Task 1.3.1 – Biogenic carbon for Methanol

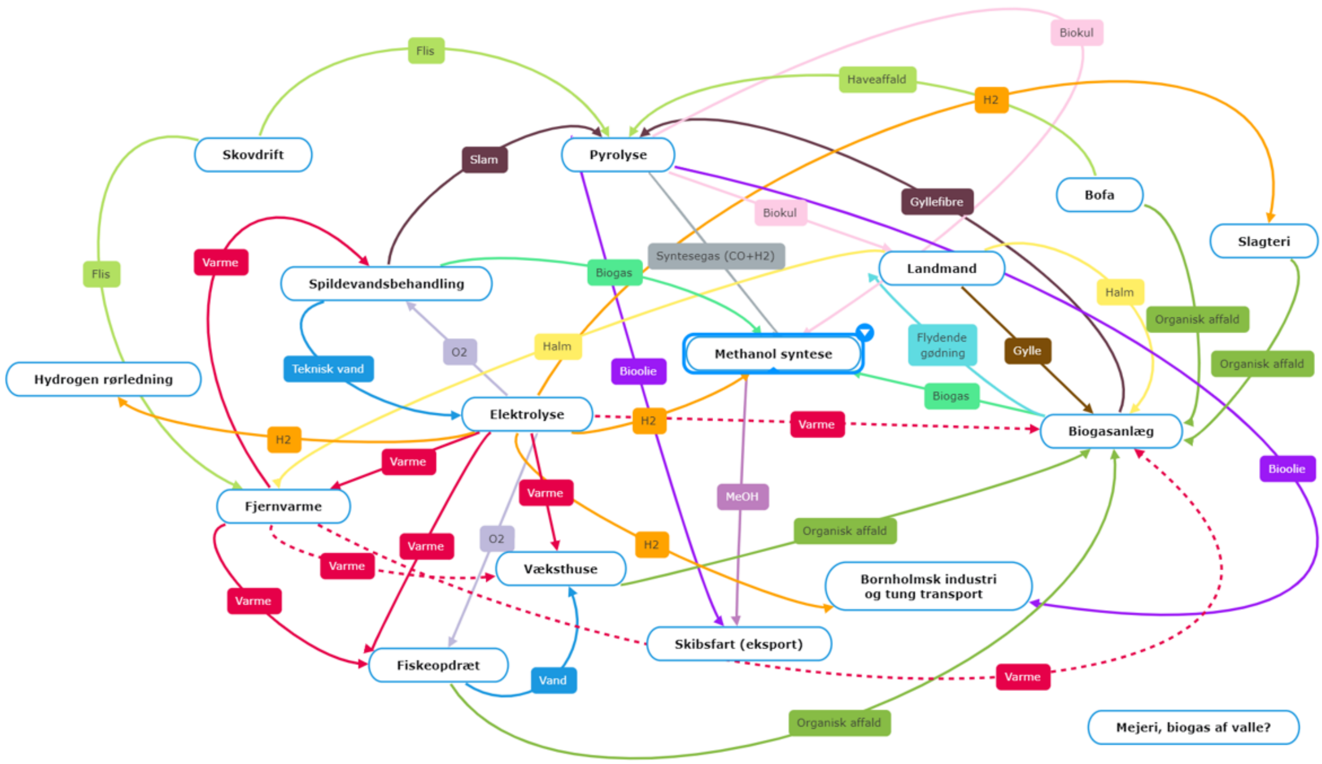
The task includes mapping all potential biomass streams that could feed into a methanol production, either via increased biogas production or as syngas from pyrolysis:

- A mapping of all biomass streams available
- Quantification of the different biomass streams
- A Sankey diagram with respective shares of different biomasses
- An update of the WP1 report with the findings in WP1.3

1.3.1. – Background

In task 1.3 the availability of CO2 on Bornholm was investigated. Both the baseline for CO2 availability and the possibility to increase the amount by increasing the production of biogas.
It was concluded, that in 2030 the most reliable and continuous source of biogenic CO2 is from the biogas plant – Bigadan's plans of increasing the biogas production, and separate the CO2 from the methane, will increase this CO2 source from app 5.000 tons/year to app. 20.000 tons/year if the plans are successful.
In Task 1.3.1 we have a different focus: *How much biogenic carbon for Methanol is available*, when we quantify all the different biomass streams available.

