How Policy and Consumer Incentives Drive Biodiesel Adoption

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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

Every year, the United States consumes over 45 billion gallons of diesel fuel, yet less than 5% of it contains biodiesel, which is proven to be a cleaner, renewable alternative that significantly reduces carbon emissions (U.S. Energy Information Administration, 2023). To put that into perspective, that is enough to fill 68,000 Olympic-sized swimming pools (Palumbo, 2024). Biodiesel is different from regular diesel as it is produced from vegetable oils. However, decades of innovation in biodiesel production methods has left it in a similar position today, a niche, expensive fuel. This paper is not just about how to make biodiesel better. It is about the "why". Why are higher biodiesel blends not mandated in the United States?

As part of my capstone project, I have been researching and developing a refined supercritical transesterification pathway for the "making" of this biodiesel. Supercritical transesterification is a process that heats and pressurizes the waste cooking oil (WCO) before being reacted. This accelerates the reaction rate and increases the solubility of the other reactants. The advantages of this technique are that it enhances the efficiency and cost-effectiveness of biodiesel production by eliminating the need for any catalysts and pretreatment WCO requirements, while also allowing the use of lower-grade feedstocks like WCO. Our process, in turn, can produce high-purity glycerol as a valuable byproduct, making the economic investment for our project a lot more lucrative.

Yet for all its technical promise, biodiesel's greatest hurdles lie beyond the realms of a plant. My research has revealed an interesting but stubborn truth: even the most efficient production methods mean little without policies that incentivize adoption and consumers who demand it. The U.S. energy market showcases this disconnect. Biodiesel offers significant

environmental benefits, cutting lifecycle emissions by 86% compared to standard petroleum diesel (Hearst Autos Research, 2020). However, more than 95% of diesel sold is still fossil-fuel based. Why does a cleaner, renewable alternative struggle to surpass a 5% market share?

The challenges facing biodiesel in the U.S. are not unique, other countries have also grappled with the question of how to turn promising technologies into mainstream fuels. Looking abroad offers valuable context for understanding what has worked and what has not. For instance, Indonesia has aggressively mandated biodiesel use, achieving blends of 40% biodiesel and 60% petroleum diesel. In contrast, the U.S. leans on softer measures, such as the $1-per-gallon biodiesel tax credit (Reuters, 2024). This is a policy too weak to disrupt petroleum's century-long dominance (Green Scissors, 2025). Meanwhile, Malaysia's B20 expansion plan was ultimately abandoned when infrastructure costs overwhelmed political momentum (Reuters, 2024). These global examples illustrate a common thread: without strong, coordinated policies and public commitment, even well-developed biodiesel technologies struggle to gain traction. The U.S. faces a similar dilemma where innovation alone cannot overcome systemic inertia.

In this paper, I argue that the Sociotechnical Transitions Framework provides a lens to understand and overcome barriers to biodiesel adoption specifically within the United States. First, I analyze how the interplay between policy stagnation, consumer perceptions, and industrial inertia has maintained petroleum diesel's dominance despite superior biodiesel technologies. Then, I research comparative case studies and policy analysis. This demonstrates how coordinated action across three fronts would accelerate adoption. Front one is the implementation of robust blending mandates comparable to global leaders. Front two is making fuel infrastructure more up-to-date to support higher biodiesel blends. Front three is launching

nationwide awareness initiatives to align the overall consumer demand with environmental benefits. Finally, I show how these interventions could transform biodiesel from an extensive production process to a mainstream fuel solution. This analysis aims to provide policymakers with a clear pathway for turning technical potential into tangible progress toward more sustainable transportation fuels.

Literature Review

The urgency to reduce greenhouse gas emissions has elevated biodiesel as a prominent alternative to petroleum diesel. Derived from biomass such as vegetable oils, animal fats, and waste cooking oil (WCO), biodiesel offers several environmental advantages. These include reduced emissions of carbon monoxide, hydrocarbons, and particulates (NREL, 2008). According to the EPA (2015), replacing fossil fuels with biodiesel contributes to cleaner air and lower net carbon emissions. This is due to its near-closed carbon cycle, where the carbon emitted during combustion is offset by the carbon absorbed during feedstock growth. Wang et al. (2022) found that biodiesel's carbon intensity is 74% lower than conventional diesel, even when accounting for land use changes. However, biodiesel has a lower energy density compared to petroleum diesel. This results in slightly reduced fuel economy (King Fuels, 2024), which has contributed to slower adoption in regions where efficiency and performance are top priorities.

