Production of a Butanol Based Biofuel from Second Generation Feedstock

Analysis of Resource Extraction Working Environments and Consequences

A Thesis Prospectus

In STS 4500

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Chemical Engineering

By

Kevin London

10/26/23

Technical Team Members

Isabella Powell, Rachel Rosner, Jason Thielen, Olivia Wilkinson

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

ADVISORS

Eric Anderson, Department of Chemical Engineering

William Davis, Department of Engineering and Society

Introduction

Revolutionizing the ways in which we source our energy has been a divisive topic societally, politically, and economically for the better part of a century. Globally, humanity has begun to realize that the ways in which we produce energy can have a profound effect on our environment, our lives, and the longevity of our world (Kralova & Sjoblom, 2010, p. 2-6). As such, delving into the options for sustainable energy production across a variety of scales and purposes has been the focus of much research and debate. One such option has been biofuels: combustible liquids formed from the fermentation of organic matter (Hoekman, 2008). The focus of my capstone project will be the efficient production of bio-butanol as an alternative fuel source. In addition, I will investigate how manipulation of economically disadvantaged groups systemically occurs in the process of resource extraction, and apply this knowledge to the question "How can we transition to sustainability equitably? "

Technical Topic

By advancing the efficiency of bio-butanol production I hope to provide a valuable step towards the global transition to sustainable fuel sourcing and energy production and ascertain at what scale the process is most economically viable. In doing so I will be able to develop a process capable of supplementing gasoline in automotive applications without the addition of greenhouse gasses to the atmosphere or the use of ecologically harmful production methods. Additionally, I hope to understand the reasons that much of the current collection of raw materials for energy production relies on underpaid and mistreated workers and generate a framework that does not rely on such subjugation for production of bio-butanol.

Emissions from internal combustion engines have driven the world's air pollution, a significant concern in the global warming phenomenon (Manzetti & Andersen, 2015). The pollution from these emissions is attributed to the extensive burning of fossil fuels, which are non-renewable fuels (EPA, 2023, *The sources and solutions: Fossil fuels*). To help mitigate this problem, the United States federal government has implemented the addition of alcohol-based fuel additives to gasoline, which reduces the carbon emissions from internal combustion engines and partially replaces a finite fuel resource (i.e. petroleum) with a sustainable, renewable fuel source (EPA, 2023, *Economics of biofuels*). Ethanol is commonly added into gasoline for this purpose, as well as to better oxygenate the fuel. 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, J., & Helliwell, R, 2016). Like ethanol, butanol can be produced from this type of feedstock. Controversies arise concerning the use of these food crops for biofuel production because such use drives increases in food prices, with some regions seeing food prices rise up to 83% in recent years (Tenenbaum, 2008). Second generation feedstocks are lignocellulosic agricultural residues such as corn stover. These byproducts have been presented as an innovative, low-cost way to repurpose waste into usable biofuel and prevent food price hikes (Bušić et al., 2018). (Tomei & Helliwell, 2016). 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 large-scale commercialization; however, the team is optimistic in this regard due to recent research that has proposed cheaper, innovative pretreatment methods, such as the use of alkali as a hydrolyzing agent (Baral et al., 2016; Chen et al., 2021).

This project is intended to 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 primary product, with byproducts of acetone and ethanol to be used as is most economically viable. 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 below depicts the general process to be designed by the team (Figure 1).

