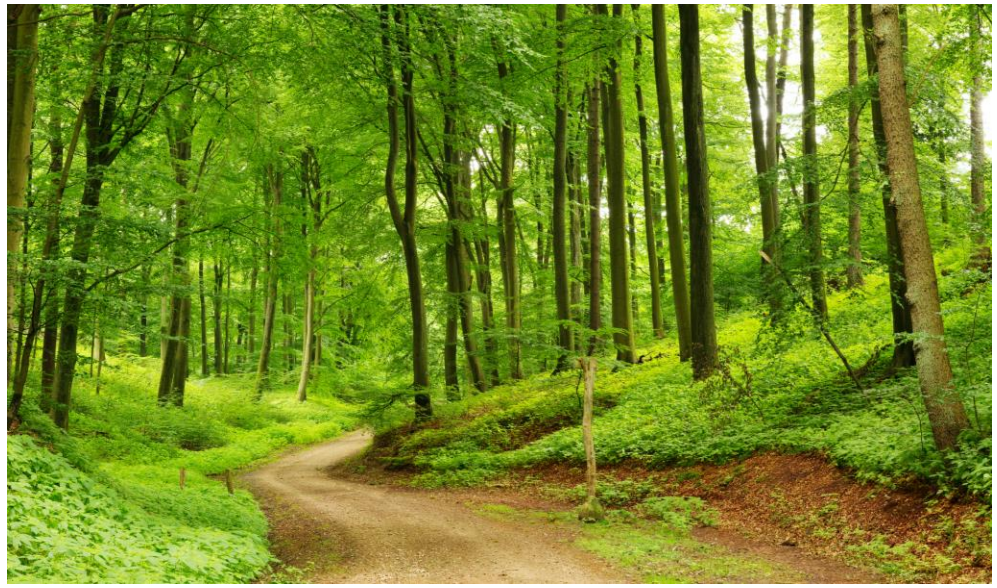
IEA Bioenergy
Technology Collaboration Programme



Options for net negative GHG emissions with biomass combustion

- modelling full-scale implementation of CCUS at large wood chip fueled CHP plant in Denmark

Morten Tony Hansen
Ea Energy Analyses/IEA Bioenergy Task 32 Biomass Combustion

BBEST 2024 - IEA Bioenergy Conference, São Paulo, Brazil

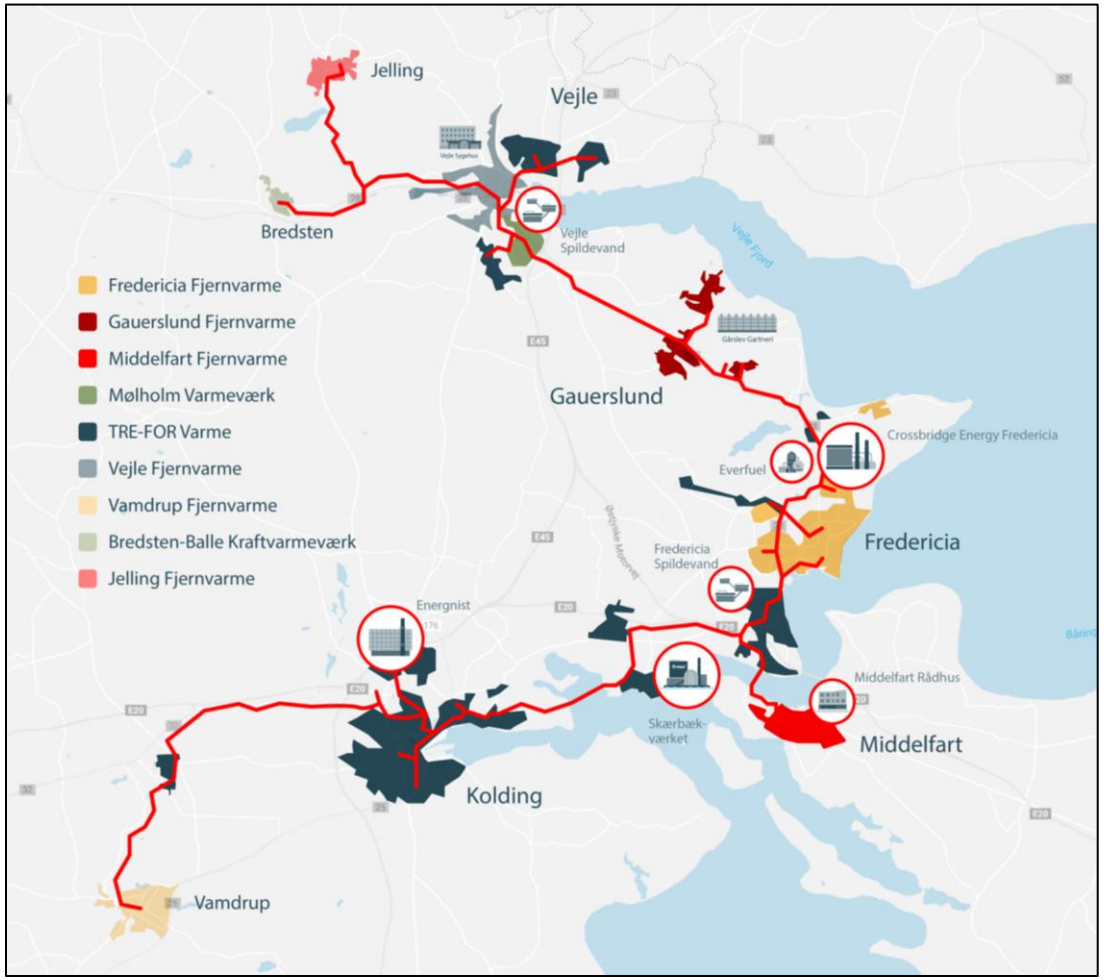
23rd of October 2024

The Skærbæk CHP plant

- The Skærbæk CHP plants is located in the Western part of Denmark
- Owned and operated by Ørsted
- The first production was established in 1951 and was based on coal
- Today the plant's production consists of:
  - A natural gas CHP plant from 1997 with an electrical capacity of 392 MW
  - Two wood chip fired boilers with flue gas condensation from 2017. Provides steam for the same turbine as the natural gas boiler
  - Heat storage tank – 25,000 m^3 water
- The plant uses app. 550,000 tonnes of wood chips per year

The TVIS district heating system

- The district heating system of TVIS is one of the largest in Denmark
  - 139 km transmission grid
- It delivers heat to Kolding, Middelfart, Frederica, Vejle, and smaller towns
- The main production units are
  - The Skærbæk CHP plant – biomass and natural gas
  - Surplus heat from the Crossbridge refinery
  - The waste combustion plant in Kolding (two separate units)
  - Some smaller local production units
  - Gas and oil boilers for peak load and reserve
- Annual heat production is 6.6 PJ (2022)
  - 50% biomass, 25% waste, 25% surplus heat



Why CC(U)S on Skærbæk?

