EFI FOUNDATION

A Strategic Roadmap for Decarbonizing the U.S. Ethanol Industry

Executive Summary

SEPTEMBER 2024

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Executive Summary

Emergence of Ethanol as a Key Enabler of the Transition to Low-Carbon Fuels

The U.S. clean energy transition requires a transition to both carbon-free electricity and clean fuels. Ethanol has been the leader in the move to low-carbon fuels, as long-standing attempts to develop other advanced low-carbon liquid fuels (cellulosic biofuels, algae-derived fuels, e-fuels, etc.) have not succeeded in achieving scalable production at an acceptable cost.

Since 2005, the overall carbon intensity (CI)[a] of ethanol has decreased by 23%.[1] Ethanol's CI today is 53.6 grams of carbon dioxide equivalent per megajoule of ethanol produced (gCO_2e/MJ), 42% lower than unblended gasoline. This has enabled blends of ethanol and gasoline to reduce on-road vehicle greenhouse gas (GHG) emissions by over 544 million tons of CO_2.[b,2]

This reality leads the EFI Foundation (EFIF) to present in this report a strategic roadmap to further decarbonize the U.S. ethanol industry through a portfolio of actions that can help it reach a goal of net-zero carbon intensity by midcentury, and several additional options that can achieve net-negative carbon intensity. The strategic roadmap will enable ethanol to play a central role in decarbonizing the transportation sector, which accounted for 29% of total U.S. GHG emissions in 2021.[3]

Continued decarbonization of ethanol, combined with higher blend levels, can complement the shift to electrification of light-duty vehicles—both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—in achieving further reductions in 2030 and beyond.[4] Conversion of ethanol into aviation fuel will allow blends of sustainable aviation fuel (SAF) at a significant scale. Further decarbonization of the U.S. ethanol industry also will strengthen its contribution to the U.S. economy, particularly to the rural economy.

In 2023, the United States produced 15.6 billion gallons of ethanol, making it the world's leading producer and exporter of ethanol, responsible for producing over half of the global supply.[5,6] The ethanol industry accounted for 28% of farm GDP, contributing $57 billion to total U.S. GDP in 2022. The ethanol industry supports more than 420,000 jobs.[7,8]

Corn production for ethanol[c] is a high value-added proposition—ethanol producers use about 30% to 40% of the U.S. corn crop, spending $38 billion, but require only about 1.5% of total U.S. farmland (an estimated 13.9 million acres).[9,10,11,12,13] Since 2001, the

[a] Carbon intensity (CI) refers to the amount of carbon dioxide emitted per unit of energy or activity.
[b] In the United States, nearly all gasoline sold today is blended with ethanol at a 10% rate (E10). E10's CI is 3% lower than unblended gasoline's.
[c] Corn-based ethanol currently accounts for an estimated 94% of total U.S. ethanol production.

U.S. food crops industry overall has maintained relatively consistent land use for planting while yields have continued to increase, indicating that corn is not in direct competition for acreage with other food crops.[d, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23] This report does not assume any increase in corn planting for ethanol production.

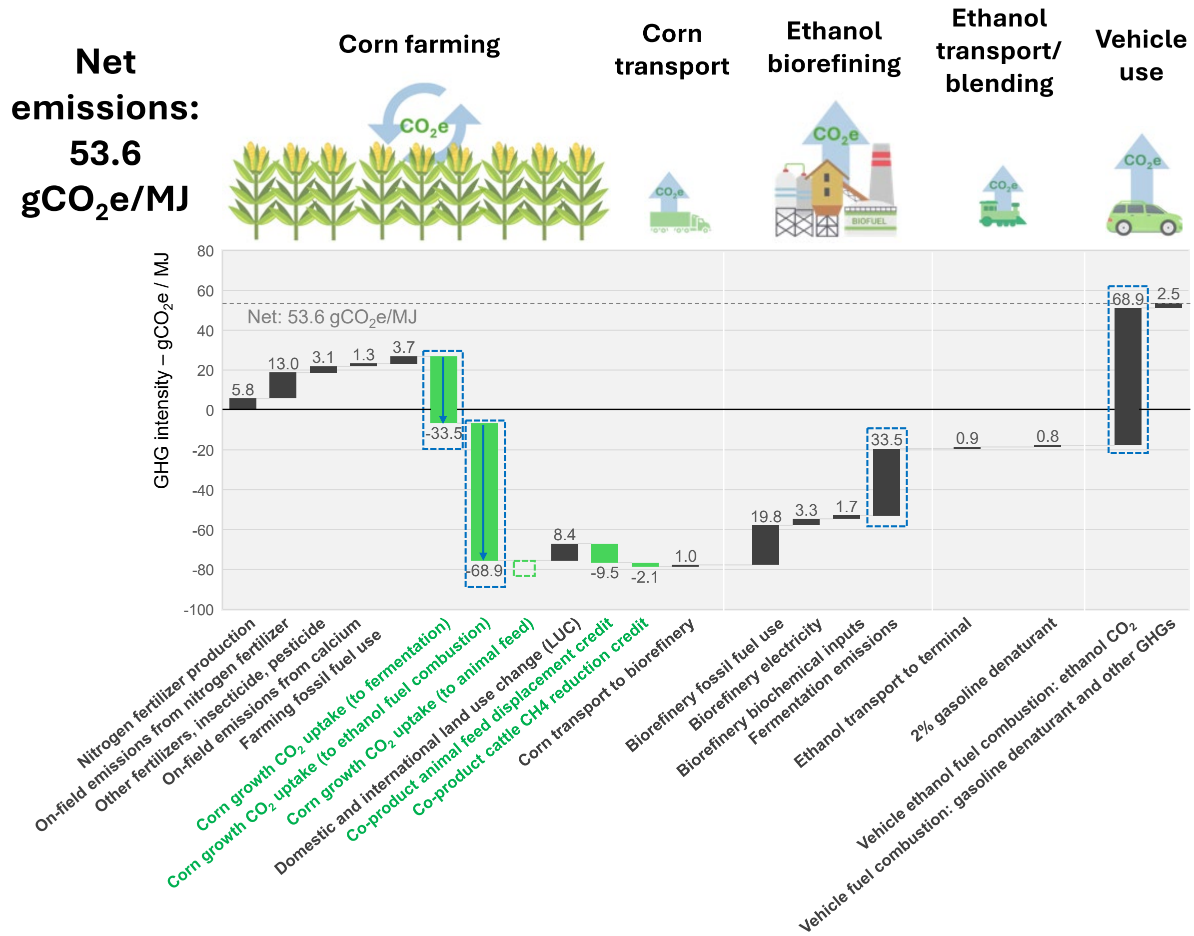
Assessment of Measures to Further Decarbonize the Life Cycle Carbon Intensity of Ethanol

