MANDATED MIX: THE POLICY PLAYBOOK DRIVING TODAY'S FUEL STANDARDS

Abstract

Across the world, the transportation fuel industry is undergoing significant changes designed to reduce petroleum dependency and greenhouse gas emissions. However, these changes diverge not only by market forces but by the evolving regulatory mandates. Three policy instruments including the United States Renewable Fuel Standard (RFS), international and national Sustainable Aviation Fuel (SAF) mandates, and California's Low Carbon Fuel Standard (LCFS), an emission focused standard, are crucial in determining what specifically goes into fuel tanks, the operations of refineries, and the flow of investment capital. The lifecycle and mechanisms of these policies will be explored in this paper, emphasizing how mandates serve as not only a foundation for change but also an unforeseen ceiling that creates pressures which misalign market signals with true environmental goals. This paper asserts the necessity of technology neutral policy design to successfully translate legislative ambition into true measurable emission reductions by examining federal rulemaking records, industry data, and regulatory analysis.

Introduction

For more than a century, the global economy has been dominated by liquid fuels. Yet challenges in urban air quality to climate change from the environmental costs of petroleum combustion, have urged governments to re-evaluate global fuel marketplace standards. Governments across the world have chosen to navigate the fuel industry together, resulting in a regulatory architecture, incentivizing fuel production, mandates blending minimums, and penalizes high-carbon fuel pathway, influencing the fuel chemistry in every automobile, aircraft, and diesel truck.

This paper will focus on three policy instruments: The Renewable Fuel Standard (RFS), Sustainable Aviation Fuel (SAF) mandates, and California's Low Carbon Fuel Standard (LCFS). Established by the Energy Policy Act of 2005 and expanded by the Energy Independence Security Act of 2007, the RFS mandated that transportation fuel sold in the United States (US) must have a set minimum volumes of renewable fuel [1]. In Europe, the ReFuelEU campaign facilitated the implementation of SAF mandates in the European Union. Specifically, the SAF mandate controls Aviation regulation by requiring the blending of low-carbon alternatives into aviation kerosene [2]. In academic reviews of the RFS, the program has clearly driven biofuel market growth by implementing statutory targets in cellulosic biofuel production [3]. Finally, emission-based regulations including California's Low Carbon Fuel Standard (LCFS) sets declining carbon-intensity benchmarks rather than volumetric mandates. This approach allows fuel produces to generate tradable credits when they surpass the targets.

Collectively, these frameworks shape the economic and technological environment where fuel refiners, biofuel producers, investors, and agricultural stakeholders operate. The central purpose of this paper is to examine how regulatory design decisions including volume requirements, eligibility criteria for fuel pathways, and compliance flexibility mechanisms, can influence supply chains, future investment patterns, and the global pace of decarbonization.

1. How the Renewable Fuel Standard Operates

1.1 The Structure and Mechanism

The RFS is the primary policy mechanism driving US biofuel demand. Specifically, the program requires that producers and importers of gasoline and diesel fuel ensure that a designated portion of their fuel supply achieves the renewable fuel requirements. These obligations are expressed as Renewable Volume Obligations (RVOs) where compliance is monitored through Renewable Identification Numbers (RINs). RINs are digital credits generated whenever qualifying renewable fuel is produced or imported. Producers and importers have the choice to blend renewable fuel themselves and generate RINs or purchase RINs from other market participants in order to satisfy the compliance requirements [4]. The lifecycle of a RIN is shown in Figure 1, where the RINs are generated for each renewable fuel producer or importer.

Example lifecycle of a Renewable Identification Number (RIN)