- The CHP plant provides green CO_2 that can be utilised to deliver negative emissions (CCS) or input for green fuel (CCU)
- As base load in the district heating system the biomass boiler has a high number of operating hours that can improve the economy of carbon capture and storage and/or usage
- The plant is close to possible off takers and infrastructure: possible hydrogen backbone, local industry and port facilities for shipping of CO_2 or green fuels
- There is a large district heating network that can utilise surplus heat from the plant, carbon capture and fuel production
- And, the framework conditions support BECCUS in Denmark
  - A new public tender indicates a value corresponding to EUR 100/ton CO_2

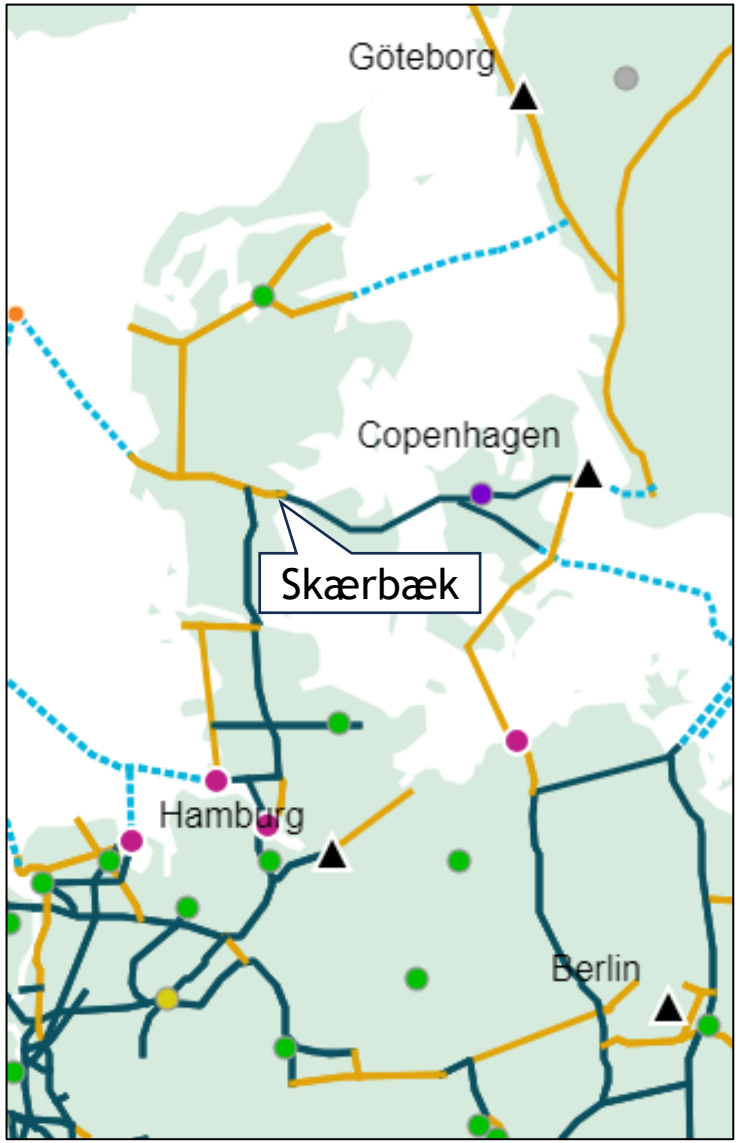
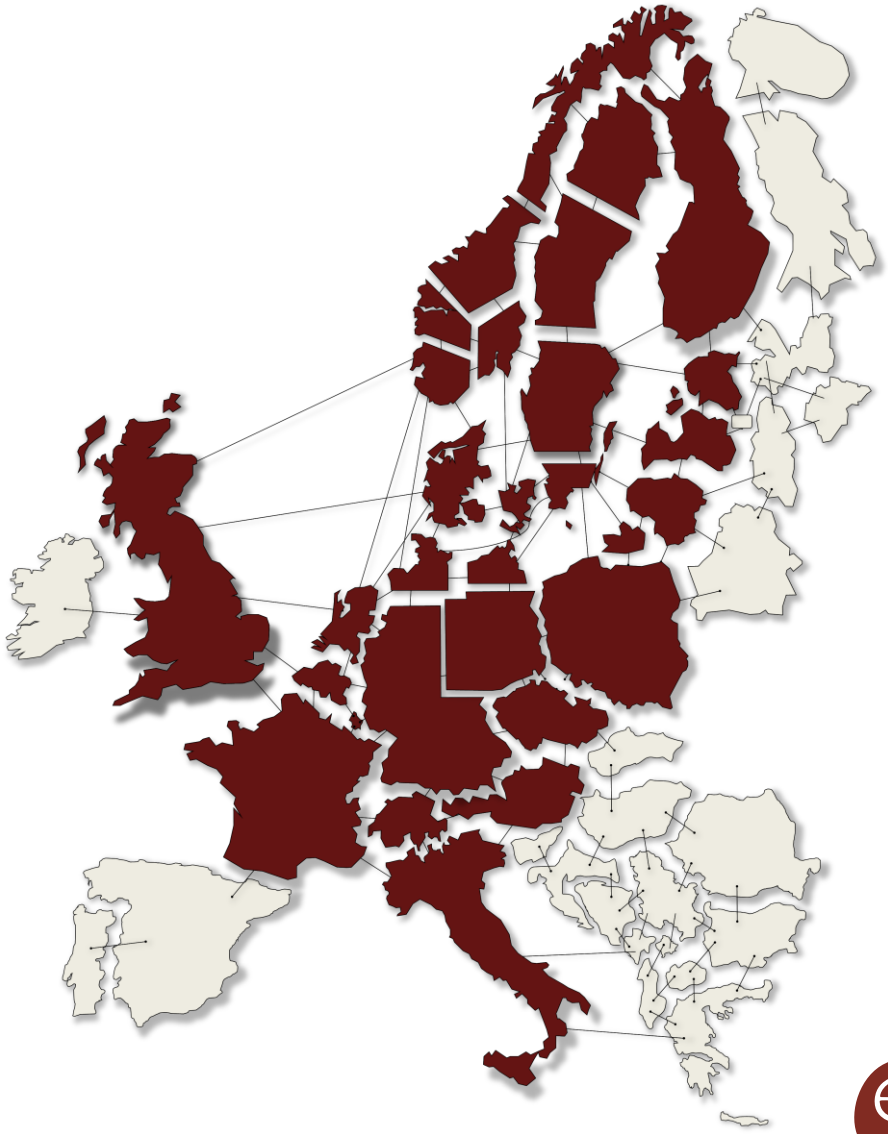