The strategic roadmap for decarbonizing the U.S. ethanol industry was developed based on current estimates in the U.S. Department of Energy (DOE)-sponsored GREET model, developed at Argonne National Laboratory.[e] The model provides estimates of carbon uptake and emissions across the entire ethanol life cycle, including corn farming, biorefining, and end use.

Currently, the R&D GREET model[f] (hereafter referred to as “GREET”) estimates that, on average, U.S. corn ethanol emits around 53.6 gCO_2e/MJ throughout its life cycle. Figure ES1 illustrates the composition of the emissions sources and sinks that comprise ethanol’s net carbon footprint.

[d] The land use for planting U.S. food crops has decreased by 2.1% from 2001 to 2024, while the yield has increased by 25.1%, showing the industry has been able to increase crop yield substantially while keeping land use relatively consistent.
[e] The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model is a tool developed by Argonne National Laboratory with support from the U.S. Department of Energy to evaluate the energy and environmental impacts in the energy systems of various technology and fuel combinations.
[f] R&D GREET is used to guide research, development, and decision-making for researchers, industry, or fuel consumers. A specific GREET model could be developed for a policy program. For example, tax credits 40B and 45V and California’s Low-Carbon Fuel Standard have their own versions of GREET.

Figure ES 1. Components of the dry mill ethanol life cycle (emissions in gCO_2e/MJ)



Ethanol emissions in a dry mill facility (the production method most common in the U.S.) occur during corn farming, fuel production, and consumption. Emissions sources are depicted in black, and emissions sinks in green. Data from: GREET, 2024; Horizon Climate Group for fermentation emissions.

The GREET estimates are used as the baseline for developing the strategic decarbonization roadmap. The estimates are based on the dry mill biorefining process for ethanol production, the most commonly used technology in the United States. The baseline shows significant variation among sources and sinks of CO_2 emissions throughout the ethanol life cycle.

The three largest sources of emissions are end-use combustion, the fermentation process, and the use of fossil fuels to provide process heat. CO_2 uptake occurs in the corn-growing process and is also accounted for, or “scored,” in GREET as a “credit” in the life cycle analysis. The credit covers emissions from the fermentation and end-use combustion processes. Also noteworthy in the GREET estimates is that the indirect emissions associated with electricity used in biorefining are included in the model, as well as the carbon footprint of the production of fertilizer used to support corn growing.

EFIF's assessment of the ethanol life cycle identified a broad range of measures that can significantly reduce the CI of ethanol. The assessment incorporated four factors: adoption readiness, the feasibility for widespread adoption, the magnitude of CI reduction potential, and cost-effectiveness, as measured in terms of cost per ton (t) of CO_2 removed from the life cycle baseline. The measures examined included modifications in agricultural practices for corn growing, improvements in biorefining, use of low-carbon fuels and electricity, and carbon capture from the biorefining process. Figure ES2 provides a summary of the assessment.

Figure ES 2. Assessment of ethanol decarbonization measures

Decarbonization measures		CI reduction potential (% of ethanol CI)	Cost	Feasibility: Feasibility for widespread adoption	Feasibility: Readiness for adoption
Corn yield improvement		0.7%	< zero	High	Near term
Adopt climate-smart agricultural practices	No-till farming	6%	< zero	High	Near term
	4R nitrogen management	4%	< zero	High	Near term
	Enhanced efficiency fertilizers	4%	< zero	Medium	Near term
	Cover crops	45%	\$24 to \$64/tCO_2	Medium	Near term
Use low-carbon fertilizers	Blue ammonia-based fertilizers	10%	\$29 (with 45Q) to \$100/tCO_2	Medium	Mid term
	Green ammonia-based fertilizers	10%	\$0 (with 45V) to \$526/tCO_2	Medium	Mid term
Use renewable diesel in farm machinery		< 4%	\$127 to \$139/tCO_2	Medium	Near term
Use renewable diesel for corn transport		< 2%	\$127 to \$139/tCO_2	Medium	Near term
Ethanol yield improvement		6%	< zero	High	Near term
Fermentation CCUS		57%	-\$48 (with 45Q) to \$37/tCO_2	High	Mid term
Carbon-free electricity use		6%	-\$49 (PPAs) to \$18/tCO_2 (RECs)	High	Near term
Decarbonize thermal energy use	Fuel switching to hydrogen	37%	\$124 (with 45V) to \$412/tCO_2	Medium	Long term
	Fuel switching to RNG	32%-160%	\$76 to \$220/tCO_2	Medium	Mid term
	Biomass CHP	37%	< zero	Medium	Near term
	Hydrogen CHP	37%	\$71 (with 45V) to \$376/tCO_2	Medium	Long term
	RNG CHP	32%-160%	\$57 to \$201/tCO_2	Medium	Mid term
	CCUS in thermal energy generation	37%	\$21 (with 45Q) to \$106/tCO_2	Medium	Mid term
Use renewable diesel in ethanol delivery		< 2%	\$127 to \$139/tCO_2	Medium	Near term

