Gasification of residual biomass offers a flexible route to recover energy and carbon from heterogeneous streams that are otherwise difficult to valorize. Its scale-up, however, requires the integrated management of feedstock variability, gas-solid hydrodynamics, tar formation, and process CO_2 emissions. This presentation describes the design and development of a gasification platform combining fluidized-bed conversion with CO_2 capture and utilization, supported by numerical modeling and the experimental validation of key reaction and hydrodynamic aspects. The core concept is a dual fluidized-bed system in which a pressurized gasifier/carbonator is coupled with a combustor/calciner through the continuous circulation of a calcium-based sorbent. In situ CO_2 removal promotes the production of hydrogen-rich syngas, while sorbent regeneration generates a concentrated CO_2 stream. The system has been studied through a multiscale approach integrating thermodynamic and kinetic modeling, three-dimensional computational particle fluid dynamics simulations, laboratory experiments, and testing on a pressurized cold model. This methodology is used to investigate reaction performance, fluidization behavior, reactor geometry, and the controlled withdrawal and replenishment of the circulating sorbent. Overall, the combined numerical and experimental results support the main design choices and provide a basis for scaling the system toward hydrogen-rich syngas production and circular carbon utilization.