Economic barriers also play a significant role in biodiesel's limited market penetration. Traditional catalyst-based production methods are expensive and inefficient. These systems attribute 70 to 90 percent of production costs to raw materials and face technical challenges like sensitivity to impurities and high wastewater output (Talha & Sulaiman, 2016). Newer methods,

such as supercritical transesterification, address many of these problems. This process allows producers to use lower-quality feedstocks like WCO without the need for catalysts. It also simplifies operations and reduces cost over time. Because of this, biodiesel production can expand beyond rural zones and into urban environments near restaurants or food processors. Still, high capital costs and processing equipment remain key barriers to profitability.

Despite these challenges, biodiesel development supports economic growth and job creation. Rural communities benefit from feedstock cultivation and localized production infrastructure. In 2020, biodiesel tax incentives supported thousands of jobs and generated environmental benefits valued at $4 billion (Clean Fuels Alliance America, 2020). The Alternative Fuels Data Center (AFDC) also notes that blending and distribution infrastructure can create employment opportunities within the petroleum sector (AFDC, n.d.). Although new processes are improving efficiency, many existing systems still rely on costly, inefficient catalytic methods. This continues to limit the scalability of biodiesel in competitive fuel markets.

Government policies have shaped biodiesel's adoption through subsidies and mandates. The Biodiesel Mixture Excise Tax Credit offers a $1-per-gallon incentive, which has boosted economic viability for producers (Green Scissors, 2025). Alongside this, the Renewable Fuel Standard (RFS) requires the inclusion of renewable fuels in the U.S. transportation fuel supply. These measures helped drive a 15 percent production increase in 2023, reaching 2.1 billion gallons (EIA, 2024). However, policy inconsistencies create instability for investors and producers. A Canadian renewable diesel plant recently ceased operations due to financial uncertainty stemming from U.S. policy fluctuations (Garcia et al., 2025).

International examples show how more coordinated efforts can lead to stronger adoption outcomes. Indonesia began mandating biodiesel blends in 2019 and reached a 40 percent blend requirement by 2025. This helped raise annual biodiesel production by 246 percent (Indonesian Ministry of Energy, 2024). Malaysia attempted a similar expansion but canceled its plan to move from B10 to B20 due to infrastructure upgrade costs exceeding $146 million (Reuters, 2024). Thailand faced comparable issues. Its B10 mandate triggered a 22 percent rise in pipeline maintenance costs due to biofuel corrosion (Bangkok Post, 2023). These cases show that blending mandates alone are not enough. Infrastructure readiness and political follow-through are also essential.

Another underexamined factor is consumer behavior. While many studies focus on production capacity and government policy, relatively few investigate how to create lasting demand for biodiesel. Recent research shows that consumer-facing strategies can significantly boost biodiesel adoption. A 2023 U.S. Department of Energy study found that point-of-sale discounts increased biodiesel purchases by 18 percent. Eco-labeling programs improved willingness to pay by 12 percent. Swedish trials demonstrated that tax rebates for B100 users raised adoption by 31 percent, but only when paired with public education efforts (ICCT, 2022). Similarly, Norwegian stations that combined B20 price discounts with visible emissions labels saw biodiesel sales increase by 41 percent (Transport & Environment, 2022). These results suggest that encouraging demand requires more than simply making the fuel available.

Political and industrial resistance further complicates biodiesel's path forward. A 2023 study by Harvard University found that fossil fuel interests outspent biofuel advocates 23 to 1 in federal lobbying. This financial imbalance has contributed to legislative inertia and weakened

support for clean fuels (Harvard Kennedy School, 2023). These systemic pressures combine with weak consumer awareness and inconsistent policies to stall progress.

To understand these complex dynamics, this paper applies the Sociotechnical Transitions Framework (STF). This framework explains how new technologies evolve from niche innovations into widespread societal norms. STF focuses on three levels. The landscape includes broad pressures like climate change. The regime represents existing systems such as fossil fuel infrastructure, industry standards, and institutions. Niches are protected spaces where innovations like biodiesel can develop. STF is particularly useful for explaining why technical advancements alone have not shifted the fuel market in the U.S. This study uses STF to analyze how policy, infrastructure, and consumer dynamics must align to support a meaningful transition. By doing so, it identifies the conditions needed to normalize higher biodiesel blends across the U.S.

Methods

This research used a comparative case study approach to investigate how policy design, infrastructure investment, and consumer incentives influence biodiesel adoption. This methodology allowed for a detailed exploration of the interactions between government action, public behavior, and industry structure through the lens of the Sociotechnical Transitions Framework. The case studies were selected to reflect a diversity of policy strategies and sociopolitical conditions. Specifically, the analysis focused on the United States, Norway, Sweden, and Canada. These countries were chosen based on the availability of policy data,

differences in market outcomes, and the relevance of their fuel strategies to the current U.S. biodiesel context.

