Cost-benefit analysis of alcohol-to-jet sustainable aviation fuel

Assessment of Gevo Inc.'s Net Zero 1 alcohol-to-jet sustainable aviation fuel opportunity

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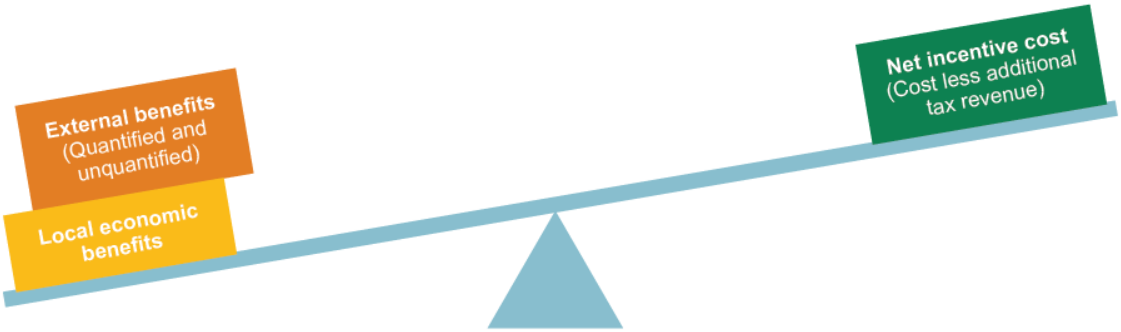
1. Objectives & scope

Sustainable aviation fuel (SAF) presents the most promising pathway to decarbonize aviation, a key component of the American and broader global economy. However, current **levelized production costs** (inclusive of capital returns) for low-carbon aviation fuels substantially exceeds the sales price of fossil jet fuel, and while that differential may narrow or close with SAF technology improvements, the formation of a meaningful SAF industry will require investment incentives or mandated SAF usage to grow demand. Not currently captured in the levelized production cost of SAF are external benefits and economic benefits at the local and state level. The question of costs versus benefits is often raised when policy measures are under consideration, with a cost-benefit analysis being a helpful tool for policymakers and other stakeholders to evaluate a policy option.

The objective of this report prepared by Charles River Associates (CRA) is to recognize and attempt to quantify total benefits and incentive costs associated with Gevo Inc.'s ("Gevo") planned Net Zero 1 **Alcohol-to-Jet** (ATJ) SAF facility. The values derived in this report are estimates derived from currently available data and should be interpreted as approximations. Reference sources include both publicly available data and research papers as well as information provided by Gevo.

Two key forms of SAF benefits accrue to the economy and society: (i) benefits that are not normally captured by pure market prices and are known in economic terms as **externalities** as they are external to the product's actual price; and (ii) **economic benefits** at local and state levels associated with direct, indirect, and induced economic activity associated with large-scale capital investment and operations. Furthermore, there are benefits that are beyond the scope of this work to quantify but that do merit qualitative recognition in the body of the report. The total benefits will be weighed against the net federal incentives to determine if the benefits outweigh the costs (Figure 1).

Figure 1. Total benefits and net incentive costs



This report compares the calculated estimates of the benefits of ATJ SAF to the current level of federal incentives and analyzes the scope for additional incentives needed to incentivize the development of an ATJ-based SAF industry that can scale to meet the demand of the aviation industry.

1.1. Key findings

Cost-Benefits on a Unitized Basis

- Annually, the value of total benefits of ATJ SAF is estimated to be more than **four to six times** the cost of current federal incentives. On a unitized basis, every $1.00 of federal incentive costs for ATJ SAF yields an estimated $4.85-$6.53 of total quantified benefits. Total benefits are comprised of 73%-80% from external benefits and 20% from local economic benefits. The low end of the external benefits estimate includes near-term benefits of the technological spillover, and the high end includes long-term benefits of the technological spillover.

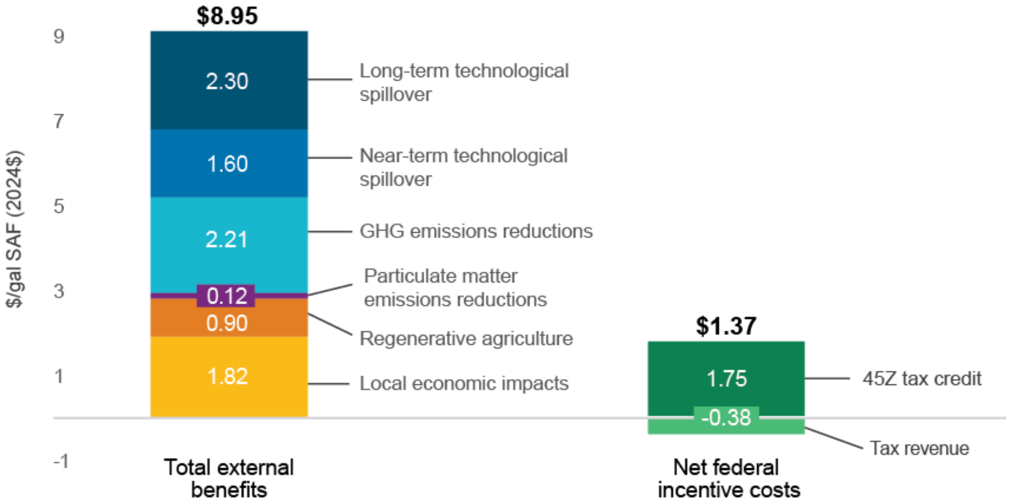
Cost-Benefits on a Per-Gallon SAF Basis

- **Total benefits**: On a per-gallon basis, the value of SAF's benefits (as extrapolated from NZ1) are estimated at **$6.65–$8.95 per gallon** versus a net incentive cost of $1.37 per gallon ($1.75 per gallon less $0.38 per gallon of incremental federal tax benefits flowing back to the government), as shown in Figure 2. Net federal incentive costs do not include the value of RFS RINs which are not a U.S. federal government cost for SAF. Federal programmatic costs are also excluded in this analysis. The low end of the estimate considers near-term benefits of the technological spillover, and the high end includes long-term benefits of the technological spillover. Not all benefits could be quantified. Additional benefits from SAF which were considered qualitatively in this analysis include benefits to energy security and the positive impact in a rapid decarbonization scenario on the future competitiveness of agriculture, ethanol, and aviation industries as well as the wider U.S. economy.
- **Incentivizing the SAF industry:** Fully scaling up the ATJ SAF industry to produce the volumes needed to meet the goals set by the U.S. SAF Grand Challenge will require additional incentives to SAF producers or purchasers. Even though ATJ SAF cash production cost is on par with the commodity price of fossil jet fuel, the levelized cost of ATJ SAF includes return of and on capital and is currently higher. The price of fossil jet fuel also benefits from legacy capital investment and long-term subsidies. Leveraging the current federal incentives narrows but does not eliminate this difference. Leveraging both the 45Z tax credit and RFS RINS credit values, the price differential between the price of fossil jet fuel and the levelized cost of ATJ SAF is estimated at $1.24/gal. However, the 45Z tax credit will expire after 2027 under current law. Leveraging only the RFS RIN results in the ATJ SAF being $2.99/gal greater than the fossil jet price. State incentive programs could also contribute to reducing this difference. However, none of the current state programs result in a total incentive value that exceeds $2.99/gallon, leaving a gap in the near-term with the pending expiration of the federal 45Z credit. The next generation of ATJ SAF will benefit from the cumulative experiential learnings of the first generation of production facilities. These future production facilities could realize production costs that

are 53% lower by 2030. However, this decrease in production costs will only be realized if the private sector and government work together to rapidly scale production to meet the U.S. SAF Grand Challenge goals.

- Federal tax incentives don't need to be permanent. However, near-term investment to build a SAF production facility will be based on current technology, current production costs and currently available incentives. Extension of the 45Z tax credit will support these needed investments.

Figure 2. Total Annual Benefits and Net Incentive Costs[1]



External benefits assessed included the following:

Formative technology and technological spillover: The initial investment in the nascent industry will contribute to experiential learning and the resulting technological spillover to other firms will yield production cost reductions in the next generation of ATJ SAF plants. These future production facilities could realize production costs that are 53% lower by 2030 if the industry is properly incentivized to invest in SAF production capacity. Near-term technological spillover yields a benefit of $1.60/gal SAF, and long-term spillover produces additional benefits valued at $2.30/gal.

Greenhouse gas (GHG) emissions reductions: The NZ1 facility produces ATJ SAF that has a drastically reduced lifecycle GHG emissions, approximately 107% lower than that of fossil-based jet fuel. By adopting ATJ SAF, we avoid these additional GHG emissions, which lessens the climate change impacts to society and the environment. Benefits from reducing GHG emissions in the production processes inclusive of indirect land use change impacts total $2.21/gal.

Particulate matter emissions reductions: ATJ SAF also contains fewer impurities than fossil jet fuel, and aircraft powered by ATJ SAF will produce fewer particulate matter

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[1] Note: Net federal incentive costs do not include the value of RFS RINs which are not a U.S. federal government cost for SAF. Programmatic costs are also excluded.

emissions. This is important because particulate matter has negative impacts on human health. The benefit of avoiding these additional air pollutants by adopting ATJ SAF totals $0.12/gal.

Regenerative agriculture: Conventional farming practices negatively impact soil quality, cause significant soil erosion, which impacts air and water quality, and produce significant GHG emissions. Regenerative agriculture practices can be implemented to lessen these impacts. The NZ1 facility plans to source their corn feedstock from farms that have adopted regenerative agricultural practices. In doing so, the facility produces benefits to water and air quality, reduces farming GHG emissions, and increases farming income. These benefits total $0.90/gal.