1.3.1. – Mapping of biomasses for Methanol production on Bornholm



Dependencies of biomass streams for methanol production (mapped by Maja Felicia Bentzen, Rønne Harbor)

The current biogas production via digestion on Bornholm, and description of a case for upgrading CO2 from Biogas combustion (in CHP) to Methanol:

In the EU Horizon project, INSULAE, DTU in Deliverable 6.4 has described the current production of biogas on the local Biogas Plant, Bornholms Bioenergi, and a case for upgrading CO2 to Methanol:

"3.2.2 Assessment of biogas and methanol production
The biogas production process starts with the delivery of slurry from local farmers on Bornholm that live in close vicinity to the plant. Deliveries take place around 60 times a week on working days, i.e., around 12 deliveries each day from Monday to Friday, with an average driving distance of 13.8 km. One delivery comprises on average 36 tons of, e.g., animal slurry or slaughterhouse waste. The average price the biogas plant must pay is around 2 € per ton of slurry. By processing local organic waste, the biogas plant contributes to the island's decarbonization. In the current structure of the plant, the average substrate composition consists of 70.48 % cow slurry, 19.82 % of pig slurry, 6.17 % of slaughterhouse waste, 3.30 % of corn and 0.22 % of fish waste, with an average percentage of total solids in the feedings of 12–14 %. The island of Bornholm possesses a large feedstock potential both from animal husbandry, household wastes, and secondary crops which is currently not fully exploited: from a total estimated amount of 741,425 tons the biogas plant currently has a permission to treat only 120,000 tons per year ….

Upgrading to methanol (MeOH)
An alternative to the upgrading to SNG could be the upgrading to methanol (MeOH, chem.: CH3OH). Methanol is discussed as potential motor fuel, e.g. for ferries, to offset the use of CO2-intensive diesel or marine diesel. As the largest shipping company worldwide, Mærsk has recently ordered new container ships with two-stroke engines running on methanol. For the sake of providing a reference, the amount of methanol that can be produced from the operation at Bornholm's Bioenergi biogas plant is investigated in this section. It is assumed here that the CO2 of the combustion process of biogas can be captured and reutilised for methanol production. The combustion of 1 m^3 biogas releases approximately 1.8 kg of CO2. With a monthly production of biogas of 750,000 m^3 and presuming that all biogas will be burned in the generators, a maximum amount of 1,350 t CO2 will be released within one month. If presuming a 9 MW electrolyser to be installed on-site, analogously to the previous examination, approx. 120 t H2 can be produced. Based on the mass balance, 120 t H2 can react with 856.25 t CO2 which corresponds to capturing 63.43 % of the CO2 released from the burning process. Considering these input values, 625 t MeOH can be produced which corresponds with a density of 0.79 kg/l to 791,139 litres of MeOH. The electrical energy needed for the electrolysis – approx. 6,655 MWh. Methanol has an energy content of 16 MJ/l. Hence, the produced 791,139 litres of MeOH hold 3,516 MWh, being around 53 % of the input energy. To give a reference of the potential offset of marine diesel in the case of Bornholm, the produced methanol is compared with the energy requirement of the ferry connecting Bornholm with the mainland of Sweden. The seaborne passenger transportation is a large contributor to the island's GHG emissions. ….. In a month, approximately 1668 t of fuel are consequently used for the seaborne passenger transportation from and to the island of Bornholm. As calculated above, around 625 t of MeOH may be produced from the biogas. Considering that MeOH with around 16 MJ/kg has a lower energy content than marine diesel (42 MJ/kg), approximately 2.6 times the amount of MeOH must be used in the ferries for the same energy requirement. This would result in a requirement of 4337 t of MeOH to substitute the monthly requirement of the ferry. The 625 t MeOH produced at the ferry would hence provide only a share of 14.41 %. In other words, the ferry could be fuelled only in 4.3 out of 30 days in a month with the generated MeOH – presuming that a one-toone transition of fuel in the ferry's engines is possible. Aiming to fuel only the five trips going from Bornholm to the mainland, the generated MeOH can accordingly cover a share of 28.82 %."