Strategies for corn farms (green): corn yield improvement through use of renewable diesel for corn transport. Strategies for biorefineries (blue): ethanol yield improvement through use of renewable diesel in ethanol delivery.

The CI reduction potential is the maximum potential for full adoption of each measure, estimated using the GREET model. The cost is a levelized cost of carbon abatement (LCCA), relative to the cost of the business-as-usual alternative. It is calculated by dividing cost by CO_2 abated. Negative LCCA results from reducing energy or fertilizer inputs, selling energy back to the grid, or obtaining tax credits. The market feasibility was evaluated by reviewing publicly available data and literature on technological and economic feasibility and the barriers to adoption.

Notes: 4R – right source, time, rate, and place; blue ammonia – produced with capturing and sequestrating CO_2 from hydrogen production; green ammonia – produced with renewable energy for hydrogen production (note that hydrogen is a primary feedstock for making either blue or green ammonia); CCUS – carbon capture, utilization, and storage; RNG – renewable natural gas; CHP – combined heat and power; PPAs – power purchase agreements; RECs – renewable energy certificates; 45Q – tax credit for carbon oxide sequestration; 45V – clean hydrogen production tax credit. Source: EFI Foundation analysis.

As shown in the figure, the measures providing the largest reductions, in terms of the magnitude of CI reduction potential, include:

- Carbon capture, utilization, and storage (CCUS) in the fermentation process[g]
- Replacing the use of natural gas for process heat with low-carbon process fuels such as renewable natural gas (RNG)
- Planting cover crops in corn farms in intervals between regular corn cropping

These three measures alone could lead to an estimated reduction of up to 140 gCO_2e/MJ, resulting in a net-negative CI score.

The mix of options changes when other factors are considered, such as cost-effectiveness and feasibility for adoption. Widespread adoption of RNG is limited by high costs, limited current supply, and competition with other uses. Even if all available U.S. RNG is dedicated to the ethanol industry, it could replace only 76% of the natural gas used in the industry.[24]

Options that are ready for widespread adoption at a relatively low cost per ton of CO_2 removed (less than $18 per ton reduced) can reduce overall CI by 14 gCO_2e/MJ (a 26% reduction from the current baseline) and include:

- Purchasing carbon-free electricity in the biorefinery
- Continuously improving ethanol yield
- Procuring corn from farms continuously improving corn yield
- Employing no-till farming
- Using enhanced efficiency fertilizers (EEFs)
- Adopting 4R (right source, time, rate, and place) nitrogen management practices

Introducing a combined heat and power (CHP) system running on biomass, such as corn stover and other residual agricultural wastes, also can be a cost-efficient option for the long term because of the low cost of biomass and increased energy efficiency.

CCUS is a low-hanging fruit for ethanol decarbonization. Capturing CO_2 emissions from the biorefining process is technologically feasible at a relatively modest cost of capture of about $37/$tCO_2$. This cost could be covered by the carbon sequestration tax credit (Section 45Q), which pays $85/$tCO_2$; however, transportation and sequestration of CO_2 are challenging. As most ethanol plants are in areas unsuitable for geologic sequestration of CO_2, the captured CO_2 in ethanol plants would have to be transported via pipelines to suitable sites.

Uncertainties surrounding permitting of the CO_2 pipeline infrastructure and geologic storage site (Class VI)[h] have been the most significant barriers to scaling up CO_2 transportation and sequestration infrastructure. The permitting issues are complex because the pipeline infrastructure would cross multiple states (e.g., five states in the

[g] CO_2 utilization is considered with CO_2 sequestration as the technologies converting captured CO_2 into products are under development.
[h] A Class VI well is a well for CO_2 geologic sequestration.

Summit pipeline project, three states in the Tallgrass Energy Gas-to-CO_2 project) and require permit approvals by state and local governments.