Energy security: Ensuring a stable supply of energy at an affordable price is essential to the U.S. economy. This includes protecting existing energy assets and reducing exposure to volatile prices. SAF can increase energy security and energy independence because it reduces reliance on crude oil imports and distributes jet fuel production more broadly across the country. This benefit was assessed qualitatively.

The **aviation industry** benefits from investments in foundational low-carbon technologies such as ATJ SAF. In the absence of scaling effective decarbonization pathways such as SAF, the aviation industry and the broader economy would be negatively impacted under a more rapid decarbonization scenario such as net zero by 2050.

Local economic impacts assessed included the following:

Kingsbury County, South Dakota and the surrounding counties would experience local economic benefits that are separate from, and in addition to, external benefits. This includes direct, indirect, and induced economic impacts. These benefits produce $1.82/gal in value (less taxes). An incremental economic value is returned to the federal government in the form of tax revenue ($0.38/gal).

Total cost-benefits per year from NZ1 annual production

- Total dollar benefits from the NZ1 facility are estimated at $399–$537 million per year.
    - Total dollar external benefits from the NZ1 facility are $290–$428 million per year.
    - Total dollar local economic benefits from the operations of the NZ1 facility are estimated at $116 million from direct, indirect, and induced impacts. Additionally, NZ1 is estimated to generate 836 jobs (100 at the plant and 736 in other local jobs). We estimate the federal tax revenue generated from the economic value-added at approximately $23 million annually.
- The annual federal net incentive cost from the NZ1 facility is estimated at $82 million.

Ethanol stranded production asset scenario

Agriculture communities in particular benefits from the current demand for ethanol. Unused ethanol-production capacity would represent a loss in potential economic value and a loss in jobs, which are essential to these rural communities. As the nation moves toward a future where electric vehicles (EVs) gain a larger market share, there will be a decrease in demand for gasoline and likewise a reduced demand for ethanol for fuel blending. This presents an opportunity for another end use for ethanol to develop and provide continued support for the many jobs in agriculture and other supporting industries. If the ATJ SAF industry is incentivized to fully develop, the increase in demand for ethanol would help to offset the declining demand from other industries. This would provide continued support for the rural economies and make use of the corn crop production that continues to increase its yield.

We estimate that the ATJ industry's scale-up could generate a cumulative economic benefit of about $254 billion by 2050. The net economic benefit, representing the overall gain after recovering from stranded assets, is estimated to reach approximately $75 billion by 2050.

1.2. Assumptions and scenarios

It is useful to define up front the key economic and policy assumptions that drive our analysis. The calculations represent midpoint estimates based on current available data and are approximations of the actual values.

Our analysis assumes that the United States and other countries will need to make significant progress in decarbonizing their economies over the period from 2025 to 2050. As a major and growing contributor to global carbon emissions, the commercial aviation sector will need to deploy new technologies to make low-carbon transportation a reality, and at massive scale. While a range of SAF and other technologies are in early stages of deployment, decarbonizing the aviation sector by 2050 will require investment in an SAF industry capable of producing billions of gallons of low-carbon SAF per year for the United States alone.[2] Meeting this challenge will require investment today in **foundational technologies** like ATJ SAF that can provide a basis for further scale and development—just as the solar photovoltaic (PV) technology, wind turbines, and many other technologies have done in other contexts.

Our core analysis focuses on the development of ATJ SAF on time horizons consistent with current economics (and U.S. government targets) to achieve net zero by 2050, requiring a switch to low-carbon fuels in aviation and other transportation sectors. While these decarbonization targets are ambitious compared to current efforts and imply a significant shadow price on current and future carbon emissions, it is representative of a pathway to decarbonization over the next quarter century.

In this report we examine the external benefits in the U.S. that could be realized by adopting ATJ SAF, which would occur as the ATJ SAF produced by NZ1 replaces fossil jet fuel. We value the benefits on a dollar per gallon, per-year basis. Benefits realized by the future ATJ SAF industry due to the initial NZ1 investment are based on the rapidly decarbonizing scenario described above, which assumes that the ATJ SAF industry can fully develop.

We also examine two specific issues on a sectoral and regional level. First, using standard economic techniques, we examine the potential local economic benefits of the NZ1 plant to the local economy in South Dakota (Kingsbury County and surrounding counties), in terms of direct, indirect, and induced economic impacts. Previous economic analyses have shown that

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[2] NREL, "A Roadmap toward a Sustainable Aviation Ecosystem," 2022, https://www.nrel.gov/docs/fy22osti/83060.pdf.

ethanol production has significantly impacted farming communities, and corn-based ATJ SAF production would continue this trend.

We also examine the potential role of corn-based ATJ as a key method to preserving the value of corn ethanol demand in the U.S. agricultural economy. As corn yields continue to increase and ethanol demand for gasoline blending flattens (and eventually falls in low-carbon scenarios), the U.S. agricultural sector faces a potential drop in demand. American farms will be capable of producing more corn than can be sold at prices that support incomes in farming states. Corn-based ATJ can play a major role in diverting corn production into a higher-value sector, aviation, which is otherwise costly or impossible to electrify at scale.

In the absence of scaling effective decarbonization pathways such as SAF, the aviation industry and the broader economy would be negatively impacted under a more rapid decarbonization scenario such as net zero by 2050. The aviation sector, which is currently almost entirely dependent on fossil fuels and is central to the U.S. economy's operation, would be at particular risk under a net zero by 2050 scenario. The success of stringent decarbonization policy hinges on having a commercially viable decarbonization solution. Given these risks, investment in foundational low-carbon technologies like ATJ, which will take years to build and scale, can be seen as prudent insurance against a potential future for which we are otherwise unprepared. While this value is not quantified in detail in this report, it should not be overlooked.

1.3. Report organization

Section 1 presents key findings and objectives of the cost-benefit analysis.

Section 2 discusses the significant challenges related to the decarbonization of the aviation industry and the role of ATJ SAF compared with other possible decarbonization pathways.

Section 3 details the NZ1 facility design, including the sources of energy, feedstock consumption, and yield.

Section 4 details the current production economics, including the estimated levelized production costs of SAF and commodity price of fossil jet fuel, as well as current government incentive programs for the production and purchase of SAF.

Section 5 details the external benefits resulting from the Gevo NZ1 investment and adoption of ATJ SAF.

Section 6 presents the key findings of the cost-benefit analysis on a national level, the role of current incentives, and the potential impact on the future growth of the SAF industry.

Section 7 details the local- and state-level impacts due to the development of NZ1 in rural South Dakota, inclusive of incremental tax revenue to government bodies.

Section 8 presents potential impacts to the corn and ethanol industry under a rapid decarbonization policy scenario involving vehicle electrification.

Section 9 presents findings and conclusions on the potential benefits of SAF.

2. SAF and the challenges of aviation decarbonization

2.1. Decarbonizing aviation

Aviation is currently responsible for about 2% of global **GHG emissions**, contributing 1 Gt of GHG emissions in 2019.[3] In the United States alone, commercial aviation emits ~222 million tons of CO_2 per year(~2.7% of all domestic emissions).[4] Energy efficiency has improved for aviation but not enough to compensate for the continued overall growth in aviation activity.[5] Aviation activity is forecasted to increase ~3.5% each year through 2050.[6] In the US, ~4.2% of the **gross domestic product** (GDP) is supported by the aviation industry through direct employment and spend by airlines and along their supply chain as well as due to the value generated from trade, tourism, and investments.[7] There is momentum within the industry to pursue decarbonization, and the global aviation industry and the member states the International Civil Aviation Organization (ICAO), a United Nations agency, have committed to the goal of net-zero carbon emissions by 2050.[8,9]

Smaller, battery-powered electric aircraft have shown promise for shorter routes. However, the deployment of battery powered aircraft over long distance flights is limited by current battery technology, which has low energy density by weight.[10] Hydrogen is another potential decarbonization option, as this fuel can be combusted in jet engines and refueling occurs in a similar manner as existing fossil fuel processes. However, it has low energy density by volume, and implementing aircraft storage that can hold sufficient hydrogen energy for longer flights will be challenging.[11] The ICAO forecasts that hydrogen will not be a major aviation fuel until well after 2050 (predicting ~1.9% energy share forecast in 2050).[12]

These are completely novel technologies in aviation and will require many years of testing to be certified for commercial airline use. Approving minor modifications to an existing aircraft can take three to five years to be certified, while a new model of a conventional fossil jet fired aircraft can require between five and nine years.[13] Stringent safety requirements within

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[3] NREL, “A Roadmap toward a Sustainable Aviation Ecosystem,” 2022, https://www.nrel.gov/docs/fy22osti/83060.pdf.

[4] U.S. Federal Aviation Administration, “2021 Climate Action Plan,” 2021, https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf.

[5] IEA, “Energy Intensity of Commercial Passenger Aviation in the Net Zero Scenario, 2000–2030,” 2023, https://www.iea.org/data-and-statistics/charts/energy-intensity-of-commercial-passenger-aviation-in-the-net-zero-scenario-2000-2030 (analysis based on IEA Energy Balances).

[6] ICAO, “Post-COVID-19 Forecasts Scenarios,” 2021, https://www.icao.int/sustainability/Documents/Post-COVID-19%20forecasts%20scenarios%20tables.pdf.

[7] IATA, “The Importance of Air Transport to the United States,” 2018, https://www.iata.org.

[8] ICAO, “States Adopt Net-Zero 2050 Global Aspirational Goal for International Flight Operations,” 2022, https://www.icao.int/Newsroom/Pages/States-adopts-netzero-2050-aspirational-goal-for-international-flight-operations.aspx.

[9] ICAO, “ICAO Welcomes New Net-Zero 2050 Air Industry Commitment,” 2021, https://www.icao.int/Newsroom/Pages/ICAO-welcomes-new-netzero-2050-air-industry-commitment.aspx.