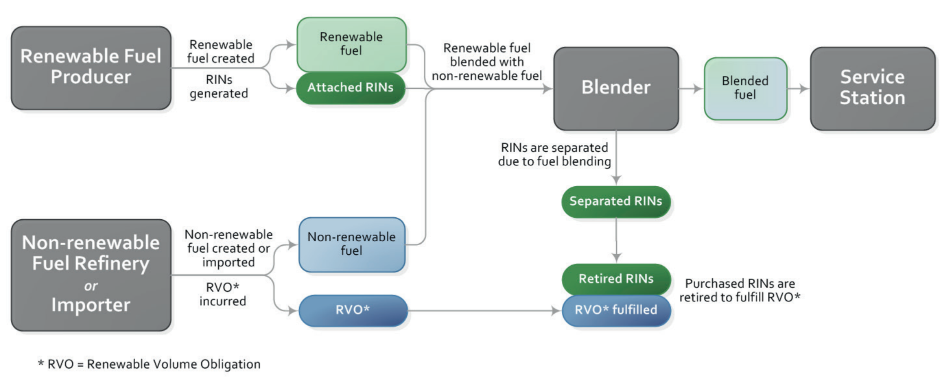

Figure 1: Example lifecycle of a Renewable Identification Number (RIN). Reproduced from the EPA, Renewable Identification Numbers (RINs) under the Renewable Fuel Standard Program (2025) under the CC0 Public Domain Dedication [5].

The RFS categorizes eligible fuels into four interconnected groups: total renewable fuel, advanced biofuel, biomass-based diesel, and cellulosic biofuel. Each category has their own volume mandate which creates a compliance system that clearly rewards fuels with lower lifecycle carbon emissions through higher-valued RIN credits. Typically, conventional corn ethanol accounts for most of the total renewable fuel production. Advanced biofuels must demonstrate at least a 50% reduction in lifecycle Greenhouse gas emissions relative to petroleum fuels, while cellulosic biofuels are required to achieve a minimum 60% reduction. Economic evaluations of the program estimate that inflation-adjusted compliance costs from 2011 to 2025 total approximately $252.1 billion indicating the significant the scale of government intervention necessary to enforce renewable fuel blending requirements [3].

In June 2023, the Environmental Protection Agency finalized the "Set 1 Rule" which established volume requirements 2023 through 2025. The rule set renewable fuel obligations at 20.94 billion gallons in 2023, 21.54 billion gallons in 2024, and 22.33 billion gallons in 2025, corresponding to percentage standards of 11.96%, 12.50%, and 13.13%, respectively [6]. These targets reflect expectations for increased production capacity over time. The EPA further stated that multi-year rules set the foundation of an appropriate balance by improving the program by looking to the future through the multiple number of years. A long-term projection allows for the recognition of uncertainty and ideal goals. The EPA further finalized volume requirements for 2026 and 2027 in early 2026 representing the highest mandated volumes in program history [7].

1.2 Changes to Fuel Formation Characteristics

One of the most visible effects of RFS has been the widespread adoption of E10 gasoline which contains 10% ethanol and has become the standard fuel blend for US vehicles. This transition was driven by the fact that ethanol provides valuable octane enhancement and oxygenation properties that would otherwise require more expensive additives. Consequently, fuel suppliers blend approximately 10% of ethanol "with or without the RFS, because doing so supplies needed levels of octane and oxygenate," indicating how ethanol is more economically attractive [8].

Additionally, the more dynamic area of RFS-driven formulation change has been in the biomass-based diesel and renewable diesel segments. With expanding volume obligations that cannot be entirely fulfilled by ethanol, refiners have begun analyzing hydrogenated vegetable oils and animal fats to produce renewable diesel. In the same study by Gerveni et al., economic analysis showed that the 2024 generation total for renewable diesel represented a quarter of all RIN generation for that year. Furthermore, the study illustrates that the primary driver of the renewable diesel boom over 2021-2024 was the use of high biomass-based diesel blends to achieve California carbon intensity targets under the LCFS. Therefore, the paper coins the interconnected nature of biomass-based diesel policy as a "policy stack" [3].

