Undergraduate Thesis Prospectus

Production of Sustainable butanol biofuel from lignocellulosic biomass

(technical research project in Chemical Engineering)

Land for food or fuel: the struggle over biofuel policies

(sociotechnical research project)

by

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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General Research Problem: The implications of increased global biofuel use

How can biofuels best serve energy transition objectives globally?

Biofuels, fuels made from organic matter, are a promising replacement for fossil fuels. Replacing fossil fuels is needed to reduce climate change and improve sustainability. Right now, most biofuels are produced using food crops, such as corn, soy, or sugarcane. This causes friction over whether these crops should be food or fuel. Using leftover parts of food crops stops this competition and recycles more organic material into fuel.

Production of sustainable butanol biofuel from lignocellulosic biomass

How can we effectively produce biobutanol from corn stover?

Ethanol is commonly added to gasoline to reduce emissions and improve fuel quality. Research has shown that butanol, a longer chain alcohol, has a higher heating value, lower volatility, increased ignition performance, and higher energy density, making it a more promising fuel additive alternative (Trindade & Santos, 2017).

First generation feedstocks such as corn, sugarcane, oil palm, wheat, and soy are commonly used in ethanol production today (Tomei & Helliwell, 2016). Like ethanol, butanol can be produced from this type of feedstock. Second generation feedstocks are lignocellulosic agricultural residues such as corn stover. These byproducts could be an innovative, low-cost way to convert waste into usable biofuel (Bušić et al., 2018). One impediment of this material is the requirement of advanced pretreatment technologies for successful fermentation, since microorganisms cannot digest cellulose as easily as sugars and starches (Taha et al., 2016). This poses obstacles for commercialization, but the team is optimistic here due to recent research that

has proposed new, cheaper pretreatment methods, such as the use of alkali as a hydrolyzing agent (Baral et al., 2016; Chen et al., 2021).

This project will examine the production of biobutanol from a corn stover feedstock using an acetone-butanol-ethanol (ABE) fermentation process (Buehler, 2016). Fuel-additive grade butanol is the main product, with byproducts of acetone and ethanol. Conversion of corn stover to butanol will be accomplished through pretreatment of the feedstock, followed by biological fermentation using the bacteria *Clostridium Acetobutylicum ATCC 824* (Buehler, 2016; Rao et al., 2016), and separation steps. The unit operations that will likely be used and designed in this process include reactors and washers for the pretreatment hydrolysis; a reactor for the fermentation reactions; and interconnected distillation columns to separate components and break aqueous ABE azeotropes (Pudjiastuti et al., 2021). A block flow diagram depicts the general process to be designed (Figure 1).

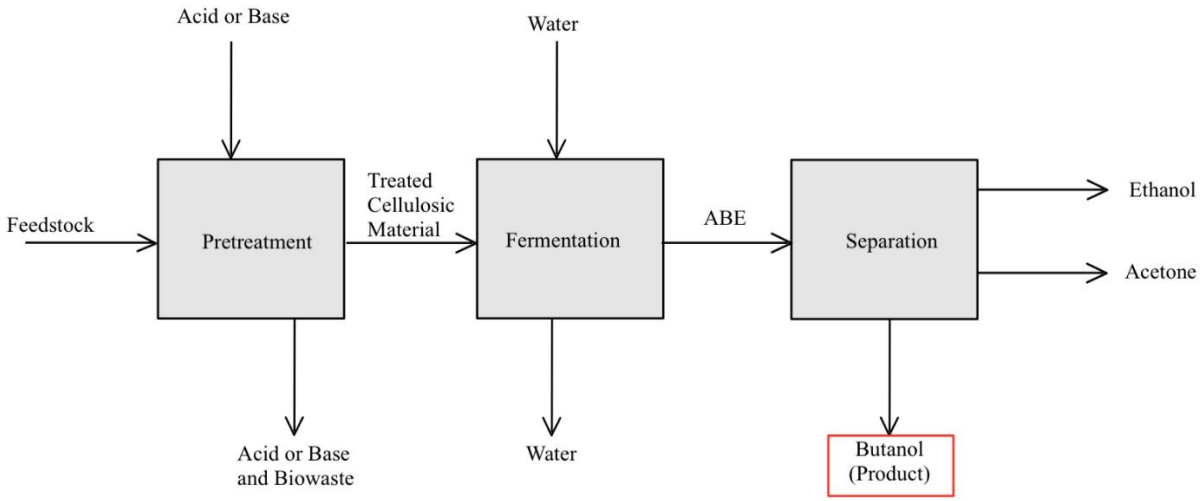

Figure 1. Butanol from ABE fermentation block flow diagram

The team, consisting of members Kevin London, Rachel Rosner, Isabella Powell, Olivia Wilkinson, and Jason Thielen, will use Aspen Plus Simulation software to design a plant for the

