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Project Title: Development of a novel gasification technology for distributed power generation from solid wastes

Contract Number: RD4-1 Milestone Number: 3 Report Date: April 3, 2018

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Congressional District: 5

Congressional District: 4

MILESTONE REPORT

Executive Summary: Unlike biomass combustion to electricity technology that directly burns biomass to supply steam for steam-electric generators, gasification to electricity technology converts solid feedstock to a combustible gas that can then fuel steam generators or gas turbines. Compared with direct combustion, gasification has higher conversion efficiency; its gas products are easier to handle; it has less emission problems; it has less solid residue left in the equipment; and last but not the least, gas product can be used in a greater variety of power plant configurations, either internal – combustion engines, gas turbines or CHP units. Gasification is considered by most the “Clean Biomass Technology”, the equivalent of Clean Coal Technology. In addition, gasification technology can be operated in scales suitable for distributed/ decentralized power generation, and hence compatible with the distributed nature of biomass feedstock production.

The University of Minnesota (University) is conducting a three-year research project to develop a fast gasification-based electricity generation technology. The University is investigating and fabricating a gasification method based on microwave heating to raise the process temperature and increase heating rate. This is expected to improve biomass conversion efficiency and syngas quality and cleanness. A fast microwave assisted gasification (fMAG) system for electricity generation is being designed and demonstrated as a prototype to evaluate techno-economic and other benefits of the proposed technology. Incorporated into the prototype system we developed will be microwave susceptors (MWS) which are effective at raising temperatures to a high level at extremely fast rates efficiently. The technology to be developed is scalable and portable which will enable distributed and decentralized electricity generation from biomass and other sold wastes that are intrinsically widely distributes in loose form.

The goal of this milestone period was to study the interactions between biomass and MWS to gain knowledge on interactions and relations among heating rate, temperature, amount of MWS, ratio of biomass to MWS, and power input for development of gasification processes and system. Experiments were carried out to study the effect of amount of SiC on heating characteristics, product yields and composition. We also investigated how catalysts could be used to alter the gas composition and convert/reduce tar for cleaner gas product. We also developed and characterized new SiC foam supported catalysts and evaluated the effects of this new catalyst and its placement on gasification of biomass in different conditions. In summary, the findings from this milestone period provides good understanding of the interactions between biomass and microwave absorbents. We therefore conclude that the current milestone has been completed and the outcome meets the expectation.

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Technical Progress: We carried out experiments to study the interactions between microwave absorbents and biomass feedstock under microwave radiation. With fixed amount of biomass (25g), we varied the amount of SiC (microwave absorbent) from 200g to 600g. Our experimental results showed that heating varied with biomass to SiC ratios. With the current experimental setup, the fastest heating was obtained when a biomass to SiC ratio of 1:12 was used. The product yields were correlated well with the heating rates. The ratios also affected the chemical composition of the products. It was observed that an increase in SiC weight increased yields of hydrogen and methane and decreased carbon dioxide and carbon monoxide.

In order to convert tar to gaseous products, catalysts were used. We developed a SiC supported catalyst for gasification. The novelty of our approach is that we are using a SiC foam (sponge like) as catalyst support so that the temperature of the catalyst bed can be controlled through microwave heating. We characterized the catalysts using X-ray diffractometer (XRD) and scanning electron microscopy (SEM). Our study showed the catalysts had a uniform temperature distribution and mechanical stability.

The performance of this catalyst system was examined in different conditions including the placement of the catalysts and ratios of catalyst to biomass (C/B). The bare SiC foam in the catalytic bed led to a lower bio-oil yield (36.5%) and correspondingly a higher gas yield (35.2%) compared with 40.2% and 31.4%, respectively, for the control experiment with no catalysts. This could be due to the secondary cracking reactions of the pyrolytic vapors within the hot SiC foam matrix. The ex-situ packed bed configuration delivered the lowest yield of bio-oil and the highest gas yield. We found that bio-oil yield decreased from 40.2% to 33.5% and gas yield increased from 31.4% to 39.7% as the C/B ratio increased from 0 to 1/2. The results showed that the catalytic activity of ZSM-5 is gradually lost during the process due to coking, which was produced as a result of formation of heavy hydrocarbon oils and carbonaceous residues (usually referred to as coke or carbon) during gasification. Coke tends to physically cover the active surface.

