**Sociotechnical Synthesis**

As society transitions away from fossil fuels, there is no clear, scalable solution that both replaces carbon-intensive energy sources and supports the communities whose livelihoods depend on them. At the core of both my technical and sociotechnical theses is the shared problem of managing the human and environmental consequences of moving away from fossil fuels. On the technical side, current energy alternatives often fall short in terms of infrastructure compatibility, cost-effectiveness, or environmental impact. Simultaneously, on the social side, fossil fuel-dependent regions face job loss, economic decline, and cultural disruption, with few policies in place to ensure an equitable transition. My research explores this duality: the sociotechnical systems required to enable a just transition to low-carbon energy and the technological advancements that make sustainable energy solutions, such as biofuels, feasible. Understanding both dimensions is essential. Without effective policy, new technologies may fail to assist displaced workers. Conversely, without viable technologies, policy efforts to create green jobs remain merely aspirational.

Climate change is accelerating, yet global dependence on fossil fuels persists due to the structure of existing energy infrastructure, which overwhelmingly relies on liquid fuels that are difficult to replace with electricity alone. This dependency limits the pace of decarbonization and contributes to continued greenhouse gas emissions. Our research aims to address this issue by designing a bioprocessing facility that converts acid whey into biobutanol and whey protein powder. This comprehensive process included ultrafiltration, reverse osmosis, and fermentation using *Clostridium acetobutylicum*, followed by a separation system to yield both whey protein and biobutanol as valuable products. Using MATLAB, we modeled the kinetics of acetone-butanol-ethanol fermentation and simulated downstream separations and energy systems using

Aspen Plus. The process proved capable of handling 214 million kg/year of acid whey, producing over 8 million kg/year of whey protein and 1 million kg/year of biobutanol. A 20-year cash flow analysis revealed a 730% return on investment and a 36% internal rate of return, demonstrating that circular waste-to-fuel systems can be both profitable and environmentally beneficial.

Efforts to reduce greenhouse gas emissions through decarbonization displace workers in fossil fuel-dependent communities without providing compensatory economic or social support. As climate policy accelerates the transition away from coal, oil, and gas, many regions that rely on these industries face rising unemployment, loss of community identity, and economic decline. These harms are not evenly distributed; they fall disproportionately on low-income, rural, and historically marginalized populations that already face limited access to retraining opportunities or geographic mobility. My research investigates how policymakers can design more equitable job transition policies by applying the ethics of care framework, which prioritizes empathy, relational responsibility, and the well-being of affected individuals. Using case studies, policy analysis, and historical comparisons, I examined examples from Appalachia, Germany's coal phaseout, and the U.S. manufacturing decline to identify which factors contribute to successful transitions. I found that while net job creation is possible through the growth of renewable energy industries, these jobs often do not emerge in the same regions or require the same skillsets as those being lost. Therefore, the most effective transition policies are those that include regionally tailored investment, local decision-making authority, and support systems for displaced workers. Without these measures, climate action risks entrenching inequality even as it solves environmental problems.

Together, these projects allowed me to make meaningful contributions to the broader challenge of enabling a just and sustainable energy transition. My technical research provided a tangible solution for renewable fuel production, while my STS work contextualized how such technologies must be supported by thoughtful, inclusive policy. While both projects highlighted promising pathways forward, they also underscored the limitations of partial approaches; technical solutions alone are insufficient without addressing the socioeconomic landscapes in which they are deployed. Researchers should build on this dual perspective; for instance, future work could explore how waste-to-fuel plants like ours could be co-located in fossil fuel-reliant regions to create accessible green jobs for displaced workers, thereby uniting the technological promise with human-centered policy.

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