[10] IEA, “Aviation,” accessed June 2024, https://www.iea.org/energy-system/transport/aviation.

[11] IEA, “Aviation,” accessed June 2024, https://www.iea.org/energy-system/transport/aviation.

[12] ICAO, *Report on the Feasibility of a Long-Term Aspirational Goal for International Civil Aviation CO2 Emission Reductions* (Montreal: ICAO, 2022).

[13] U.S. Federal Aviation Administration, “Airworthiness Certification,” February 6, 2023, https://www.faa.gov/aircraft/air_cert/airworthiness_certification/aw_overview.

commercial aviation will likely delay the adoption of these technologies, making them infeasible as an option to meet current decarbonization targets by 2050.

SAFs are renewable jet fuels derived from renewable feedstocks such as agriculture crops, vegetable and other oils and fats, and forestry and municipal wastes. SAF can be used in existing infrastructure and aircraft, currently as a drop-in substitute for fossil jet fuel, and has significantly lower **lifecycle GHG** emissions.[14] Compared to other decarbonization technologies, SAF represents a pathway that can currently be scaled up and implemented. Several production pathways for SAFs have already been approved for use in blending with fossil-based Jet A fuel. However, it is important to consider the entire lifecycle emissions when considering its net impact on GHGs. Corn-based ATJ is one potential methodology to produce SAF that is carbon neutral and potentially even carbon negative.[15]

In 2021, the U.S. federal government announced the "Sustainable Aviation Fuel Grand Challenge." This program set goals for SAF production of 3 billion gallons by 2030 and 35 billion gallons by 2050 to reduce aviation lifecycle GHG emissions by 50%.[16] Global aviation fuel consumption is currently met by petroleum jet fuel with only ~0.1% via SAF.[17] The demand for SAF is forecasted to experience rapid growth from current low levels of use. United Airlines, Southwest Airlines, Delta, and America Airlines are among the airline companies that have already entered into SAF offtake agreements. Globally, a total of over 51 billion liters of SAF have been announced in offtake agreements.[18] Among SAF producers, Gevo Inc. has announced the highest total offtake volume and currently has 350 million gallons of SAF offtake contracted.[19]

2.2. SAF production pathways

There are several production pathways to produce SAFs. Jet fuel, including SAF produced from new pathways, must be certified to meet ASTM International specifications, as the Federal Aviation Administration only certifies aircraft to operate using ASTM-certified fuels. Currently, eight SAF fuel pathways have been approved by ASTM for blending with jet fuel (see the appendix for more details). These production pathways use different technologies to produce SAF and rely on different feedstocks ranging from fossil fuels to cooking oils and various biomass sources. The different SAF pathways have a wide range of potential lifecycle GHG emissions and production costs.

ATJ SAF is one of the eight certified fuel pathways. In the ATJ process, alcohols such as ethanol or isobutanol are converted into hydrocarbons suitable for jet fuel blending. Residual carbohydrates from the food/feed industry, such as corn starch, are commonly used feedstocks and are converted to ethanol or isobutanol via **fermentation**. The remaining

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[14] NREL, "A Roadmap toward a Sustainable Aviation Ecosystem," 2022, https://www.nrel.gov/docs/fy22osti/83060.pdf.

[15] NREL, "A Roadmap toward a Sustainable Aviation Ecosystem," 2022, https://www.nrel.gov/docs/fy22osti/83060.pdf.

[16] U.S. Department of Energy, Alternative Fuels Data Center, "Sustainable Aviation Fuel: Review of Technical Pathways," accessed June 2024, https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html.

[17] IEA, "Aviation," June 2024, https://www.iea.org/energy-system/transport/aviation.

[18] ICAO, "Tracker of SAF Offtake Agreements," January 2024, https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx.

[19] Gevo investor presentation, January 2024.

components of corn are converted to high-protein feed for the feed industry. The **animal feed** output of such a plant is greater than the fuel output; in fact, on a pounds-produced basis, the animal feed produced can be up to 35 times greater than the fuel output.[20] The alcohol (ethanol or butanol) is then dehydrated and oligomerized, meaning smaller molecules are combined to form larger ones and then undergoes hydrogenation, where hydrogen is added to generate a product suitable for fuel blending.

Currently, **hydroprocessed esters and fatty acids** (HEFA) SAF is the mostly widely used of the certified SAF fuels. HEFA is a more mature technology at a commercial scale. In the HEFA process, vegetable oils, waste oils, or fats are converted into a blend of hydrocarbons suitable for mixing with conventional jet fuel. Using hydrogenation, these feedstocks are then refined into SAF.[21] Compared to the ATJ process, the HEFA process relies on a considerably more limited feedstock. The most sustainable source of feedstock for the HEFA process are waste oils, but demand is already outpacing domestic sources and used oils are increasingly being imported from international sources (mainly Asia).[22,23] To further expand production capabilities, the HEFA process will have to use less sustainable sources, such as virgin oils generated from seed crops,[24] which will lower HEFA's utility as a decarbonization pathway. In contrast, the ATJ process predominantly uses ethanol, which has higher availability because it can be generated from many sources at a lower cost.[25] In the United States, corn ethanol production capacity already exceeds current demand.[26]

While the ATJ production costs including capital return currently exceed that of HEFA, the eventual limitation in HEFA feedstock will drive up its variable costs and limit further production capacity. Seed oil crops are the primary alternative to scale up HEFA production, and as mentioned above, they present a less sustainable feedstock source than waste oils. Additionally, they require more processing and will require additional investment to build out facilities that can crush and process the seed oil. The HEFA technology is more mature, and future cost reductions will be more modest.[27] Meeting the aviation decarbonization targets that the U.S. government has proposed will require producing 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050. Other SAF pathways like ATJ that are not limited by feedstock availability will need to be implemented.[28]

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[20] CRA analysis based on GEVO NZ1 estimates.

[21] SkyNRG, "Technology Basics," accessed June 2024, https://skynrg.com/sustainable-aviation-fuel/technology-basics/.

[22] IEA, "Is the Biofuel Industry Approaching a Feedstock Crunch?," 2022, https://www.iea.org/reports/is-the-biofuel-industry-approaching-a-feedstock-crunch.

[23] ICF, "Fueling Net Zero: How the Aviation Industry Can Deploy Sustainable Aviation Fuel to Meet Climate Ambitions," 2021, https://www.icf.com/insights/transportation/deploying-sustainable-aviation-fuel-to-meet-climate-ambition.

[24] IEA, "Is the Biofuel Industry Approaching a Feedstock Crunch?," 2022, https://www.iea.org/reports/is-the-biofuel-industry-approaching-a-feedstock-crunch.

[25] Jude A. Okolie et al., "Multi-Criteria Decision Analysis for the Evaluation and Screening of Sustainable Aviation Fuel Production Pathways," *iScience* 26, no. 6 (2023).

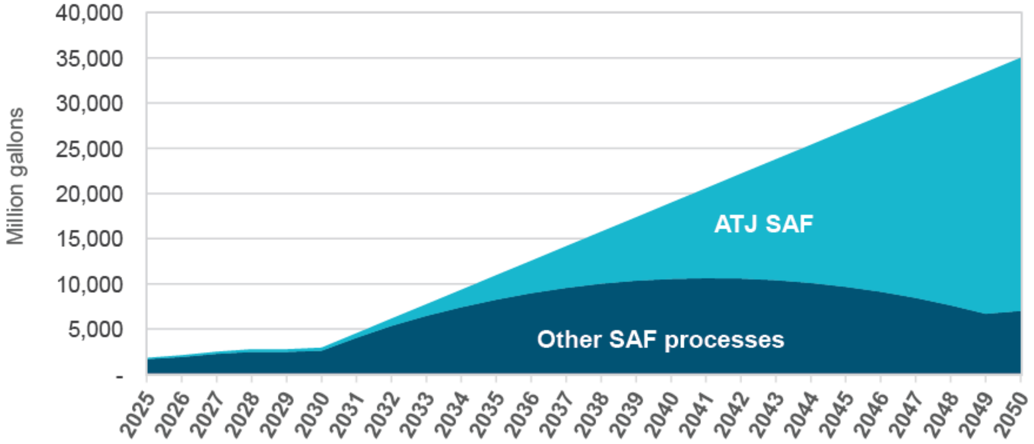
[26] Steven Ramsey et al., *Global Demand for Fuel Ethanol through 2030* (Washington, DC: USDA, 2023).

[27] World Economic Forum, *Scaling Up Sustainable Aviation Fuel Supply* (Cologny, Switzerland: World Economic Forum, 2024).

[28] ICF, "Fueling Net Zero: How the Aviation Industry Can Deploy Sustainable Aviation Fuel to Meet Climate Ambitions," 2021, https://www.icf.com/insights/transportation/deploying-sustainable-aviation-fuel-to-meet-climate-ambition.

Currently, the HEFA process accounts for 99% of the SAF production capacity. But as highlighted in Figure 3, HEFA's share of the SAF market is expected to decline and ATJ to increase particularly beyond 2030, if investment incentivization occurs in the early stages of the industry's formation. ATJ can be produced from starch/sugar feedstocks (e.g., corn, sugarcane) as well as cellulosic crops (non-food-based sources including crop residues; industrial wastes; and energy crops like grasses, woody plants, and algae). This feedstock flexibility enables a greater upward production potential. The forecast shown in Figure 3 assumes that the U.S. decarbonization goals for SAF are met. The share of technologies is forecasted based on predictions of HEFA's limited production growth and the need for other advanced pathways to develop.[29,30]

Figure 3. U.S. forecast of SAF production[31]



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[29] ICF, "Fueling Net Zero: How the Aviation Industry Can Deploy Sustainable Aviation Fuel to Meet Climate Ambitions," 2021, https://www.icf.com/insights/transportation/deploying-sustainable-aviation-fuel-to-meet-climate-ambition.

