

The European Commission's Energy Union strategy aims to transform Europe's energy system to be smarter, more flexible, integrated, and secure, with the ultimate goal of achieving climate neutrality by 2050 as part of the European Green Deal. The Strategic Energy Technology Plan (SET-Plan) outlines ten priority actions to accelerate the development of innovative energy technologies, emphasizing renewable energy sources (RES) and diversified energy systems. By 2030, 40% of energy must come from renewables to meet the "Fit for 55" target of reducing greenhouse gas emissions by 55% compared to 1990 levels.

EU expects to have a consistent average supply of approximately 4000 TWh of sustainable biomass in 2050 that should be utilized efficiently and effectively. Biogas production plants utilize sustainable biomass to generate biogas/biomethane and digestate. European Biogas Association (EBA) has predicted that biogas plants will be able generate 1000 TWh of biogas and biomethane in 2050 utilizing sustainable biomass. Currently, biogas production plants generate 190 TWh of biogas/biomethane in addition to digestate (dry 87000 tons per TWh of biogas) as a by-product. 90% of the digestate is used as an organic biofertilizer, whereas 98% of the biogas/biomethane generated today is used to generate heat and power. However, the Renewable Energy Directive (REDII) states that from 2026, EU Member States should not give support anymore to electricity-only plants, unless the installations are in regions with a specific use status as regards their transition away from fossil fuels or if the installations use carbon capture and storage. An alternative is to produce biofuels that can be utilized in sectors that are difficult to decarbonize through electrification, like the aviation and maritime transport.

Also, carbon capture and storage (CCS) and carbon capture and utilization (CCU) are essential for achieving significant emission reductions, with sustainable biofuels playing a crucial role in sectors like transport, maritime, and aviation. The EU's circular economy concept, aiming to minimize waste and maximize resource efficiency, supports this transition by promoting the use of bio-based materials and energy from waste.

The proposed project aligns with these trends by maximizing the use of sustainable biomass in biogas (and wastewater treatment) plants to generate biofuels from both biogas and digestate. It integrates hydrogen production, renewable energy, CO₂ utilization, and energy storage in the form of fuels, aiming for negative emissions by capturing and utilizing CO₂ from natural sources. This innovative approach fits into the circular economy by using waste feedstock to produce valuable products, such as fuels, heat, and fertilizers.

The project aims to:

1. Utilize low-quality biomass for fuel production, mainly methanol, reducing greenhouse gas emissions.
2. Produce high-quality energy carriers for various uses (transport, power sector, chemical sector).
3. Pyrolyze digestate to generate useful products and decrease CO₂ emissions.
4. Produce fertilizers from fermentation residues, fitting the circular energy concept.
5. Achieve carbon sequestration through biochar, leading to negative emissions.

The system processes biomass through anaerobic digestion to produce biogas, which is then treated to separate CO₂ and produce biomethane or subjected to dry-reforming for syngas generation. This syngas can be adjusted for methanol synthesis through co-electrolysis. Pyrolysis of digestate generates biofuels and biochar, with non-condensable gases reformed for further use. The project focuses on maximizing biomass use, integrating CO₂ recycling, and producing sustainable fuels with minimal emissions.

This approach will be tested through system modeling, thermodynamic, economic, and environmental analysis, and experimental work. The project's objectives include developing mathematical models, experimenting with digestate pyrolysis and CO₂ separation, integrating processes into a comprehensive system, optimizing for fuel production, and evaluating the environmental impact using Life Cycle Assessment (LCA).