Illustration from European Hydrogen Backbone of possible hydrogen infrastructure

Everything combined in one energy system model

- The energy system model Balmorel is applied
- The North European power system is modelled to provide the power price as an important input to optimising the CHP plant including CCUS
- Heat consumption, production units and network constraints in the TVIS district heating system are modelled in detail including off take of heat production from the plant
- Details of the CHP plants and the CCUS-process are modelled in a special extension to Balmorel, the OptiFlow module, that also allows for modelling of mass balances and more detailed energy conversion processes



Three scenarios simulated in the year 2035

BAU scenario

- Business as usual scenario representing how the plant would operate in 2035 without CCUS

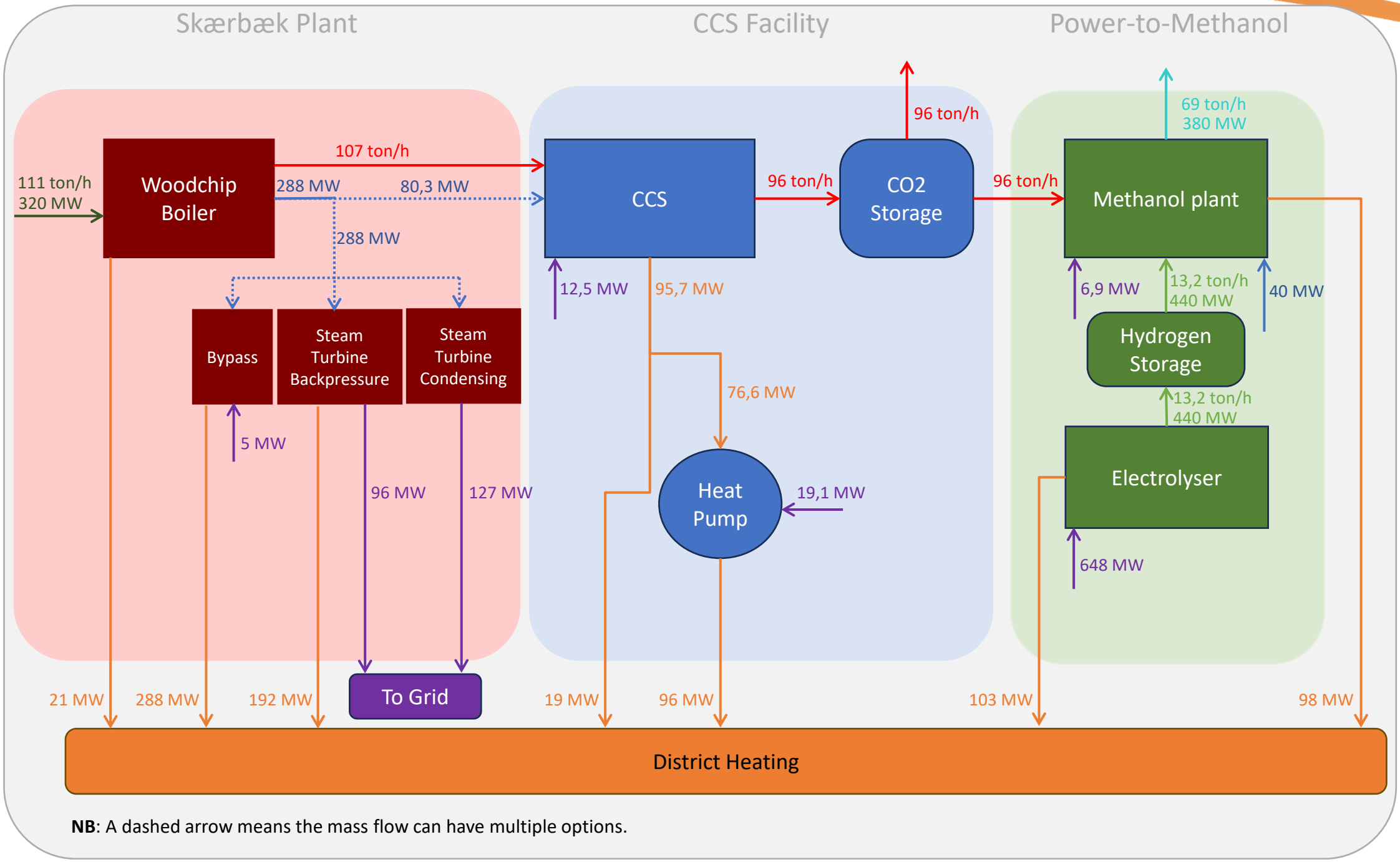
CCS scenarios

- **Fixed** - 4,500 full load hours operation of the wood chip boilers resembling an agreement of a fixed offtake of CO_2
- **Market** - optimised capture and sale of CO_2 with an assumed market price of 133 EUR/ton CO_2