[30] CRA analysis based on Bloomberg Forecast, U.S. SAF Grand Challenge Goals, and Gevo estimates as informed by US EIA and ICF Resources.

[31] CRA analysis based on Bloomberg Forecast, U.S. SAF Grand Challenge Goals, and Gevo estimates as informed by US EIA and ICF Resources.

3. Gevo NZ1 SAF approach

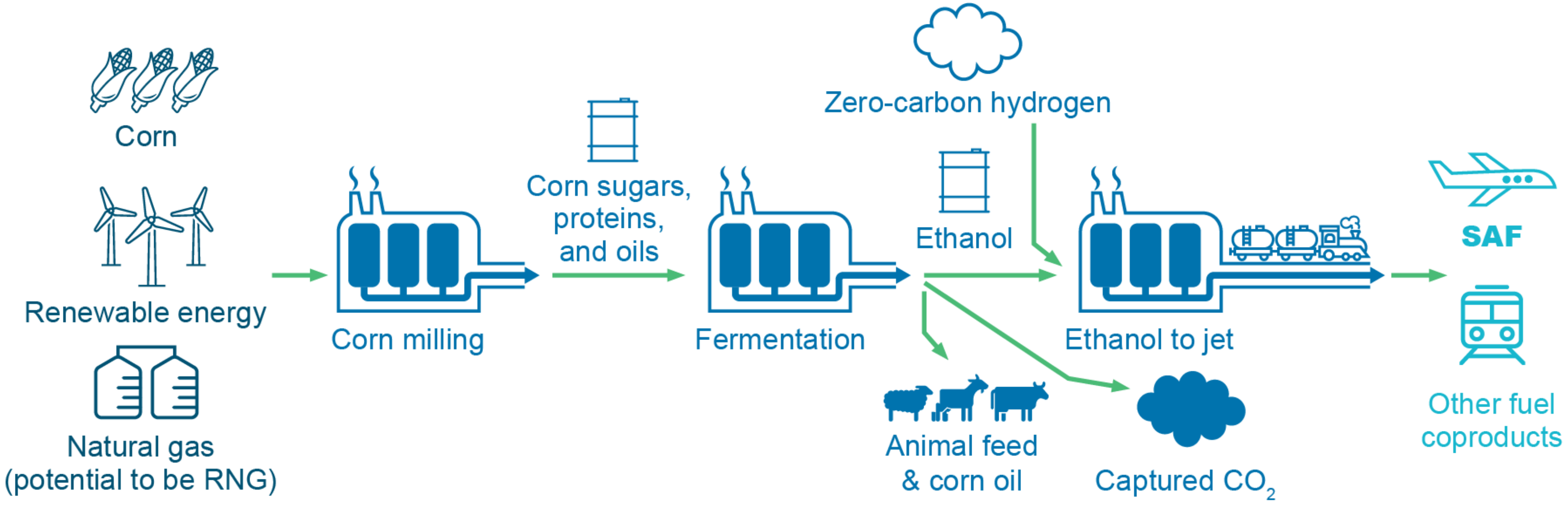
Gevo’s planned Net Zero 1 facility will produce 65 million gallons per year of liquid hydrocarbons as well as 0.6 million tonnes of animal feed and 30 million pounds of corn oil. The facility will be constructed in a rural region of South Dakota and use corn as the primary feedstock, which is widely available in this region, to produce ATJ SAF, animal feed, **corn oil**, renewable diesel, and renewable naphtha. Electricity will be supplied via a dedicated wind farm that will also be built in the same region. Additionally, natural gas will be supplied to the process for heating, though this could be substituted with renewable natural gas in the future to further reduce the carbon intensity (CI) of the process.

As illustrated in Figure 4, the process begins with corn feedstock that is milled to produce a corn slurry mix made up of corn sugars, proteins, and oils. The sugars from the corn will then be converted to ethanol via fermentation. The fermentation step produces a concentrated stream of CO_2, which will be captured at the facility and transported by a third party for sequestration. The process produces low-CI high-protein animal feed and corn oil. These products have a lower CI than conventional products and the animal feed can also be formulated to have lower sugar content than conventional feed.

The ethanol will be converted to longer hydrocarbon chains to produce fuels (primarily SAF but also renewable diesel and naphtha). This step requires the input of hydrogen, which will be zero-carbon hydrogen supplied from an electrolyzer process powered by renewable electricity.

The Gevo NZ1 process improves upon the conventional ATJ process by implementing process designs that further reduce the lifecycle GHG emissions such as heat integration between the ethanol production and ethanol to jet processes. The NZ1 process also has lower GHG emissions due to carbon capture, use of low-carbon hydrogen, and use of corn feedstock sourced from farms with regenerative agricultural practices.

Figure 4. Gevo NZ1 ATJ SAF production process



4. Current production economics

4.1. Jet fuel production costs

Gevo estimates that the Net Zero 1 facility will produce SAF at a levelized cost of approximately $7.75/gal SAF, inclusive of returns of and on invested capital, operating expenses, and feedstock costs.[32] Comparatively, a theoretical future net-zero HEFA process has an estimated production cost of $9.20–$11.00/gal SAF.[33] However, the net-zero HEFA process is not currently being planned or developed. In addition, there are limitations to the HEFA process that hinder its ability to scale production far beyond the current capacity, and this would negatively impact future costs (as discussed in Section 2.2). The standard HEFA process in practice today has an emissions intensity closer to ~42 gCO_2/MJ if using soybean oil as the feedstock.[34] ATJ SAF presents a promising pathway that is ready for commercial-scale development and has a lower carbon abatement cost than other SAF pathways. The ATJ SAF industry is also in the early commercial phase and will continue to reduce its production cost as the industry accumulates greater learnings. Fifty percent of the levelized cost of ATJ SAF is due to capital expenses (inclusive of high early-stage financing costs) ($3.90/gal), 23% is for the corn feedstock ($1.75/gal), and the remaining 27% represents operational expenses ($2.10/gal).

Even though ATJ SAF cash production cost is on par with the commodity price of fossil jet fuel, the levelized cost of ATJ SAF includes return of and on capital and is currently higher. The price of fossil jet fuel also benefits from legacy capital investment and long-term subsidies. Leveraging the current federal incentives narrows but does not eliminate this difference. Jet fuel prices for U.S. airlines have averaged ~$3.32/gal over the last two years (2022–2023).[35] The price for fossil jet fuel benefits from significant government subsidies to the fossil fuel industry, which totaled $3 billion in 2022.[36] These fossil jet fuel subsidies include tax breaks for fossil fuel exploration, support for research and development (R&D), subsidized costs for federal leases, and many other direct and indirect tax breaks. In addition, the price of fossil jet fuel does not reflect the negative externalities of conventional jet fuel that would be avoided by ATJ SAF, or the additional positive externalities produced by ATJ SAF that need to be considered on a holistic basis.

4.2. Current federal incentive programs

There are currently two federal incentive programs supporting SAF production, which can partially offset the current higher costs of SAF. In this section we detail their mechanisms and the incentive value on a per-gallon basis. Not included in these estimates are the federal costs to manage these programs.

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[32] Estimate from Gevo, 2023.

[33] Gevo, “Summary of Gevo NZ1 Opportunity,” November 2023.

[34] Gevo, “Summary of Gevo NZ1 Opportunity,” November 2023.

[35] US DOT, Bureau of Transportation Statistics, “Airline Fuel Cost and Consumption (US Carriers - Scheduled),” June 2024, https://transtats.bts.gov/fuel.asp.

[36] Environmental and Energy Study Institute, “Proposals to Reduce Fossil Fuel Subsidies,” January 2024, https://www.eesi.org/papers/view/fact-sheet-proposals-to-reduce-fossil-fuel-subsidies-january-2024#1.

4.2.1. Renewable fuel standard

The renewable fuel standard (RFS) program—established under the Energy Policy Act of 2005 (EPAct) as an amendment to the Clean Air Act, and later expanded under the Energy Independence and Security Act in 2007—is a national renewable fuels program overseen by the Environmental Protection Agency (EPA). The RFS mandates a specific volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil, or jet fuel. Renewable Identification Numbers (RINs), commonly referred to as RINs credits, serve as compliance credits and function as the currency within the RFS program. The value of the RFS RINs are not a U.S. federal government cost as the credits are purchased by obligated parties in the fossil fuel industry. RINs are generated by renewable fuel producers or importers and remain attached to the renewable fuel until it is acquired by an "obligated party," which typically refers to a refiner or importer of gasoline or diesel fuel, or until it is blended with a petroleum-based transportation fuel.[37] The obligated party pays for, or produces, their own RIN credits, thus funding the credit value without direct federal taxes. Notably, while there is no obligation to produce a certain quantity of renewable jet fuel (i.e., SAF) under the RFS mandates, SAF can qualify for RINs credits on a voluntary, opt-in basis.

The RFS program categorizes renewable fuels into four distinct types, each identified by its own RIN D-code.[38] ATJ SAF using corn as a feedstock would qualify for D4 RINs credits under the RFS program, assuming it complies with the RFS criteria. (Although this category is designated as covering biomass-based diesel fuels, in 2013 the EPA clarified that the D4 RIN category also includes renewable jet fuel.)