The process of utilizing the CO2 fraction from biogas, combined with Hydrogen from electrolysis, for Methanol production, has just been commercialized in DK with European Energy's new Methanol plant in southern Jutland (https://europeanenergy.com/green-solutions/ptx/)

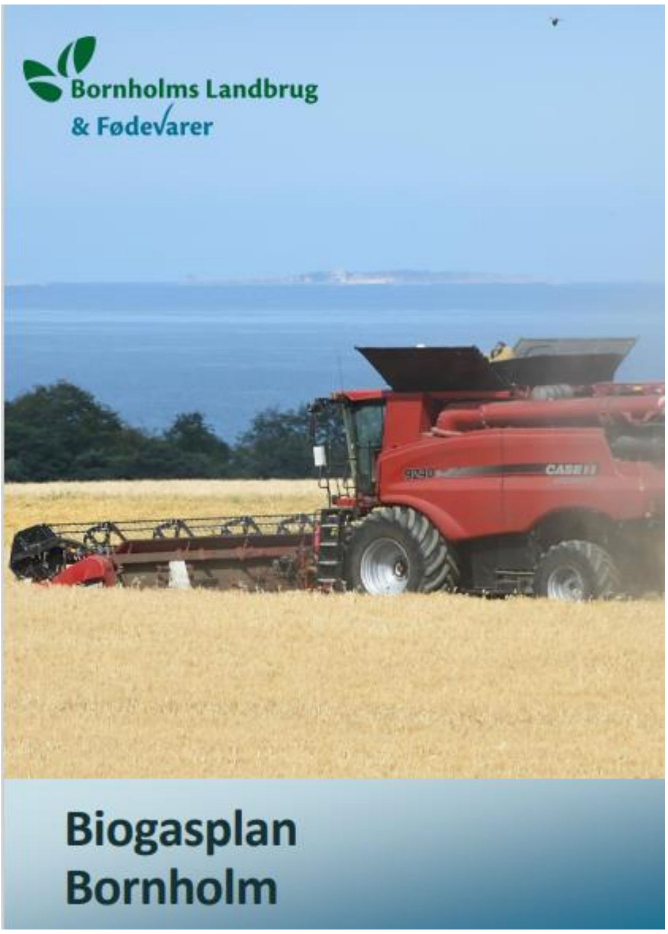
A couple of Demo's of how to convert Biogas (Methane + CO2) to Methanol are ongoing in DK: At Lemvig Biogas plant (https://lemvigbiogas.com/wp-content/uploads/2021/02/Nyhedsbrev_90-2020.pdf) and at Foulum research station (https://fortesmedia.com/files/files/Doc_Pack/h2p2x/Power_upgrade_of_Biogas_-_H2_and_P2X_Copenhagen_June_2022.pdf)

In March 2023 the lokal farmers organisation, BLF (Bornholms Landbrug og Fødevarer), published: ”Biogasplan Bornholm” (https://www.blf.dk/projekter/biogasplan-bornholm)

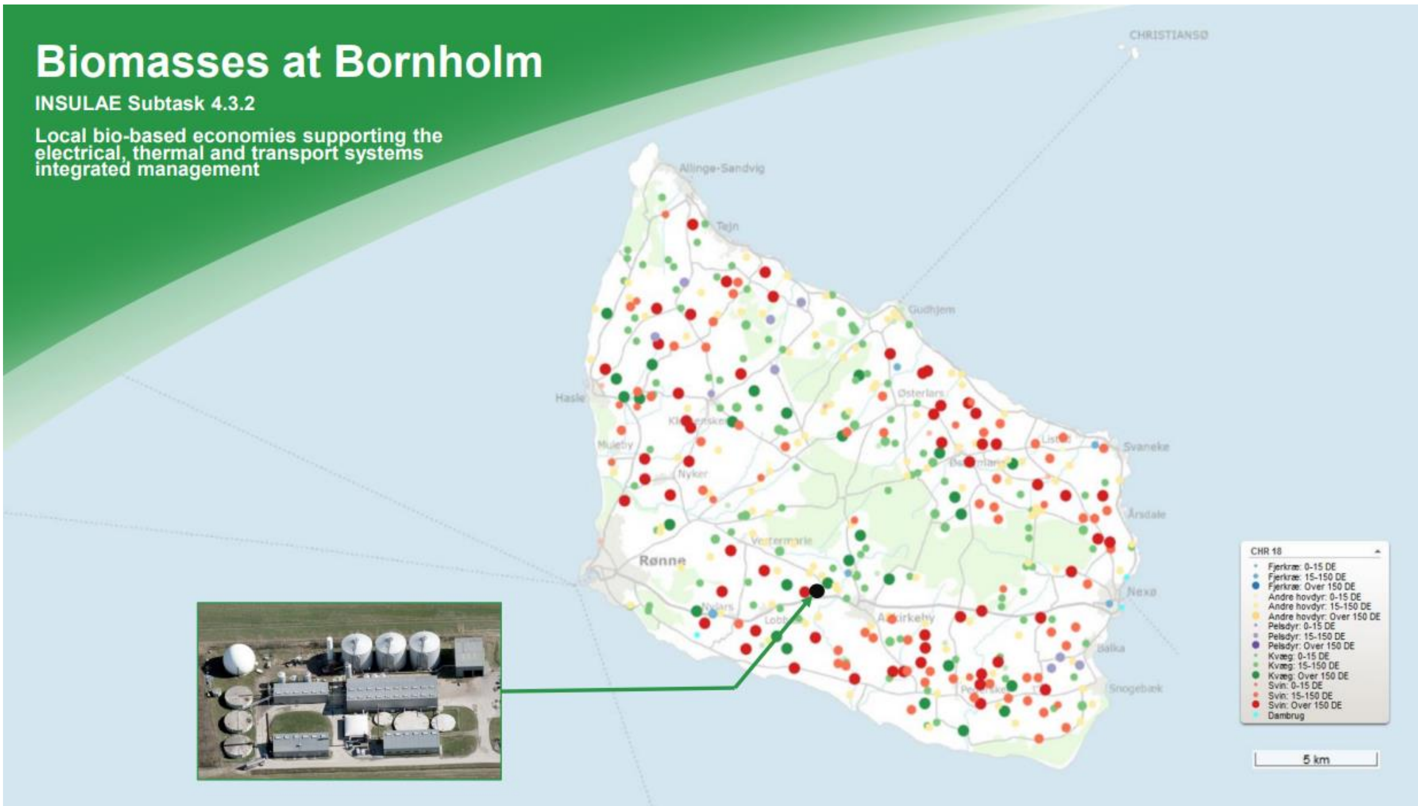
The vision of the plan is: "to scope how a significantly higher biogas production can be created on Bornholm, how this production takes part and is included in the general green transition on Bornholm." (Paige 3)