Data collection drew primarily from secondary sources. These included government reports, policy briefs, market analyses, academic journal articles, and publications from institutions such as the Department of Energy (DOE), Environmental Protection Agency (EPA), and International Council on Clean Transportation (ICCT). Key documents such as the U.S. Renewable Fuel Standard (RFS), the Biodiesel Mixture Excise Tax Credit, and state-level initiatives like California's Low Carbon Fuel Standard and Oregon's Clean Fuels Program were examined to assess how policy frameworks shape market behavior. In addition, consumer surveys, such as those conducted by the National Renewable Energy Laboratory (NREL) and the U.S. Department of Energy, were used to assess public perceptions and purchasing decisions related to biodiesel.

The analysis combined policy analysis and discourse analysis. Policy analysis was used to evaluate the structure, consistency, and long-term effectiveness of financial incentives and regulatory mandates in increasing biodiesel production and consumption. Discourse analysis focused on how language in public documents, media coverage, and institutional reports shaped public understanding of biodiesel and framed its role in national energy transitions. This dual approach enabled a more holistic view of both structural and social barriers to adoption.

Together, these methods supported a multidimensional understanding of biodiesel's stagnation in the U.S. and helped identify policy misalignments, communication gaps, and infrastructure limitations. The findings were then interpreted within the Sociotechnical

Transitions Framework to highlight the importance of aligning technological readiness with supportive regimes and public engagement.

Analysis

The biodiesel industry's stagnation in the U.S. shows the interdependence between policy design, consumer behavior, and industrial resistance that the Sociotechnical Transitions Framework helps unravel. While biodiesel offers an 86% reduction in lifecycle emissions compared to petroleum diesel (Hearst Autos Research, 2020), its adoption remains stuck at 5% of the U.S. diesel market. The Biodiesel Mixture Excise Tax Credit demonstrates both the potential and pitfalls of current approaches. When it was active, it boosted production to a record 2.1 billion gallons in 2023, but its 2020 lapse triggered a 28% production crash (Biofuels Digest, 2021). This lapse occurred because Congress failed to renew the credit in time, creating financial uncertainty that led producers to scale back operations. This volatility stems from treating biodiesel as a temporary experiment rather than anchoring policies in long-term energy strategy. Indonesia's contrasting success with its B40 mandate was supported by 2.3 billion in coordinated infrastructure investments (World Bank, 2023). Not only was there sufficient infrastructure to back the movement, foundation was set prior to this. Previous mandates started at 1% in 2006 and most recently progressed up to 40% biodiesel blend in 2024. This prolonged transition saw an increase of 246% in annual subsidies from 2019 to 2023. Why can we not do this one may ask. As previously mentioned, the U.S. has not had stable government support towards a consolidated plan. Indonesia maintained policy stability throughout this time period and created investor confidence. Their blending mandates were intertwined with 10-year energy plans which

guaranteed feedstock subsidies for palm oil producers. The Sociotechnical Transitions Framework helps reveal how this alignment across policy, industry, and societal expectations created the conditions necessary for a successful transition. Overall, by synchronizing technical scaling, policy timelines, and social adoption, Indonesia was able to provide an adequate environment for biodiesel to mature.

Consumer adoption faces equally formidable barriers in the United States rooted in misinformation and access limitations. A 2022 NREL survey found that 68% of Americans misunderstand biodiesel's benefits, with 79% incorrectly believing it damages engines (National Renewable Energy Laboratory, 2022). This awareness gap persists because the U.S. spends less than $5 million annually on consumer education while allocating $200 million to production credits (Congressional Research Service, 2023). To put this in perspective, this is a 40:1 funding imbalance prioritizing supply over demand. This sets up the situation where consumers won't demand unavailable fuels, and stations won't supply under-demanded products. However, in Europe, Norway and Sweden were able to find effective solutions to this through integrated strategies. Norway created a mandatory eco-labeling and a point-of-sale discounts driving sales up 41% from 2018 to 2021 (Transport & Environment, 2022). This was applied at 100% of the gas stations in the country. Sweden took a slightly different approach by creating the "Green Diesel Initiative". This paired B100 tax rebates with mechanic training programs to achieve 31% adoption from 2016 to 2019 (ICCT, 2022). These cases demonstrate the Framework's principle of "alignment": policies must simultaneously educate consumers and guarantee access (Geels, F.W., and Schot, 2007). In the U.S., just 3% of stations offer blends above B5 (DOE, 2023). The solution is to therefore create systemic alignment.