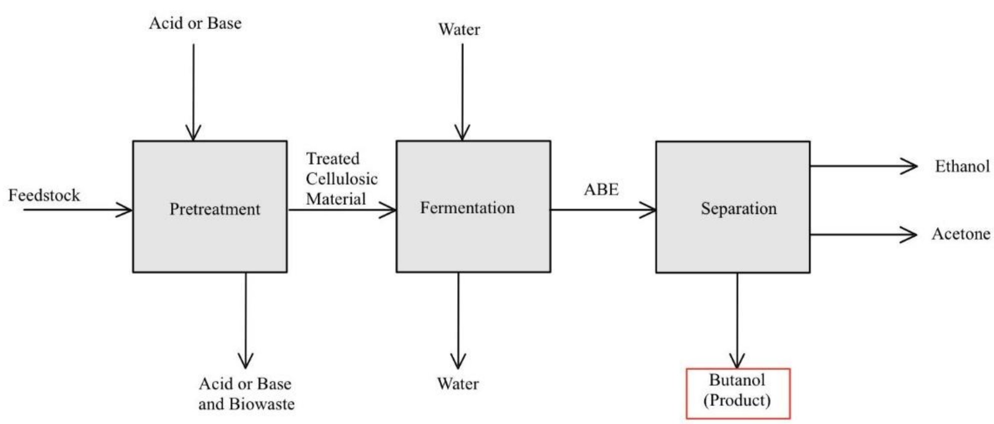

Figure 1. Butanol from ABE fermentation block flow diagram

The team will use Aspen Plus Simulation software to design a plant for the economical and sustainable production of butanol from ABE fermentation. This software allows the user to construct a process model and simulate its function using complex equations, mathematical computations, sensitivity analyses, and regressions. To begin construction, design data such as fermentation cell growth kinetics, methods of separation (e.g. azeotropic distillation, extraction, successive distillation columns), various feedstock viabilities, and economic analyses 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 help direct the team's efforts in designing a process fit for an industrial scale application. This project will take place in the Fall 2023 and Spring 2024 semester as a part of the CHE 4474 and CHE 4476 senior design courses. The team will divide work based on preliminary research focus and relative familiarity of plant unit operation. They will complete the final design report in April of 2024.

STS Topic

Many of the "sustainable" technologies of today are plagued with an origin of labor exploitation and hazardous working conditions. The resource extraction powering many of the electrified technologies western society has shifted towards reliance on unregulated, unsanctioned, and unsustainable methods (Litvinenko et al., 2022, p. 2). Batteries need lithium, windmills require dangerous maintenance, switchgrass farming uses hectares of land and hours of labor, and hydroelectric facilities can cause fish kills downstream (Rytwinski et al., 2020), the list continues. This speaks to a deeper problem with many of the emerging "environmentally friendly" technologies; they all have caveats and many of them sacrifice environmental hazards for worker exploitation (Envirochem 2023). One of the biggest proponents of these violations is the resource extraction industry especially as it relates to battery production (Amnesty International, 2023). Using actor-network theory I will analyze the causes for the proliferation of these violations in the resource extraction industry and discuss what is currently being done to stop them from recurring. I will summarize the enabling conditions, economically, environmentally, and societally that predicates these environments. Furthermore, I will consider how processes currently being developed can avoid the same pitfalls as more green technologies evolve. Finally, I will apply this methodology to bio-butanol production processes with the aim of creating a holistically ethical and sustainable product.

Raw materials, namely metals like lithium, cobalt, and other precious metals are located in deposits over most of the world, but they are most frequently mined where labor is cheap and regulations are sparse. One such location is in the Democratic Republic of The Congo, which produces over 70% of the world's cobalt (U.S. Geological Survey, 2020). The Democratic Republic of the Congo's unstable government fails to protect the rights of its workers. As such it is unsurprising that working conditions are very poor for miners. Including regular exposure to hazardous materials. These kinds of labor rights violations appear *en masse* for many raw materials, so designing a process from the ground up with the goal of avoiding the mistreatment of workers is vital. A root cause of many of the labor violations in the resource extraction industry is the lack of alternative methods of extraction. There is a substantial effort in the industry to diversify the sources of metals like lithium through methods such as geothermal extraction (Kolbel, 2023), however the progress is slow and demand for these materials has reached a fever pitch as a consequence of the rush toward electric vehicle adoption. Thus, traditional methods remain the primary source of raw materials.

One important consideration here is that there are no global standards for resource conservation or guidelines for ethical extraction practice currently used. However, several sets of such guidelines and best practices have been developed for international use, but never implemented to a sizable extent (Litvinenko et al., 2022, p.6-8). In contrast, the current rate of expansion of these processes is astounding, with a 20.4% increase in the production of lithium annually, the global market is expected to rise from around 540,000 tons to 3 million by 2030 (Shan, 2023). This creates a strong conflict of interest between creating sustainable technologies, but having to do so using unregulated and unsustainable methods. With the potential for incredibly lucrative business in this sector, the workers who gather the material are going to be overlooked until far after the damage is done. It is very probable that the industry will continue its exploitation of workers under the guise of “sustainable products” if no steps are taken to correct the ways we produce these goods.