- Cellulosic biofuel (RIN D3) credits are generated from a renewable fuel produced from cellulose-rich materials like corn stover, wood chips, miscanthus, or biogas into gasoline. It must reduce lifecycle GHG emissions by at least 60% compared to petroleum fuel.
- Biomass-based diesel (including renewable jet fuel) (RIN D4) credits are generated by producing a renewable fuel from various sources such as soybean oil, canola oil, waste oil, or animal fats. It must reduce lifecycle GHG emissions by at least 50% compared to petroleum fuel.
- Advanced biofuel (RIN D5) credits are generated by producing a renewable fuel from any type of renewable biomass except for corn starch ethanol. It must reduce lifecycle GHG emissions by at least 50% compared to petroleum fuel. Examples include fuel produced from sugar cane to create ethanol, biobutanol, or bionaphtha gasoline, which can be blended with gasoline.
- Renewable fuel (RIN D6) represents the most common and voluminous RIN, which is typically generated by producing ethanol from corn starch but can also include other qualifying renewable fuels. It must reduce lifecycle GHG emissions by at least 20% compared to petroleum fuel.

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[37] EPA, "Renewable Identification Numbers (RINs) under the Renewable Fuel Standard Program," January 23, 2024, https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard.

[38] EPA, "What Is a Fuel Pathway?," February 23, 2024, https://www.epa.gov/renewable-fuel-standard-program/what-fuel-pathway.

4.2.2. Clean fuel production credit (45Z tax credit)

The Inflation Reduction Act (IRA) introduced the Clean Fuel Production Credit (CFPC, i.e., the 45Z tax credit), which provides tax incentives for qualifying low-emission transportation fuels (including SAF) produced after 2024 and sold on or before December 31, 2027.[39] The IRA also included an SAF blenders tax credit, effective 2023 and 2024.[40] However, because that credit will expire before the Gevo NZ1 facility will be completed, it is not considered in this analysis. While the 45Z tax credit will be applicable, its impact is currently only short term as the tax credit is only guaranteed to 2027. Incentives with longer-term assurances would be more effective in stimulating investment in SAF production. The short-term incentive may temporarily reduce the difference between SAF levelized cost and the price of fossil jet fuel, but there is a risk that this tax credit will not be renewed.

The CFPC is designed with a sliding-scale structure, allowing producers to qualify for larger credits as the GHG emissions of the fuels they produce approach zero. The tax credit amount is set at $0.20 per gallon for non-aviation fuel and $0.35 per gallon for SAF. Producers who meet prevailing wage requirements and registered apprenticeship requirements can avail themselves of a maximum credit of $1.00 per gallon for non-aviation fuel and $1.75 per gallon for aviation fuel.

For any given taxable year, the CFPC is determined by multiplying the applicable credit amount per gallon by the fuel's carbon dioxide emissions factor. These emissions factors will be published annually by the Secretary of the Treasury. Additionally, the maximum credit values are adjusted each year for inflation using the GDP implicit price deflator.

It is important to note that firms are prohibited from using the same production facility to claim both the CFPC and the Section 45Q credit for carbon oxide sequestration, ensuring that credits are not duplicated for the same emissions reductions.[41]

4.3. Impact of current federal incentives

Gevo's NZ1 plant will use corn as a feedstock to produce a bio-based SAF qualified as D4 under the RFS program. SAF produced by the plant would carry an energy value of 1.6, meaning each gallon of SAF produced yields 1.6 RINs credits. To date, the 2024 average D4 RIN credit price has been $0.90/credit, which translates to $1.44/gal SAF.[42]

The NZ1 facility would also be eligible for up to $1.75 per gallon of aviation fuel via the CFPC (45Z). Leveraging both the 45Z tax credit and RFS RINS credit values, the price differential between the price of fossil jet fuel and the current levelized cost of ATJ SAF is estimated at $1.24/gal. However, the 45Z tax credit will expire after 2027 under current law. Leveraging only the RFS RIN results in the levelized cost of ATJ SAF being $2.99/gal greater than the fossil jet price. State incentive programs could also contribute to reducing this difference.

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[39] IRS, "45Z Tax Credit," May 31, 2024, https://www.irs.gov/pub/irs-drop/n-24-49.pdf

[40] IRS, "Sustainable Aviation Fuel Credit," Notice 2023-06, December 15, 2023, https://www.irs.gov/credits-deductions/businesses/sustainable-aviation-fuel-credit.

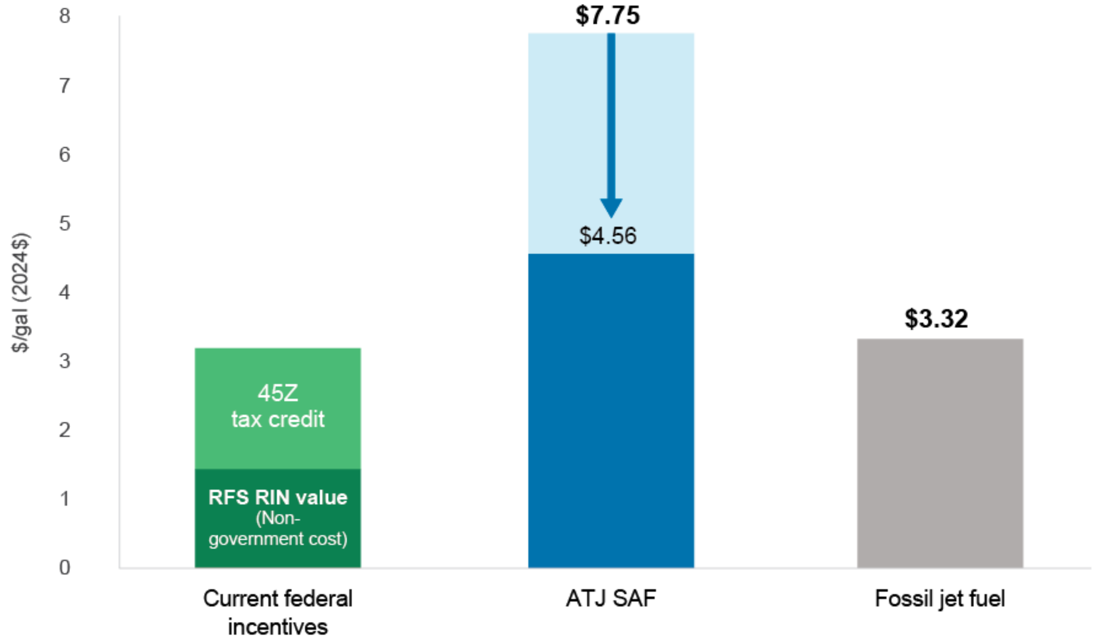
[41] Congressional Research Services, "The Section 45Z Clean Fuel Production Credit". September 27, 2023. https://crsreports.congress.gov/product/pdf/IF/IF12502

[42] EPA, "RIN Trades and Price Information," June 20, 2024, https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information.

However, none of the current state programs result in a total incentive value that exceeds $2.99/gallon, leaving a gap in the near-term with the pending expiration of the federal 45Z credit. Some of these state-level programs are detailed in Section 4.4. Future SAF production facilities could realize a decline in production costs as experiential learning accumulates, which will reduce the incentives required in the future. However, current investment in an SAF production facility will be based on the current technology and production costs.

The total cost of ATJ SAF fuel before and after applying the economic incentives from both federal programs is shown in Figure 5 alongside the value of the economic incentives and the unchanged price of fossil jet fuel.

Figure 5. Production cost of ATJ SAF after accounting for existing federal economic incentives compared to the price of fossil jet fuel (which benefits from long-term subsidies to the fossil fuel industry)



4.4. State-level incentive programs

At the state level, only a handful of states offer incentives specifically tailored to support the SAF industry. California, Oregon, and Washington offer low carbon fuel credits for SAF. Illinois, Minnesota, and Washington offer government tax credits for producers or purchasers. These state incentive costs are not included in the net incentive costs that are calculated for the cost-benefit analysis in this report as this analysis is only considering the net benefit at the federal level. However, to acknowledge the additional incentives available in certain states, in this section we provide a description of these programs. The state incentives are specific to the states in which the SAF is delivered or produced. These state-level incentives could be used in addition to the federal-level incentives, but as detailed above, the 45Z tax credit is currently only guaranteed to 2027, after which the national incentives will consist only of the RIN credits.

Therefore, even with one of the existing state incentives, there will likely remain a difference between the current levelized cost of ATJ SAF and the price of fossil jet fuel.

4.4.1. California

California operates a comprehensive **low carbon fuel standard** (LCFS) program designed to reduce the CI of transportation fuels. The LCFS program not only sets CI targets but also facilitates a market for trading credits. Fuel providers can generate credits by supplying fuels below the CI benchmark, while fuels that are above the benchmark incur deficits. These credits and deficits can be traded within the market, allowing providers to buy and sell to meet compliance obligations efficiently. This trading mechanism adds flexibility to the program, incentivizing innovation and investment in low-carbon fuel technologies while ensuring overall compliance with CI standards.[43] Based on the weighted average credit price thus far in 2024 and the calculated lifecycle GHG emissions, the ATJ SAF fuel would yield an estimated credit of $0.86/gal.[44]

4.4.2. Oregon

Oregon's **Clean Fuels Program** operates similarly to California's LCFS, setting CI standards for transportation fuels and allowing for the trading of credits. Fuel providers must demonstrate compliance by supplying fuels meeting the CI standard, with credits earned for exceeding reduction goals. These credits can be traded within the market, providing a mechanism for offsetting deficits and generating revenue for emissions reduction projects. This trading system incentivizes the adoption of low-carbon fuels while promoting innovation in the transportation sector.[45] Based on the weighted average credit price thus far in 2024 and the calculated lifecycle GHG emissions, the ATJ SAF fuel would yield an estimated credit of $1.45/gal.[46]

4.4.3. Washington

Washington State offers two distinct incentives to promote the production and usage of SAF. The **SAF Price Incentive**, introduced in 2023, establishes a per-gallon incentive structure for SAF based on its lifecycle GHG emissions. This incentive begins with a base rate for SAF with emissions at least 50% lower than traditional jet fuel. Notably, the incentive escalates with each additional 1% reduction in lifecycle GHG emissions, potentially reaching up to $2/gal. This progressive structure encourages producers to continually improve the environmental profile of their SAF, aligning with Washington's commitment to sustainability and carbon emission reduction in the aviation sector.