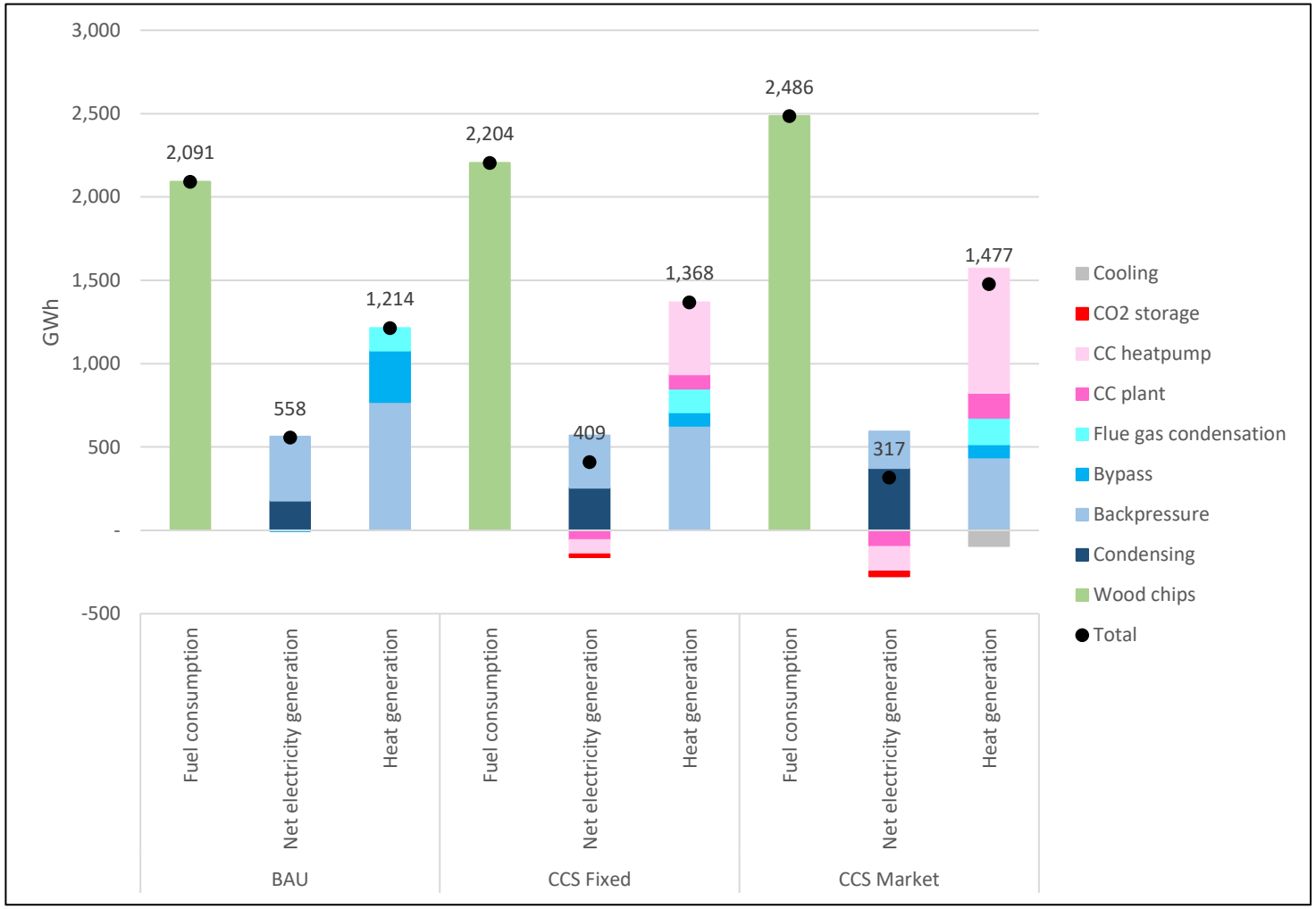
CCUS scenario

- Assuming 4,500 full load hours for methanol plant with 380 MW fuel output capacity resembling an agreement of a fixed offtake of methanol
- No market for green methanol yet established - thus no market price scenario

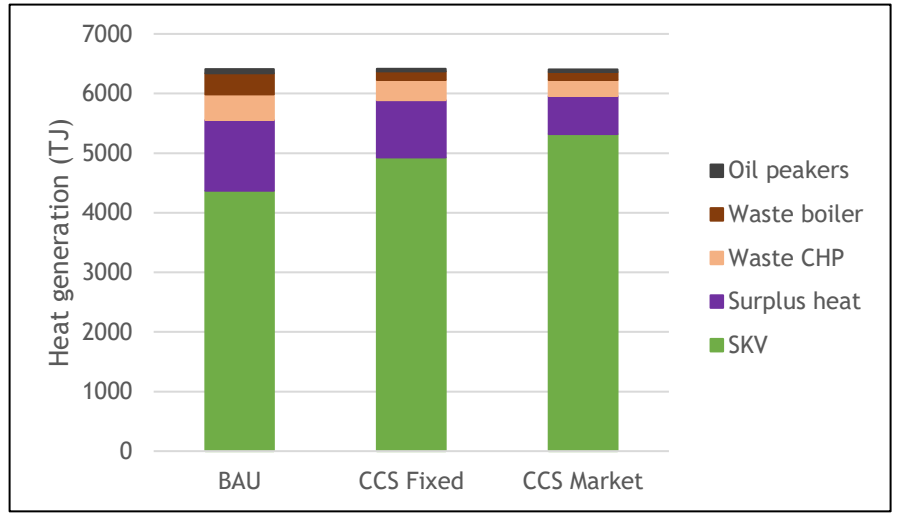
Scenarios and input data set up by Ea Energy Analyses in dialogue with TVIS and Ørsted. All data is based on publicly available sources


Skærbæk Plant
CCS Facility
Power-to-Methanol
111 ton/h
320 MW
Woodchip Boiler
107 ton/h
288 MW
80,3 MW
288 MW
Bypass
Steam Turbine Backpressure
Steam Turbine Condensing
5 MW
96 MW
127 MW
To Grid
CCS
96 ton/h
CO2 Storage
96 ton/h
12,5 MW
95,7 MW
76,6 MW
Heat Pump
19,1 MW
Methanol plant
69 ton/h
380 MW
6,9 MW
13,2 ton/h
440 MW
40 MW
Hydrogen Storage
13,2 ton/h
440 MW
Electrolyser
648 MW
21 MW
288 MW
192 MW
19 MW
96 MW
103 MW
98 MW
District Heating
Legend
Woodchips
Heat
Hydrogen
Electricity
Steam
CO_2
Methanol
Data about the plant and technologies is based on public sources
NB: A dashed arrow means the mass flow can have multiple options.

