Designing Novel Modular Biodiesel Plant

Caleb Moellenhoff, Shyam Paudel, Joseph D. Smith, PhD.
Bioenergy and Systems Technology Laboratory, Linda and Bipin Doshi Department of Chemical and Biochemical Engineering

Objective

To design a transportable, modular biodiesel plant in which the novel process design will increase yield of fatty acid methyl esters (biodiesel) while meeting industry standards of quality and reducing the required space and energy input for production from waste cooking oil.

Background

- By reducing the output of carbon dioxide to the atmosphere by 74% over the course of its life-cycle and eliminating the waste of used cooking oil, biodiesel remains an environment-friendly alternative to fossil fuels.
- The cause for biodiesel's current impracticality lies in its costly production involving a relatively slow catalyzed transesterification reaction and energy intensive distillation.
- We aim to solve these problems through the development of a process involving a novel reactor, a supercritical uncatalyzed transesterification reaction, and multiple unique membrane separation schemes.

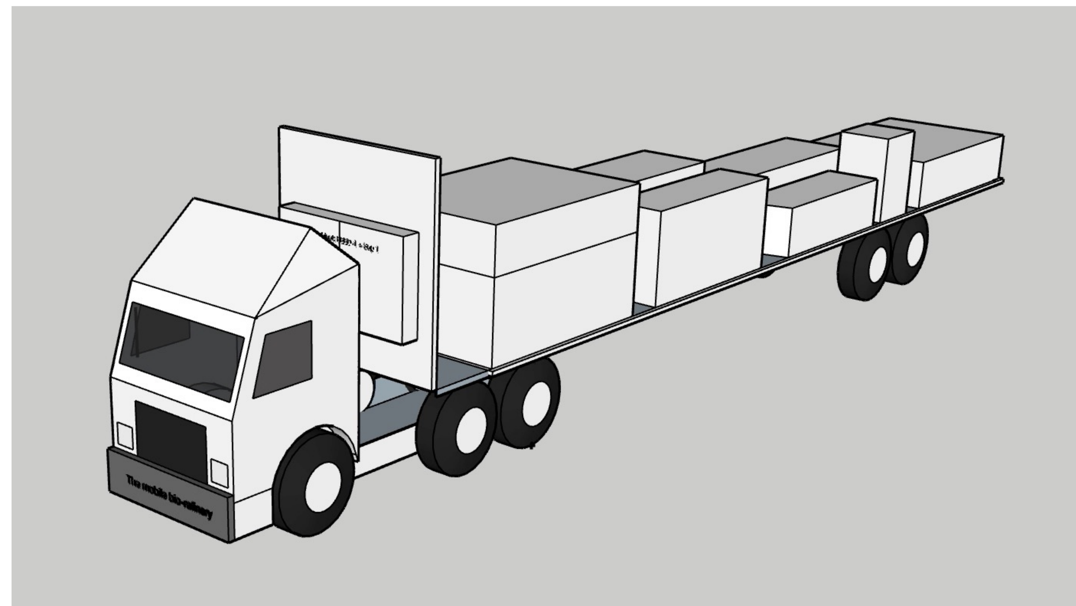

Fig. 2: Conceptual 3D sketch of modular design

Modular Design

Being able to easily transport the plant on the back of a semi-truck would be an advantageous business model. However, fitting the entire process in a space that is approximately 40 ft. x 20 ft. x 10 ft. while making the equipment adequately accessible to inspection and servicing is anticipated to be a challenge in sizing and further developing this design.