In parallel, Washington State has implemented a **clean fuel standard**, akin to similar programs in California and Oregon. Under this initiative, SAF qualifies as an "opt-in" fuel, generating credits that can be used to offset CI deficits. By aligning with the principles of the

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[43] California Air Resources Board, "Low Carbon Fuel Standard," June 2024, https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard.

[44] California Air Resources Board, "Monthly LCFS Credit Transfer Activity Reports," accessed June 2024, https://ww2.arb.ca.gov/resources/documents/monthly-lcfs-credit-transfer-activity-reports.

[45] Oregon Department of Environmental Quality, "Clean Fuels Program Overview," accessed June 2024, https://www.oregon.gov/deq/ghgp/cfp/pages/cfp-overview.aspx.

[46] Oregon Department of Environmental Quality, "Credit Clearance Market," accessed June 2024, https://www.oregon.gov/deq/ghgp/cfp/Pages/Credit-Clearance-Market.aspx.

California program, Washington aims to incentivize the adoption of cleaner fuels while reducing overall carbon emissions. This framework not only supports the growth of the SAF market but also encourages innovation and investment in sustainable aviation solutions.[47] Based on the weighted average credit price thus far in 2024 and the calculated lifecycle GHG emissions, the ATJ SAF fuel would yield an estimated credit of $0.84/gal.[48]

4.4.4. Illinois

Unlike the aforementioned states, Illinois offers a **tax credit incentive** for the purchase of SAF. Available from July 1, 2023 to December 31, 2032, Illinois provides an SAF Purchasers' Credit aimed at air carriers operating within the state. Unlike incentives in other states, this credit is tailored specifically for airlines purchasing SAF, not fuel producers. The credit amounts to $1.50/gal purchased and can be applied toward the state sales or use tax liability on aviation fuel purchases, further incentivizing the transition to environmentally sustainable aviation practices. Additionally, to qualify for the credit, SAF must achieve a 50% lifecycle GHG reduction, aligning with Illinois's commitment to reducing carbon emissions in the aviation sector.[49]

4.4.5. Minnesota

Minnesota's **Sustainable Aviation Fuel Credit**, a tax credit, offers $1.50/gal SAF produced or blended in-state and sold for use in aircraft departing from Minnesota airports. Effective after December 31, 2023, until July 1, 2030, with a budget of $11.6 million, this refundable credit promotes the production and use of environmentally friendly aviation fuel. To qualify, taxpayers must produce or blend SAF meeting specific criteria, including deriving from biomass, and reducing GHG emissions by at least 50%.[50]

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[47] Port of Seattle, "Sustainable Aviation Fuels," accessed June 2024, https://www.portseattle.org/page/sustainable-aviation-fuels.

[48] Washington Clean Fuels Program, "Monthly Credit Transaction Reports," accessed June 2024, https://www.ezview.wa.gov/site/alias__1962/37916/clean_fuel_standard_data__reports.aspx.

[49] Illinois General Assembly, "Illinois Compiled Statutes," June 2024, https://www.ilga.gov/legislation/ilcs/fulltext.asp?DocName=003501050K3-87.

[50] Minnesota Department of Revenues, "Sustainable Aviation Fuel Credit", accessed June 2024, https://www.revenue.state.mn.us/sustainable-aviation-fuel-credit

5. External benefits of Gevo NZ1 investment

External benefits are positive impacts to third parties that are not directly producing or consuming a product, so the value of external benefits is not captured in the product price. For example, the levelized cost of ATJ SAF does not account for SAF's external benefits. The values of the external benefits were measured in monetary terms using metrics derived from current research to capture resulting impacts. This analysis compares total benefits of SAF with the net incentive costs delivered through current federal programs.

For each external benefit, we will first provide a background of the mechanism by which these benefits are generated, either during the production or consumption of the ATJ SAF. The benefit is valued on a monetary basis to the extent feasible to calculate the total external benefit resulting from the NZ1 facility. Figure 6 demonstrates the general methodology by which the benefits are quantified first in physical units and then valued on a monetary basis to determine the total value of the external benefit.

External benefits analyzed in this section

- Avoided climate impacts from **reduced lifecycle GHG emissions** resulting from substituting fossil jet fuel with ATJ SAF. Inclusive of GHG emission impacts due to indirect land use change. (Section 5.1)
- Avoided health impacts from **reduced particulate matter emissions** during aircraft flight resulting from substituting fossil jet fuel with ATJ SAF. (Section 5.2)
- Use of **regenerative agricultural practices** to grow the SAF corn feedstock produces a number of benefits, and the following external benefits are quantified in this analysis (Section 5.3):
    - Improved water and air quality from reduced soil erosion.
    - Avoided GHG emissions compared to conventional farming practices.
    - Increased yield and reduced farming expenses.
- **Indirect land use change** (LUC) impacts on soil carbon sequestration are assessed as an impact to the GHG lifecycle emissions (Section 5.4)
- The initial investment in the nascent industry will contribute to experiential learning and the resulting **technological spillover** to other firms will yield production cost reductions in the next generation of ATJ SAF plants (Section 5.5)
- **Improved energy security** by reducing reliance on oil imports and distributing jet fuel production more broadly across the country (Only assessed qualitatively). (Section 5.6)

  Although not assessed within this report, we also acknowledge potential **economic benefits to the aviation industry** due to the development of the SAF industry due to investments in foundational low-carbon technologies such as ATJ SAF. In the absence of scaling effective decarbonization pathways such as SAF, the aviation industry and the broader economy would be negatively impacted under a more rapid decarbonization scenario such as net zero by 2050.

Figure 6. Quantifying external benefits

5.1. Avoided GHG emissions

The primary goal in adopting SAF is to reduce the GHG emissions associated with aviation. The reduction in GHG emissions brings environmental and other external benefits that are not fully captured in the price of the fuel. Thus, it is important to understand the lifecycle GHG emissions of the SAF as compared to conventional fossil-based jet fuel. A lifecycle accounting of GHG emissions will include the emissions involved in producing the fuel as well as the emissions associated with consumption of the fuel. The boundaries of the assessment begin with emissions from farming the biomass used as a feedstock and end at the emissions associated with the aircraft's combustion of the jet fuel. The majority of the lifecycle GHG emissions for fossil jet fuel come from the combustion emissions (>80%).[51] The key components of the lifecycle GHG emissions from well-to-jet for fossil jet fuel and farm-to-jet for an SAF are presented in Figure 7.

5.1.1. Biogenic CO_2 emissions

SAF's lifecycle GHG emissions are not dominated by its combustion emissions due to the way that biogenic CO_2 emissions are accounted for. The EPA defines biogenic CO_2 emissions as "CO_2 emissions related to the natural carbon cycle, as well as those resulting from the combustion, harvest, digestion, fermentation, decomposition, or processing of biologically based materials."[52] The carbon cycle of fossil jet fuel occurs over a geological timescale, so the carbon emitted from the combustion of fossil jet fuel will not be offset by the natural carbon cycle on a policy-relevant timeline. As such, the emissions from the combustion of fossil jet fuel are not offset by any process and are directly accounted for in the lifecycle carbon analysis.

During the carbon cycle of a plant, carbon is removed from the atmosphere during the growing process. This is represented as the first phase in the lifecycle GHG emissions of an SAF, as visualized in Figure 7. The crop is then harvested and processed, and carbon is returned to the atmosphere through combustion or decomposition (the last phase in Figure 7). This process occurs annually, so it is possible that the net CO2 emissions to the atmosphere are zero over the plant's lifetime. Thus, it is appropriate to assume that emissions from the combustion of corn-based ATJ SAF are offset by the plant's natural carbon cycle.[53] The ATJ SAF process is also versatile in the type of biomass that it can use, ranging from corn, sugarcane, bagasse, or even wood waste. The process requires a biomass with fermentable

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[51] Eunji Yoo, Uisung Lee, and Michael Wang, "Life-Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel through a Net-Zero Carbon Biofuel Plant Design," *ACS Sustainable Chemical Engineering* 10, no. 27 (2022): 8725–8732.

[52] EPA, "Carbon Dioxide Emissions Associated with Bioenergy and Other Biogenic Sources," June 2024, https://19january2017snapshot.epa.gov/climatechange/carbon-dioxide-emissions-associated-bioenergy-and-other-biogenic-sources_.html.

[53] Note that this is dependent on assumptions around LUC.

sugars, and the feedstock can then be selected based on regional, environmental, social, and monetary factors.[54]

5.1.2. Lifecycle GHG emissions for jet fuels

The base case of Gevo's ATJ SAF process is estimated to have a lifecycle GHG emission intensity of ~70 gCO2e/MJ.[55,56] The GHG emission intensity of the NZ1 ATJ SAF is planned to be reduced further than the base case to an estimated negative 6.6 gCO2e/MJ. This would produce a jet fuel with a substantially lower GHG emission intensity than fossil-based jet fuel, which has an estimated CI of 84–90 gCO2e/MJ.[57,58] The NZ1 facility plans to reduce its GHG emission intensity by implementing the following: the use of renewable energy to power the plant, use of low-carbon hydrogen, **carbon capture and storage** (CCS), coproduction of animal feed and other products, and implementation of regenerative agricultural practices, which further lower the CI of the biomass feedstock. These methodologies are described in greater detail below.

The number of additional GHG reduction strategies that are available to the ATJ process are a nature of the synergies afforded by bringing the key value chains closer together, namely agriculture, chemical processing (biomass to ethanol), and fuel production (ethanol to SAF). This differs from the HEFA process, which relies on used fats, oils, and greases and oil from seed sources that are more distributed. Additionally, the process has fewer available levers to further reduce GHG emissions.[59]

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[54] Jude A. Okolie et al., "Multi-Criteria Decision Analysis for the Evaluation and Screening of Sustainable Aviation Fuel Production Pathways," *iScience* 26, no. 6 (2023).

