IEA Bioenergy
Technology Collaboration Programme

Task 34
Direct Thermochemical Liquefaction

BIOENERGI TIL HELE VERDEN – NYT FRA DANMARKS REPRÆSENTANTER I IEA BIOENERGY
22ND JANUARY 2025

DANIELE CASTELLO

AALBORG UNIVERSITY
DENMARK

EUDP

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IEA Bioenergy Task 34 in a nutshell

- Develop **Biofuel standards** to support commercialization of DTL technologies.
- Validate and standardize **analytical methods** for thermally liquefied biomass
- Encourage **exchange of information** with our stakeholders
- Support **technoeconomic assessment** of biomass liquefaction technologies

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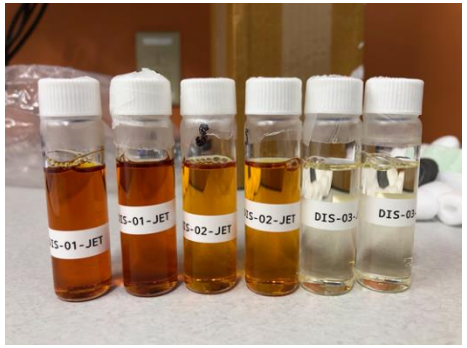
Direct thermochemical liquefaction

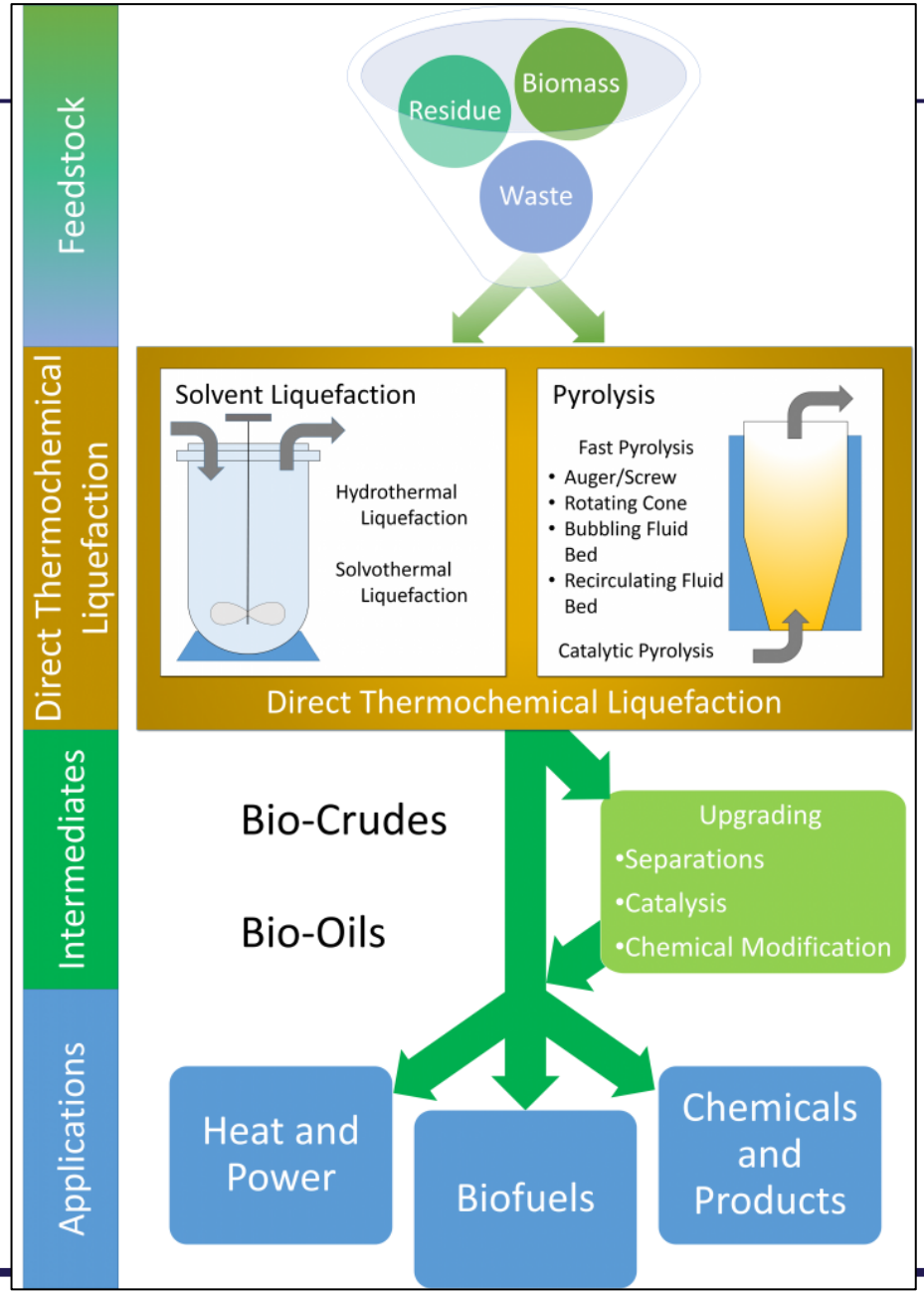
- Biomass to liquid products
- Direct conversion into liquids (intermediates)
  - Pyrolysis
  - Hydrothermal liquefaction
  - Solvothermal liquefaction
- Conversion of intermediates to final products
- Management of side streams

Biomass

Liquefaction



Upgrading



Reports published in this triennium (so far…)

task34.ieabioenergy.com/task-34-reports/

Technical Notes	Year	Author
Assessment of individual compounds for DTL oil safety aspects	2022	Funke, A.
Technical note mass balances	2022	Funke, A.