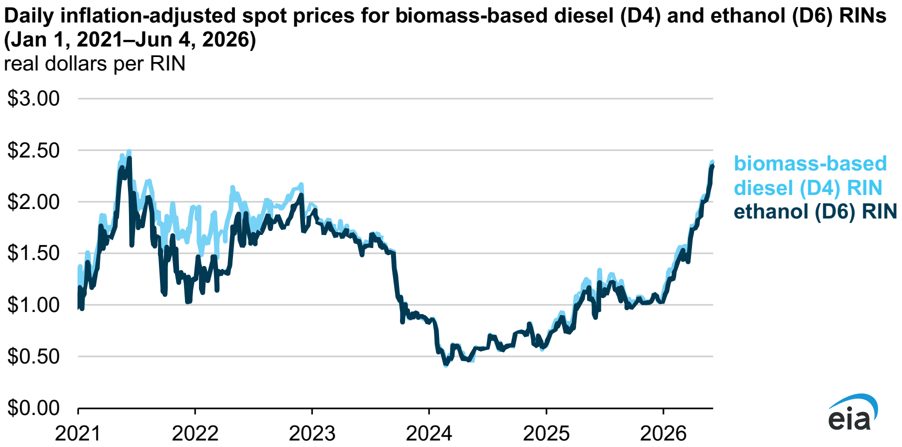

Figure 2: Daily inflation adjusted spot prices for biomass-based diesel (D4) and ethanol (D6) RINs from January 1, 2021, to June 4, 2026. Reproduced from the EIA, Higher blending targets drive RIN prices close to record highs (2026) under the CC0 Public Domain Dedication [9].

This economic incentive is reflected in historical RIN price trends shown in Figure 2. In the figure, biomass-based diesel (D4) RIN spot prices spiked alongside higher blend mandates and tight compliance targets, showing frequent trades at a premium over conventional ethanol (D6) RINs. In a different report, the USDA identified that imported biodiesel feedstocks including used cooking oil, tallow, and canola oil all increased substantially in 2023 and 2024 as domestic feedstock costs remained elevated, with the US consuming nearly 30% of globally exported biofuel feedstocks in the 2023-2024 marketing year [10].

2. Sustainable Aviation Fuel (SAF) Mandates and Decarbonization

2.1 The RefuelEU Framework

Aviation remains one of the most difficult sectors to decarbonize because aircraft require highly energy-dense fuels and can remain in service for decades. Research conducted by Khujamberdiev et al. concluded that SAF technologies, including hydro processed esters and fatty acids (HEFAs), Fischer-Tropsch fuels, and alcohol-to-jet processes, have the potential to significantly lower greenhouse gas emissions compared to conventional jet fuel Despite these environmental benefits, widespread adoption faces major economic and supply-chain challenges. Their analysis suggests that if SAF production continues to expand at a rate similar to the 57% increase observed between 2022 and 2023, followed by annual growth of approximately 13% thereafter, achieving net-zero aviation emissions could be feasible [11].

The EU's ReFuelEU aviation regulation represents one of the most comprehensive SAF policies currently in force. Approved in 2023 and implemented in 2025, the regulation requires fuel suppliers serving EU airports to blend increasing amounts of SAF into conventional jet fuel. The mandate begins at 2% in 2025 and gradually rises to 70% by 2050. In addition, the policy includes a separate requirement for synthetic e-fuels, which must account for at least 0.7% of aviation fuel by 2030 and 35% by 2050 [12]. According to the European Commission, these measures could reduce aviation-related carbon dioxide emissions by roughly two-thirds by 2050 compared to a baseline scenario if no action is taken [13].

2.2 The Production Capacity Gap

The most significant challenge facing SAF policy is the mismatch between mandated demand and actual production capacity. Research by Martulli et al. found that although global SAF production capacity reached approximately 9.1 million tons per year by 2024, only about one-quarter of those projects were completed on schedule. Furthermore, more than 40% of the production capacity projected for 2030 was considered vulnerable to delays or cancellation. Even under optimistic growth scenarios modeled after the rapid expansion of solar and wind energy industries, the study projected that global and European SAF production capacity would still fall short of 2030 policy targets by 42% and 18% respectively [14]. These findings suggest that regulatory mandates alone cannot overcome physical limitations in infrastructure development.

Table 1: Comparison of different SAF Pathways. Reproduced from MDPI, Analysis of the Potential of Meeting the EU's Sustainable Aviation Fuel Targets in 2030 and 2050 (2023) under the CC 4.0 Creative Commons License [15].