economical and sustainable production of butanol using ABE fermentation. This software simulates process dynamics, material properties and economic analysis realistically, and offers other modeling tools. Design data such as fermentation cell growth kinetics, methods of separation, feedstock viability, and an economic analysis of the process, will be collected from peer-reviewed journal research and industrial data. Consultation with UVA Professor Ronald Unnerstall, who has 34 years of experience in the Oil and Gas industry and further experience writing BP's company directive for biofuel use in 2001, will also direct the team's efforts in designing a process fit for an industrial application. This project will take place in the Fall 2023 and Spring 2024 semester as a part of the Chemical Engineering Department's CHE 4474 and CHE 4476 senior design courses, under the direction of technical advisor Professor Eric Anderson. They will complete the final design report in April of 2024.

Land for food or fuel: the struggle over biofuel policies

How are interest groups competing to draw the line between responsible biofuel policies that drive energy transition and irresponsible policies that destabilize global food supplies?

Biofuels are a valuable resource in the global energy transition. Biofuel production relies on crop availability. Many of the crops turned into biofuels are food crops, such as corn and soy. As more food crops go to fuel production, less are available for consumption (Tenebaum 2008). Benefits such as renewability, lessening dependence on foreign fuel supplies, and cutting greenhouse gas emissions are benefits of biofuel use (EPA 2023). Biofuel production is a major policy issue, as governments subsidize crop production for use in biofuels and mandate biofuel use, often at the behest of powerful lobbying interests (Runge 2010). Policymakers must weigh

the green energy transition potential of biofuels against higher food prices, land degradation, and environmental damages.

Farmers' advocacies see biofuel use as a new market. Their policy goals are aimed at increasing biofuel use. The National Farmers Union, a trade association for American farmers, seeks to reduce competition with biofuels. In a letter to the EPA, the NFU seeks emissions evaluations policies that "account for all emissions relating to different fuel and engine technologies and equitably incentivize emissions reductions from all of those technologies" (NFU 2023). This serves the group's goal of reducing competition with biofuels by reducing the viability of electric vehicles. Farmers' advocacy groups try to steer technological development by influencing policy. In response to changes on fuel consumption regulations, the National Corn Growers Association (NCGA 2023) President Tom Haag noted that many proposed laws push too hard against fuel use. Mr. Haag stated that with current policy directions, "…auto manufacturers will be forced to overlook viable solutions, such as high-octane biofuels like corn ethanol, as they rush to meet these standards."

Industrial advocates tout biofuels as a solution to the energy transition. These industry advocacies see biofuels as a greener path forward, worth the risks for land and food stocks. They seek policies that drive increased biofuel use. Biofuel companies are aware that their product necessarily competes with food stocks. To address food supply concerns, some industrial groups look to shift blame. The Minnesota Biofuels Association points to market hiccups, not supply competition, as the cause of food price volatility (Smith 2023). Other groups try to change the narrative. Growth Energy, an ethanol producers' trade association, points to biofuels' ability to reduce greenhouse emissions. As governments push for cleaner transportation, Growth Energy CEO Emily Skor, in remarks to the group's annual summit, said *"*Today, with the right policies,

biofuels can take up a larger part of our nation's fuel supply to lower emissions; tomorrow, with the right modeling, farm-based biofuels will serve as the cornerstone feedstock for SAF that dramatically decarbonizes the aviation sector" (Growth Energy 2023). With White House climate advisors and secretaries from the Departments of Transportation and Agriculture present at these events, industry influence on policymakers is clear. Some have pointed to the need for more electrification to stop climate change, instead of better fuels. The Renewable Fuels Association (RFA), another biofuel manufacturer trade association, notes that combustion engines won't go away. RFA CEO Geoff Cooper remarked "Americans will continue to rely upon hundreds of millions of combustion engines and hundreds of billions of gallons of liquid fuels for many decades to come, even as more EVs enter the fleet," (RFA 2023).