[55] This estimation is based on the Argonne GREET model inclusive of biorefinery fuel production and displacement credits from animal feed coproducts.

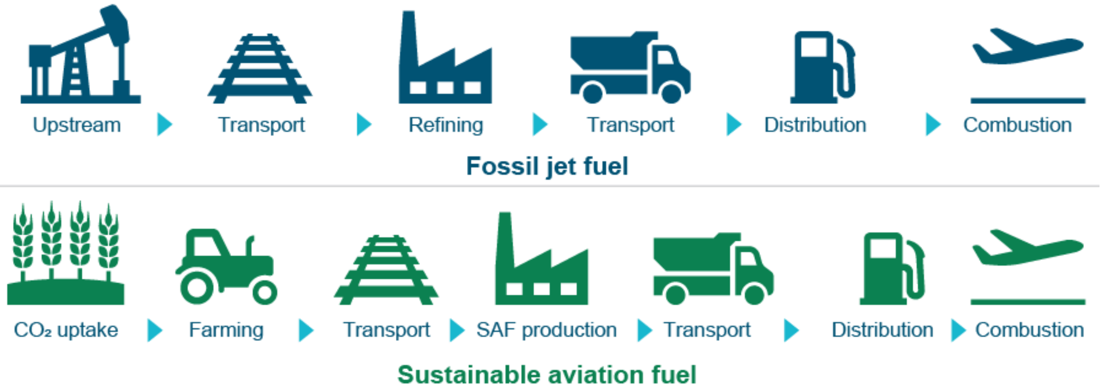
[56] Eunji Yoo, Uisung Lee, and Michael Wang, "Life-Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel through a Net-Zero Carbon Biofuel Plant Design," *ACS Sustainable Chemical Engineering* 10, no. 27 (2022): 8725–8732.

[57] Eunji Yoo, Uisung Lee, and Michael Wang, "Life-Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel through a Net-Zero Carbon Biofuel Plant Design," *ACS Sustainable Chemical Engineering* 10, no. 27 (2022): 8725–8732.

[58] Liang Jing et al., "Understanding Variability in Petroleum Jet Fuel Life Cycle Greenhouse Gas Emissions to Inform Aviation Decarbonization," *Nature Communications* 13 (2022).

[59] Nikolaos Detsios et al., "Recent Advances on Alternative Aviation Fuels/Pathways: A Critical Review," *Energies* 16, no. 4 (2023), https://doi.org/10.3390/en16041904.

Figure 7. Lifecycle GHG emissions of fossil jet fuel compared to that of SAF



Renewable electricity

A significant component of GHG emissions associated with SAF production is electricity demand from the plant, the majority of which is used to power process units and CCS and to generate hydrogen via electrolysis. By building a dedicated renewable energy facility, the SAF production facility will be able to drastically reduce the emissions associated with electric demand. In the case of the Gevo NZ1 facility, the biorefinery will be accompanied by a wind farm capable of producing 367,000 MWh of emissions-free electricity each year. Energy not needed by the plant will be sold into the local market, helping reduce the overall emissions of the electric generation mix. As previously mentioned, the planned facility is located in a rural region of South Dakota, which allows access to plentiful biomass feedstock such as corn and plentiful wind resources. Since this region has limited local electricity demand, there has not been as great of a driver to take advantage of the wind resources, as building high-voltage, long-distance transmission lines are hindered by their high cost, system complexities, and the current extensive interconnection backlog. Since the SAF plant will be co-located with the wind farm, it will be able to directly use the electricity produced and will not require construction of high voltage transmission.

The construction of this wind farm will invest capital in renewable electricity technology in this region, which could potentially be expanded in the future to meet other sources of local electricity demand in the area. This could enable the rural community to electrify other end uses with renewable electricity. The increasing local demand to power electric heating and EVs could then be met by the local wind resource. The wind plant will also power a hydrogen production facility, detailed in the following section, and there are also incremental benefits that can be yielded from this initial capital investment. The hydrogen facility could be expanded in the future to produce more low-carbon hydrogen for other end uses in the region. This local source of hydrogen could contribute to decarbonizing other sectors such as hydrogen-fueled vehicles or encourage the growth of industrial sectors in this area such as fertilizer production, which requires hydrogen to produce ammonia.

Hydrogen production

Currently in the Unites States, about 95% of hydrogen is produced through steam methane reforming without carbon capture.[60] This process uses methane as a feedstock to produce hydrogen, with carbon dioxide as a byproduct, and emits about 12 kg of CO_2e per kg of H_2 produced. However, hydrogen can also be produced via electrolysis, which uses electricity to split water into hydrogen and oxygen. If this is done using renewable energy, then the associated GHG emissions can be essentially zero.

Carbon capture on fermentation process of SAF plant

CCS can remove CO_2 emissions before they are released to the atmosphere by capturing carbon when it is emitted in the process and then sequestering it underground. CCS can be used in a wide array of industrial settings but is generally the most cost-efficient in natural gas processing, ammonia production, and ethanol production sectors.[61] In ethanol applications, this is due to the concentration of CO_2 being extremely high in the exhaust stream.[62] Ethanol production yields a CO_2 stream with a purity greater than 85% by volume, whereas CO_2 concentrations from hydrogen refining, steel and iron manufacturing, and cement production range from 21% to 45%.[63] Currently, there are 15 operational CCS facilities in the United States. Of these, 4 are in the ethanol production industry, totaling about 1.8 million metric tons of CO_2 captured per year.[64] Further, the CO_2 being captured is from a biogenic source of carbon and represents CO_2 that was sequestered over the lifecycle of the plant's growth. By capturing the CO_2 and sequestering it underground, this effectively removes the CO_2 from the atmosphere permanently. CO_2 captured from a fossil fuel combustion process will also remove the CO_2, but burning fossil fuels releases CO_2 that was initially sequestered on a longer geologic timescale, and the creation of more fossil fuels will not sequester carbon on the timescale at which it is consumed.

Regenerative agricultural practices

Regenerative agricultural practices can reduce farming's GHG emissions, which further decreases the CI of the ATJ SAF. Gevo proposes to encourage the implementation of these practices by offering a premium for corn products with CI that has been verified as reduced. Some of these practices have already been implemented at farms in this region of South Dakota, and with improved tracking and incentives to use these practices, their adoption can be accelerated across the United States. Please refer to Section 5.3 for a detailed explanation of regenerative agricultural practices.

Coproduction of animal feed products at SAF plant

The largest product from the SAF facility by mass is the animal feed (~0.6 million tonnes/year) and vegetable oil (30 million pounds/year). The animal feed produced in this process has lower sugar content than conventional animal feed and allows for farmers to adjust the sugar content of the feed that their animals consume. The animal feed will also have a lower CI than

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[60] Climate Portal, "How Clean Is Green Hydrogen," February 27, 2024, https://climate.mit.edu/ask-mit/how-clean-green-hydrogen.

[61] US Congressional Budget Office, "Carbon Capture and Storage in the US," December 2023, https://www.cbo.gov/publication/59832.

[62] US Congressional Budget Office, "Carbon Capture and Storage in the US," December 2023, https://www.cbo.gov/publication/59832.

[63] Sydney Hughes et al., *Cost of Capturing CO2 from Industrial Sources* (Pittsburg, PA: National Energy Technology Laboratory, 2022).

[64] US Congressional Budget Office, "Carbon Capture and Storage in the US," December 2023, https://www.cbo.gov/publication/59832.

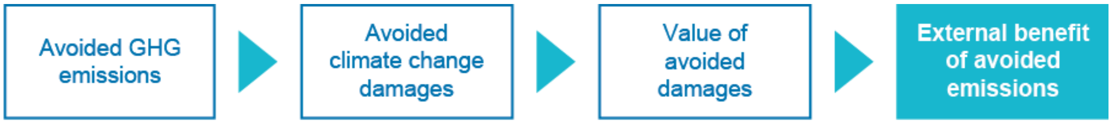
conventionally produced animal feed and will be grown using regenerative agriculture practices. This will result in a decrease in the carbon footprint of the food chain, helping food manufacturers achieve their carbon reduction and sustainability goals. Additionally, the SAF facility produces renewable diesel and renewable naphtha fuels. These coproducts lower the CI of the SAF by using a portion of the energy and feedstock, allowing the GHG emissions to be allocated among the different products. This approach not only reduces the emissions associated with SAF but also enables the production of other valuable products to ensure more efficient use of the corn feedstock.

Another benefit, although not quantified in this analysis, is the avoided GHG emissions resulting from the low-carbon animal feed also produced at NZ1. The animal feed will have a lower CI than other conventionally produced animal feed due to the process designs described above. Additionally, the NZ1 animal feed has a lower sugar content than conventional feed, which can further lower GHG emissions by reducing methane emissions from ruminant livestock.[65] In ruminant livestock such as goats and cattle, sugars undergo fermentation during their digestion process and methane is produced. While the type and structure of carbohydrates influence methane production, higher sugar content leads to increased methane emissions.[66]

5.1.3. External benefit of avoided GHG emissions

To determine the external benefit, we consider the reduction in lifecycle GHG emissions when substituting fossil jet fuel with ATJ SAF. The avoided GHG emissions result in avoided climate change impacts, which are valued using an estimation of the future damages they would cause to society and the environment. Figure 8 outlines the process followed to value the external benefit. Standard Fossil Jet A has a lifecycle GHG emissions of ~84–90 gCO2e/MJ, with most of the emissions due to combustion of the fuel itself. We consider the reference CI for fossil jet to be 89 gCO2e/MJ, which aligns with the industry references as a measure of the current global volume-weighted average CI of fossil jet.[67]

Figure 8. Quantifying benefits from reduced GHG emissions



The GHG emission intensity of the NZ1 ATJ SAF is planned to be reduced beyond that of their base case ATH SAF design. In this analysis, we consider the planned design for the NZ1 facility to assess potential emission reduction opportunities and the resulting lifecycle GHG emissions analysis.[68] Figure 9 illustrates the lifecycle emissions of fossil jet fuel alongside the base case ethanol production process, which has a CI of 60 gCO2e/MJ (the NZ1 ethanol to jet

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[65] Xuezhao Sun et al., “A Review: Plant Carbohydrate Types—The Potential Impact on Ruminant Methane Emissions,” *Frontiers in Veterinary Science* 9 (2022).