Title	Year	Author
Flexibility by fast pyrolysis in renewable energy systems	2024	van de Beld, B.; Leijenhorst, E.
Production of Chemicals and Materials from Direct Thermochemical Liquefaction	2024	Thorson, M.; Howe, D.; Valdez, P.; Herren, H., van de Beld, B.; Funke, A., Castello, D.
Gasification of Liquids derived from Direct Thermochemical Liquefaction	2023	van de Beld, B.; Leijenhorst, E.; Fleck, S.; Funke, A.
Commercial status of direct thermochemical liquefaction technologies	2023	Collard, F.-X.; Wijeyekoon, S.; Bennett, P.
Registration of DTL products and derivatives	2023	Van de Beld, B.; Herres, H.
Electrochemical upgrading of bio-oils	2022	Song, B.; Collard, F.-X.; Kirk, T.: Vellacheri, R.: Sandström, L.: Johannsson, A.; Venderbosch, R.; Lopez-Ruiz, J.

Aalborg University as NTL

AAU ENERGY

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Daniele Castello
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- World-class expertise in HTL
- Task on hydrogen utilization
- Task on direct use of biocrude as a fuel
- National country report (*will be published soon*)
- Several articles on PyNe newsletter
- Networking events

EUDP
Grant no. 134-21040

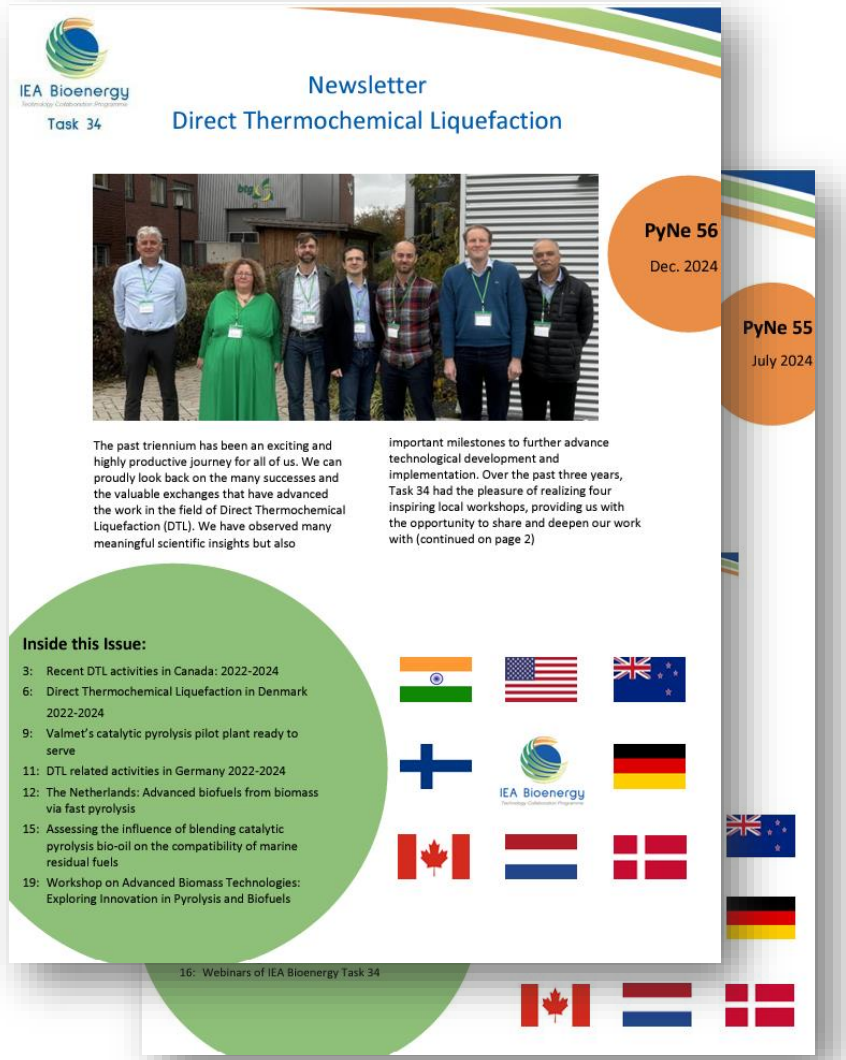
PyNe newsletter

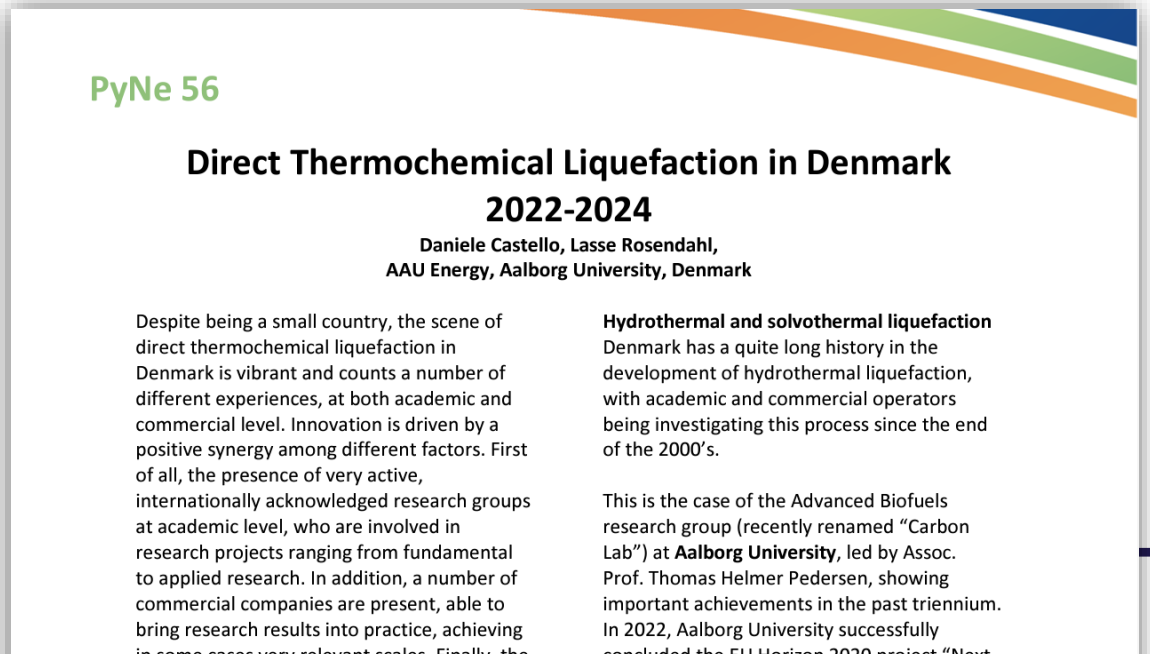
PyNe is the official newsletter of IEA Bioenergy Task 34