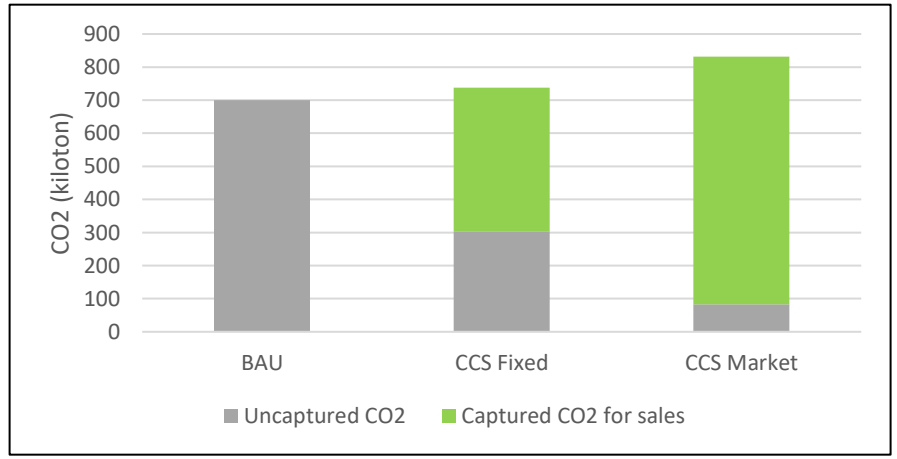
Impact of CCS on the operation of Skærbæk CHP



