Sustainable Utilization of Whey By-Product For the Production of Biobutanol

(Technical Paper)

An Evaluation of Trade-offs in a Transition to Cleaner Energy Sources

(STS Paper)

A Thesis Prospectus Submitted to the
Faculty of the School of Engineering and Applied Science
University of Virginia, Charlottesville, Virginia
In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

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November 8, 2024

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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Introduction

Climate change is possibly the hottest issue facing the world today, and for justified reasons. Carbon emissions have exponentially risen over the past few decades due to industrial advancements, and in turn the world is warming at its fastest rate in recorded history. Combined land and ocean temperatures have risen by an average of 0.11°C per decade since 1850, and this rate has tripled since 1982 (Lindsey, 2024). Though there are many generations of people to blame for the current climate disaster, the common trend in destruction of our planet has been gaseous carbon release from fossil fuels. Coal, oil, and gas have combined to account for more than 75% of global greenhouse emissions and about 90% of all carbon dioxide emissions into the atmosphere (UN, 2024). The impact of fossil fuels on human health has been striking, with an estimated 7 million people worldwide killed as a result of air pollution every year (Ritchie, 2024).

Renewable energy sources such as wind, solar, geothermal, and hydroelectric power have been implemented and have become commonplace in many parts of the world as ways to combat increased energy demand. Carbon sequestration and capture are techniques that have had recent initiatives to lower the amount of greenhouse gasses in the atmosphere and help reverse damage done over the past few centuries. A combination of reliability issues, scale-up deficiencies, high upfront costs, and energy storage challenges have stymied the progress of these green solutions, and thus society has continuously fallen back on fossil fuels as a reliable path forward, neglecting environmental impacts.

To further swing the balance back to renewable energy, a new powerhouse needs to be created that addresses the weaknesses of current renewable technologies. Biofuels have the potential to fill this niche as they can turn waste products into valuable fuels. Specifically, channeling whey waste from dairy factories into a bioprocess to form biobutanol has the ability to massively transform the energy industry. In 2006, whey products contained about 2.5 billion pounds of surplus lactose, which had the capability to produce over 203 million gallons of biofuel (USDA, 2008). Through a carefully designed process headlined by fermentation and distillation units, a purified and fully recycled fuel source can be produced at feasible costs to aid in a last gasp attempt to salvage our planet.

Technical Topic

During the formation of Greek yogurt, a problematic and abundant waste product in isolating solids is liquid whey. Whey is rich in organic acids, lactose, and proteins, and as such has high utility to produce alcohols during fermentation. Through a process including ultra-filtration, reverse osmosis, drying, and ABE fermentation, biofuels can be produced in mass quantities from a whey feedstock. ABE fermentation is a groundbreaking unit operation in which fermented substrate can be converted to acetone, butanol, and ethanol (Karimi, 2014). At this point, butanol can be isolated from the other products using liquid-liquid extraction and distillation, which has shown to be the highest efficiency and lowest cost method of producing biobutanol, the key product for commercial fuel use (Kraemer, 2011).

Butanol provides several benefits as a renewable energy source, particularly in the transportation sector. First, it helps reduce greenhouse gas emissions as a stand-alone fuel or in combination with gasoline. The combustion process of butanol-based fuels burns cleaner than traditional fuels, thereby reducing pollutants such as carbon dioxide and particulate matter. This makes it especially valuable in meeting air quality requirements set by environmental regulations including the Clean Air Act amendments of 1990 (U.S. Energy Information Administration, 2024). Butanol's high oxygen content gives it a high calorific value, meaning its energy content per unit mass is comparable to traditional gasoline. Butanol has a high affinity for mixing with both gasoline and diesel and can be utilized in current-day engines. Additionally, butanol's low miscibility in water and weak corrosiveness make it a great choice for pipeline transportation (Zhen et al., 2020). These attributes make use of pre-existing infrastructure, further enhancing its role as a transitional fuel in the broader shift towards clean energy. By domestically producing butanol, the US can reduce dependence on imported oil, contributing to energy security. This support for domestic agriculture, primarily corn production, strengthens rural economies and helps stabilize fuel supplies. Future policies aimed at reducing carbon emissions, such as expanding the Renewable Fuel Standard or implementing low-carbon fuel incentives, could potentially stimulate another increase in butanol production. Butanol additionally has a 35% higher energy density and gives 30% more miles per gallon as opposed to ethanol, another popular fuel choice (Zhen et al., 2020).