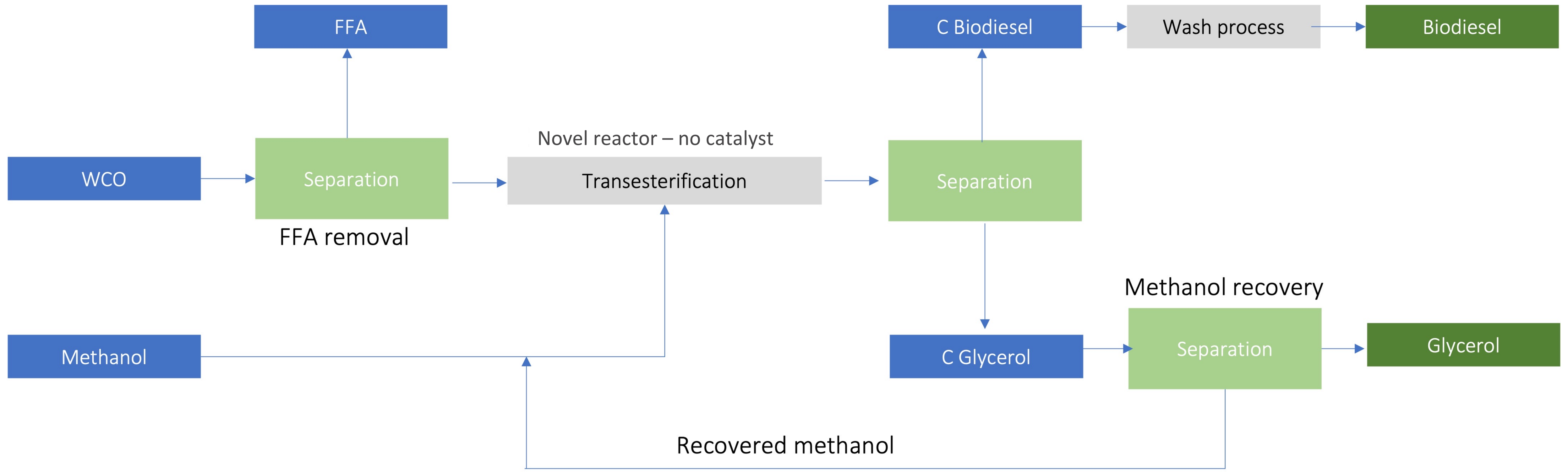

Fig. 1: Process flow diagram of novel process (note: FFA = free fatty acid, WCO = waste cooking oil, C = Crude)

Process and Instrumentation Design

The P&ID was sectioned into eight different nodes for the feed, the novel tubular reactor, the three separation systems, the washing of crude biodiesel, the waste, and the chiller. Proper considerations to ensure safe and environment-friendly production have been made including pressure relief as well as containment and treatment of combustible vapors. Additionally, necessary process indicators, transmitters, and controllers have been added to further safeguard from disaster.