Catalyst deactivation is a critical issue facing catalytic gasification or fast pyrolysis. We designed an experiment with 7 repeated reaction-regeneration cycles to test the stability of the catalyst system. In each cycle, the spent composite catalysts were regenerated by calcination in air at 500 oC for 8 h, and then used in conversion at a constant catalyst to biomass ratio (C/B) of 1/4. During the 7 cycles of experiments, both yields and compositions were very similar, indicating that the catalyst system was very stable. ZSM-5 coating weight decreased slightly from 3.887 g to 3.763 g after 7 cycles, which indicates a strong adherence of the coating to the support. The slight loss of activity was probably due to ZSM-5 crystals from the composite catalyst according to morphology study.

In the steam gasification experiments, the steam (produced from a steam generator) was introduced onto the surface of the char with fixed steam/biomass (S/B) mass ratio (S/B=1). Flowing through the condensers, the gas product was collected into sampling bags for offline analysis, with tar condensed into the liquid collectors for subsequent analysis. The results show that steam increased gas yield while decreasing tar and char and also resulted in higher H_2/CO ratio.

We conducted gasification experiments using our larger system, on which a continuous gasification process was implemented. The system has a capacity of 30kg/hour. The microwave chamber was filled with SiC balls as the reaction bed. During the gasification process, the SiC bed was stirred continuously with an auger pre-inserted in the microwave chamber for even heating and char discharging. Prior to gasification, the SiC bed was heated to 550 ℃ under the microwave irradiation. After that, the wood pellet in the hopper was introduced into the reactor through a feed elevator. Before the gas collecting, the condensable vapors were quenched in the spraying tower and shell-and-tube condenser and collected in the bio-oil tank. The gas products were collected with gas sampling bags for further analysis. The temperature was monitored, fractional yields were determined, and the composition of the gas and bio-oil was characterized.

Additional Milestones: N/A
Project Status: The project is on schedule and within budget.

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Appendixes

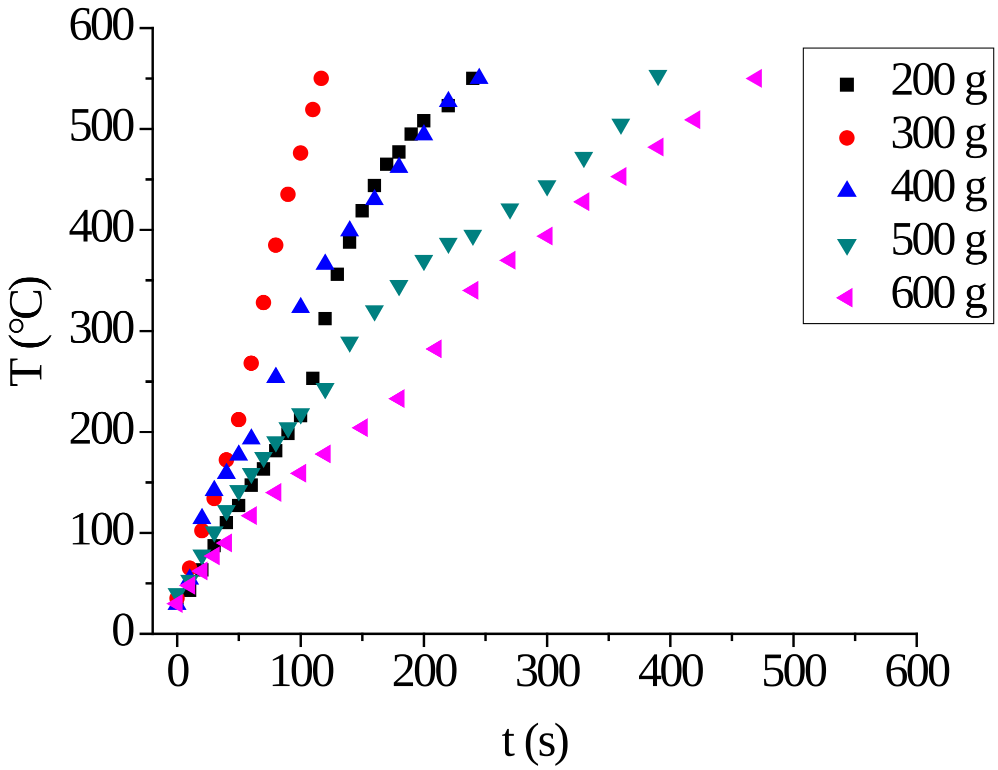

Fig. 1. Heating of mixture of biomass and SiC as a function of different amount of SiC under microwave radiation.