Biofuels derived from first-generation feedstocks directly compete with food supplies; what we turn to fuel cannot be eaten. Supply concern advocacies seek policies to prevent swapping food production for biofuel production. The United Nations Human Rights Council (UNHRC), one such advocacy in this instance, notes the dangers biofuel demand poses for developing nations. Developing countries risk selling their food crops as cash crops. The UN's Special Rapporteur on the right to food, Jean Ziegler, stated in a report to the General Assembly that "There are serious risks of creating a battle between food and fuel that will leave the poor and hungry in developing countries at the mercy of rapidly rising prices for food, land and water" (Ziegler 2007). Of special interest for this prospectus is the assertion in the same UN report by Mr. Ziegler that "…biofuels should be made from non-food plants and agricultural wastes, reducing competition for food, land and water," (Ziegler 2007). The International Union of Food Science and Technology (IUFoST), notes that current policy warrants ethical concern. As an advocacy group on behalf of international food suppliers, the IUFoST raises the question

of resource allocation. With subsidies rising for biofuels in the developed world, the IUFoST notes that continued food insecurity around the world should "…raise ethical and moral concerns regarding the failure of the international community to make decisive progress towards achieving world food security," (Spiess 2013).

Environmental advocacies largely oppose biofuel expansion. They seek policies to limit or prevent biofuel use. Advocacies such as Friends of the Earth (FOE) seek to reduce biofuel demand by agitating for policy that removes biofuel consumption quotas, such as the Renewable Fuel Standard in the United States (Fox 2012). Other advocacies, such as the World Wildlife Foundation, oppose biofuel expansion because of land availability. As demand for food rises, more land must be brought under cultivation; biofuels add another new source of land demand. As the WWF noted in a report, the only solution is to meet both demands is "…the expansion of the existing areas under cultivation," (Pastowski 2007), jeopardizing local ecologies. biofuelwatch, a grassroots advocacy organization, oppose biofuel expansion policy due to the failure of biofuels to meaningfully reduce climate change and the industry's reliance on subsidies. In an open letter to the U.K. government, biofuelwatch endorsed the sentiments of scientists who stated that current biofuel policy will result in "…adding millions of tonnes of carbon dioxide emissions every year" (biofuelwatch 2011).

References

Baral, N. R., Slutzky, L., Shah, A., Ezeji, T. C., Cornish, K., & Christy, A. (2016). Acetone-butanol-ethanol fermentation of corn stover: Current production methods, economic viability and commercial use. *FEMS Microbiology Letters, 363*(6). doi.org/10.1093/femsle/fnw033

biofuelwatch (31 May 2011), "Biofuels and Climate Change – Biofuelwatch." www.biofuelwatch.org.uk/wp-content/uploads/Biofuels-Scientists-Letter2.pdf.

Buehler, E. A., & Mesbah, A. (2016). Kinetic Study of Acetone-Butanol-Ethanol Fermentation in Continuous Culture. *PloS one, 11*(8), e0158243. doi.org/10.1371/journal.pone.0158243

Bušić, A., Marđetko, N., Kundas, S., Morzak, G., Belskaya, H., Ivančić Šantek, M., Komes, D., Novak, S., & Šantek, B. (2018). Bioethanol production from renewable raw materials and its separation and purification: A Review. Food Technology and Biotechnology, 56(3). /doi.org/10.17113/ftb.56.03.18.5546

Chen, X., Yuan, X., Chen, S., Yu, J., Zhai, R., Xu, Z., & Jin, M. (2021). Densifying lignocellulosic biomass with Alkaline Chemicals (DLC) pretreatment unlocks highly fermentable sugars for bioethanol production from Corn Stover. *Green Chemistry, 23*(13), 4828–4839. doi.org/10.1039/d1gc01362a

EPA. (2023). "Economics of biofuels" . US EPA - U.S. Environmental Protection Agency. www.epa.gov/environmental-economics/economics-biofuels

Fox, Audrey. "Joint Advocacy Efforts on Biofuels Policy." Friends of the Earth, March 18, 2012. foe.org/blog/biofuels-coalition-work/.