Type	ASTM Approved	TRL	Feedstock Type	Feedstock Availability	Geopolitical/ Geographical Concerns
FT-SPK	2009	6-8	Waste and biomass residues	High	No
HEFA-SPK	2011	7-9	Bio-oils, animal fat, vegetable oils, ICO	Low	Yes
HFS-SIP	2014	5-7	Sugarcane, sugar beet	Medium	Yes
ATJ-SPK	2016	4-7	Sugarcane, sugar beet, sawdust, lignocellulosic residues	Medium	Yes
CHJ-SKA	2020	6-7	Triglyceride oils (soybean, jatropha, camelina)	Low	Yes
HC-HEFA-SPK	2020	4	Algae	N/A	No

Table 1 breaks these constraints down by pathway, showing technology maturity and feedstock dependencies that help explain why capacity growth lags projections. Specifically, technological readiness drops sharply for more recently approved routes, shown from a mature TRL of 6-9 for FT-SPK and HEFA-SPK down to just 4 for HC-HEFA-SPK. Additionally, several pathways with the largest potential contribution including HEFA-SPK, ATJ-SPK, and CHJ-SKA rely on feedstocks rated "Low" or "Medium" availability which carry geopolitical sourcing risk. This combination of technological immaturity is consistent with the finding that over 40% of projected 2030 capacity remains vulnerable to delay or cancellation.

SAF mandates primarily function as mechanisms for creating future supply chains [16]. By embedding long-term demand into law, governments provide investors with certainty needed to support large-scale capital expenditures for SAF production facilities. To reinforce this market signal, the European Union introduced financial support measures. In 2024, the European Commission allocated 20 million emissions allowances valued at roughly 1.5 billion euros to encourage the adoption of alternative aviation fuels.

The ReFuelEU framework also includes operation provisions that are designed to prevent airlines from avoiding SAF purchases. One measure targets the practice of "tankering," in which aircraft carry excess conventional fuel from previous airports to reduce the need for refueling at locations where SAF blending requirements apply. By limiting this practice, regulation helps ensure compliance with blending mandates [13].

3. Emission-Based Standards and their Structures

3.1 The California Low Carbon Fuel Standard

Unlike the RFS which mandates specific renewable fuel volumes and blending percentages, LCFS is built around declining carbon-intensity (CI) targets [17]. Instead of requiring the use of fuels, the program establishes progressively lower CI benchmarks for transportation fuels. Fuel pathways that achieve emission levels below the benchmark earn tradable credits, while fuels exceeding the benchmark generate compliance deficits. This structure creates a performance-based system that retains a technology-neutral perspective by rewarding fuels according to environmental performance rather than production method.

In a study by Axsen and Wolinetz on LCFS programs, they concluded that "low-carbon fuel standards have reduced GHG emissions, can effectively complement carbon pricing, and have received substantial public support in recent years," [18]. They further observed that California's LCFS was originally developed in response to shortcomings of the federal RFS. While the RFS required the use of renewable fuels, it initially did not adequately distinguish among fuels based on differences in lifecycle CI. Consequently, the LCFS was designed to provide a more precise mechanism for rewarding fuels with greater emissions reductions.

A major development occurred in November 2024 when the California Air Resources Board (CARB) approved amendments to strengthen the LCFS. These changes established a one-time reduction in the CI benchmark equivalent to a 22.75% reduction from 2018 levels beginning in 2025. The revised program aims to achieve a 30% reduction in CI by 2030 and 90% by 2045. [19]. Although implementation was delayed until July 1, 2025, the stricter benchmark took effect during the third quarter of 2025. The new requirements immediately shifted the LCFS credit market from a surplus position into a deficit position, increasing demand for low-carbon fuel credits.