Published twice per year

A Denmark-related article in each issue

task34.ieabioenergy.com




PyNe 56

Direct Thermochemical Liquefaction in Denmark 2022-2024

Daniele Castello, Lasse Rosendahl,
AAU Energy, Aalborg University, Denmark

Despite being a small country, the scene of direct thermochemical liquefaction in Denmark is vibrant and counts a number of different experiences, at both academic and commercial level. Innovation is driven by a positive synergy among different factors. First of all, the presence of very active, internationally acknowledged research groups at academic level, who are involved in research projects ranging from fundamental to applied research. In addition, a number of commercial companies are present, able to bring research results into practice, achieving

Hydrothermal and solvothermal liquefaction

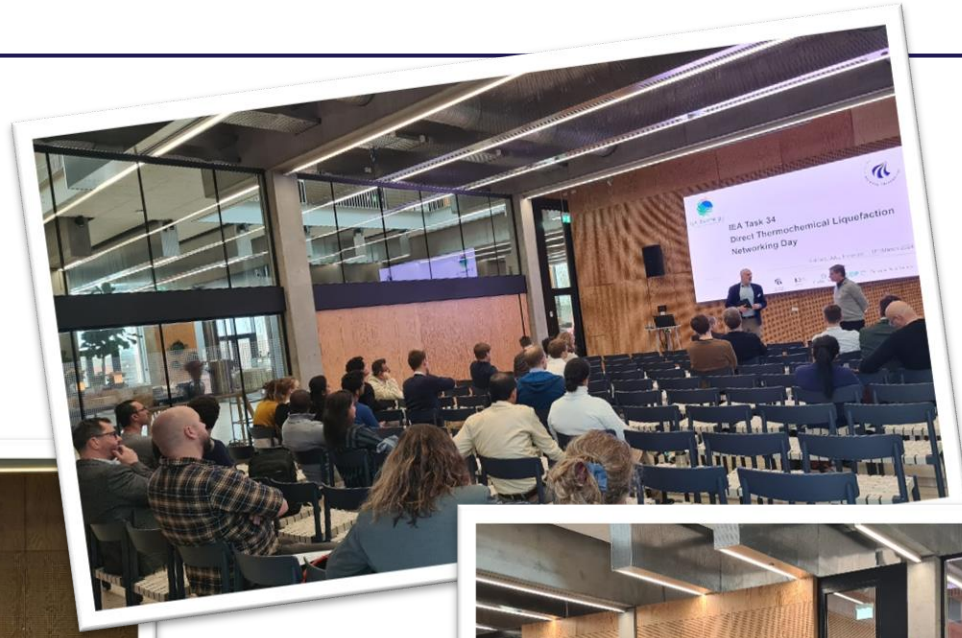
Denmark has a quite long history in the development of hydrothermal liquefaction, with academic and commercial operators being investigating this process since the end of the 2000's.

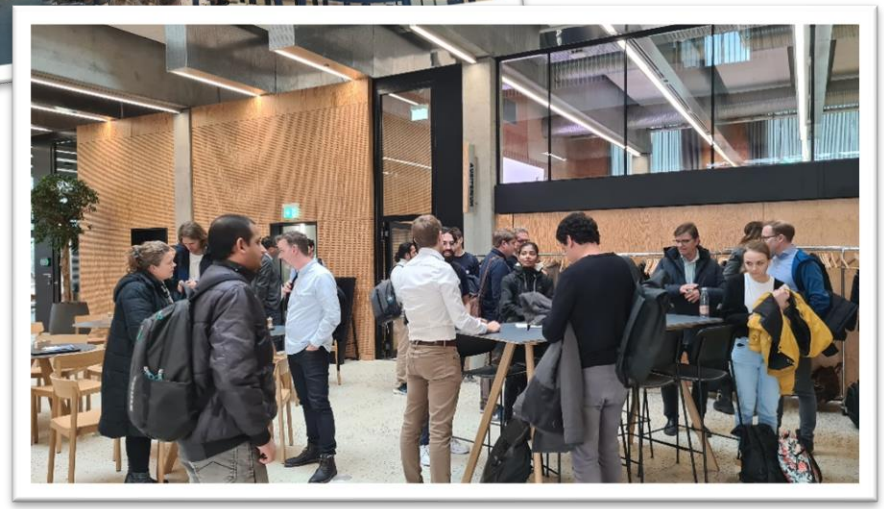
This is the case of the Advanced Biofuels research group (recently renamed "Carbon Lab") at **Aalborg University**, led by Assoc. Prof. Thomas Helmer Pedersen, showing important achievements in the past triennium. In 2022, Aalborg University successfully

