Bioenergy via Char Gasification with Carbon Capture and Storage: An Alternative to BECCS

Dave Chun[a], Peter Zhao[a], Anila Antony[b], Dr. Benjamin Davis[a], and Dr. Amanda Simson[a]
[a]: The Cooper Union for the Advancement of Science and Art, Department of Chemical Engineering
[b]: Pennsylvania State University, Department of Agricultural and Biological Engineering

Motivation

IPCC techno-economic models suggest that staying below the 2°C limit set forth by the Paris Agreement will require negative emissions technologies, with most models incorporating bioenergy with carbon capture and storage (BECCS). However, there are several limitations to the most commonly described BECCS approach (biomass-fired powerplants with CCS). This includes competition for water, land, and energy resources as well as CO_2 separation difficulties. We propose a novel BECCS alternative which uses biowaste pyrolyzed into biochar to be gasified in a solid oxide fuel cell (SOFC) power plant. This SOFC power plant enables easier separation and sequestration of CO_2.

Problem Statement

We investigated a proposed process via simulations and experiments. For the simulations, we compared a model of the proposed process with literature values for traditional BECCS.[1] For the experimental study, we looked at the reactivity of biochar derived from biowaste feedstocks in varying testing conditions, such as ramp rate, moisture content, inert environment, and pyrolysis temperature.

Methods: Experimental

Biowaste samples were pyrolyzed in a tube furnace at 400-500°C to maximize solid char yield. The biowaste feedstocks studied were pistachio shells, corncob, pumpkin seeds, and walnut shells. To test char reactivity, temperature-programmed oxidation (TPO) tests were run. Only data for walnut shell feedstock is shown in the results.

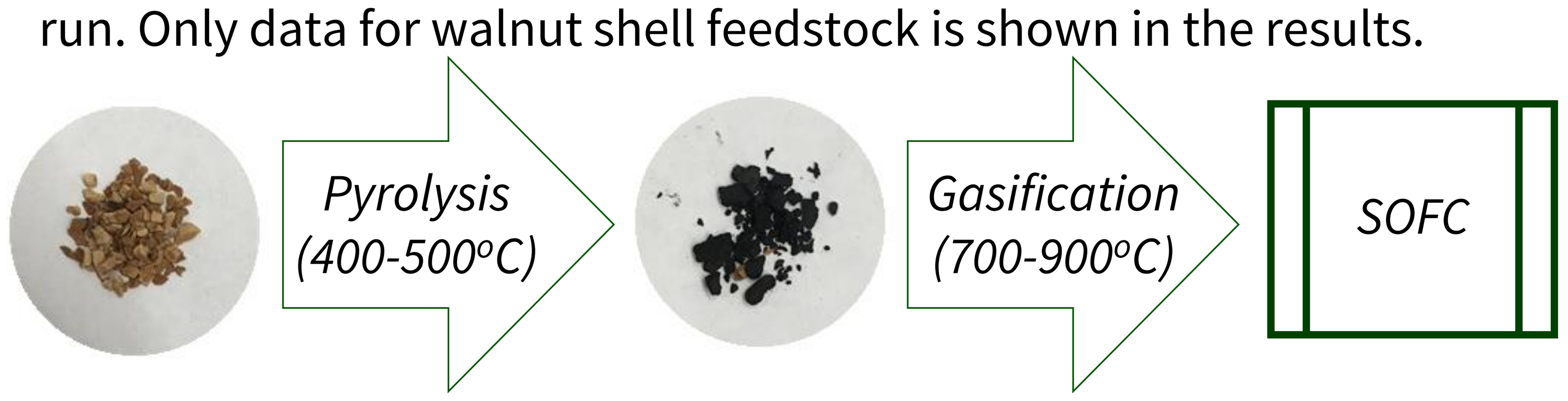

Figure 1: Biowaste (Walnut Shell) Processing Flow Diagram

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References

[1] Fajardy, M; Dowell, N. "Can BECCS deliver sustainable and resource efficient negative emissions?" *Energy Environ. Sci.*, **2017**, *10*, 1389-1426.
[2] Mohanty, P.; Nanda, S.; Pant, K. K.; Naik, S.; Kozinski, J. A.; Dalai, A. K. Evaluation of the Physiochemical Development of Biochars Obtained from Pyrolysis of Wheat Straw, Timothy Grass and Pinewood: Effects of Heating Rate. *J. Anal. Appl. Pyrolysis* **2013**, *104*, 485–493.

