Biogas plants are producing a significant amount of digestate as a by-product. Digestate contains high concentrations of nutrients than required for plant growth, particularly nitrogen, as well as high chemical oxygen demand (COD), biological oxygen demand (BOD), and suspended solids (SUD), low dissolved oxygen (DO) make it not being able to be discharged directly. Although digestate could be useable as fertilizer without any pretreatments, the storage, handling, and transportation of digestate create visible costs for farmers because of its low dry matter content and large volume. For these reasons, digestate is needed to be handled in environmentally friendly ways. Biogas solid residue (BSR) is the solid part of the digestate obtained by physical separations. This project proposes a new technology- super-heated steam (SHS) torrefaction for BSR wastes.

SHS torrefaction technology with simultaneous pressure and temperature control contributes to the development of a thermochemical conversion of biomass that is cheaper technology than classic torrefaction application. Allows precise control affects the safety of the process, i.e., limiting potential fire or explosion. The traditional torrefaction methods are not able to recover valuable by-products. Therefore, for SHS torrefaction processes, it is possible to recover condensate by-products (ammonia, furfural, formic acid, and acetic acid). Economic profitability depends on the use of low-temperature waste heat for pre-drying the biomass and the use of steam instead of other gases such as N2, helium, fossil fuels, or gases generated during the torrefaction process, so-called "Torgas." The torrefied product becomes homogeneous with lower moisture, higher calorific value, lower O/C and H/C value, and higher energy content (per unit volume). Torrefied biomass can be used as an additive for fertilizer, fuel, and filters for flue gas purification. The higher heating value of torrefied biomass (biocoal) is almost getting similar to coal, allowing to use of biocoal instead of coal as a fossil fuel.

This project will investigate the SHS torrefaction of BSR and optimize the process efficiency with TGA and thermo-kinetic analysis. With the gained parameters, a lab-scale batch SHS torrefaction reactor will be constructed and operated to achieve solid carbonized biofuel, and valuable condensate components (acetic acid, ammonia, furfural, 5-HMF etc.). Agri-woody biomass will be considered an additional feedstock (90% of the feed) for coprocessing in the torrefaction unit with 10% BSR. BSR contains 10-20% TS on average; thus, it is not efficient to be used directly in the torrefaction process. Co-torrefaction of BSR with agri-woody biomass mix will be able to investigate as a 10 to 90 % mixing ratio. The exact percentage will depend on the total solid (TS) and volatile solid (VS) results of the biomasses. Feedstocks of the process will be; industrial waste (BSR), agricultural waste (beet pulp residues), energy plant (sorghum), and woody biomass (pinewood). All experiments will be applied to each feedstock and BSR-agri/woody biomass mix.

The elemental and characteristic analysis will be carried out for raw biomass (BSR mix and agri-woody biomass). Laboratory-scale analysis of torrefaction optimizations; TGA analysis and calorific value analysis for biomass will be carried out to optimize data for the SHS torrefaction process. Kinetic evaluation (k1, k2, k3, $\gamma 1$, $\gamma 2$, $\gamma 3$, A1, A2, A3, and the activation energy for each reaction) of TGA data will be investigated to obtain relatively simple models, describing the torrefaction of biomass. As the primary purpose of the project; batch laboratory scale SHS torrefaction reactor design and construction will be carried out. The reactor will be operated with BSR and woody/agri biomass under a dry steam atmosphere fed with a steam generator and pre-heated by electrical heaters. Elemental, characteristic, calorific value and emission analysis will carry out for torrefied biomasses. Pelletizing performance of torrefied biomass and recovery of value-added chemicals will be studied. The recovery of chemicals (ammonia, furfural, propionic acid, acetic acid etc.) from the side-product (liquid condensate) will be investigated using TGA-FTIR, an analytical method that identifies different substances within a test sample. Life cycle calculations (LCC), and techno-economic analysis will be conducted for the overall SHS torrefaction process.

Recovery of BSR from the biogas process to power the torrefaction process and generate torrefied pellets as a transportable solid fuel for use in agro-industries will be another innovative part of the project. It will allow the recovery of valuable by-products without burning them, such as propionic acid, acetic acid, ammonium, etc., in addition to classic torrefaction products- biochar and syngas. The project will create a new source of literature since there are no information and applications.