National networking event

Danish National Networking Day on Direct Thermochemical Liquefaction

Aalborg, 11th March 2024





AALBORG UNIVERSITY

Energi

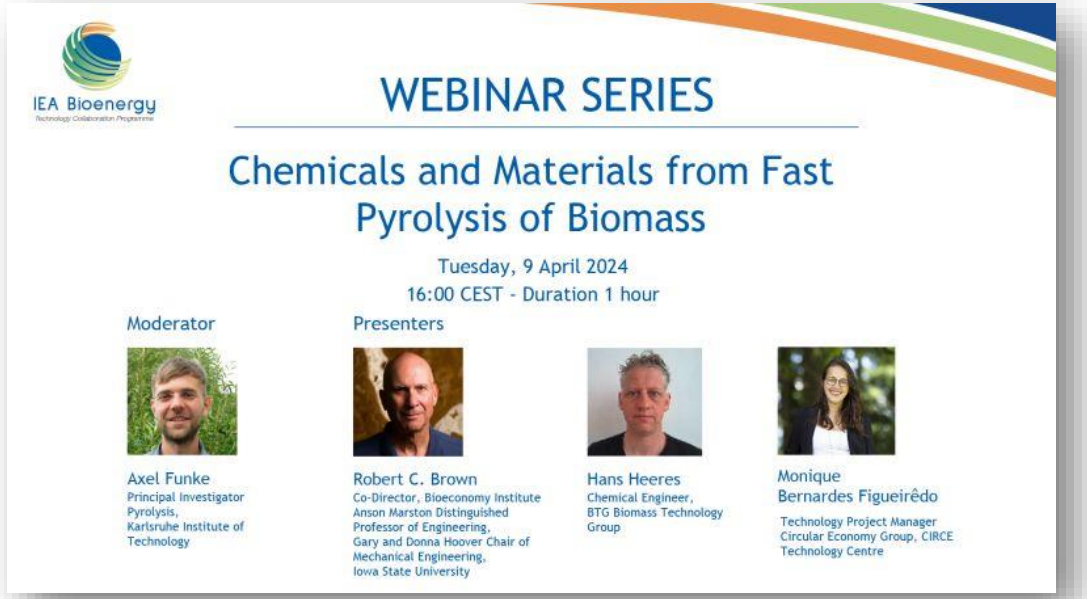
Low Carb Fuels

EUDP

Innovation Fund Denmark

BREAKING NEW GROUND
AALBORG UNIVERSITY

Webinars

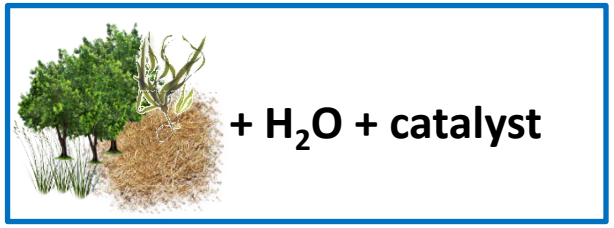


- Periodically organized around topics of interest
- Free attendance
- High participation from all around the world

Danish DTL landscape …

	Currently identified & active
Commercial & SME – primary conversion	Steeper Energy ApS - HTL **Circlia Nordic - HTL** Kvasir Technologies – Solvolysis **MASH Makes – PYR (waste materials, nuts)** Stiesdal SkyClean – PYR (agriwaste) Organic Fuel Technology – PYR (micowave)
Other commercial	Topsoe A/S **Crossbridge Energy (former Shell DK)** COWI A/S (consultancy, Power-to-X with bio)
Research and higher education	Aalborg University, AAU Energy, Dept of Chemical Engineering (H2020, multiple feedstocks, stable processing, upgrading, blending/miscibility, biojet, road transport fuels) Aarhus University, Dept of Chemistry, Dept of Engineering (H2020, ERC, multiple feedstocks, HTL implementation) Technical University of Denmark, Dept of Chemical Engineering (FP, hydrocatalytic pyrolysis, fundamentals)

Hydrothermal Liquefaction (HTL)



+ H_2O + catalyst

Off-gases

CO_2, CH_4, H_2, CO

Slurry making (typically: 20% DM)

Pump

Heater

HTL reactor
(300-400 °C – 150-300 bar)

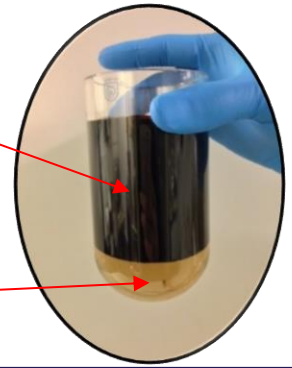
Cooler

Expansion

Residence time
~ 15 mins.