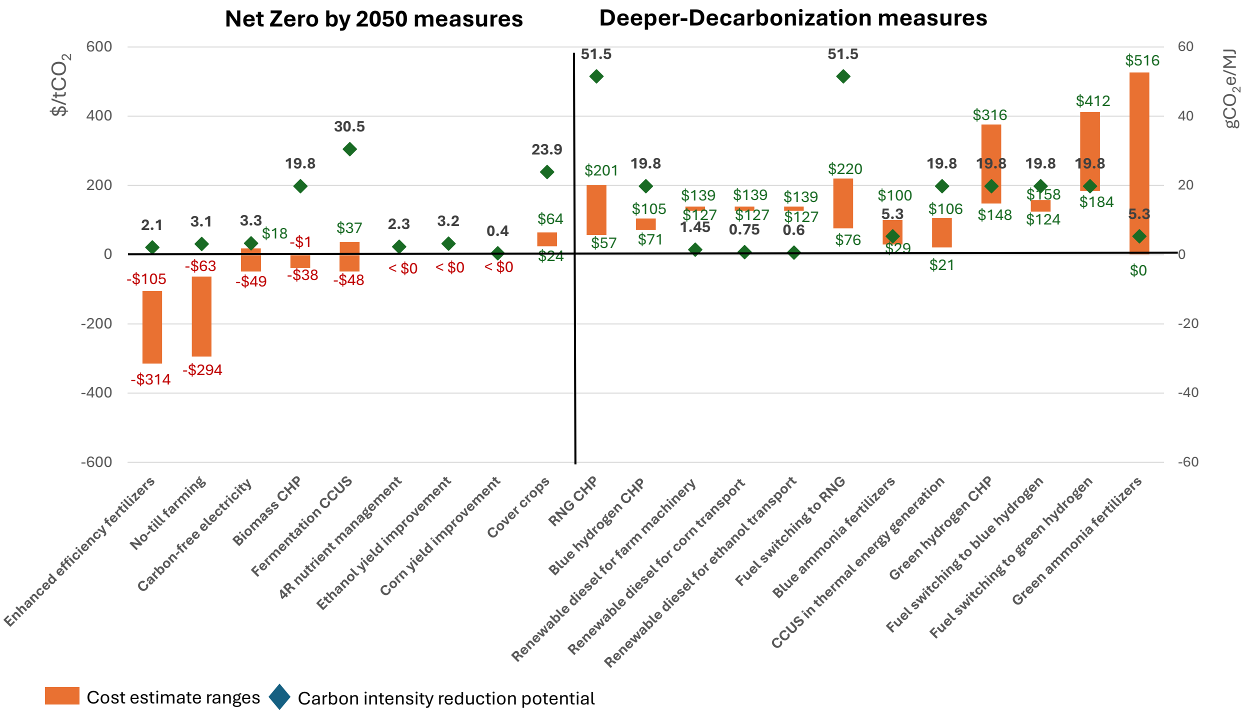
Strategic Decarbonization Pathways for the U.S. Ethanol Industry

Based on the assessment of options, EFIF developed two strategic pathways that the ethanol industry could take to achieve net-zero or even negative emissions by midcentury:

- ***Net Zero by 2050 Pathway***: This pathway includes core decarbonization measures to enable the ethanol industry to reach net-zero emissions by midcentury, with substantial progress toward that goal by 2035. The core decarbonization measures are ready to adopt and have a relatively low cost per ton of CO_2 removed. Many measures have a net cost of less than zero because of the cost savings that accompany them, and the most expensive measure costs at most \$64/tCO_2. Note that costs are relative to the current practice.
- ***Deeper-Decarbonization Options***: Adopting additional measures enables the ethanol industry to reach almost net-zero emissions by 2035, and negative emissions in 2050. The additional measures are not yet ready-to-adopt and their costs are relatively higher or uncertain, with a wide range of estimates. Since most measures, such as clean ammonia, are in the early phases of market development, their degree of penetration into the ethanol supply chain is uncertain for the near term and midterm. The costs of these additional measures range from zero to \$516/tCO_2.

Figure ES3 shows that the core measures combined offer a portfolio to reach net-zero emissions by 2050 at a relatively small cost per ton and in some cases a negative cost per ton relative to the cost of current practices. The additional measures could provide even deeper decarbonization, but the range of costs is much greater and more uncertain.

Figure ES 3. Cost and carbon intensity reduction potential by decarbonization measure

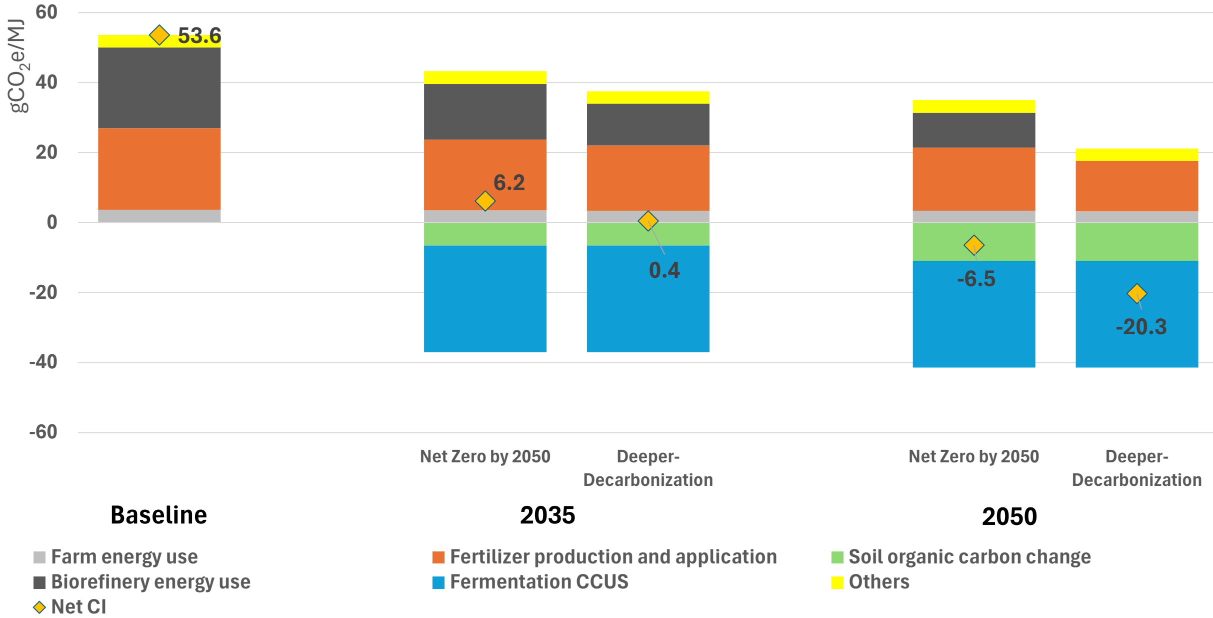


A negative cost means that the new measure costs less than the currently adopted measure because of reduced energy or fertilizer inputs (e.g., no-tillage farming, 4R nitrogen management), a lower cost for securing energy (e.g., PPAs), policy incentives (e.g., fermentation CCUS), or additional electricity production (e.g., biomass CHP). Source: EFI Foundation analysis.