Annual fuel consumption, heat and electricity generation at the plant

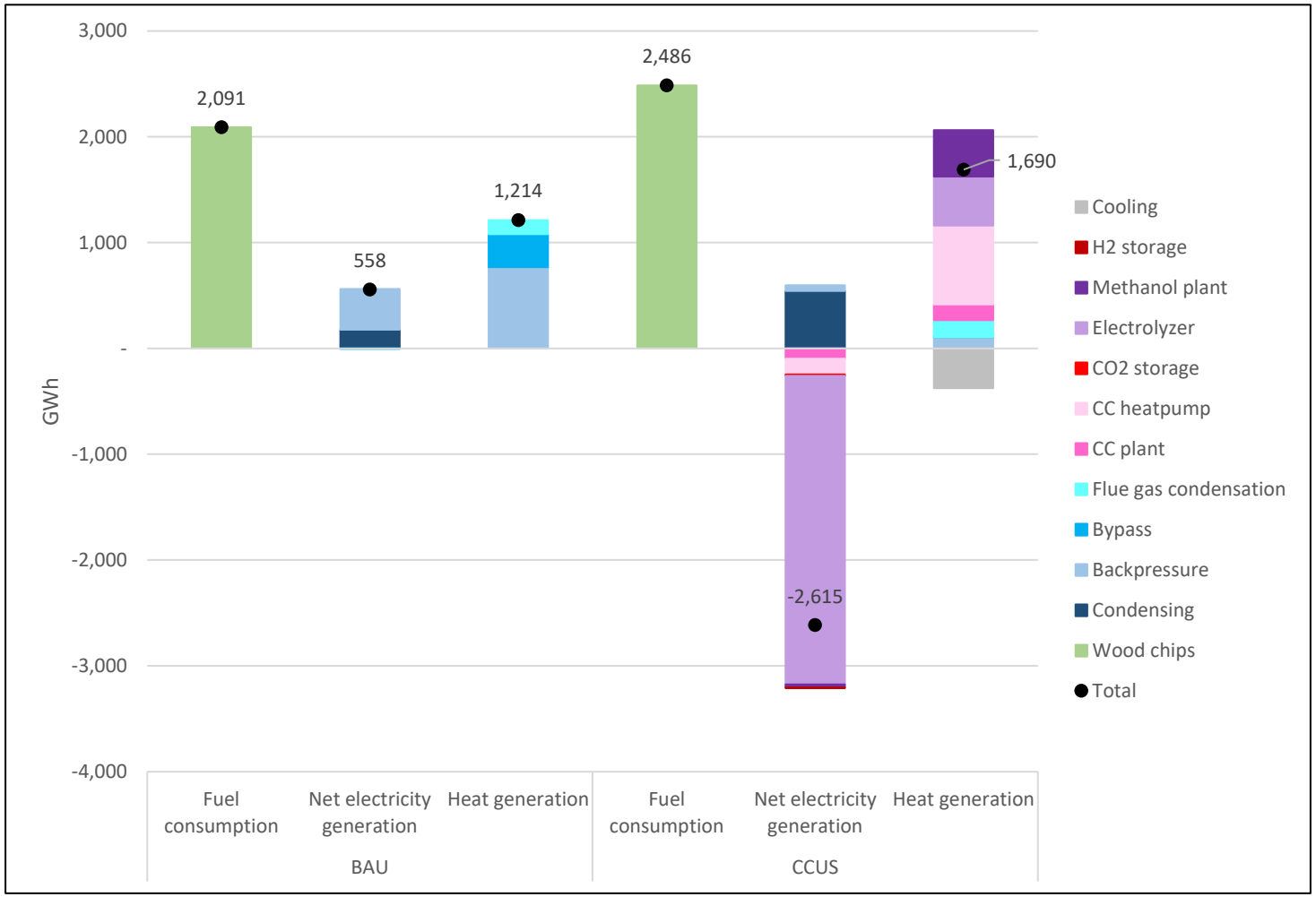


Annual heat generation in the TVIS system

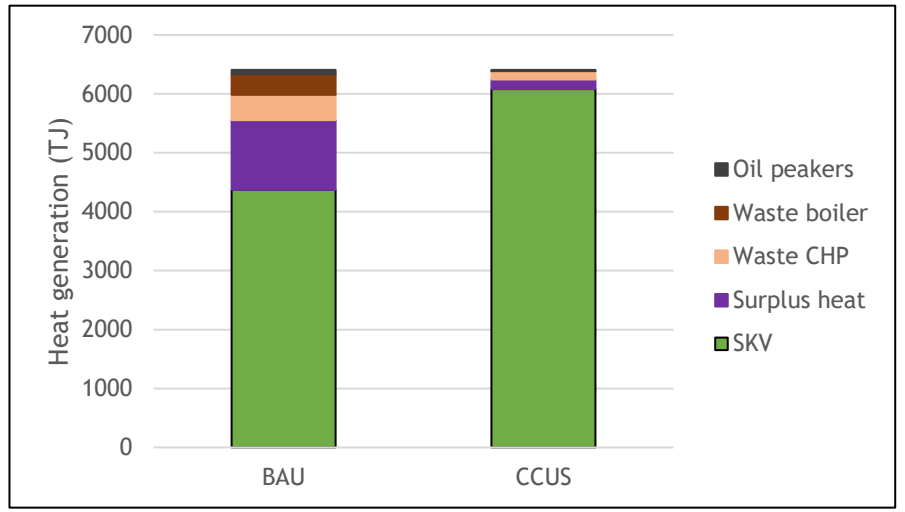


Annual amount of CO_2 captured

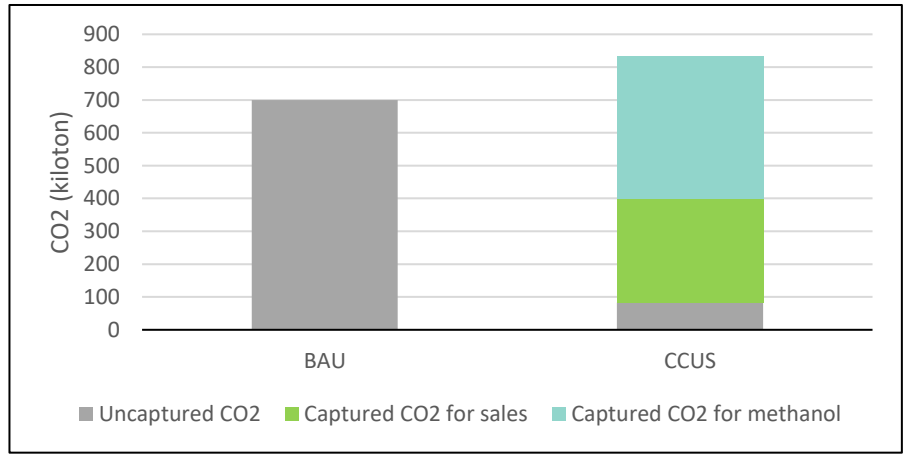
Impact of CCUS on the operation of Skærbæk CHP



Annual fuel consumption, heat and electricity generation at the plant



Annual heat generation in the TVIS system



Annual amount of CO_2 captured and utilised

Conclusions

In the BAU-scenario:

- Operating hours increase - the plant becomes more competitive and heat production increases from app. 3.5 PJ today to 4.5 PJ in 2035
- Also, the plant is competitive in the power market when power prices are moderate/high - generation of 230 GWh power in condensing mode

In the CCS-scenarios:

- Operation of the plant is further increased, especially in the CCS Market Scenario
- The district heating generation increases further - a significant part of the heat is delivered as surplus heat from the CC-facility

In the CCUS-scenario:

- A significant shift is observed in the dynamics of net electricity production, transitioning from positive to negative on average over the year
- District heating generation is further increased - heat from the plant can fully cover the district heating demand in the TVIS area (also heat needs to be cooled away)
- Most of the heat generation is delivered as surplus heat from the CC-plant, the electrolysers and the methanol plant, while the CHP plant delivers process heat for the CCUS-processes and increases power production in condensing mode

Thank you!

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IEA Bioenergy
Technology Collaboration Programme

www.ieabioenergy.com

Extra slides: About BECCS in Denmark

Background – Danish climate targets and highlighted government CCUS policy

2020

The Danish Climate Act adopted target of a **70% reduction in emissions by 2030** compared to 1990 levels and climate neutrality by 2050

Danish State establishes a **market-based "CCUS Fund" of DKK 16 bn*** (EUR 2.1bn) to support execution of Danish Climate Act targets. CCUS Fund (at the time) divided into two Tenders: 1) CCS (2023), and 2) CCUS (Year TBD at a later point)

2021

In December of 2021, Danish State introduced a **market-based "NECCS Fund" of EUR 0.35 bn*** dedicated to the establishment of a value-chain for **negative carbon emissions.**

2022

In May of 2022, The Danish Energy Agency (DEA) **launches first tender from CCUS Fund, EUR ~ 1 bn***, with the objective to actualise reductions of 0.4 Mt of CO_2 yearly from **2026 through Carbon Capture and Storage (CCS)**

In August of 2022, the Danish Energy Agency launched the first tender for exploration permits for the **offshore storage of CO_2** in the Danish subsurface in the North Sea.

2023

In February of 2023, **three exclusive licenses for exploration and full-scale CO_2 storage in the Danish** were granted. Two permits to TotalEnergies and one to a consortium consisting of INEOS E&P and Wintershall Dea International.

In May of 2023, the **winner of the of the first tender was announced**, as the DEA awarded Ørsted a 20-year contract for its carbon capture and storage (CCS) project '**Ørsted Kalundborg Hub'.**

In August of 2023, the DEA launched the tender for the NECCS Fund. The goal is to **achieve 0.5 Mt of negative emissions annually** from 2025 to 2032 from the EUR 0.35 bn* fund.

In September of 2023, a political agreement updating the CCUS fund was reached. By merging funds from another agreement, the pool grew to **EUR 3.6 bn***. Via two separate tenders, the aim is to achieve **CCS** reductions of 2.3 Mt annually by 2029 **(update – one tendering round, 2.3 Mt/year by 2030.**

In December of 2023, the DEA launched the first licensing round in Europe for **full-scale onshore licences for exploration and storage of CO_2**. Involves subsurface exploration of potential CO_2 storage under five designated areas: Gassum, Havnsø, Rødby, Stenlille and Thorning.

2024

In April of 2024, the DEA announced the NECCS fund results. Contracts were awarded to three companies for new CCS projects. In total, **160,350 tonnes of biogenic CO_2 will be captured and stored annually** during the period 2026 to 2032. All of the CO_2 will be captured and stored in Denmark.

In June of 2024, the DEA announced that it had **awarded 3 exploration licenses for onshore geological storage of CO2, at Gassum, Havnsø and Rødby**

In Oct of 2024, the DEA launched the CCS tender with the objective to realise reductions of **2.3 Mt of CO_2 yearly from 2030-2044 via Carbon Capture and Storage (CCS)**

Danish emissions of CO_{2e} were ~45 Mt in 2020 and must fall to ~23 Mt in 2030. Denmark will rely heavily on CCS to achieve this target.

