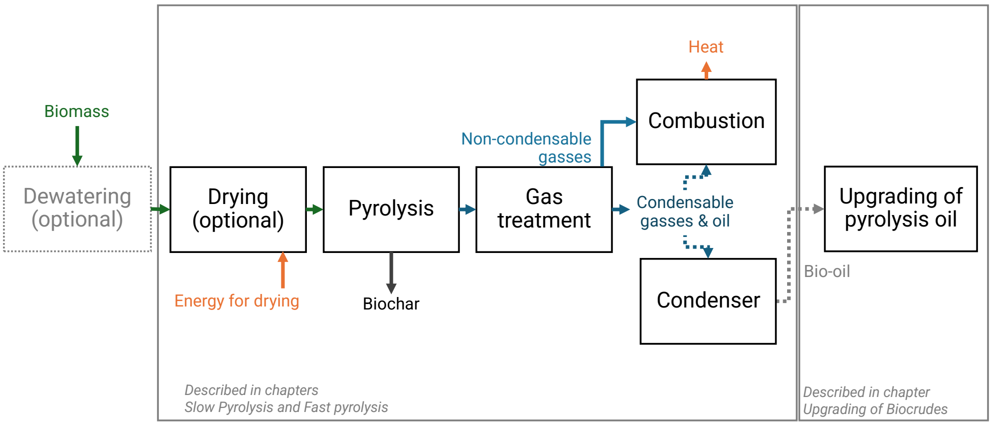

Figure 1: Simplified flowsheet for the pyrolysis process main process stages following the biomass from input to end products. Electricity will be needed for the operation of machinery used in the process.

There are significant differences between the two archetypes of pyrolysis described in the update. Fast and catalytic pyrolysis is generally characterised by the production of biooil as primary product, short residence time of biomass in reactor

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(hence the name) and high operating temperatures (450 – 600°C). Slow pyrolysis is characterized by the production of biochar as primary product, longer residence time and a wider range of operating temperatures (300-700°C).

Major changes in updated Technology Catalogue

Based on the latest publicly available data and newest projects, the updated pyrolysis chapters give an up-to-date perspective on technical and economic assumptions behind the expected future development of the technologies accounting for latest information on Danish first-of-a-kind commercial plant.

Fast and catalytic pyrolysis

The chapter was last updated in 2018 using data from demonstration plants. Technology has progressed since, but few plants commercial plants exist, still indicating uncertainties with performance, scalability and cost competitiveness. With this background, the update handles the fast and catalytic pyrolysis of wood and the fast pyrolysis of straw.

Fast pyrolysis is now estimated to have higher pyrolysis oil yield per unit biomass input than previously described (+10-15%), and investment costs in real terms lower by 30% in 2030, while this difference reduces to 5% towards 2050 compared to the old catalogue.

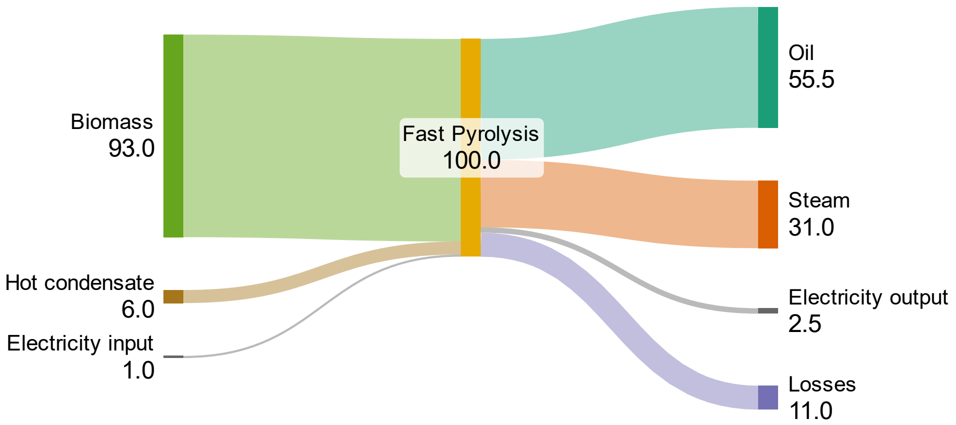

Figure 2: Energy balance based on BTG's Empyro plant in Hengelo

The chapter has also been expanded to include catalytic pyrolysis, a variation of the fast pyrolysis that uses a catalyst to reduce the amount of oxygen in the pyrolysis oil, therefore improving its quality. The technology has a TRL of 7, meaning it has reached pre commercial demonstration scale. This type of pyrolysis is however significantly more expensive than fast pyrolysis due to the use of catalyst and lower oil yield per unit of biomass.

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Slow pyrolysis

The chapter was last updated in 2022. The new chapter goes into greater details on energy and carbon balances and updates economic and technical data.