Biocrude

Aqueous phase



Char

Hydrofaction® process: supercritical HTL

Constructed in 2021

Strategic Partner

Silva Green Fuel, Steeper's first commercial licensee, chose to invest in Hydrofaction® after extensive diligence on ~40 competing technologies

Phase I: Demo Plant

A € 50M Demo Plant with capacity of 30 BPD converting forestry residues to renewable biocrude

Engineering Verification

We are currently in the process of having Steeper's commercial plant capital costs and engineering verified by an engineering firm

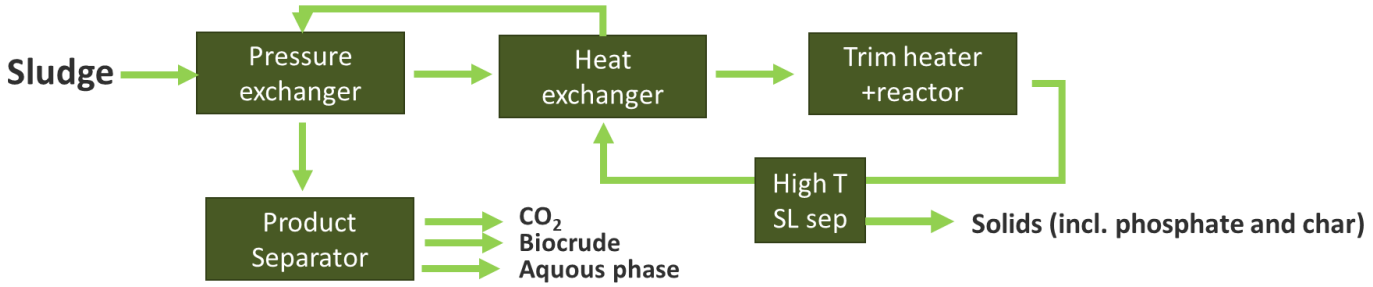
Operations

Construction of Phase I completed in 2021 and startup in progress with operation through 2023. Phase II to follow

Phase II: Commercial Plant

Average production of 2,000 BPD or 125,000 Fuel Tonnes per Annum to be built adjacent to the Demo Plant

HTL of sewage sludge in modular plants



- Successful commissioning in an industrial site in Germany
- Final location to be in **Fredericia**
- Circlia plans to build a plant with a capacity of **25.000 t per year** of wet sludge

EUDP
Sludge2Fuel

Kvasir Technologies

KVASIR TECHNOLOGIES

Solvothermal conversion of lignocellulosic biomass

1 **Agricultural waste residue**

Unutilized feedstock abundantly available globally

(40% oxygen)

2 **New technology**

Biomass breaks into smaller fragments expelling oxygen

(Heat to 400°C with recycleble alcohol solvent)

3 **Sustainable marine fuel**

Can be used directly in existing engines and infrastructure

(<10% oxygen)

- Demo plant to be built in Fredericia (South Denmark), expected in 2024
- Capacity of 2 TPD.

EUDP

Straw-Fuel-Oil

A sustainable drop-in biofuel for the decarbonization of the marine transportation sector

KVASIR TECHNOLOGIES · Crossbridge ENERGY FREDERICIA · AALBORG UNIVERSITY · NORDEN

BREAKING NEW GROUND AALBORG UNIVERSITY

Pyrolysis

Biomass (dry)

Vapors

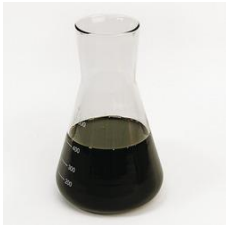
Condenser

Off-gases

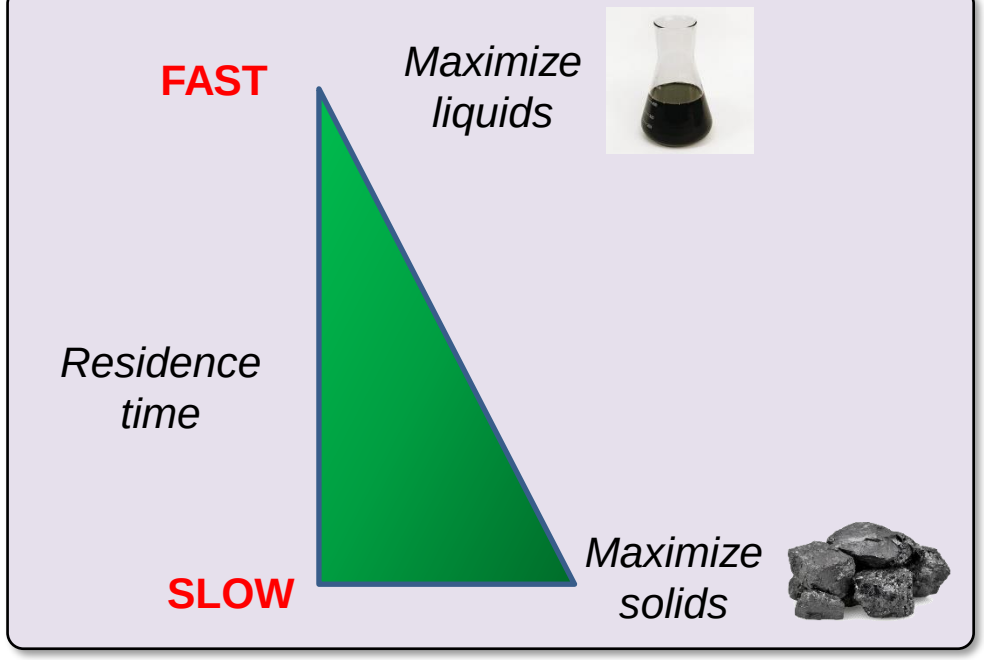
Pyrolysis reactor
(~ 500 °C)