Oct 2024 call for tenders – Key elements

- Purpose:
  - To achieve CO_2 emission reductions and/or negative emissions by Storing Fossil CO_2 and/or Biogenic CO_2 or Atmospheric CO_2 (and thereby **contribute to Denmark's climate targets**)
- The DEA wishes to enter into one or more contract(s)
  - Contract(s) covering the full Value Chain
  - Minimum of 100,000 tonnes annually from 2030-2044
- Funds for 2029-2044 (in 2025 DKK):
  - Subsidy is paid per tonne CO_2 captured and Stored
  - Annual max is ca. 1.8 billion DKK
    - Note: 1.8 billion DKK/ 2.3 million tonnes = 783 DKK/tonne, while max cap is 1750 DKK/tonne
  - Total max for period is ca. 28.7 billion DKK
  - Above values include VAT and potential derived tax losses in (Danish: "afledt afgiftstab")
    - Fund shall cover potential derived tax losses that stem from the award of Contract(s) to tenderers who will avoid national CO_2 related taxes by capturing and Storing their CO_2 emissions. As such, the total available annual funds depend on the composition of the final contract recipient(s)

Extra slides: About Task 32 Biomass Combustion

What is Task 32?

- Task 32 focuses on biomass combustion
  - Design, operation, efficiency, emissions etc.
  - From wood stoves to large power plants
- Task 32 members are experts from
  - Austria - Canada - Denmark - Germany - Japan - Netherlands – New Zealand - Norway - Switzerland - U.S.
- Activities include
  - Collect/generate and disseminate expert knowledge for the benefit of interested people in the target group
  - Exchange experiences between member countries as well as with groups inside and outside of IEA Bioenergy
- More information
  - Task 32 website
  - IEA Bioenergy website

Task 32 work programme

Clear challenges for biomass combustion:

- Conversion of industries from fossil fuels
- Emissions (PM + NOx) - from smaller plants
- Sustainability discussion
- Integration of biomass combustion in future energy in energy systems
  - Especially with capture, sequestration and use of carbon from the flue gases (BECCUS)
  - Reduced fuel intensity – hybrid solutions

Task 32 current work

1. Biomass conversion in industry
   - Case studies
   - Database of cases/references
2. BECCS and BECCU
   - Case studies and modeling
   - Options for smaller plants
3. Innovative biomass combustion with low emission
   - State-of-the-art report
   - Studies of N-emissions and of advantages of cascading
4. Stoves and boilers for residential heating
   - Focus on emissions
   - Design (primary & secondary measures), testing, operation, user influence and automation
   - National strategies to reduce impact on air quality from residential combustion

Task 32 projects - industry

- Biomass for HT Heat in Industry
  - An intertask project
  - Case studies with good examples of transitions
  - Policy report
- More case studies coming up
  - Where biomass combustion has replaced fossil fuels
- Assist decision makers
  - Database of case studies and references being established

Task 32 projects - negative emissions

Biomass combustion with negative CO_2 emission

- Overview of technical options for CO_2 capture
- Case studies of BECCUS projects
- Modeling of the consequences of carbon capture on an existing Danish biomass-fired cogeneration plant
- Overview of opportunities for BECCUS on small biomass combustion plants
- Workshop on biomass consumption and BECCUS (held on 21st September 2023)

Task 32 projects – medium sized plants

Innovative biomass combustion with low emission

- Report: Low emission biomass combustion in automated boilers for heat and power
- Study of the nitrogen cycle in biomass combustion plants (Netherlands + Austria)
- Report on how heat storage and boilers in cascade provide low emissions (Swiss study)

Task 32 projects – stoves and boilers

- Testing methods and real-life performance for pellet stoves (Report)
- Guideline for the design of low-emission wood-burning stoves (Guide)
- Study of national strategies to reduce emissions from biomass combustion (Report)
- Report on state-of-the-art biomass boilers
- Workshops and webinars on wood stoves and boilers (Events)
- Highlighting benefits for carbon balances and sustainability when using wood stoves

Extra slides: About IEA Bioenergy

IEA Bioenergy in brief

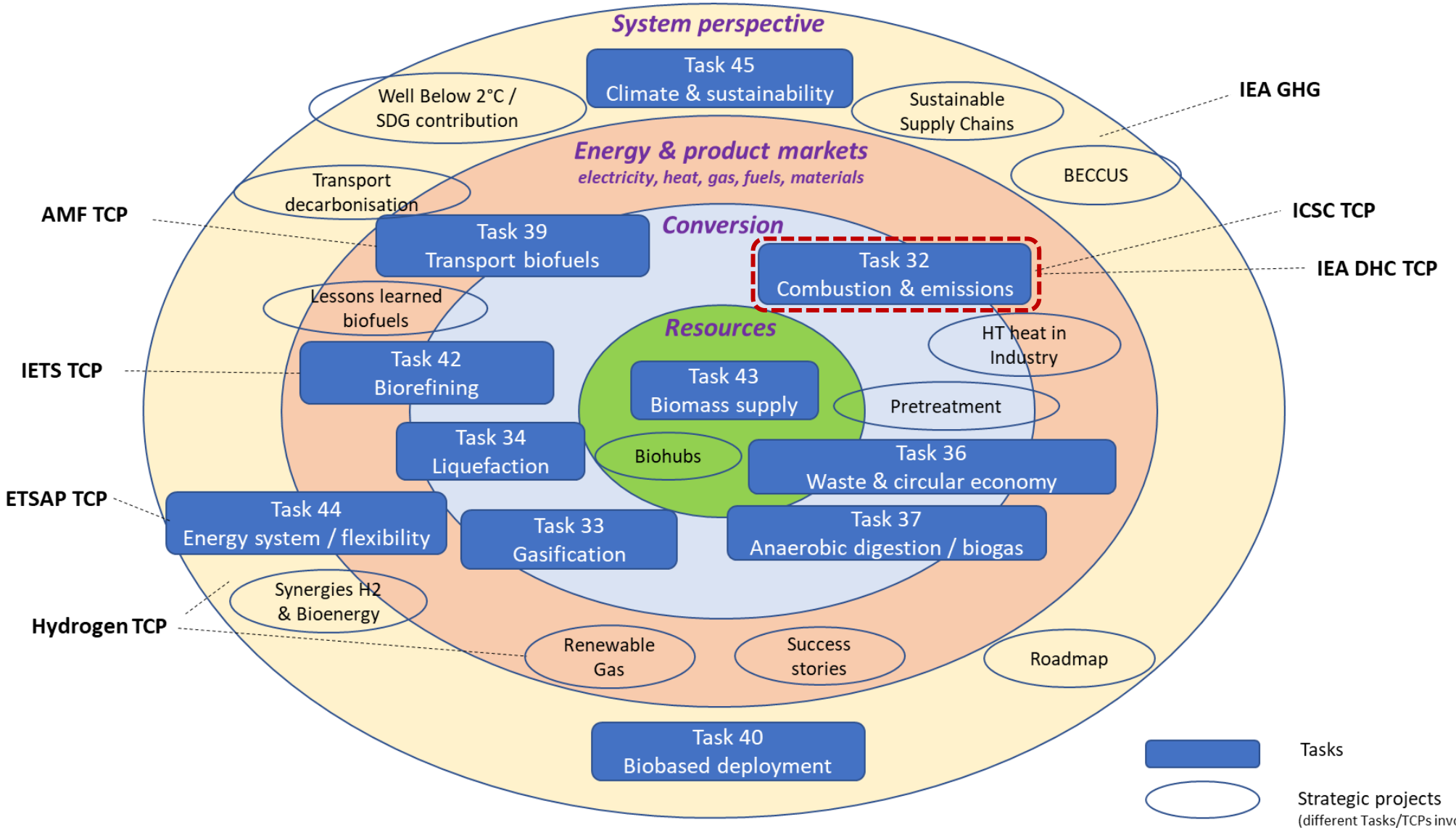
Technology Collaboration Programme (TCP), functioning within a framework created by the **International Energy Agency** (IEA)