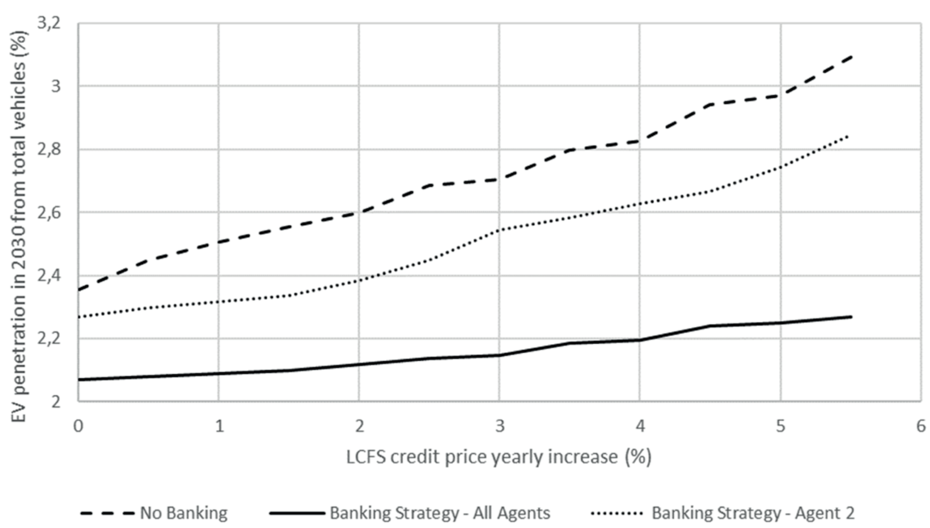

Figure 3: Impact of LCFS credit prices increase on EV penetration. Reproduced from MDPI, Impacts of Low-Carbon Fuel Standards in Transportation on the Electricity Market (2018), under the CC 4.0 Creative Commons License [20].

Consequently, as credit demands rise, the credit prices also increase. This price signal matches directly with the EV adoption trend illustrated by Figure 3. The graph shows that EV penetration responds most sharply to rising credit prices when no banking occurs. However, when all agents adopt a banking strategy, this sensitivity is reduced, suggesting that while a deficit driven rise in LCFS credit prices can accelerate EV adoption, the extent of acceleration depends on how widely credit banking is used.

3.2 Consequences of Fuel Formulation

The LCFS has produced measurable changes to California's fuel mix. By assigning lifecycle CI scores to individual fuel pathways, the program evaluates emissions generated throughout the entire supply chain, including feedstock production, fuel processing, transportation, and final combustion. This comprehensive accounting framework creates incentives for producers to reduce emissions at every stage of fuel production. A wide range of energy sources participate in the LCFS, including renewable diesel, biodiesel, ethanol, biomethane, electricity, hydrogen, and alternative aviation fuels [17].

The 2024 amendments introduced several structural changes affecting which fuels and feedstocks can qualify for credit generation. One significant provision phases out credits for hydrogen produced from fossil natural gas beginning in 2035. Additional restrictions limit the number of credits available for biodiesel produced from virgin soybeans and canola oils, capping them at 20% of annual production. These changes are intended to encourage the use of waste-derived feedstocks rather than agricultural crops. These amendments require all existing fuel pathways to transition to CARB's updated GREET 4.0 lifecycle emissions accounting model beginning with 2024 reporting periods [21].

Beyond influencing liquid fuel markets, the LCFS has encouraged broader transportation infrastructure development. By late 2024, the implementation of hydrogen refueling stations and fast electric vehicle charging sites have been approved by LCFS supported programs [22]. CARB projects that the continued adoption of lower-carbon fuels and more efficient transportation technologies could reduce fuel costs per mile by approximately 42% by 2045, producing annual consumer savings exceeding $20 billion.

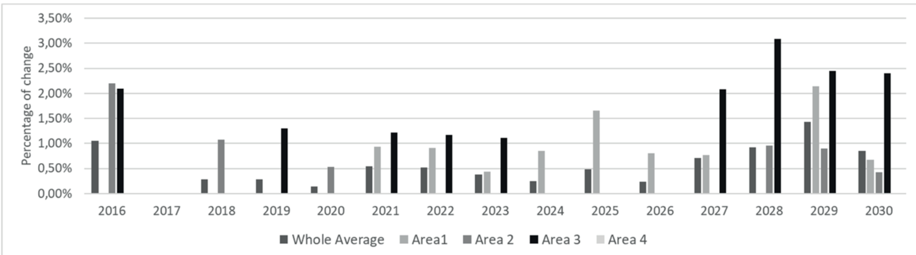

Figure 4: Change in electricity price (%) with EVs and LCFS (with banking). Reproduced from MDPI, Impacts of Low-Carbon Fuel Standards in Transportation on the Electricity Market (2018), under the CC 4.0 Creative Commons License [20].