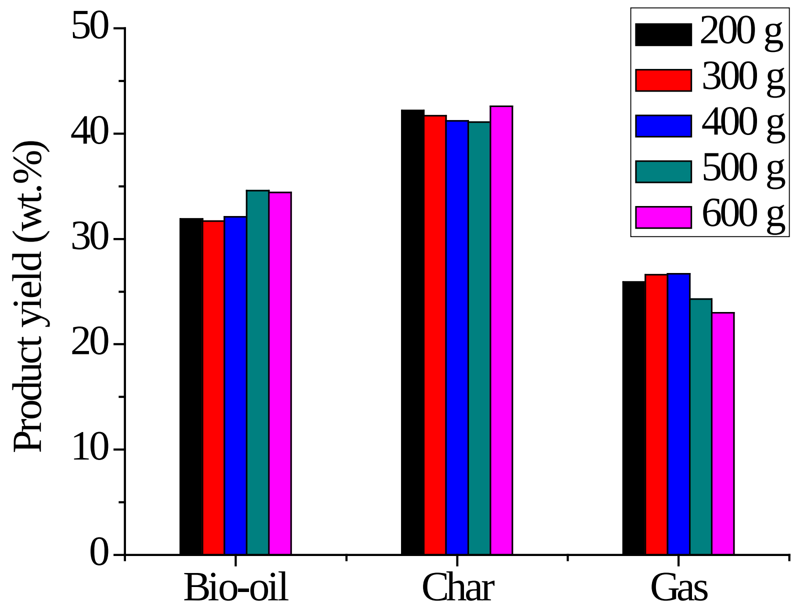

Fig. 2. Effect of SiC weight on lignin pyrolysis product yield.

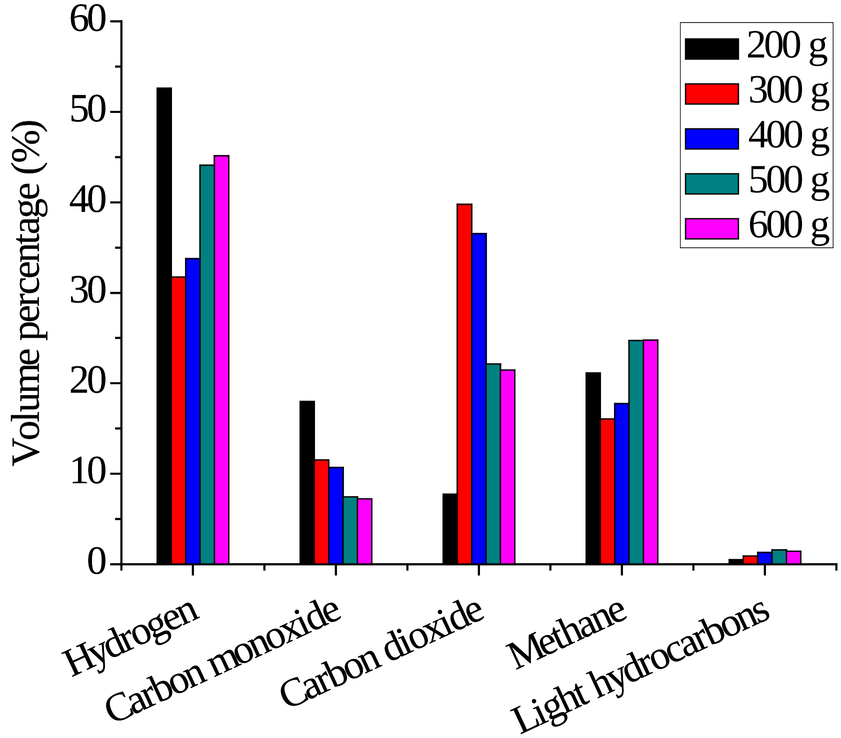

Fig. 3. Effect of SiC weight on gas composition.