The midterm pathway (by 2035) and the long-term pathway (by 2050) were modeled with varying assumptions about the prevalence of each decarbonization measure. Further details on assumptions can be found in Chapter 4 of the report.

Under the Net Zero by 2050 Pathway, a biorefinery can reduce almost 90% of its ethanol CI by 2035 and reach net-zero emissions by 2050. With the Deeper-Decarbonization Options, a biorefinery can reach almost net zero by 2035 and negative emissions in 2050 (Figure ES4).

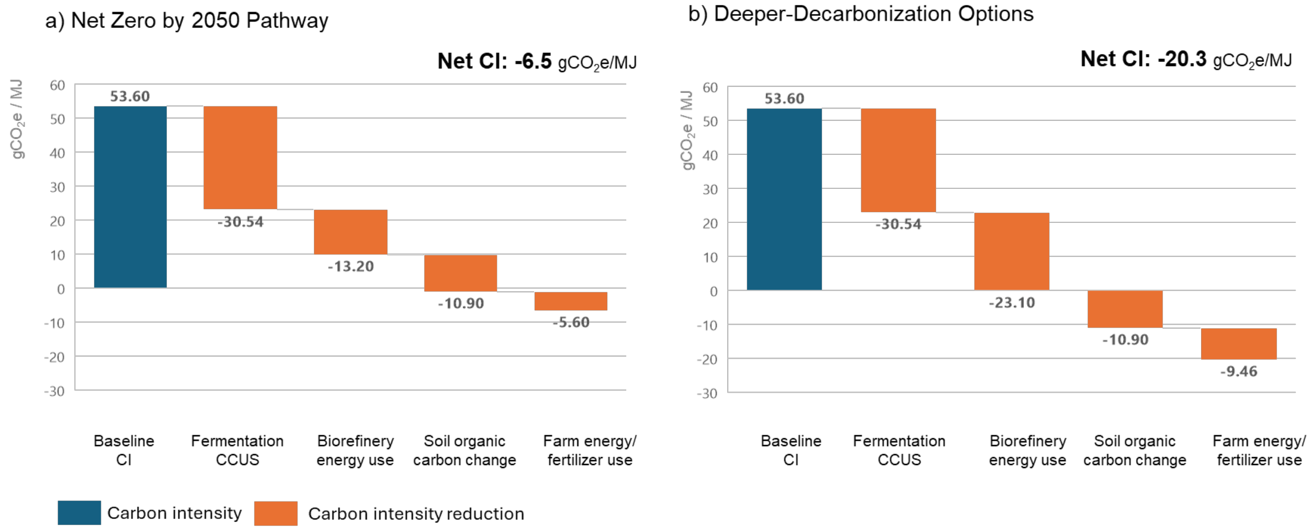
Figure ES 4. Ethanol carbon intensity in the baseline, Net Zero by 2050 Pathway, and Deeper-Decarbonization Options, 2035 and 2050



Source: EFI Foundation analysis.

Under the Net Zero by 2050 Pathway, the largest reduction comes from CCUS in the fermentation process, which reduces CI by 60%, a 30.5 gCO2e/MJ reduction from the baseline CI of 53.6 gCO_2e/MJ. Decarbonizing energy use in a biorefinery is the second-largest source of reductions. With the Deeper-Decarbonization Options, the largest reduction also comes from CCUS in the fermentation process. But, compared to the Net Zero by 2050 Pathway, decarbonizing energy use in the biorefinery reduces a larger amount of the CI as natural gas use for thermal energy generation is completely replaced by a mix of low-carbon fuels. See Figure ES5 for more detail.

Figure ES 5. Sources of CI reduction, Net Zero by 2050 and Deeper-Decarbonization, 2050



Source: EFI Foundation analysis.

Enabling Decarbonization of the Transportation Sector

The decarbonization pathways for the U.S. ethanol industry allow ethanol to play a much larger role in decarbonization across the entire transportation sector.

Lower-CI ethanol can complement electric vehicles in decarbonizing the light-duty vehicle fleet. As mentioned, transportation is the largest source of GHG emissions in the United States. The Biden-Harris administration has called for half of all new vehicles sold by 2030 to be electric vehicles (EVs), with a longer-term goal that most light-duty vehicles (LDVs) will be electric by 2050.[25,26] Achieving these goals alone is insufficient to reach a net-zero transportation sector.[27] Decarbonizing ethanol can substantially complement strategies for electrification of LDVs in reducing vehicle transportation emissions.[28]