However, these savings are not distributed evenly across California. In a study by Karnama et al., Figure 4 shows the percentage change in electricity prices attributed to EV adoption under the LCFS by year. The graph breaks down California into four regions and are compared against the statewide average from 2016 to 2030. Area 3 particularly stands out with price changes exceeding 2% while Area 1 has a more gradual upward drift from 1% in 2018 to 2% in 2029. Despite the regional unevenness, the whole-state average change has stayed relatively modest and stable, around 1.5% per year. Therefore, some regions may experience sharper electricity price swings than others as EV adoption accelerates under the LCFS.

4. Policy Comparison and Interaction Effects

4.1 Volumetric vs Carbon-Intensity Approaches

RFS and LCFS reflect two fundamentally different regulatory philosophies. The RFS operates as a quantity-based mandate by requiring specific volumes of renewable fuels to enter the marketplace. This approach provides predictable demand for renewable fuel production but only offers limited incentives to reduce carbon emissions with each compliance category. Research by Lark et al. demonstrated that the lack of precision can produce unintended consequences including land-use changes driven by biofuel production that can offset the anticipated climate benefits [23]. By contrast, the LCFS functions as a CI based mechanism that rewards incremental reductions in lifecycle emissions. The LCFS creates ongoing incentives for producers to lower the CI of feedstocks, production methods, and supply chain operations facilitating continuous improvement rather than simple compliance with minimum volume requirements.

Corn ethanol provides a useful example of the difference between the two approaches. Under RFS, corn ethanol qualifies as a conventional renewable fuel and contributes towards the compliance requirements regardless of how it is produced. On the other hand, under the LCFS, the CI of corn ethanol can vary substantially on various factors including the energy source at the production facility, whether methane capture technologies are employed, and the agricultural practices used to grow feedstocks [3]. Consequently, the LCFS encourages ethanol producers to pursue additional emissions reductions, whereas the RFS generally provides no further incentive when volume obligations are met.

4.2 The Policy Stack

While multiple policies can apply simultaneously to the same fuels and industries, their combined effects can generate outcomes that are difficult to understand when examining each policy individually. In Gerveni et al. study, they identified the interconnected nature of biomass-based diesel as a "policy stack" dynamic that "cannot be fully understood one policy at a time". They noted that renewable diesel boom of 2021-2024 was not only driven by RFS in isolation but also through the interaction of RFS compliance needs, LCFS carbon-intensity targets, and the economics of renewable diesel as a drop-in replacement [3]. RFS volume obligations, 45Z tax credits, LCFS credits, and state-level incentives are all ways that can make the economic case for certain fuel pathways compelling at relatively high production costs but can also distort feedstock markets in ways that undermine sustainability goals.

5. Overall Assessment and Emerging Directions

5.1 Policy Achievements

The regulatory frameworks examined in this paper have produced significant and measurable outcomes across the transportation fuel sector. The RFS has successfully established a large-scale renewable fuel market in the US. For example, Iowa's biofuel industry consumed nearly 60% of the state's 2024 corn harvest and produced approximately 4.61 billion gallons of fuel ethanol, demonstrating the economic influence of policy on agricultural and energy markets [10] as shown in Table 2. Additionally, the increased ethanol production capacity in the US is illustrated by the ethanol bio-refineries increasing by state in Table 2.

Table 2: Ethanol production capacity (million gallons/year) and production facilities by state. Reproduced from MDPI, Land-Use, Crop Choice, and Proximity to Ethanol Plants (2019) under the CC 4.0 Creative Commons License [24].

State	Production Capacity	Operating Production	Installed Ethanol Bio-Refineries
1) Iowa	3947	3921	44
2) Nebraska	2119	2066	26
3) Illinois	1635	1597	15
4) Minnesota	1190	1172	22
5) Indiana	1163	1163	14
...	...	...	...
15) California	223	218	6

Therefore, the SAF mandates have stimulated investment and technology innovation in an industry that lacked commercially viable pathways ten years prior. Similarly, the LCFS has also contributed to lowering the CI of the state's transportation fuel supply and the transition of the LCFS credit market into deficit territory during the third quarter of 2025 indicates that the strengthened program requirements are already influencing market behavior and accelerating the adoption for low-carbon fuel alternatives [19].