Results: Simulation

The alternative BECCS model is shown in the diagram below:

Proposed Process:

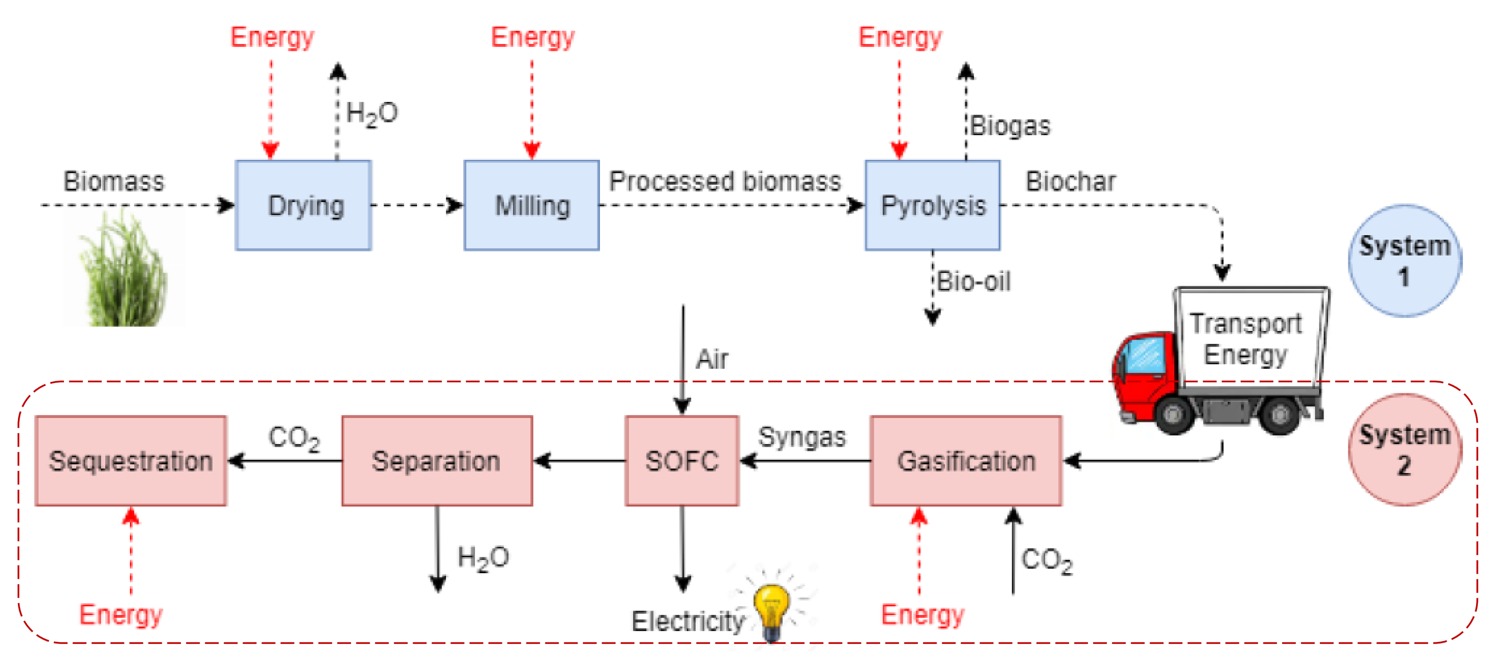


Figure 2: Proposed BECCS Process

System 2 was studied in Aspen Plus V10. The feedstock used was *Miscanthus sacchariflorus* in order to directly compare with the literature results of the BECCS process operating on *Miscanthus sacchariflorus.*[1] Pinch analysis was applied to optimize utility demand for the process streams. A PFD is shown below:

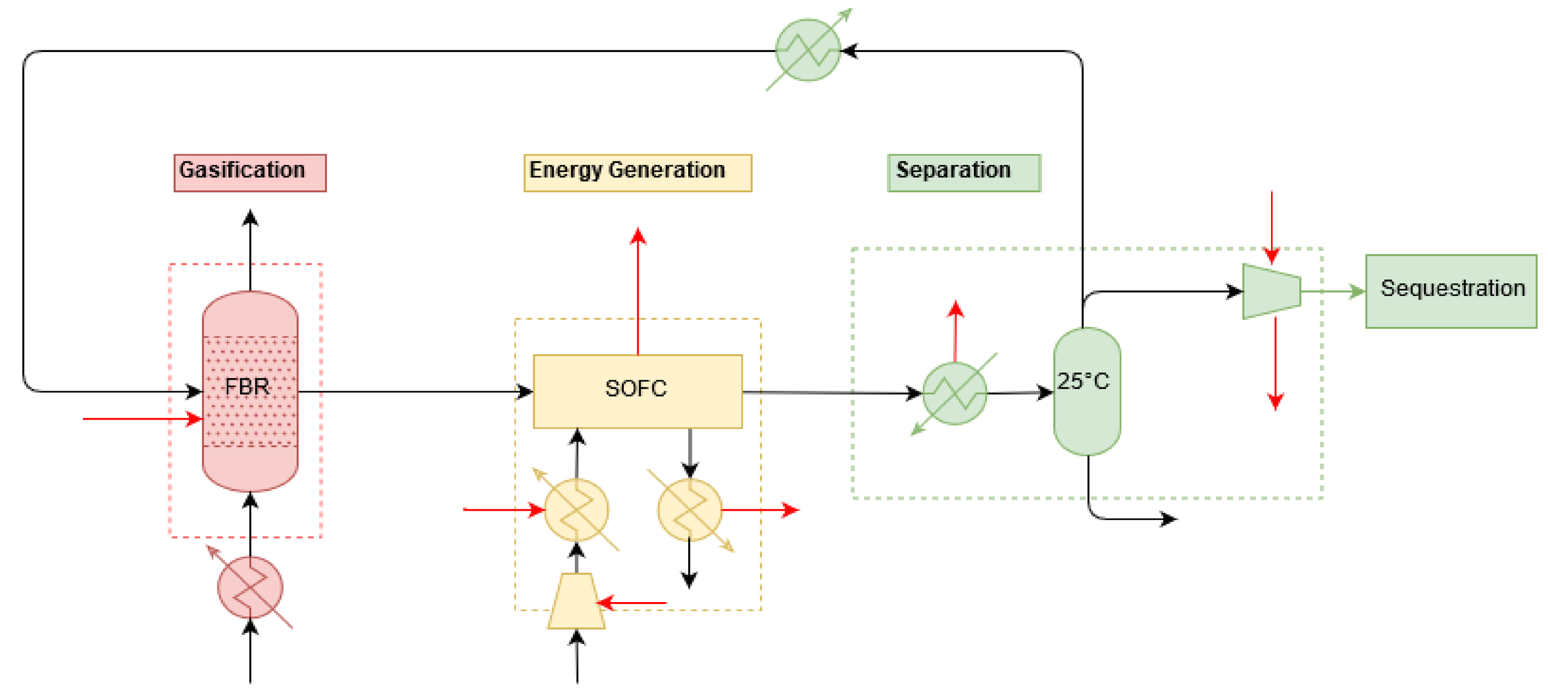


Figure 3: System 2 Process Design for Simulating BECCS Process

	Traditional [1]	Proposed
Biomass Requirement (Mt_{DM}/yr)	2.3 – 3.9	2.0
Carbon Sequestration (Mt/yr)	0.7 – 1.0	1.5