Carrier gas
no O_2

Char



Bio-oil



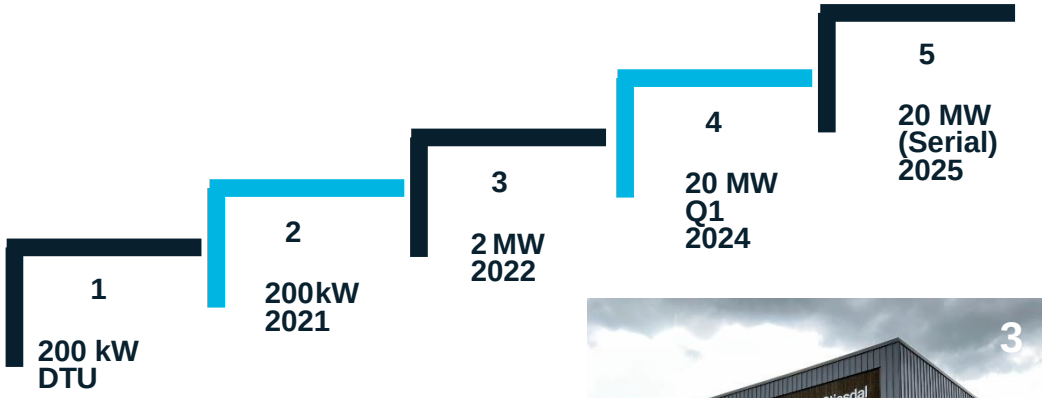
Stiesdal – SkyClean process

Stiesdal

SkyClean® process

2 MW plant in Skive (DK)

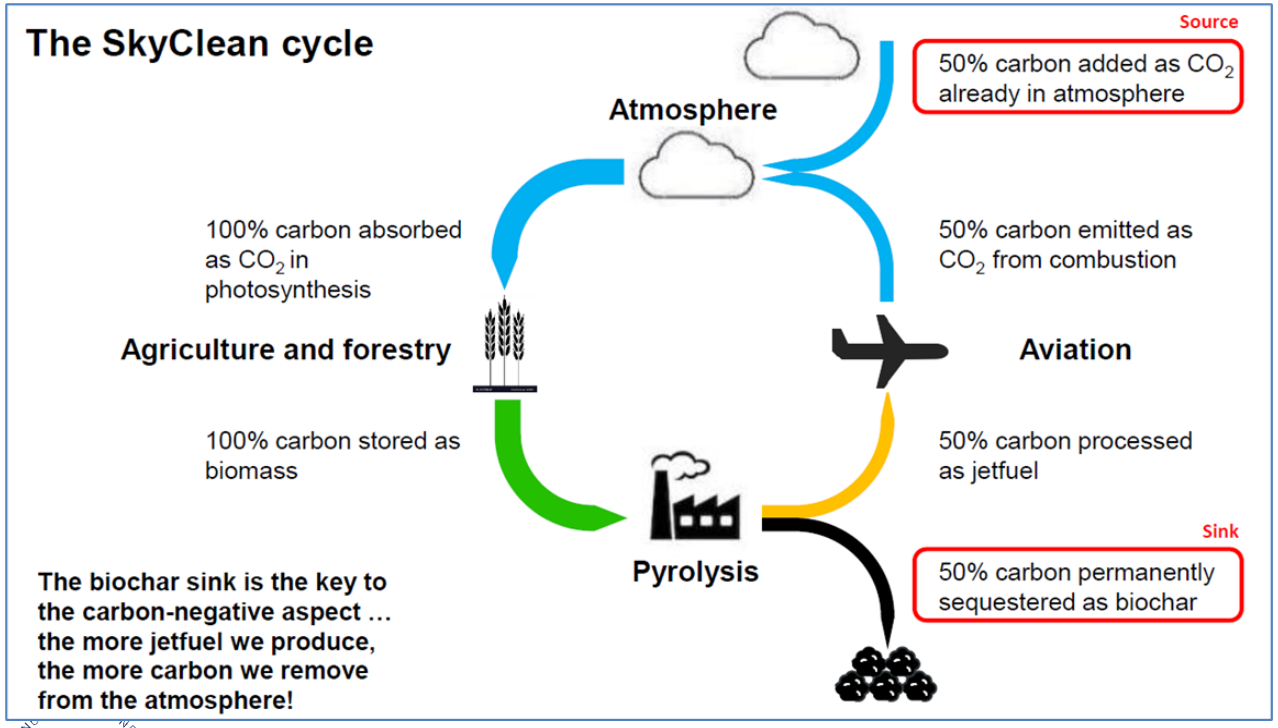
The 3 year road to launch SkyClean's commercial size plant - launch in 2024



August 2021: Inauguration in Brædstrup.

March 2022: Inauguration at GreenLab, Skive.

Q1 2024: 20 MW plant starts operating at BB Energi.



Mash Makes

MASH MAKES

Pyrolysis in auger reactor

Marine fuels

NORDEN

Use with high flash-point fuels (ISO 8217)

Boiler use

Organic Fuel Technology

ORGANIC
FUEL TECHNOLOGY

Project WAVEFUELS (EUDP)

ORGANIC
FUEL TECHNOLOGY

OFT8 – Full-scale demonstration plant

Capacity:

6 x 12 kW microwave generators

400 kg dry matter / hour

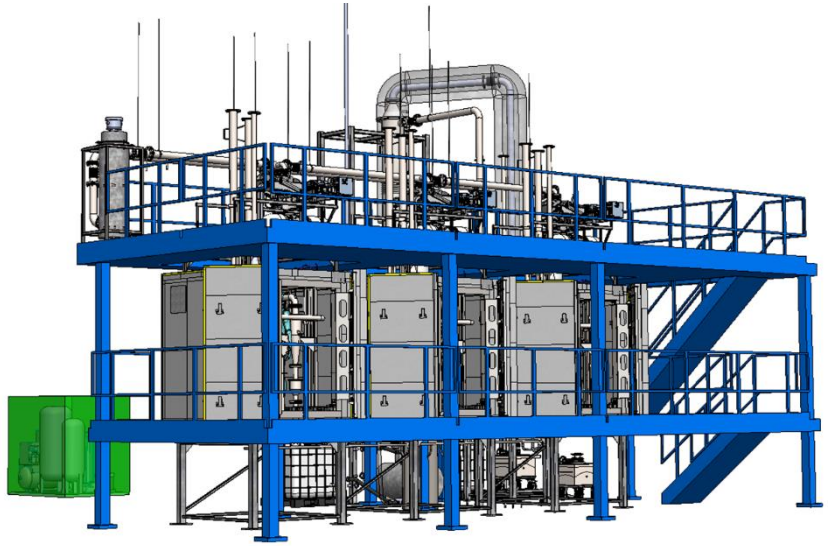
Focus on wastewater sludge

10-03-2024

Projected production:

	Tons / year
Sludge (DM 25%)	10.000
Oil	1.200
Biochar	1.200
Carbon	400
CO_2e	1.467

Targeting marine fuels



Academic research

HTL, solvolysis and upgrading to drop-in fuels

HTL and wet-oxidation of AP
Microwave pyrolysis

Hydropyrolysis and catalytic pyrolysis

Research projects: Lowcarbfuels.dk

Low Carb Fuels

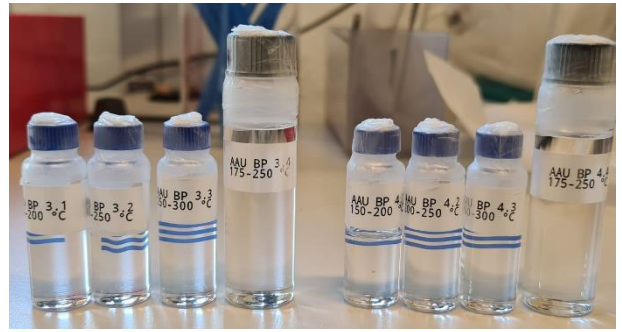
Technology developers & providers	Analysis and certification	Logistics and commercialization	End users & hosts
Crossbridge Energy Fredericia, Haldor Topsoe, steeper energy, Aalborg University	DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center, IFP Energies nouvelles, Alfa Laval, COWI	SkyNRG, GREENFUELHUB, DCC & Shell Aviation Denmark A/S	Aalborg Lufthavn Airport, Port of Aalborg, Aarhus Airport, Aarhus Havn Port of Aarhus, Billund Airport, Maersk
Globally leading HTL implementer, refinery and knowledge institution	Globally leading expertise in certification, analysis, full scale testing, LCA and scenario evaluation	Globally leading sustainable fuel providers with extensive networks into aviation and marine sectors; DK leading aviation fuel supplier	Globally leading end user (marine); majority of DK domestic airports; major DK ports (potential hosts)