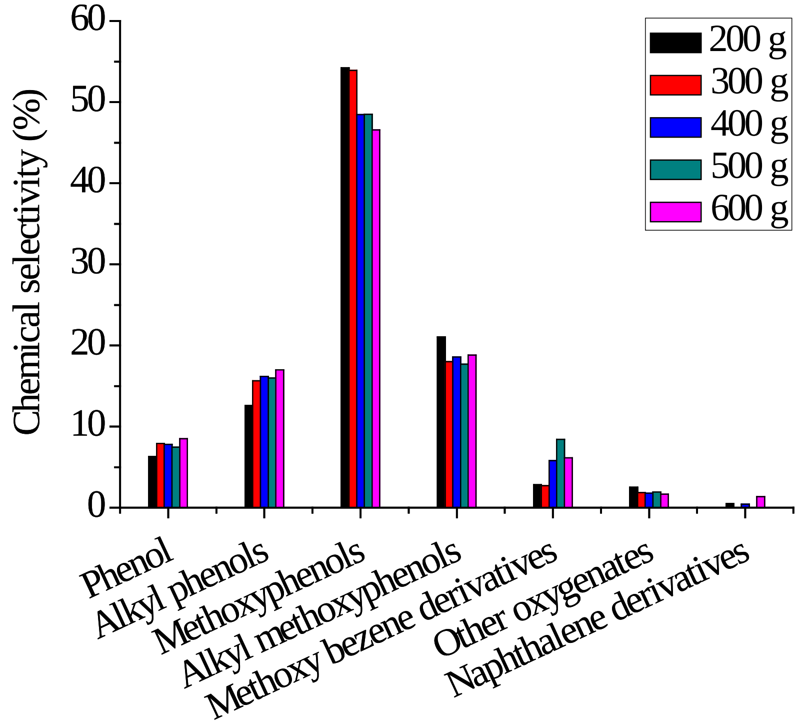

Fig. 4. Effect of SiC weight on chemical selectivity of bio-oil.

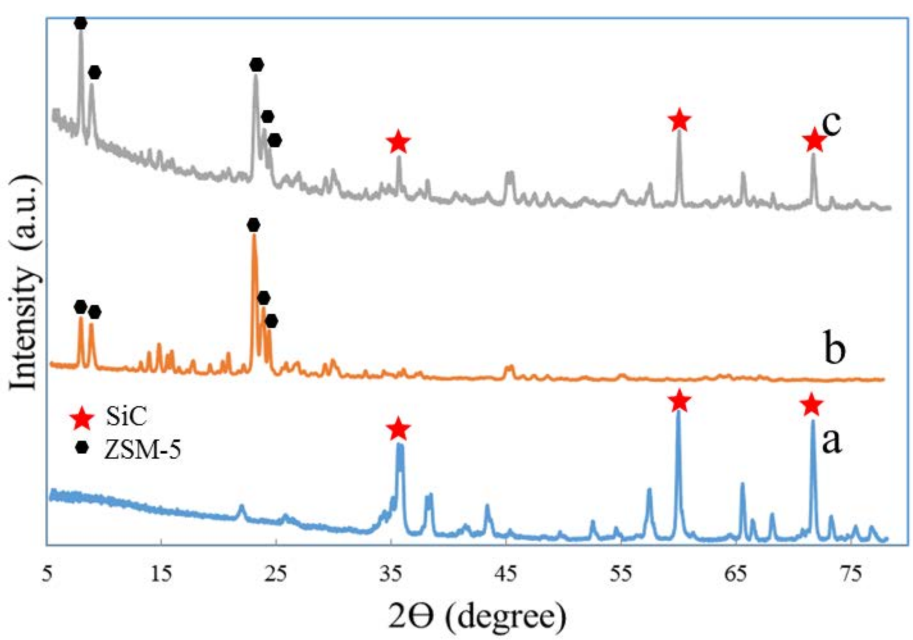

Figure 5. XRD patterns of (a) SiC foam, (b) ZSM-5 powder, and (c) ZSM-5/SiC foam composite