"With the existing biomass, Bornholm has the potential to produce up to 4 times more biogas and thus far more biogas for e.g. LBG (Liquified Biogas), CBG (Compressed Biogas) and included in the production of methanol. These are fuels that the heavy transport sector, shipping, traffic, and industry on Bornholm will soon need" (Paige 4).

The aim of the plan is to increase the Biogas production from 1,000,000 m3/year to 30-35,000,000 m3/year, mainly by utilizing a large part of the straw produced in agriculture on Bornholm as source of organic carbon,



Biogas plan Bornholm is the strategic frame for the application to the municipal council to increase the production on the local Biogas plant: “Bornholms Bioenergi” by the owners, Bigadan Aps. The municipal council decided the 21. September 2023 to begin the physical planning process to make it possible to rebuild the plant and increase the production according to the application.



The tables of available biomasses on Bornholm (below), and their biogas potentials, is mainly taken from the report: Biomasses at Bornholm, that was produced in the EU Horizon 2000 project: INSULAE, by FREMSYN Aps. (INSULAE subtask 4.3.2)

Here, for the sake of maximising the possible production of Methanol, the different biomass streams are placed in two categories:

- **Suited for biogas production via digestion**
- *all the biogas produced is assumed to be converted to Methanol and the necessary hydrogen for optimization of the process is produced by electrolysis.*
- **Suited for pyrolysis**

all the syngas produced is assumed to be converted to Methanol and the necessary hydrogen for optimization of the process is produced by electrolysis.

Biomass for digestion	Potential source [tonnes/year]	Biogas yield Nm3/tons	Biogas potential [1000 m3/year]	"Biogasplan Bornholm" m3/year
Liquid manure	547.530	20	11.000	X
Deep litter	29.700	89	2.500	X
Horse stable deep litter	?	?	?	
Sludge (dry matter)	2.400	130	300	
Seaweed (15% sand)	3.000	40	100	
Straw	88.480	355	31.500	X
Secondary crops	4.450	39	200	
Landscaping	2.195	76	1.107	
Garden waste	8.920	76	2.285	
Slaugterhouse waste	9.000	350?	3.150?	X
KOD	2.350	152	400	
Deiry waste (as COD)	5.000	350	1.750	
Total	703.025		54.192	30-35.000

Biomass for pyrolysis	Potential source [tonnes/year]	syngas yield Nm3/tons	Syngas potential [1000 m3/year]	Biochar yield m3/year
wood chips	50.000	Proces dependent	Proces dependent	Proces dependent
Wood waste	4.550	Process dependent	Process dependent	Process dependent
Digestat dry matter *	70.000	Proces dependent	Proces dependent	Proces dependent
Total	124.550	Proces dependent	Proces dependent	Proces dependent

*Digestat dry matter is here assumed to be 10 % in average.

PYROLYSIS

Refinement of syngas from pyrolysis of organic matter is another realistic pathway for Methanol production.