Table 1: BECCS Comparison Values

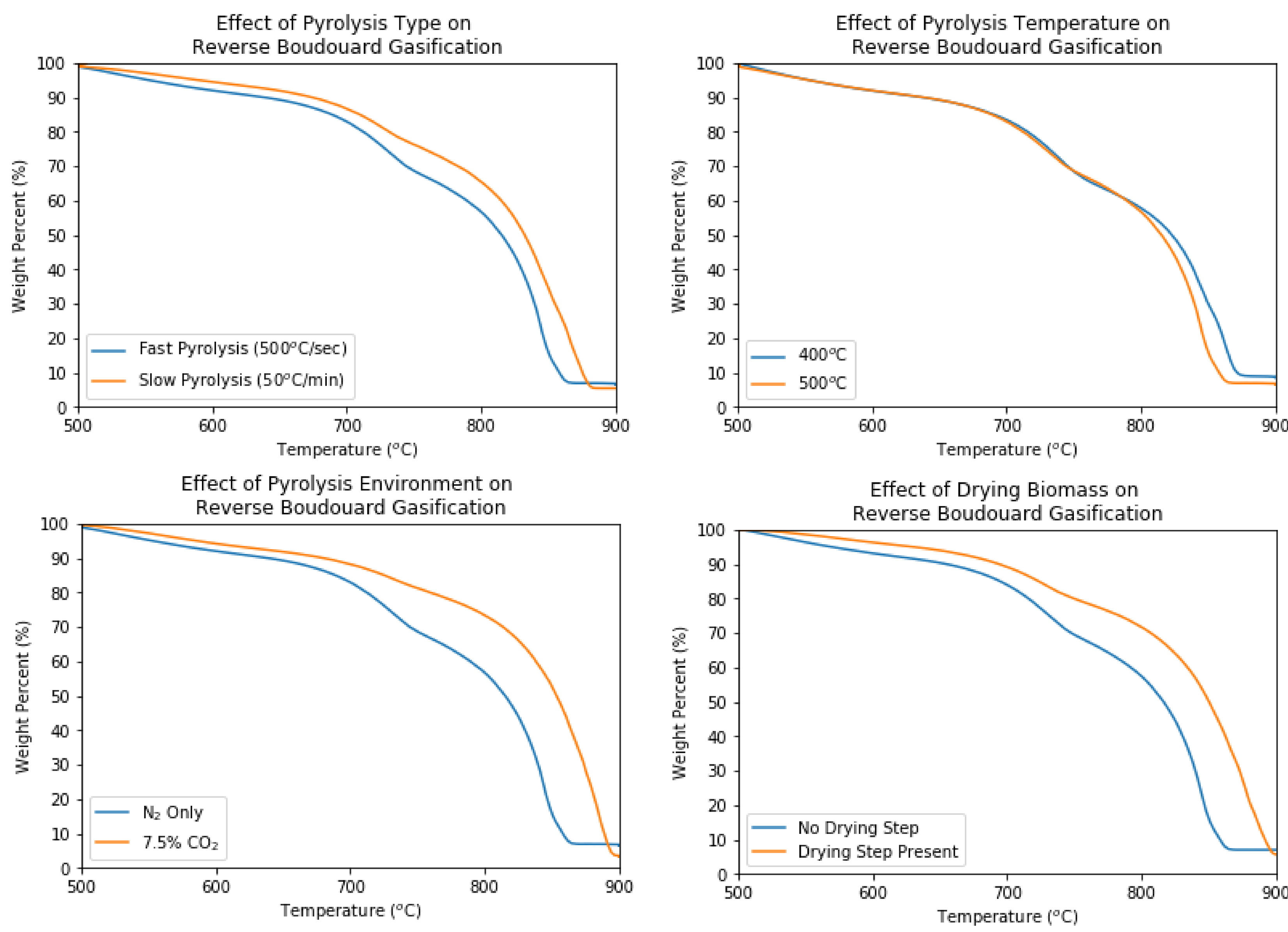
For a 500 MW power plant (with 80% efficiency), 0.5 megatons/yr of biochar is needed (2 megatons/yr of biomass assuming a 25% biochar yield). With heat integration, a minimum of 140.6 MW and 5.9 MW of heating and cooling utility is needed, respectively.

Results: Experimental

Biowaste is converted to char at varying conditions. We studied how reactive the resultant chars for the reverse Boudouard reaction:

$$C_{(s)} + CO_{2(g)} \rightleftharpoons 2CO_{(g)} \qquad \Delta H = 172\ kJ/mol$$

We investigated the influence of pyrolysis ramp rate, moisture content, inert atmosphere, and pyrolysis temperature in CO_2 gasification. The plots for the walnut biochar are shown below:



For each feedstock (not shown), the typical reaction range of the biochar is 700-900°C, consistent with SOFC operating conditions. Of the pyrolysis variables tested, pyrolysis temperature didn't significantly impact char reactivity, while pyrolysis atmosphere and use of a drying step affected the char reactivity more significantly.

Conclusions & Future Work

The alternative BECCS approach proposed is shown to potentially be an effective process to produce energy in a carbon negative manner. Simulations results suggest that the alternative BECCS model can be a more viable pathway for carbon-negative energy generation. Pyrolysis parameters, such as heat ramp, temperature, use of drying step, and use of CO_2, can be used to create a more reactive char. Addition of steam in gasification can also be pursued for better optimization of the BECCS process.