Conclusion

In summary, this project is centered around the design of a process to convert agricultural waste from corn farming into a direct replacement fuel additive. The benefit from this is that it circumvents the current production methods utilizing fossil fuels and does not introduce any new carbon into the atmosphere. Additionally, the product of this process, butanol, is a more energy dense replacement of ethanol, and has less of an effect on net vapor pressure, reducing evaporative losses. In conjunction with this, an analysis of the sociotechnical forces that are currently driving labor abuses in the pursuit of sustainable technology will be completed. The goal of this analysis will be to understand the causes that lead to the current working conditions, and hypothesize ways to mitigate and prevent similar situations evolving from other green technologies, such as biofuel production. In a larger sense, this project seeks to develop a holistically green process from cradle to grave which delivers a superior product and empowers those involved in its creation to create a truly sustainable product ecosystem.

References

Advanced biofuel production grants and loan guarantees. Alternative Fuels Data Center: Advanced Biofuel Production Grants and Loan Guarantees. (n.d.). https://afdc.energy.gov/laws/8502

Algera, D.A., Rytwinski, T., Taylor, J.J. *et al.* What are the relative risks of mortality and injury for fish during downstream passage at hydroelectric dams in temperate regions? A systematic review. *Environ Evid* 9, 3 (2020). https://doi.org/10.1186/s13750-020-0184-0

Amnesty International. (2023, September 27). *Forced evictions at industrial cobalt and copper mines in the DRC*. Amnesty International. https://www.amnesty.org/en/latest/news/2023/09/drc-cobalt-and-copper-mining-for-batteries-leading-to-human-rights-abuses

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. https://doi.org/10.1039/d1gc01362a

Economics of biofuels | US EPA - U.S. Environmental Protection Agency. (n.d.-a). https://www.epa.gov/environmental-economics/economics-biofuels

Edwards, C. (2023, August). *Cutting Federal Farm Subsidies*. Cato.org. https://www.cato.org/briefing-paper/cutting-federal-farm-subsidies

Hoekman, K. S. (2008, July 9). *Biofuels in the U.S. – challenges and opportunities*. Renewable energy. https://www.sciencedirect.com/science/article/abs/pii/S0960148108001341

Iva Kralova & Johan Sjöblom (2010) *Biofuels–Renewable Energy Sources*: A Review, Journal of Dispersion Science and Technology, 31:3, 409-425, DOI: 10.1080/01932690903119674

Kölbel, L. Kölbel, T. Herrmann, L. Kaymakci, E. Ghergut, I. Poirel, A. Schneider, J (2023). Lithium extraction from geothermal brines in the Upper Rhine Graben: A case study of potential and current state of the art, *Hydrometallurgy*, *Volume 221*. https://www.sciencedirect.com/science/article/pii/S0304386X23001135

Litvinenko, V., Bowbrick, I., Naumov, I., & Zaitseva, Z. (2022, January 17). Global guidelines and requirements for professional competencies of Natural Resource Extraction Engineers: Implications for ESG principles and sustainable development goals. *Journal of Cleaner Production.* https://www.sciencedirect.com/science/article/pii/S095965262200172X

Manzetti, S., & Andersen, O. (2015). A review of emission products from Bioethanol and its blends with gasoline. background for new guidelines for emission control. *Fuel*, *140*, 293–301. https://doi.org/10.1016/j.fuel.2014.09.101

Shan, L. Y. (2023, August 30). *A worldwide lithium shortage could come as soon as 2025*. CNBC. https://www.cnbc.com/2023/08/29/a-worldwide-lithium-shortage-could-come-as-soon-as-2025.html#:~:text=The%20world%20produced%20540%2C000%20metric,the%20end%20of%20this%20decade.

The sources and solutions: Fossil fuels | US EPA. (n.d.-b). https://www.epa.gov/nutrientpollution/sources-and-solutions-fossil-fuels

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. https://doi.org/10.1016/j.copbio.2016.02.012

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. https://doi.org/10.1016/j.rser.2016.11.213

United States Geological Survey, & Shedd, K. B., *Mineral Commodity Summaries* 50–52 (2020). Reston, Virginia; Geological Survey.