Growth Energy. "Growth Energy Urges Action after Administration Officials Show Commitment to Biofuels at 2023 Advocacy Summit." *Growth Energy* (blog), September 19, 2023. growthenergy.org/2023/09/19/growth-energy-urges-action-after-administration-officials-show-commitment-to-biofuels-at-2023-advocacy-summit/.

National Corn Growers Association (Sep. 27, 2023). "NCGA Launches Advocacy Campaign Calling on Feds to Establish Level Playing Field for Biofuels." National Corn Growers Association. www.ncga.com/stay-informed/media/in-the-news/article/2023/09/ncga-launches-advocacy-campaign-calling-on-feds-to-establish-level-playing-field-for-biofuels.

National Farmers Union. “Biofuel, Farm, Fuel Marketer Groups Urge Fairness in Tailpipe Emissions Standards - National Farmers Union,” July 5, 2023. nfu.org/2023/07/05/biofuel-farm-fuel-marketer-groups-urge-fairness-in-tailpipe-emissions-standards/.

Pastowski, Andreas, Sven Gärtner, Guido Reinhardt, and Nils Rettenmaier (April 2007). Rain Forest for Biodiesel? Ecological Effects of Using Palm Oil as a Source of Energy, 2007. doi.org/10.13140/RG.2.1.5129.0325.

Pudjiastuti, L., Widjaja, L., Iskandar, K., Sahid, F., Nurkhamidah, S., Altway, A., Putra, A. (2021) Modeling and simulation of multicomponent acetone-butanol-ethanol distillation process in a sieve tray column, *Heliyon*, Volume 7, Issue 4, doi.org/10.1016/j.heliyon.2021.e06641.

Rao, A., Sathiavelu, A., & Mythili, S. (2016). Genetic Engineering In BioButanol Production And Tolerance. *Brazilian Archives of Biology and Technology*, *59*.

Renewable Fuels Association. (June 13 2023) “RFA’s Cooper: Let’s Fuel the Energy Transition With Ethanol.” Renewable Fuels Association. ethanolrfa.org/media-and-news/category/news-releases/article/2023/06/rfa-s-cooper-let-s-fuel-the-energy-transition-with-ethanol.

Runge, C. Ford. (March 11 2010) “The Case Against Biofuels: Probing Ethanol’s Hidden Costs.” Yale E360. e360.yale.edu/features/the_case_against_biofuels_probing_ethanols_hidden_costs.

Smith, Alan. (2023) “Food Vs Fuel.” www.mnbiofuels.org/resources/facts-about-ethanol/food-versus-fuel.

Taha, M., Foda, M., Shahsavari, E., Aburto-Medina, A., Adetutu, E., & Ball, A. (2016). Commercial feasibility of lignocellulose biodegradation: Possibilities and challenges. *Current Opinion in Biotechnology*, *38*, 190–197. doi.org/10.1016/j.copbio.2016.02.012

Spiess, Walter E. L. “Does Biofuel Production Threaten Food Security?” In *Advances in Food Process Engineering Research and Applications*, edited by Stavros Yanniotis, Petros Taoukis, Nikolaos G. Stoforos, and Vaios T. Karathanos, 629–44. Food Engineering Series. Boston, MA: Springer US, 2013. doi.org/10.1007/978-1-4614-7906-2_31.

Tenenbaum, D. J. (2008, June). *Food vs. Fuel: Diversion of Crops Could Cause More Hunger*. NCBI. www.ncbi.nlm.nih.gov/pmc/articles/PMC2430252/

Tomei, J., & Helliwell, R. (2016). Food versus fuel? Going beyond biofuels. *Land Use Policy*, 56, 320–326. doi.org/10.1016/j.landusepol.2015.11.015

Trindade, W. R., & Santos, R. G. (2017). Review on the characteristics of butanol, its production and use as fuel in internal combustion engines. *Renewable and Sustainable Energy Reviews, 69*, 642–651. doi.org/10.1016/j.rser.2016.11.213

Ziegler, Jean. "Report of the Special Rapporteur on the Right to Food." *United Nations General Assembly* Sixty-second session, document ref. no. A/62/289 (August 22, 2007): 23.