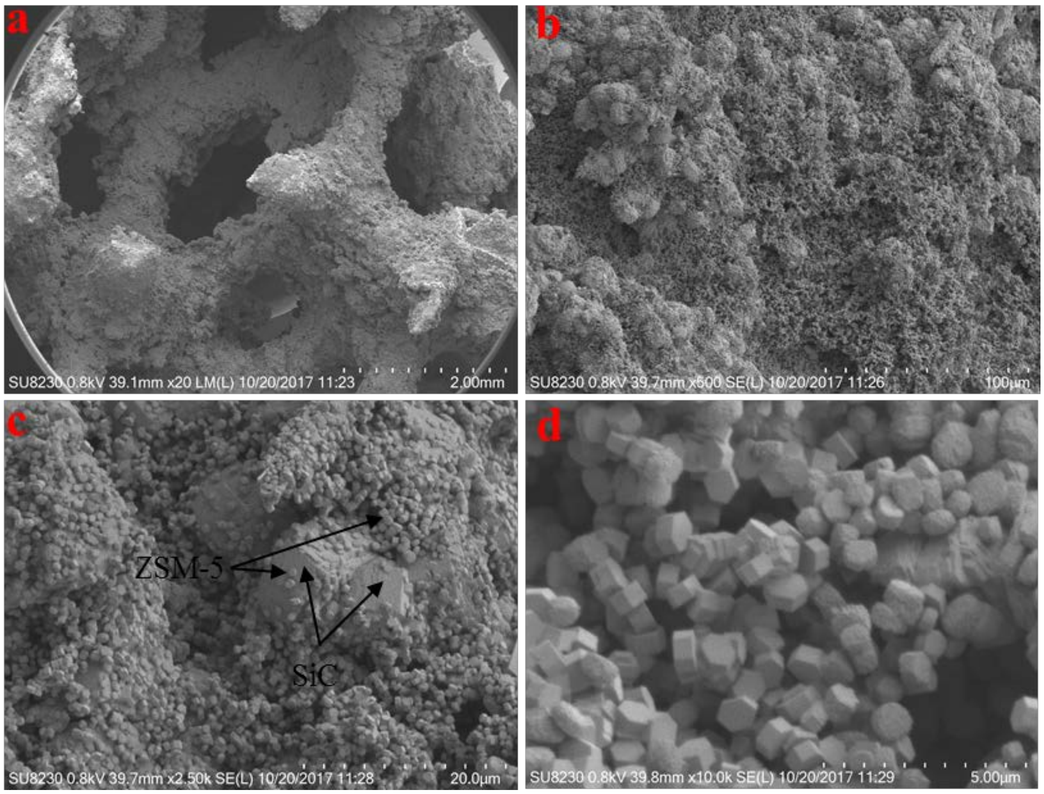

Figure 6. SEM micrographs of ZSM-5/SiC foam composites of different magnifications: 20 (a), 500 (b), 2500 (c), and 10000 (d).

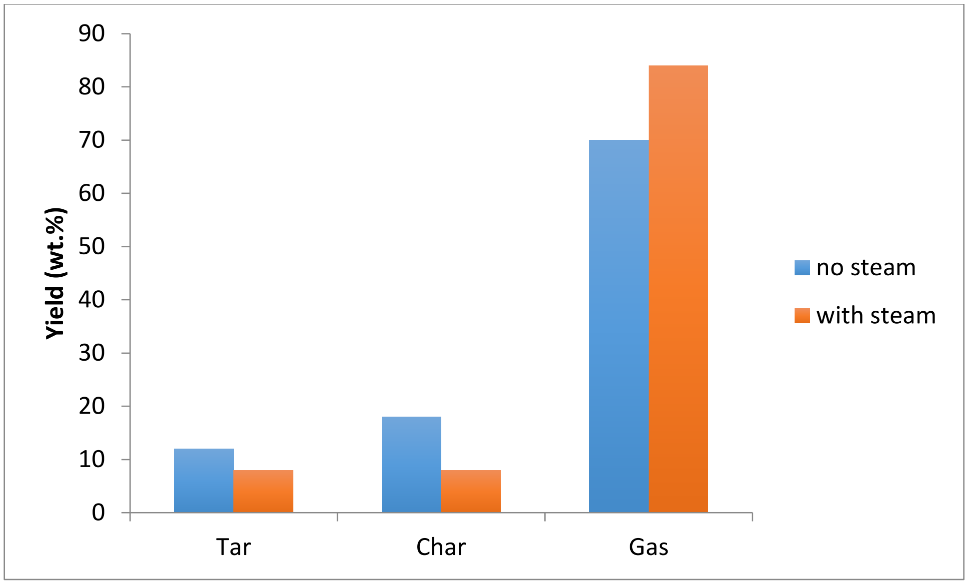

Fig. 7. Effect of steam on product distribution from corn stover gasification. Gasification temperature: 900 °C

