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

The Sociotechnical Challenges of a Transition
Away from Fossil Fuels

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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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Introduction

Advancements in sustainable energy technology are critical in achieving long-term climate goals, yet their adoption will pose a risk to jobs in fossil-fuel reliant regions.

The difficulty in decarbonizing the energy infrastructure through renewable solutions, such as biofuels, is compounded by the challenges of ensuring an equitable transition. The design for biobutanol production addresses the urgent need for sustainable energy solutions to combat climate change by transforming liquid whey by-products from Greek yogurt—a challenging waste stream—into biobutanol (Buchanan et al., 2023). This process effectively synthesizes a renewable fuel that reduces greenhouse gas emissions and supports the shift away from fossil fuels. Meanwhile, the sociotechnical aspect focuses on how the net zero transition displaces workers in fossil fuel industries, disproportionately impacting marginalized communities (Krawchenko & Gordon, 2021). Both problems need to be studied because they intersect with global energy sustainability and social equity goals; my technical research will focus on biofuel production from dairy waste, while my STS research will examine the socio-economic impacts of the energy transition on vulnerable populations. As biofuel production advances sustainable energy, the broader energy transition risks job displacement in fossil fuel industries, highlighting the need for policies to support affected workers.

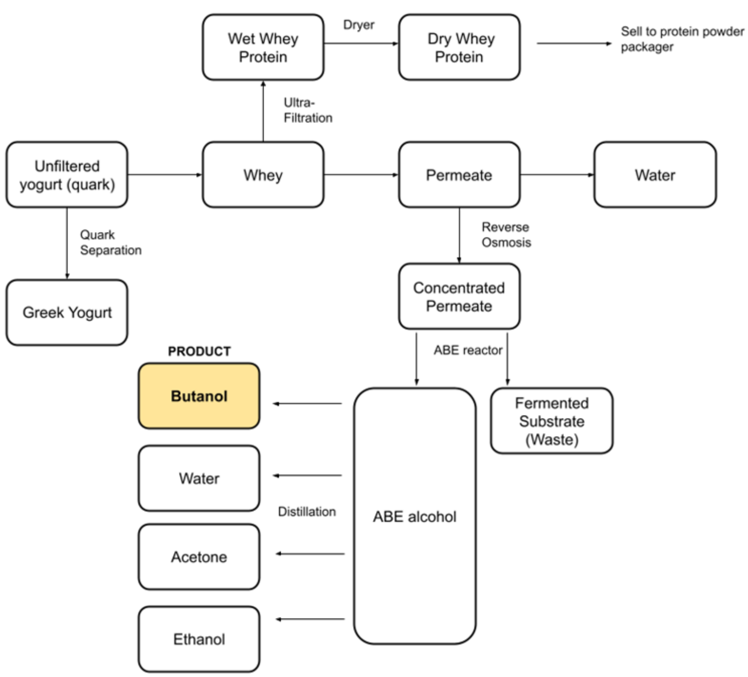
Technical Topic

Current energy infrastructure, particularly within the transportation sector, is unsustainable for achieving long-term climate and emission targets due to its heavy reliance on fossil fuels. The urgent need for scalable, low-emission energy solutions has made biofuel production a critical area of study. Biofuels present a renewable alternative capable of reducing greenhouse gas emissions, making them essential for sustainable transportation. However, biofuel development requires innovative approaches to feedstock and production methods that are economically viable and environmentally sound. This project addresses these needs by transforming liquid whey by-products from Greek yogurt production into biobutanol.

The process begins with whey separation, where proteins are isolated through ultrafiltration and sold as a secondary product. The remaining lactose-rich whey is concentrated through reverse osmosis (RO) and then fermented using an Acetone-Butanol-Ethanol (ABE) process, as shown in Figure 1. The fermentation produces acetone, butanol, and ethanol, which are then separated and purified to yield biobutanol. This effectively generates a renewable fuel that aligns with the circular economy framework (Geissdoerfer et al., 2017), promoting closed-loop systems to reduce waste and maximize resource efficiency.

Figure 1

Process Flow Diagram



Experimental research will focus on ABE fermentation, varying key parameters like pH and lactose concentration to maximize biobutanol yield. Evidence on fermentation efficiency, bacterial growth rates, and yield will be collected and analyzed to identify optimal conditions; maintaining pH levels between 4.5 and 6.5 and controlling lactose concentrations are critical for stable bacterial growth in whey-based fermentation, establishing foundational parameters for the experimental setup (Chandan & Kilara, 2013). This source, a comprehensive text on dairy processing, is highly reliable due to its consolidation of industry best practices and research-backed guidelines. The recommended pH and lactose conditions provide a scientifically sound starting point for my experiments, ensuring that initial trials are aligned with established dairy fermentation principles. This approach enables a experimental process that is grounded in reliable dairy science and adaptable.

Aspen Plus simulation software will be used to model each stage of the process—ultrafiltration, reverse osmosis (RO), fermentation, and distillation—to optimize energy inputs, equipment design, and yield. Evidence from waste-to-energy applications in the dairy industry demonstrates that computational modeling, such as Aspen Plus, is effective in enhancing process efficiency and modeling energy recovery, which is essential for scaling biofuel production (Casallas-Ojeda et al., 2021). This source is highly relevant, as it not only highlights the role of Aspen Plus in resource efficiency but also validates the use of computational simulations to optimize complex processes in the dairy industry. By applying the insights from this study, I will use Aspen Plus to test various operational parameters, such as energy input and equipment load. By focusing on energy inputs, equipment efficiency, and overall resource use, these simulations align with circular economy principles by limiting waste and ensuring scalability.