energy Cluster Denmark

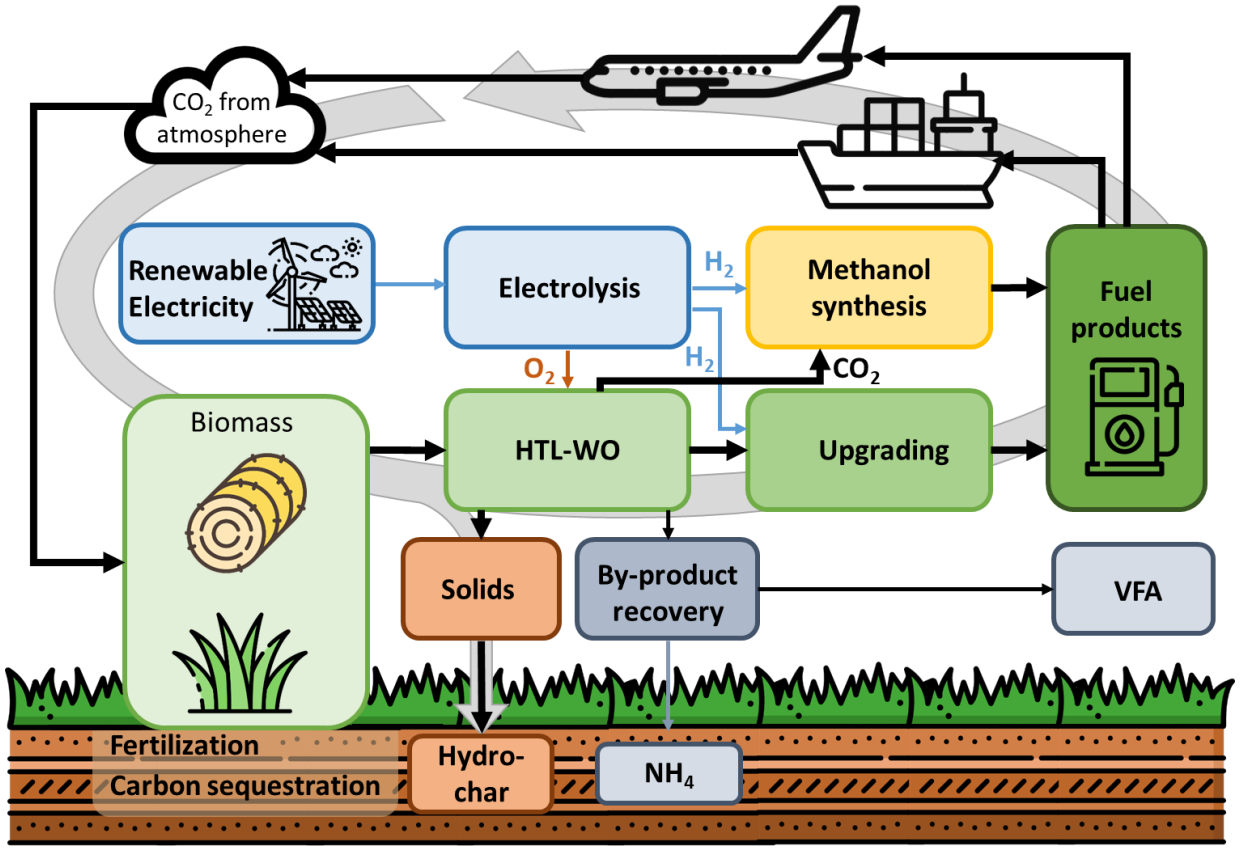
Disseminator and networking

Innovation Fund Denmark
RESEARCH, TECHNOLOGY & GROWTH

Feb 2021 – Dec 2025



Research projects: CIRCULAIR



CIRCULAIR

Circular fuel supply for air transport via negative emission HTL conversion

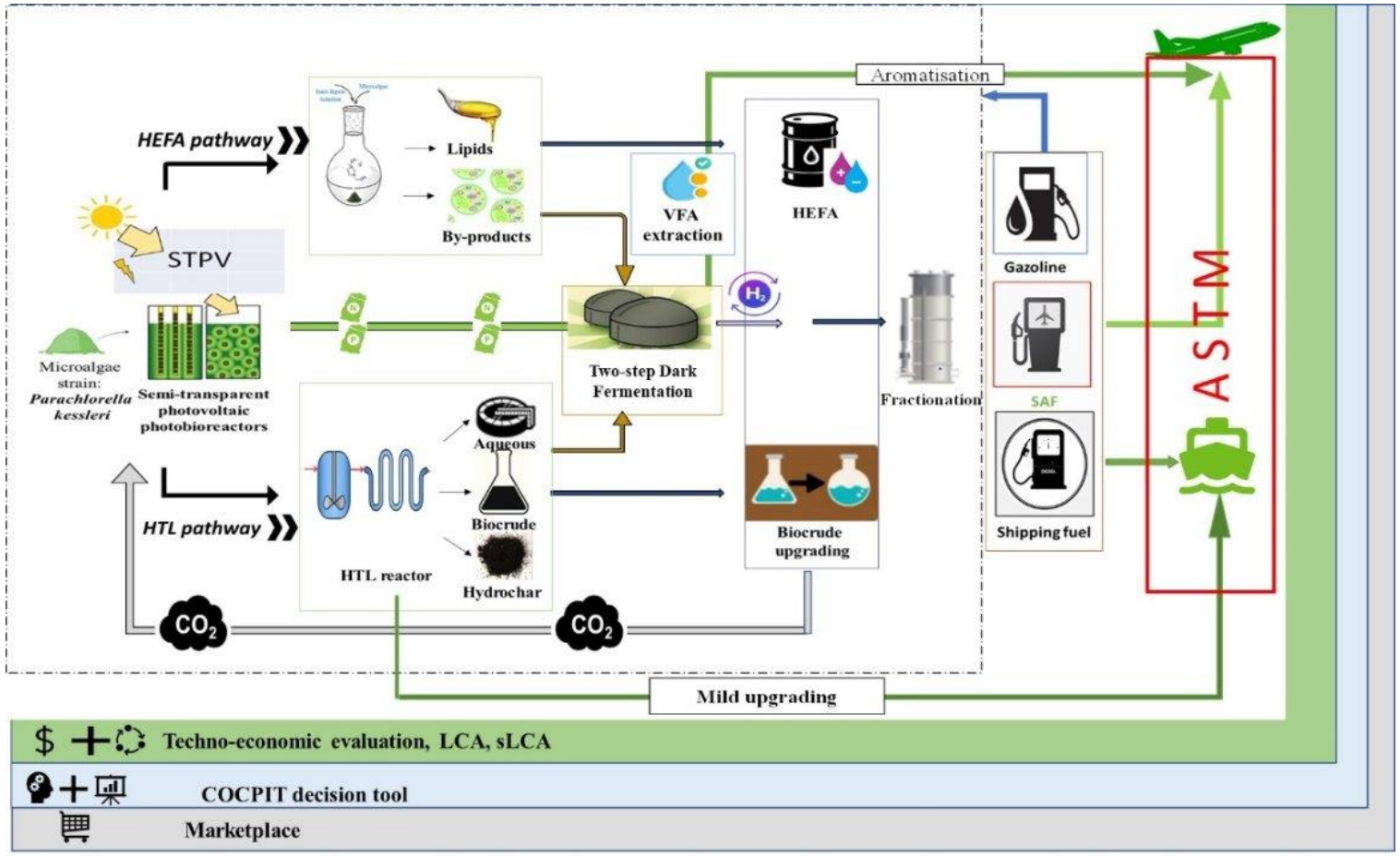
AARHUS UNIVERSITY · AALBORG UNIVERSITY DENMARK · Bauhaus Luftfahrt Neue Wege. · UNIVERSITÄT HOHENHEIM · UNIVERSIDAD COMPLUTENSE MADRID

TOPSOE · eni · Circlia NORDIC · RI.SE Research Institutes of Sweden · LUP

Starting: Jan 2023
Duration: 4 years

Funded by the European Union

Research projects: COCPIT



COCPIT

IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

AALBORG UNIVERSITET

LEITAT
managing technologies

UNIVERSITAT ROVIRA i VIRGILI

HELLENiQ ENERGY

wings.

AGRICULTURAL UNIVERSITY OF ATHENS

DLR

Nantes Université

Funded by the European Union

Outlook

- IEA Bioenergy Task 34: positive **networking** opportunity
- Denmark is one of the **leading countries** in DTL
- Great attention to the **hard-to-abate sectors**: aviation and marine
- **Marine fuels**: an achievable goal
- The importance of **certification** for produced fuels

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THANK YOU FOR YOUR ATTENTION!

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