There are new datasheets on large garden waste pyrolysis and a breakdown of straw and biogas digestion plants into small and large plants. Compared to the old iteration, the chapters now show lower investment costs by 35-45% in real terms for large straw pyrolysis plants. The plants also show increased production of biochar (+5%), even though this marginally reduces the production of pyrolysis gas and oil compared to the old chapters. The biogas digestate plants also appear cheaper to invest in by 15-30%, but show a similar biochar production as in the old catalogue.

Biochar is the main product from slow pyrolysis plants, as most of the carbon from the biomass that is not used for own consumption is converted into biochar. This applies in particular to plants using biogas digestate, which have higher own consumption than previously estimated in the old catalogue. In practice they only supply biochar and process heat as an output of the low-value pyrolysis gas.

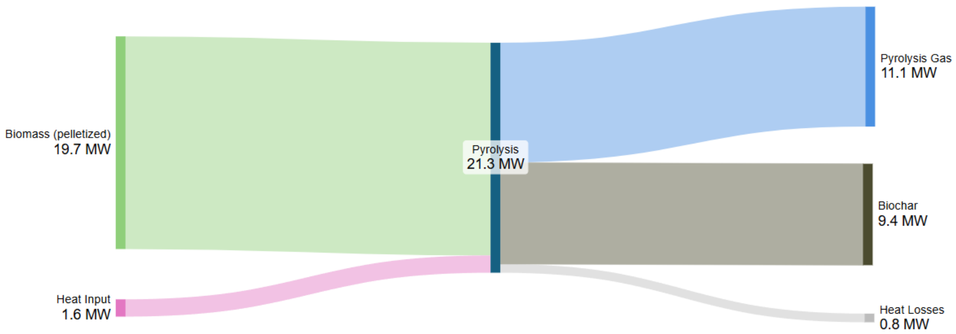

Figure 3: Sankey diagram displaying the energy distribution in the core pyrolysis process for a 20 MW biomass input. The diagram illustrates the conversion of biomass into gas and biochar. The pelletized input biomass has a water content of 10 wt%.

Upgrade of biocrudes

A new chapter on the upgrade of biocrudes was added with this update. This chapter is an extension of the chapters on fast and catalytic pyrolysis, slow pyrolysis (straw plants) and hydrothermal liquefaction (HTL), all producing a biooil that can be further prepared intro a drop-in fuel. To produce drop-in fuels from biocrudes, advanced processing is required. This involves pretreatment and upgrading steps, as shown in Figure 4. The characteristics of biocrudes from each technology (slow/fast/catalytic/HTL) differ substantially, same as depending on the type and quality of the feedstock used.

Most upgrading technologies yield a mix of fuel types, including fractions suitable for diesel, jet fuel, and sometimes naphtha. Experimental results show that 79% to 87% of the initial energy from the reactants (converted hydrogen and bio-oil) can be retained in the upgraded oil phase, depending on the upgrading pathway and biooil characteristics.

The upgrading of biocrudes into drop-in biofuels remains under active research, with technologies at an early development stage at TRL 2-5. It is estimated that the actual initiation of standalone upgrading of pyrolysis oil will realistically take place between 2030 and 2035. Due to the infancy of the technology, there are no datasheets attached for this chapter.

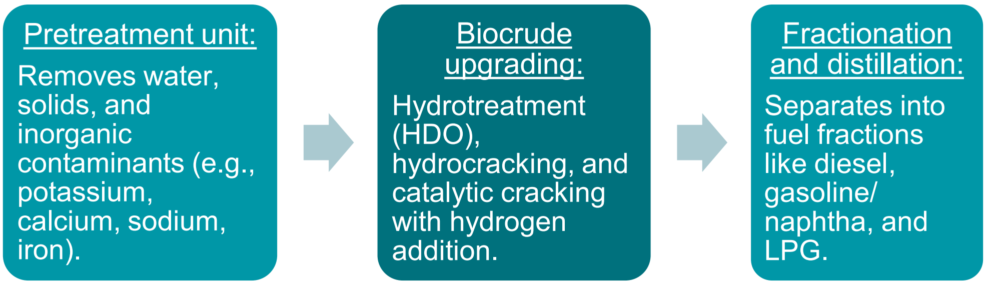

Figure 4: Steps required to prepare biocrudes for use as drop-in fuels

Perspectives for Denmark

Several countries show similar interest in pyrolysis, but differ in which specific technologies they focus on. In Finland, Sweden, Netherlands or North America the focus is on fast and catalytic pyrolysis due to the interest in biocrudes and upgrading. In Denmark, the focus is almost solely on slow pyrolysis, due to its carbon removal and storage potential and potential impact on climate targets. There is a particular interest on pyrolysis plants using biogas digestate, due to the numerous biogas plants in the country.

A challenge with pyrolysis is to ensure steady access to the required quantities and qualities of biomass. Biomass is a limited feedstock in demand by several users, in particular for straw and woodchips. Placement of the plants is essential, due the access to biomass and the potential heat symbiosis with other energy installations. Furthermore, pyrolysis plants will need to overcome technical challenges to achieve sufficient operating hours to increase profitability.