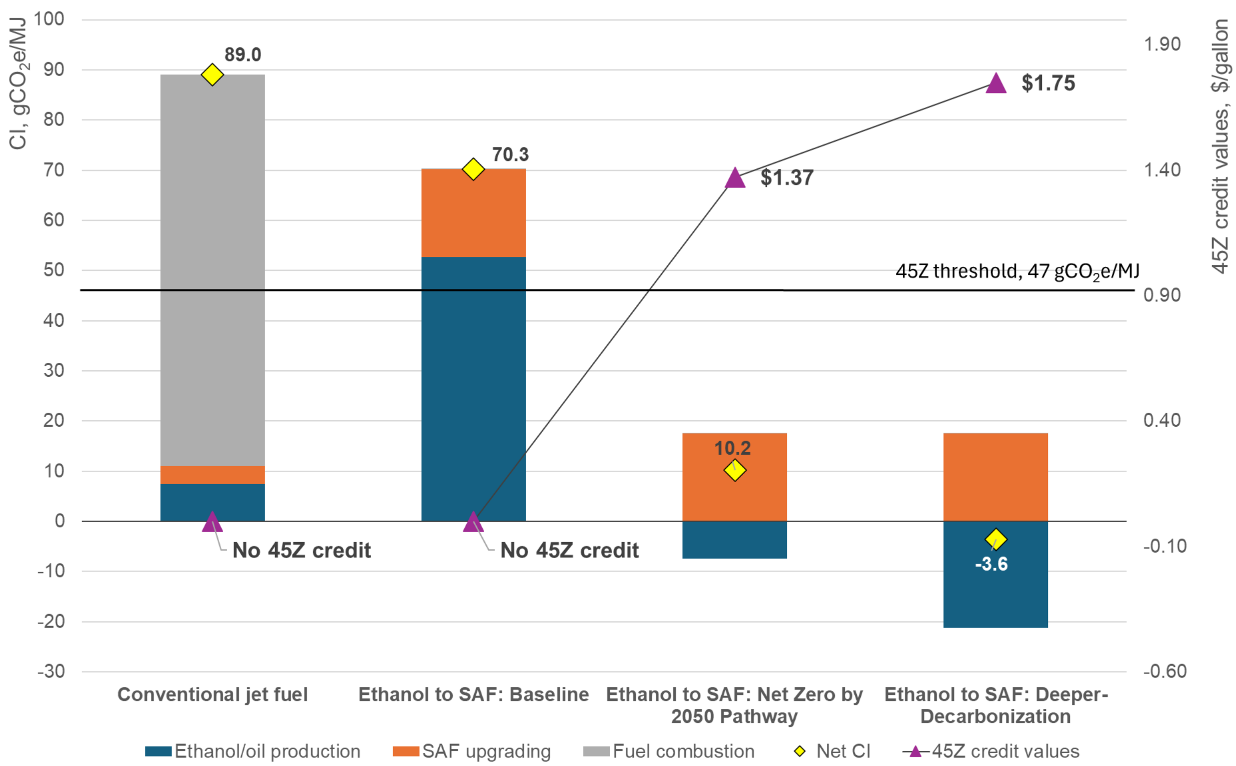
Further, plug-in hybrid electric vehicles (PHEVs), which still use some gasoline, currently make up about 27% of EVs in the United States.[29,30] Their presence in the vehicle fleet is expected to grow as automakers invest more in PHEVs, driven by consumer demand.[31] As a result, low-CI ethanol can play a role in further reducing emissions in new and in-use PHEVs alongside battery electric vehicles as transportation electrifies.

Decarbonized ethanol has the potential to be an abundant feedstock to expand the supply of sustainable aviation fuel (SAF). SAF is a drop-in fuel with jet fuel-like properties that requires no aircraft or supply chain infrastructure modifications. In the United States, SAF can take advantage of production tax credits. The clean fuel production tax credit (Section 45Z) of the Inflation Reduction Act (IRA) of 2022 goes into effect in January 2025 and requires life cycle SAF emissions to be no more than 50 kilograms (kg) of CO_2 per million British thermal units (MMBtu), or 47.4 gCO_2e/MJ.[i] The current CI score of ethanol alcohol-to-jet (ATJ) SAF is approximately 70.36,[j] meaning ethanol's carbon intensity must be reduced to qualify for tax credits.

As SAF currently costs around \$6.69 per gallon, compared to \$2.85 for fossil-based jet fuel, achieving the 45Z credit is essential for making ATJ SAF cost-competitive.[32] With the full 45Z credit plus existing state-level tax incentives for SAF, the cost of SAF could be in the range of \$2.94 to \$3.69 per gallon.

Figure ES6 demonstrates that both decarbonization pathways enable ATJ ethanol SAF (E-SAF) to achieve a CI under the 45Z threshold. The Deeper-Decarbonization pathway enables ATJ E-SAF to qualify for the maximum 45Z credit of \$1.75 per gallon.

Figure ES 6. Carbon intensity of conventional jet fuel and ATJ E-SAF, including under different decarbonization pathways



The emissions from fuel combustion are zero for ATJ E-SAF because they are offset by corn growth CO2 uptake. Source: EFI Foundation analysis.

[i] Including upstream feedstock emissions and emissions from SAF production.
[j] Estimated using the GREET model, assuming a dry mill with corn extraction facility, which represents more than 86% of ethanol production in the United States. The GREET default is 85.5% dry mill with corn extraction facility, 10% dry mill without the extraction facility, and 4.5% of wet mill.