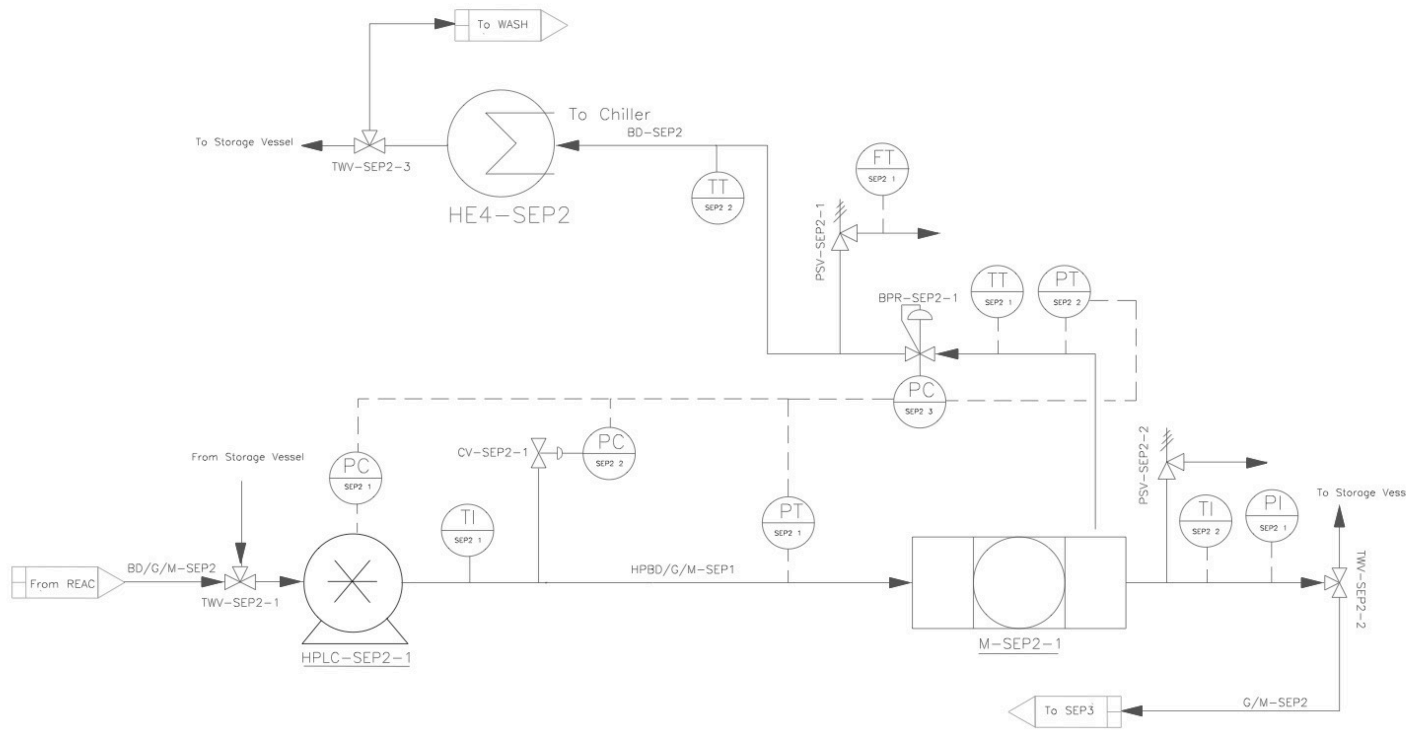

Fig. 3: P&ID of first separation node following reactor

Reaction and Reactor Design

The transesterification reaction will take place at an optimal supercritical temperature and pressure that will maximize yield while not requiring the presence of a catalyst. The kinetics are known and were entered into the process simulation on Aspen Plus. The high pressure of the reaction will be reached and held through a positive displacement diaphragm pump before and a back pressure regulator before and after, respectively, the coiled tubular reactor.

Separations

We plan to utilize membranes with varying pore sizes in order that the differing molecular weights of the components might be exploited for the purpose of separation for removing the free fatty acids from the waste cooking oil, recycling acetone, removing crude biodiesel from crude glycerol, and removing glycerol from unreacted methanol.

Component Name	Approx. Molecular Weight (Da)
Vegetable Oil	885
Free Fatty Acids	282
Acetone	58
Fatty Acid Methyl Esters	297
Glycerol	92
Methanol	32

Fig. 4: Approximate molecular weights of process components

Results	Significance for Future Work
Developed draft of P&ID on AutoCAD Plant3D	Conducting Hazard and Operability Study
Developed 3D Design on SolidWorks	Working towards and assessing feasibility of design within space requirement once scaled to size
Initiated development of Aspen Plus model	Further development will enable sizing, reactor scale-up, and economic optimization calculations
Started bill of materials using P&ID equipment tags	Making cost analysis of construction

Fig. 5: Results and Discussion

Acknowledgements

- Simon Nguyen, Wyatt Spilker, and Jay Balasubramanian

References

Hassan, A. A., & Smith, J. D. (2021). Laboratory-scale research of non-catalyzed supercritical alcohol process for continuous biodiesel production. *Catalysts*, *11*(4), 435. https://doi.org/10.3390/catal11040435

Huo, H., Wang, M., Bloyd, C., & Putsche, V. (2008). Life-cycle assessment of energy use and greenhouse gas emissions of soybean-derived biodiesel and renewable fuels. *Environmental Science & Technology*, *43*(3), 750–756. https://doi.org/10.1021/es8011436