This process is saileint because it offers a way to transform a waste stream into a valuable resource while addressing environmental and energy challenges. With further improvements, this approach could become an important part of the broader effort to create more sustainable energy systems.

STS Topic

My STS research addresses the sociotechnical problem of how the global transition to net zero emissions will displace workers in fossil fuel-dependent industries, particularly affecting marginalized communities. This transition, while necessary for environmental sustainability, poses significant challenges for workers in regions economically dependent on coal mining, oil extraction, and fossil fuel-based manufacturing. These populations are often vulnerable due to limited access to retraining programs and the mismatch between their skills and the demands of emerging renewable energy sectors (Hanna et al., 2024). The importance of this problem lies in its potential to exacerbate existing economic inequalities if not managed properly, underscoring the need for solutions that balance environmental goals with social equity.

This study will employ literature reviews to examine the sociotechnical challenges faced by workers in fossil fuel-dependent industries during the transition to net zero, with a focus on marginalized communities. Grounded in the ethics of care framework, the analysis emphasizes empathy, relational responsibility, and prioritizing the well-being of vulnerable groups (Taylor, 2020). By centering on this ethical framework, the study goes beyond economic impacts to assess the social and moral responsibilities tied to a net-zero transition.

The ethics of care framework guides an assessment of the ethical dimensions of transition strategies. While carbon-neutral strategies often emphasize technical feasibility, they frequently overlook social equity, limiting their applicability (Chen et al., 2022). This research's perspective is informative for understanding feasible pathways to carbon neutrality, but it lacks the social dimension necessary for a holistic view of the transition's impact. In contrast, frameworks that integrate social justice considerations into clean energy transitions argue for balancing environmental and social goals, promoting a more ethically sound approach that safeguards vulnerable workers (Wehbi, 2024). Comparing these sources underscores the necessity of integrating equity alongside technical solutions. This analysis, grounded in the ethics of care, argues that supporting displaced workers is not only practical but a moral imperative, and that transition policies should not prioritize efficiency at the expense of social equity.

Case studies offer insights into how the transition affects communities that are economically reliant on fossil fuels, such as coal mining and oil extraction regions. Projections suggest a growing mismatch between the skills of the current workforce and the demands of the green economy (Atiq et al., 2022). While the Smart Prosperity Institute's broad, data-driven analysis offers valuable foresight, its focus on general trends risks overlooking community-specific challenges. While the source is still valuable for identifying overarching patterns, a more detailed approach will help verify if these trends apply consistently across diverse socio-economic contexts. This potential limitation will be addressed by examining additional case studies from fossil fuel-dependent regions to provide a more granular view of the transition's impact. For example, in Appalachia, the decline of the coal industry has created profound economic and social challenges, as many families and communities have long relied on coal for their livelihood (Carley et al., 2018). This research provides valuable, region-specific insights into the unique economic and cultural challenges faced by specific coal communities, rather than a macroscopic perspective. This study's insights underscore the importance of region-specific policies that address both economic needs and cultural identities, supporting the argument that a just transition requires locally tailored strategies.

To evaluate labor market policies designed to retrain fossil fuel workers for green jobs, this study analyzes policies focused on skill-building, job quality, and economic inclusion. Research suggests that environmental labor policies in Europe, while structurally inclusive, often fall short in measuring policy effectiveness based on worker outcomes, focusing more on design than on job security or economic stability (Bohnenberger, 2022). Bohnenberger's empirical peer-reviewed study is highly reliable for assessing policy structure but lacks depth in examining worker experiences post-retraining. In contrast, evidence indicates that green jobs do not always provide economic security, suggesting that a more outcome-focused approach is needed to evaluate policy success (Valero et al., 2021). This analysis from the Grantham Research Institute emphasizes job quality and economic security, offering a worker-centered perspective that complements Bohnenberger's structural approach. Together, these sources align with the ethics of care framework's emphasis on addressing the concrete needs of affected individuals.

In line with these ethical considerations, research underscores the importance of just transition policies. Expanding technical training programs, adjusting unemployment insurance, and implementing policies to attract new investments and develop local economies are among the recommended strategies to mitigate the economic impact on communities affected by the energy transition (Hanson, 2022). Hanson's analysis is particularly valuable for its focus on localized labor market impacts, highlighting how tailored, region-specific policies can better address the diverse needs of workers in fossil fuel-dependent regions. This approach aligns closely with the ethics of care framework, which advocates for context-sensitive support based on the unique vulnerabilities of affected populations. While Hanson emphasizes the potential of these policies to build local resilience, the effectiveness of these measures depends on careful implementation, sustained funding, and collaboration between local governments, businesses, and educational institutions. Drawing on Hanson's findings, transition policies must ensure that the push for environmental goals does not come at the expense of the well-being and economic security of displaced workers and their communities.

Conclusion

In my technical research, I aim to deliver an optimized process design for butanol production from yogurt waste, focusing on improving the efficiency, safety, and sustainability of biofuel production. This will contribute to climate change mitigation by converting dairy waste into a renewable fuel with lower greenhouse gas emissions than conventional gasoline or coal, reducing reliance on petroleum-based energy. On the STS side, my research will provide a deeper understanding of the social and economic challenges faced by workers in fossil fuel-dependent industries during the transition to net zero emissions. By exploring equitable solutions for job displacement and social equity, my work will help inform policies that ensure a just transition. Together, these deliverables will address the intertwined challenges of sustainable energy development and social responsibility, offering insights into how technological advancements and policy frameworks can collaborate to create a more inclusive and sustainable energy infrastructure.

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