Current Incentives Provide a Foundation for Ethanol Decarbonization

Currently available incentives are a helpful starting point to leverage decarbonization options but are not enough on their own. Beginning in January 2025, SAF production and higher gasoline blending will be able to obtain the 45Z clean fuels tax credit. To qualify for 45Z, clean fuels must be “suitable for use as a fuel in a highway vehicle or aircraft” and emit no more than 50 kg of CO_2 per MMBtu. When combined with other eligibility criteria such as meeting wage and apprenticeship standards, producers can receive a production tax credit of up to $1 per gallon for nonaviation fuels and $1.75 per gallon for SAF.[33]

State-level low-carbon fuel standards (LCFS) have also provided an effective mechanism for gradually decarbonizing transportation fuels. Currently, an LCFS program is in place in California, Oregon, and Washington. Twelve other states have introduced or discussed LCFS-like legislation, and three of these states (New York, Michigan, and Illinois) are among the top ethanol consumers. The LCFS programs in California[34], Oregon[35], and Washington[36] have not only incentivized reductions in the CI value of ethanol[37] but also have led to reductions in the CI of other alternative fuels, including RNG. Additionally, they have provided flexible and technology-neutral compliance options, have spurred private investment in lower-CI technologies, and have incentivized cleaner fuel production beyond state borders.[38]

Policy support for climate-smart agricultural practices also has been increasing.[k] The IRA provided $19.5 billion of additional funds over a five-year period to a portfolio of U.S. Department of Agriculture (USDA) conservation programs targeted to support adoption of climate-smart practices. The $19.5 billion was allocated among six separate programs: the Environmental Quality Incentive Program ($8.45 billion), Regional Conservation Partnership Program ($4.95 billion), Conservation Stewardship Program ($3.25 billion), Agricultural Conservation Easement Program ($1.4 billion), Conservation Technical Assistance ($1 billion), and for measuring, evaluating, and quantifying GHG emissions reductions ($300 million).[39]

The USDA has committed $2.1 billion of these funds in 2022 and 2023, is estimated to commit $3.1 billion by the end of 2024, and plans to commit $5.6 billion in 2025, though farmer interest to date has far exceeded the available funds. When the USDA made $850 million of these funds available in 2023, applicants requested almost $3 billion in total.[40]

Blending requirements have become a pivotal aspect of the broader strategy to decarbonize transportation fuels. Such requirements mandate a specific percentage of renewable fuels be blended with gasoline, helping to lower the overall CI of the fuel mix. In the United States, the Renewable Fuel Standard (RFS) requires 15 billion gallons of

[k] Climate-smart agriculture is a way to build resilience in farming operations, benefiting both farmers and ranchers and the environment. The goals of CSA are to increase or maintain productivity and yield, enhance resilience to environmental changes, and reduce GHG emissions. CSA practices include many techniques already used by farmers, such as cover cropping, no- and reduced-tillage farming, and nutrient management.

conventional renewable fuels to be blended into the nation's fuel supply each year.[l] For 2024, ethanol is expected to fulfill approximately 93% of the RFS volume requirement.[41] E10 is the most common blend used to achieve these volume obligations, with states such as Minnesota, Missouri, and Oregon requiring E10 blending by law. State E10 mandates combined with the RFS have resulted in E10 becoming the de facto standard for gasoline across the country.[42]

Additional Policies Are Necessary to Accelerate the Decarbonization of Ethanol Supply Chains

Additional policy measures will accelerate the adoption of a strategic decarbonization roadmap for the ethanol industry to reach net-zero CI and move beyond to net-negative CI. Employing ready-to-adopt and modest-cost decarbonization measures will enable the ethanol industry to reach net-zero emissions, but even these measures face barriers to implementation, such as lack of infrastructure, the need for upfront investment, and uncertain implementation outcomes. To lower these barriers, a range of industry actions and policy changes are required.

The ethanol life cycle is complex, and the implementation of a strategic decarbonization roadmap requires coordinated action among five major players: corn growers, ethanol bio refiners, energy suppliers (electricity and fuels), fertilizer producers, and an emerging carbon management industry. A key factor in the design of additional policy measures is the need to address the roles of all major players, including ways to encourage cooperative and mutually reinforcing actions. The recommendations that follow are intended to comprehensively address decarbonization actions across all the players in the ethanol life cycle.

USDA support for expanding farmers' adoption of climate-smart agricultural (CSA) practices

CSA adoption rates are low because of economic challenges and uncertain outcomes because of variation in environmental factors like soil type and climate.[43,44,45] In some instances, CSA practices require significant upfront investments, such as purchasing specialized equipment that does not necessarily result in immediate productivity increases. Further, the lack of a robust measuring, monitoring, reporting, and verification (MMRV) framework for CSA practices is another critical barrier preventing farmers from ensuring the outcome of their investment. Additional policy support is needed to provide farmers with CSA data and funding.

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[l] Conventional renewable fuel refers to fuel made from renewable biomass that either achieves at least a 20% reduction in greenhouse gas emissions compared to the fossil fuel it replaces or is exempt from this requirement if produced in facilities built before December 19, 2007. Renewable biomass includes wood, agricultural crops, and wastes from municipal, industrial, and agricultural sources. Source: U.S. Environmental Protection Agency, Renewable Fuel Standard (RFS) Program: Standards for 2023, 2024, and 2025, Federal Register, July 12, 2023, https://www.govinfo.gov/content/pkg/FR-2023-07-12/pdf/2023-13462.pdf.