Converting side products to energy in the form of biofuels is an expanding field that is currently being heavily researched and invested in (Dhiman, 2020). As part of an Investing for America agenda, biofuels recently received over $500 million of funding from the US government and in the future will play a major role in the energy economy (USDA, 2023). By utilizing a waste stream such as whey, this process aligns with the principles of a circular economy, which seeks to maximize resource use and minimize waste. Converting whey, an environmental pollutant, into a biofuel represents a shift from a negative environmental impact to a positive contribution to energy production. The environmental benefit is especially significant because whey disposal is challenging. When discarded into wastewater treatment systems, whey contributes a high organic load, requiring energy-intensive aeration processes to break down

(El-Aidie, 2024). This results in a substantial energy demand and cost for treatment facilities. In contrast, fermenting whey into ethanol directly uses the energy contained in the organic compounds rather than expending additional energy to treat it. Thus, the project can reduce the overall energy footprint of dairy plants by converting waste into energy rather than burdening treatment systems.

The technical team will use Aspen Plus Software to model process flow diagrams and the individual equipment involved, such as the distillation column and the fermentation reactor. MATLAB will be used to analyze cell growth kinetics in the fermentation reactor.

STS Topic

It cannot be overstated how important an immediate switch to renewable energy is worldwide. With sustained higher temperatures, extreme weather events becoming commonplace, and continuous biodiversity loss, attention must be given to reverse the effects of climate change. The current bottleneck in replacing fossil fuels are the shortcomings of current renewable technology.

The dependence of solar and wind energy on the weather are large drawbacks when considering alternative energy sources. Fluctuations in energy usage are not always tied to increased production from wind and solar, so there is potential for insufficient production on an energy grid fed by only these renewable forms of energy (Bird, 2013). To offset this, energy storage systems in the form of batteries are paramount to successful implementation of renewable energy. Batteries come with the downsides of being expensive to scale for large amounts of energy and struggle to store energy for large time periods, necessitating more efficient methods of changing energy infrastructure. Another argument against current renewable technologies is the extensive land use they require, as large solar farms can require hundreds of acres of precious land and wind farms have the potential to disrupt coastal and aquatic ecosystems. The largest barrier to replacing fossil fuels, however, is cost. The Block Island Wind Farm, a pilot scale wind farm designed to power 15% of Rhode Island's electricity, was built on a budget of $290 million and requires constant upkeep (Ackerman, 2019). It has already faced setbacks with regards to the issues stated above and though it has made encouraging progress still shows that more advancement is needed for viability on the front of renewable energy powering the world. A significant issue within the realm of global politics is the prioritization of profit over all else, and energy does not serve as an exception to this precedent. The amount of environmental harm caused by fossil fuels is more difficult to quantify in an economic sense, especially since its effects are slow-moving and not felt by the average person on a daily basis. It is for this reason that the national rhetoric is dominated by promises of a better economy, and most Americans are clearly willing to compromise on human rights and environmental activism to obtain this goal. Therefore, a short-sighted economy that does not take into account our long-term future will persist which will sustain the use of fossil fuels until deep-seated change is enacted.

Knowing the flaws of renewable energy better frame the argument for the sustained use of fossil fuels worldwide. Reliability and affordability justify current fossil fuel usage, as natural gas and oil have a high energy density and are still extracted in mass quantities worldwide. Their high supply within the earth means that prices can be stabilized at lower thresholds than those presented by the limited renewables in place. The infrastructure in most of the world is also designed for fossil fuels, from transportation to fossil fuel extraction systems to current power plants. To further illustrate how ingrained fossil fuels are in America, 92.1% of vehicles in operation in 2023 are still gasoline operated, with most Americans unable to afford electric alternatives (IER, 2023). It is also worth mentioning that more than 11.5 million people are employed within the Oil & Gas industry, and its large profit share in the economy allows for lobbying around the sustained usage of fossil fuels (IER, 2023). These factors explain why fossil fuels will continue to dominate the energy sphere until a more reliable, cheaper, and less complex alternative overtakes them.

Conclusion

The only viable path out of the climate crisis is a groundbreaking solution that cuts through the haze of carbon emissions hanging over our planet. Though not a guarantee, biofuels have incredible potential to revolutionize the energy sphere due to their ability to turn waste products into valuable resources. To assert itself as an effective alternative, biofuel processes must address every challenge presented by current renewable technologies while outcompeting fossil fuels in their price point and volume. Our team has undertaken this project with the goal of improving upon these aspects and hopefully shedding more light on the impact biofuels will have on the balance on energy use in the future.

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