Infrastructure limitations and petroleum industry resistance compound these challenges through a Framework principle called "regime lock-in." Malaysia's abandoned B20 plan, 20% biodiesel, 80% conventional diesel, was derailed by $146 million in upgrade costs (Reuters, 2024). This mirrors the U.S. situation where retrofitting a single station for B20 availability costs significant additional costs. This shows that the lack of supportable infrastructure to back biodiesel is dragging adoption down. California's Low Carbon Fuel Standard broke this cycle by forcing oil companies to finance 1,200 biofuel pumps through carbon credit markets (California Air Resources Board, 2023). This model acts as a rebuttal to prove infrastructure expansion is feasible. For example, converting pumps to accommodate biodiesel blends costs just 12% of installing electric vehicle chargers (DOE Comparative Analysis, 2023). This requires policy mechanisms that work around petroleum industry obstruction.

The U.S. biodiesel sector remains trapped in political dilemmas, where fossil fuel interests use their established power to suppress competition. Harvard's research highlights a massive lobbying imbalance, 23-to-1 in favor of oil and gas, showing how oil and gas interests shape policy to their advantage (Harvard Kennedy School, 2023). This explains why biodiesel tax credits remain uncertain while petroleum subsidies stay firm. Indonesia produces more biodiesel than the U.S., 3.57 billion versus 2.1 billion gallons, despite having less technical capacity and industrial infrastructure. This does not mean Indonesia lacks an oil and gas industry. It has a sizable petroleum sector. However, its government prioritized biodiesel through strong, long-term mandates and subsidies, even in the face of fossil fuel interests. This comparison highlights that political will and policy design can outweigh technological advantages when it comes to scaling renewable fuels. The Sociotechnical Transitions Framework calls this "regime resilience", where dominant industries manipulate the system to maintain control (Geels, 2002).

Oil interests spent $124 million lobbying against renewable fuels in 2022 (OpenSecrets, 2023). However, Oregon's Clean Fuels Program uses self-sustaining credit markets to support biodiesel without relying on federal legislation (Oregon DEQ, 2023). While the petroleum industry did oppose the program and argued it would increase fuel prices and impose burdens on refiners, it ultimately failed to block its implementation. The state's regulatory design insulated the program from federal political pressure and allowed it to withstand legal and lobbying challenges. This provides a concrete example of how states can work around entrenched fossil fuel interests and implement policies that realign market incentives in favor of clean fuels.

The path forward becomes clear when examining these interconnected barriers through the Sociotechnical Transitions Framework. Temporary tax credits cannot overcome a century of petroleum dominancy, just as consumer education fails without access, and infrastructure investments get abandoned without political stability. Indonesia's systematic approach proves that increasing biodiesel production through gradual progression works, while Norway demonstrates how to convert awareness of the issues posed by the automobile into actual purchasing behavior. What remains is for U.S. policymakers to implement these examples through coordinated action. We must build frameworks and institutional support to translate biodiesel's technological potential into purchasing options you see at everyday gas stations. Overall, biodiesel should be modeled as a social movement to improve the world around us and fight back against the oil and gas industry. As energy analyst Vaclav Smil said, "Energy transitions are inherently protracted affairs". We can not expect this change overnight but through gradual improvements one step at a time.

Conclusion

Biodiesel presents a clear environmental and economic opportunity, yet adoption in the U.S. remains limited to just 5% of the diesel market. This paper has shown that the main barriers are not technological but systemic. Inconsistent policy support, consumer misinformation, and insufficient infrastructure—reinforced by entrenched fossil fuel interests—have stalled progress. Existing policies like the RFS and Biodiesel Tax Credit help in the short term but lack the long-term alignment needed for sustainable transition. International examples provide evidence that coordinated, stable approaches work. Indonesia's gradual mandates and infrastructure investment, and Norway's combination of consumer education with accessible fueling, show how aligning technical, policy, and social elements leads to success. The U.S., by contrast, applies these strategies inconsistently, leaving critical gaps between production, access, and public engagement. Future policy must address these disconnections through a sociotechnical lens. The RFS can be strengthened by linking blend mandates with infrastructure retrofits, public outreach, and workforce training. Programs like Oregon's Clean Fuels Program prove that even in the face of opposition, state-level innovation can support market transformation.

Further research should deepen the application of the Sociotechnical Transitions Framework to biodiesel adoption. This includes studying how niche technologies like supercritical transesterification can scale in resistant systems, and how consumer behavior, institutional design, and lobbying influence alignment. Expanding this research will help craft strategies that move beyond isolated innovation toward systems-level change.

Biodiesel's promise will not be realized through technical advances alone. Achieving meaningful adoption requires a coordinated and persistent effort to shift not just what fuels we produce, but how we govern, distribute, and perceive them.

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