Goal:

- International **collaboration** and **info exchange** on bioenergy research, technology development, demonstration, and policy analysis
- Facilitate the commercialization and market deployment of sustainable bioenergy systems = **climate positive, environmentally sound**, **socially acceptable** and **cost-competitive** (incl. external costs)

Work programme carried out through **Tasks** and **Special Projects**, covering the full value chain from feedstock to final energy product

Activities in IEA Bioenergy



IEA Bioenergy TCP Overview

ASIA/OCEANIA/AFRICA

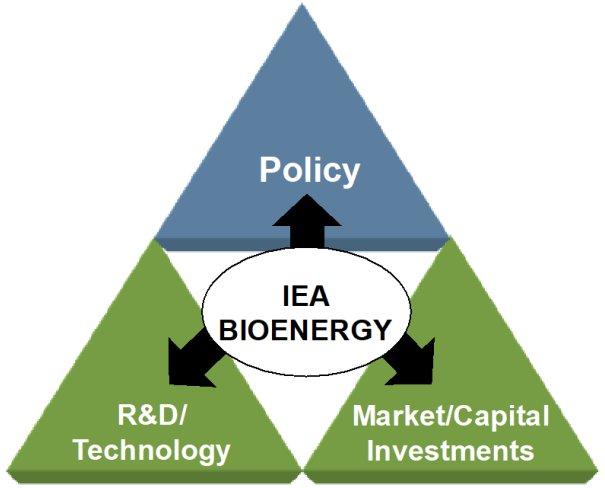
- China
- India
- Japan
- Korea
- Australia
- New Zealand
- South Africa

AMERICA'S

- Brazil
- Canada
- United States

EUROPE:

- Austria
- Belgium
- Croatia
- Denmark
- European Commission
- Finland
- France
- Germany
- Ireland
- Italy
- Netherlands
- Norway
- Sweden
- Switzerland
- United Kingdom



25 Contracting Parties

Budget in 2022: 2 Million US$
Tasks: 11 + Strategic Projects
Participation: 111
Direct participation: > 200 persons

Turkey is in the process of joining IEA Bioenergy
US Grains Council recently joined Task 39 as a Limited Sponsor

Unique role for sustainable bioenergy in the transition away from fossil energy

- **Available now** to phase out fossil fuels in existing energy infrastructure
- **Versatile:** role in different sectors – heat, power, transport fuels
- **Storable/dispatchable:** complements intermittent/seasonal renewables in power systems
- Next to producing energy, it can **remove atmospheric CO_2** ("negative emissions") via deployment of Carbon Capture & Storage (CCS) : BECCS / Bio-CCS
- Provide **atmospheric CO_2** for carbon-containing e-products/e-fuels via Carbon Capture & Utilisation (Bio-CCU)
- **Enable biomass supply chains & sustainability governance systems** for the biobased economy

Bioenergy contributes to climate change mitigation when:

- Biomass is grown **sustainably** or based on waste/residues
- **Converted** to energy products **efficiently** (often together with other biobased products)
- Used to **displace fossil fuels**

Current strategic action areas

A sustainable system for energy and materials supply with biomass

- Demonstrating the key role of bioenergy in a decarbonising world, the complementary role with other renewables, and the potential to provide negative emissions (BECCUS)
- Contribution to Sustainable Development
- Embedding bioenergy into the broader bio-economy
- Incorporating the security, flexibility and stability provided by bioenergy in the fuels, electricity, gas and heating systems

Innovative Technologies

- Enabling the development and application of innovative technologies (collaboration & best practices)
- Developing advanced biofuels from lignocellulose and waste & consider their role in hard-to-abate transport sectors (aviation, marine, long-distance transport)

Current strategic actions areas

Sustainable Supply Chains

- Mobilize biomass resources through landscape management, reuse of abandoned agricultural lands; sustainable sourcing in agriculture and forestry; logistics to mobilize underutilized residues
- Support sustainability governance & certification
- Promote market deployment of efficient biobased value chains

Operational Optimisation

- Engaging relevant stakeholders in a dialogue & science based analysis to inform political/public debates
- Expanding collaboration with emerging and developing countries
- Ensuring the optimal use of communication channels

Extra slides: About Ea Energy Analyses

Ea Energy Analyses

- Consulting company operating in the field of **energy and decarbonization**
- Established in **2005**
- Based in **Copenhagen**, Denmark
- Founding partners were managers in the TSO of Eastern Denmark

50 people

Projects in 20+ countries

3.5 m$ annual turnover

19 years of experience within the energy sector

For any inquiry, contact:
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