Pyrolysis is entering the commercial phase in Denmark, with a full-scale version (20 MW) of Stiesdals SkyClean pyrolysis process, that is under construction in northern Jutland. The nearby Biogas plant shall supply digested dry matter (fibers) to the pyrolysis process. However, the focus of this new plant is to produce biochar for carbon storage in agriculture, and not green fuels.

On Agri Energi Vrå's homepage (https://agrienergy.dk/anlaegget/) is the foto below of the new plant: " Agri Energy Vrå's SkyClean-plant will be able to treat 40.000 tons fibers and produce 14.000 tons biochar. The production of biochar alone corresponds to removal of app. 26.000 tons CO2 from the atmosphere per year."

In the publication: Thomsen, T. - Introduction to Production and Use of Biochar, working towards a more circular and bio-based Danish economy. (Roskilde Universitet, 2022), the process of Methanol production from pyrolysis is illustrated:

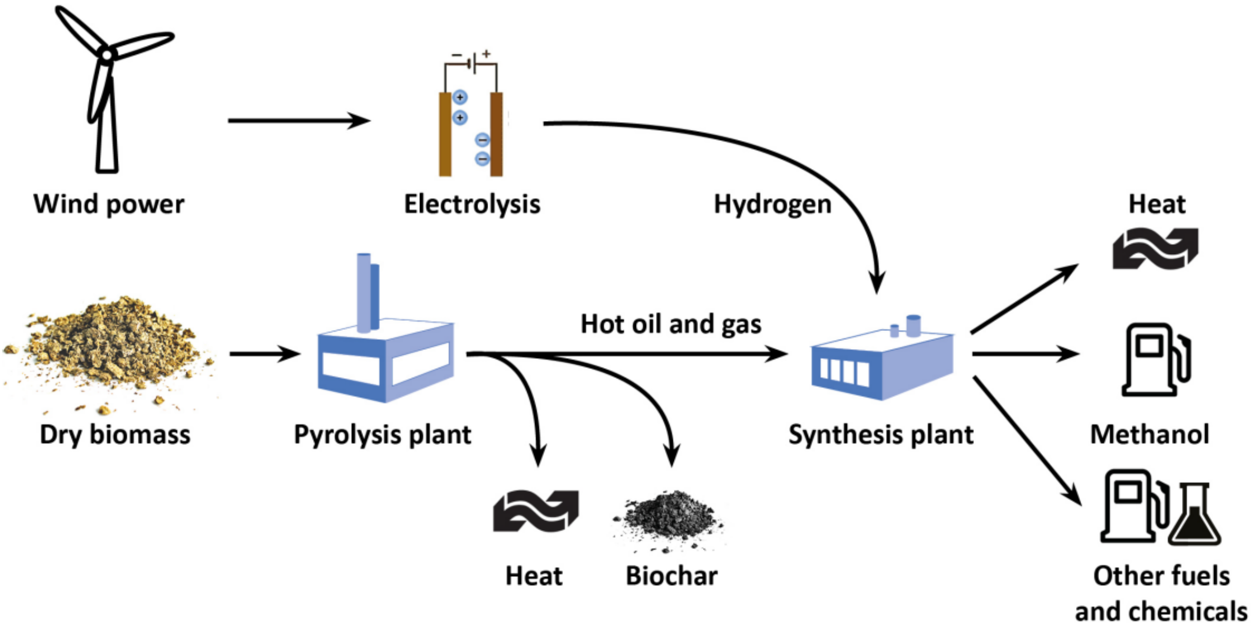


Figure 19: *Conceptualization of a system with (dry) biomass pyrolysis for the production of biochar, heat and advanced fuels and chemicals. Illustration by the author.*

In the same publication is shown a simplified table of the relation between pyrolysis temperature and the different yield of main products:

	Liquid product (bio-oil)	Solid product (biochar)	Gas product (process gas)
Fast Pyrolysis Moderate temperature (> 500 °C) and short vapor residence time (< 2 sec)	75% (25% water)	12%	13%
Intermediate Pyrolysis Low-moderate temperature (< 500 °C) and moderate vapor residence time	50% (50% water)	25%	25%
Slow Pyrolysis Low-moderate temperature (< 500 °C) and long vapor residence time	30% (70% water)	35%	35%
Gasification High temperature (> 800 °C) and long vapor residence time	5% (5% water)	10%	85%

Simplified correlation between pyrolysis process design and product mass yield. Data from the report "Biomass Pyrolysis" under IEA task 34, prepared by Professor Tony Bridgwater from Aston University, UK