5.2 Limitations

Despite their accomplishments, these policies continue to face significant challenges. Lark et al. highlight that the most significant empirical challenge is the RFS' environmental rationale where lifecycle GHG emissions of corn ethanol produced to meet RFS mandates "are no less than those of gasoline, and are likely even greater when land use emissions are included" [23]. These findings raise questions about whether volumetric mandates alone are sufficient to achieve meaningful emissions reductions. Furthermore, the results suggest that future progress will require both technology improvements and more sophisticated policy design. Mandating renewable fuel volumes without fully accounting for lifecycle emissions can produce outcomes that conflict with the environmental objectives the policies are intended to achieve.

Challenges also persist in the Sustainable Aviation Fuel (SAF). Although governments have established ambitious blending requirements and decarbonization goals, actual production capacity remains well below what is needed to satisfy future demand. However, the gap between the current trajectory has been remarked on by Martulli et al. The study quantified this gap where a scale-up scenario analysis showed that global SAF capacity would fall short of 2030 policy target by 42% [14]. This disparity underscores the importance of maintaining long-term regulatory certainty and providing complementary support mechanisms that reduce financial risks associated with large-scale infrastructure investments.

Conclusion and Future Outlook

The Renewable Fuel Standard, Sustainable Aviation fuel mandates, and carbon-intensity based standards represent complementary regulatory approaches designed to reshape transportation fuel systems. Each one demonstrates capacity to alter fuel formulation and redirect investment capital which changes the supply chain developments at both the small and large scale. They also collectively have limitations of its own design logics. Volumetric mandates can encourage land-use changes that diminish intended climate benefits, blending requirements may advance faster than production capacity can support, and CI standards can create market imbalances when regulatory stringency does not align with actual market conditions.

The effectiveness of fuel policy depends not only on regulatory design but also consistent implementation. The RFS has experienced periods of uncertainty due to the use of Small Refinery Exemptions which have altered compliance obligations and affected market expectations. Such fluctuations can weaken confidence among investors and industry participants. The biofuels industry has repeatedly demonstrated sensitivity to policy decisions, highlighting the importance of continued political advocacy for sustainable energy use.

A persistent challenge across all three policy approaches is the gap between regulatory ambitions and physical realities. Successfully closing this gap will require continued technological innovation, expanded infrastructure development, and stable regulatory frameworks that support long-term planning and investment. Future fuel policy will likely be most effective when it combines clear environmental objectives with flexible, technology-neutral mechanisms capable of delivering measurable lifecycle emission reductions while adapting to changing market and technological conditions.

References

[1] "State Regulations, Policies, and Updates on States with Retail Choice." Accessed: Jun. 04, 2026. [Online]. Available: https://www.sciencedirect.com/science/chapter/monograph/abs/pii/B9780128213650000232

[2] "SAF Policy Actions | EASA." Accessed: Jun. 04, 2026. [Online]. Available: https://www.easa.europa.eu/en/domains/environment/eaer/sustainable-aviation-fuels/saf-policy-actions

[3] M. Gerveni, T. Hubbs, S. Irwin, and J. Stock, "The Biofuels Blueprint: Understanding the U.S. Renewable Fuel Standard," Appl. Econ. Perspect. Policy, vol. 48, May 2026, doi: 10.1002/aepp.70083.

[4] "The Renewable Fuel Standard (RFS): An Overview." Accessed: Jun. 04, 2026. [Online]. Available: https://www.congress.gov/crs-product/R43325

[5] O. US EPA, "Renewable Identification Numbers (RINs) under the Renewable Fuel Standard Program." Accessed: Aug. 10, 2026. [Online]. Available: https://www.epa.gov/renewable-fuel-standard/renewable-identification-numbers-rins-under-renewable-fuel-standard-program

[6] "Renewable Fuel Standard (RFS) Program: Standards for 2023–2025 – Policies," IEA. Accessed: Jun. 04, 2026. [Online]. Available: https://www.iea.org/policies/18823-renewable-fuel-standard-rfs-program-standards-for-20232025

[7] C. Bettenhausen, "EPA bolsters biofuels with blending actions," Chemical & Engineering News. Accessed: Jun. 04, 2026. [Online]. Available: https://cen.acs.org/energy/biofuels/EPA-bolsters-biofuels-blending-actions/104/web/2026/04