- ***Recommendation 1.*** *Congress should preserve the existing IRA funds for conservation programs so the USDA can proceed with the full multiyear funding allocations to expand the adoption of CSA practices.*
- ***Recommendation 2.*** *The USDA should provide farmers with a comprehensive information package, including grants, loan programs, technical support, tools, and contracts, which can be used to invest in CSA practices.*
- ***Recommendation 3.*** *The USDA should accelerate collecting field-based data on CSA practices, develop an MMRV framework for CSA practices, and disseminate the data and framework to stakeholders, including federal agencies designing incentive programs, GREET modelers, farmers, and the ethanol industry.*
- ***Recommendation 4.*** *The IRS, working with DOE, should expand the portfolio of CSA practices that can be considered in qualification for the 45Z credit to include all GREET options. Also, the IRS should allow flexibility in letting farmers select individual measures in a practice-by-practice fashion, rather than require bundling of measures—as has been done with the current SAF tax credit (40B).*
- ***Recommendation 5.*** *In collaboration with the USDA, the IRS should consider ways to help ethanol producers share the value of these credits with corn growers who contributed to reducing the carbon intensity of ethanol by adopting CSA practices.*

Production tax credits

The 45Z production tax credit, which becomes effective in 2025, can provide a powerful incentive to produce lower-CI ethanol for use as a gasoline blending agent and to significantly expand SAF supplies. It also could further reduce the CI of ethanol blends in gasoline. Under current law, the 45Z credit will apply only until Dec. 31, 2027. This period of time is insufficient to incentivize the capital investment needed to reduce the CI throughout the ethanol life cycle.

- ***Recommendation 6.*** *Congress should modify the 45Z clean fuels production tax credit in a manner similar to other IRA incentives, i.e., extend it for 10 years to facilities that commence production of qualified transportation fuels before Jan. 1, 2033.*
- ***Recommendation 7.*** *In collaboration with the USDA, DOE should continue improving the GREET model to reflect a broader range of emissions-reduction practices, such as options for combined heat and power. These practices should be incorporated into the IRS 45Z guidance.*

Decarbonizing energy use in biorefineries

Natural gas accounts for 91% of energy consumption at biorefineries, contributing significantly to ethanol's carbon intensity. Alternatives such as renewable natural gas and clean hydrogen blended with natural gas can be used as drop-in fuels to reduce ethanol's CI score. Both agricultural and landfill biogas resources are abundant in the Midwest, but conversion to RNG production has been limited. The impediments include large upfront capital investment requirements, lack of transportation infrastructure, and fragmented market demand. Other options that could significantly lower ethanol's CI from electricity use are procuring carbon-free electricity from utilities that are decarbonizing their generation portfolio; seeking direct power purchase agreements (PPAs) with clean electricity generators; or purchasing renewable energy certificates, such as energy attribute certificates (EACs), with independent power producers.

- ***Recommendation 8.*** *Ethanol producers should seek opportunities to increase carbon-free sources of electricity for use at biorefineries—including electricity from biomass and other renewables, hydrogen, nuclear, hydropower, and others—in cases where the grid is not being decarbonized quickly enough.*
- ***Recommendation 9.*** *Ethanol producers should consider measures to decarbonize process heat, including biofuels and RNG—for example, facilitating demand aggregation that could incentivize expanded RNG production while mitigating financial risks. Market demand formation measures could range from establishing RNG certificate programs to forming buyers' cooperatives.*

Decarbonizing fertilizer

Decarbonizing the production of fertilizers could significantly reduce ethanol's CI, as the emissions from fertilizer production account for about 11% of ethanol's carbon intensity. Low-carbon fertilizer production from either blue hydrogen or green hydrogen currently is more costly than conventional fertilizer supplies. Farmers are not motivated to pay a significant premium for low-carbon fertilizers, given their small profit margins and uncertain incentives for using them. Implementation of the new 45V tax credit for clean hydrogen, as well as DOE's hydrogen hubs program and the Hydrogen Demand Initiative,[m] could potentially close this gap.

- ***Recommendation 10.*** *DOE's hydrogen hubs program and the Hydrogen Demand Initiative should consider making clean ammonia one of their early targets for financial support.*
- ***Recommendation 11.*** *The USDA should reopen and repurpose its domestic fertilizer production program, focusing on retrofitting existing facilities to produce low-carbon fertilizers using funds from the Commodity Credit Corporation (CCC).*

[m] The Hydrogen Demand Initiative is a consortium selected by DOE and led by the EFI Foundation to help accelerate the commercial liftoff of the clean hydrogen economy.

Congress should not restrict the USDA's authority to use CCC funds for this purpose in pending farm bill legislation.

Demand-side mandates for clean fuels

Demand-side mandates can have a synergistic effect when added to production incentives. State-level LCFS, for example, have proven effective in reducing the carbon intensity of ethanol. California's LCFS program has led to a 25% reduction in ethanol's carbon intensity since its implementation in 2011.[46] However, creating a national clean fuel standard (CFS) requires further investigation into policy design options, as the specifics of the standard substantially shape its efficacy. A key issue in the design of a national CFS is the interplay between a CFS and the existing federal RFS program. The current RFS implicitly considers the blend rates of ethanol in gasoline when setting the target. A CFS could encourage higher blend rates, reflecting the fact that today, the vast majority of on-road vehicles are capable of using blends up to 15%, and drive the demand for SAF.[47] It could also incentivize the ethanol industry to further decarbonize the supply chain to meet the requirements for CFS.

- ***Recommendation 12.*** *The administration should launch an interagency study of the feasibility of a national CFS, including a process for broad public engagement.*
- ***Recommendation 13.*** *Apart from the CFS, the U.S. Environmental Protection Agency should consider the feasibility of higher blending levels in the formulation of RFS standards, and states should consider expanding current mandates, including establishing requirements for E15 and higher blends in gasoline.*

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