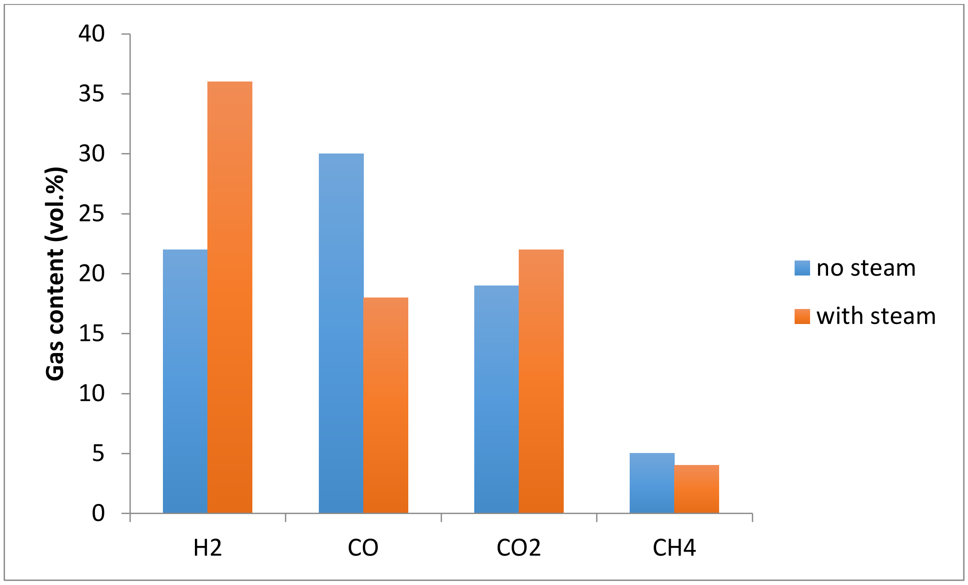

Fig. 8. Effect of steam on major gas contents from corn stover gasification. Gasification temperature: 900 °C

Dissemination of research results

- Nan Zhou, Shiyu Liu, Yaning Zhang, Liangliang Fan, Yanling Cheng, Paul Chen, Yuhuan Liu, Hanwu Lei, Roger Ruan. 2017. Coating on SiC foam support as a composite catalyst for fast microwave-assisted pyrolysis of biomass. Thermochemical Conversion of Biomass. 2017 AICHE Annual Meeting, Minneapolis, MN, USA.

- Shiyu Liu, Yaning Zhang, Liangliang Fan, Nan Zhou, Yanling Cheng, Erik Anderson, Yunpu Wang, Paul Chen, Yuhuan Liu, Hanwu Lei, Roger Ruan. 2017. Bio-fuel production from sequential two-step catalytic fast microwave-assisted biomass pyrolysis. Thermochemical Conversion of Biomass. 2017 AICHE Annual Meeting, Minneapolis, MN, USA.

- Roger Ruan, Shiyu Liu, Yaning Zhang, Liangliang Fan, Nan Zhou, Yanling Cheng, Erik Anderson, Yunpu Wang, Yuhuan Liu, Hanwu Lei, Paul Chen. 2017. Microwave-assisted catalytic pyrolysis and gasification for solid wastes conversion and utilization. Thermochemical Conversion of Biomass. 2017 AICHE Annual Meeting, Minneapolis, MN, USA.

- A book chapter titled "Biofuels from thermos-chemical conversion of lignocellulosic biomass" was submitted for publication. The book title is "BIOFUELS: ALTERNATIVE FEEDSTOCKS AND CONVERSION PROCESSES" by Elsevier Inc.

- A manuscript titled "Improving hydrocarbon yield from catalytic fast co-pyrolysis of hemicellulose and plastic in dual catalyst beds over CaO and HZSM-5" has been drafted and will be submitted to peer-reviewed journal after final revision.

- A manuscript titled "A manuscript titled "ZSM-5 Coatings on SiC Foam Support as a Composite Catalyst for Microwave-assisted Pyrolysis of Biomass" has been submitted to peer-reviewed journal