[8] O. US EPA, "Proposed Renewable Fuel Standards for 2026 and 2027." Accessed: Jun. 04, 2026. [Online]. Available: https://www.epa.gov/renewable-fuel-standard/proposed-renewable-fuel-standards-2026-and-2027

[9] "Higher blending targets drive RIN prices close to record highs - U.S. Energy Information Administration (EIA)." Accessed: Aug. 10, 2026. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=67765

[10] C. Koons, "EPA proposes historic renewable fuel blending standards • Iowa Capital Dispatch," Iowa Capital Dispatch. Accessed: Jun. 04, 2026. [Online]. Available: https://iowacapitaldispatch.com/2025/06/13/epa-proposes-historic-renewable-fuel-blending-standards/

[11] R. Khujamberdiev and H. M. Cho, "Biofuels in Aviation: Exploring the Impact of Sustainable Aviation Fuels in Aircraft Engines," Energies, vol. 17, no. 11, p. 2650, Jan. 2024, doi: 10.3390/en17112650.

[12] "Sustainable Aviation Fuels | EASA." Accessed: Jun. 07, 2026. [Online]. Available: https://www.easa.europa.eu/en/domains/environment/eaer/sustainable-aviation-fuels

[13] "New law agreed to cut aviation emissions," European Commission - European Commission. Accessed: Jun. 07, 2026. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2389

[14] A. Martulli, K. Brandt, F. Allroggen, and R. Malina, "The Potential Scale-Up of Sustainable Aviation Fuels Production Capacity to Meet Global and EU Policy Targets." Accessed: Jun. 07, 2026. [Online]. Available: https://rosap.ntl.bts.gov

[15] M. Shehab, K. Moshammer, M. Franke, and E. Zondervan, "Analysis of the Potential of Meeting the EU's Sustainable Aviation Fuel Targets in 2030 and 2050," Sustainability, vol. 15, no. 12, p. 9266, Jan. 2023, doi: 10.3390/su15129266.

[16] "Sustainable aviation fuel policy in the EU," 2025.

[17] "LCFS Basics | California Air Resources Board." Accessed: Jun. 07, 2026. [Online]. Available: https://ww2.arb.ca.gov/resources/documents/lcfs-basics

[18] J. Axsen and M. Wolinetz, "What does a low-carbon fuel standard contribute to a policy mix? An interdisciplinary review of evidence and research gaps," Transp. Policy, vol. 133, pp. 54–63, Mar. 2023, doi: 10.1016/j.tranpol.2023.01.008.

[19] "The California Low Carbon Fuel Standard (LCFS) | Stillwater Publications." Accessed: Jun. 07, 2026. [Online]. Available: https://stillwaterpublications.com/the-california-low-carbon-fuel-standard/

[20] A. Karnama, J. A. Peças Lopes, and M. Augusto da Rosa, "Impacts of Low-Carbon Fuel Standards in Transportation on the Electricity Market," Energies, vol. 11, no. 8, p. 1943, Aug. 2018, doi: 10.3390/en11081943.

[21] C. Roeder, "California Finalizes Major Changes to Low Carbon Fuel Standard (LCFS)," Christianson PLLP. Accessed: Jun. 07, 2026. [Online]. Available: https://www.christiansoncpa.com/california-finalizes-major-changes-to-low-carbon-fuel-standard-lcfs/

[22] "Advanced BioFuels USA – CARB Updates the Low Carbon Fuel Standard to Increase Access to Cleaner Fuels and Zero-Emission Transportation 0ptions." Accessed: Jun. 07, 2026. [Online]. Available: https://advancedbiofuelsusa.info/carb-updates-the-low-carbon-fuel-standard-to-increase-access-to-cleaner-fuels-and-zero-emission-transportation-0ptions

[23] T. J. Lark et al., "Environmental outcomes of the US Renewable Fuel Standard," Proc. Natl. Acad. Sci., vol. 119, no. 9, p. e2101084119, Mar. 2022, doi: 10.1073/pnas.2101084119.

[24] J. Park, J. Anderson, and E. Thompson, "Land-Use, Crop Choice, and Proximity to Ethanol Plants," Land, vol. 8, no. 8, p. 118, Aug. 2019, doi: 10.3390/land8080118.

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