[66] Xuezhao Sun et al., “A Review: Plant Carbohydrate Types—The Potential Impact on Ruminant Methane Emissions,” *Frontiers in Veterinary Science* 9 (2022).

[67] Liang Jing et al., “Understanding Variability in Petroleum Jet Fuel Life Cycle Greenhouse Gas Emissions to Inform Aviation Decarbonization,” *Nature Communications* 13 (2022).

[68] Lifecycle emission estimate based on McKinsey Analysis of Gevo NZ1 SAF.

process contributes an additional ~15 gCO2e/MJ). This value includes the emissions associated with additional natural gas fuel usage of ~14 gCO2e/MJ. It also accounts for the conversion estimate for indirect land use change (ILUC) emission intensity for SAF (~9 gCO2e/MJ) as compared to ethanol (~7.6 gCO2e/MJ).[69,70]

This base case CI for the NZ1 ethanol production can be further reduced by using electricity from a dedicated wind energy plant (~7 gCO2e/MJ). Carbon capture can also be implemented on the fermentation step of the ethanol process at a capture rate of ~80%, further reducing the CI by 31 gCO2e/MJ. Additional reductions in the process can be implemented by reducing natural gas usage via implementing electric boilers and heat integration with the ethanol-to-jet process. In addition, the allocation of emissions to the other coproducts, namely the animal feed, further reduces the emissions due to ethanol production. These strategies contribute to a reduction of 22 gCO2e/MJ.

The ethanol to jet process converts the ethanol to jet fuel. This process uses additional natural gas (11 gCO2e/MJ) and generates GHG emissions from process emissions, usage of other chemicals, and transportation of the SAF product, which together contributes an additional 3 gCO2e/MJ. This process also requires electricity; however, in this scenario the plant relies on wind-based electricity, which is assumed to not add any additional CI to the process. In addition, the process uses hydrogen, but instead of producing hydrogen from conventional carbon-intensive processes, the facility will use **zero-carbon hydrogen** produced via electrolysis powered by renewable energy, a process that does not produce direct GHG emissions. The CI of the ethanol-to-jet process is assumed to contribute an additional 15 gCO2e/MJ to the total lifecycle emissions.

The primary source of GHG emissions in the conventional ethanol production process is from corn farming, which contributes ~32 gCO2e/MJ.[71] Corn farming can further reduce GHG emissions by implementing various regenerative agricultural practices. The process we model here uses corn sourced from farms that have implemented regenerative agricultural practices to achieve further GHG emissions reductions, as detailed in Section 5.3. While these emissions reductions are shown in Figure 9, they are not included in the benefit calculation for the GHG emissions reductions included in this section as we account for them in Section 5.3 as part of the benefits received from implementing regenerative agricultural practices.

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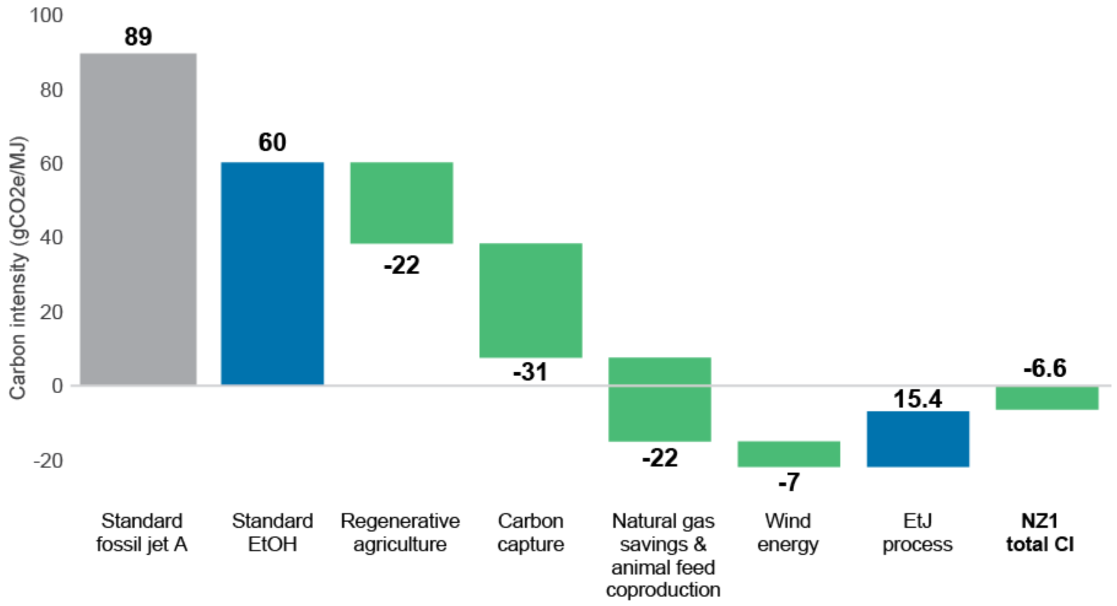
[69] Lifecycle emission estimate based on McKinsey Analysis of Gevo NZ1 SAF.

[70] Eunji Yoo, Uisung Lee, and Michael Wang, “Life-Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel through a Net-Zero Carbon Biofuel Plant Design,” *ACS Sustainable Chemical Engineering* 10, no. 27 (2022): 8725–8732.

[71] Eunji Yoo, Uisung Lee, and Michael Wang, “Life-Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel through a Net-Zero Carbon Biofuel Plant Design,” *ACS Sustainable Chemical Engineering* 10, no. 27 (2022): 8725–8732.

Figure 9. Lifecycle GHG emissions of ATJ SAF



To value the benefits from the reduced GHG emissions associated with the ATJ SAF, we rely upon the social cost of carbon as valued in 2023 by the EPA at \$228/t CO2 (2024 dollars).[72] The social cost of carbon is a monetary value of the net benefit from avoided GHG emissions and is computed by valuing future impacts from climate change. The social cost of carbon is routinely used in regulatory rulemaking to perform cost benefit analyses to examine the impact of proposed rules. In 2021, the U.S. federal government assigned an interim value of \$61/t CO2 as the social cost of carbon, while an interagency group conducted further studies.[73] However, the EPA report published a higher social cost value based on the latest research to update the socioeconomic, climate, and damages modules, as well as implemented a dynamic discounting approach using a lower near-term discount rate. These findings more closely align with current literature, which finds that the social cost of carbon is likely on the order of \$200/t CO2.[74,75]

The reduction in GHG emissions is based on the delta between the lifecycle GHG emissions of the fossil jet fuel and the ATJ SAF (excluding for now the additional reductions from regenerative agriculture). The reduction in GHG emissions is ~75 gCO2e/MJ. Following the process shown in Figure 8, the social cost of carbon values this reduction in GHG emissions at \$2.21/gal SAF.

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[72] EPA, *Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* (Washington, DC: EPA, 2023).

[73] Interagency Working Group on Social Cost of Greenhouse Gases, “Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990,” February 2021, https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

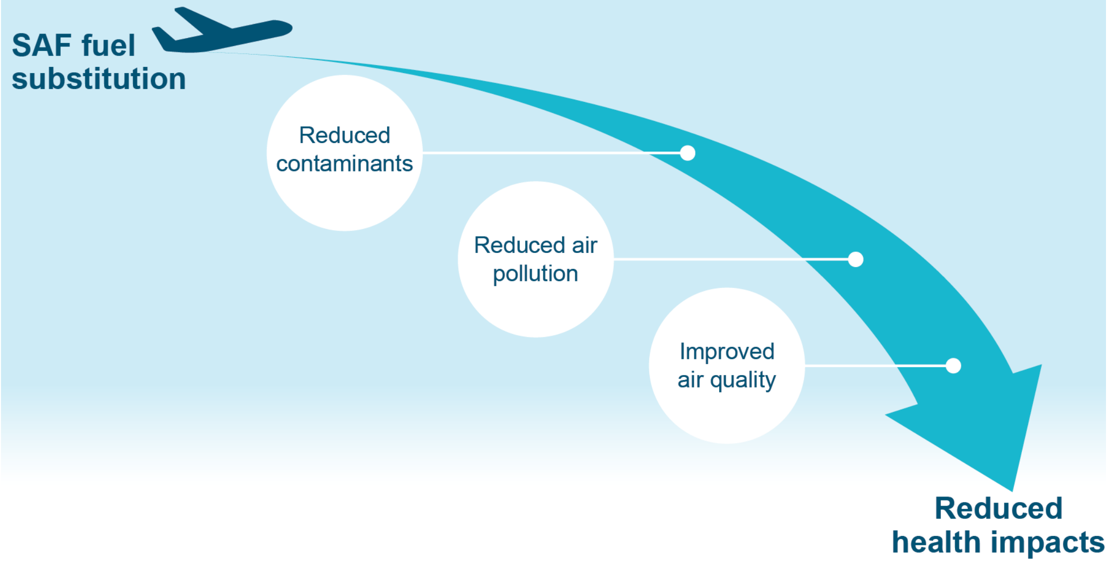
[74] Robert S. Pindyck, “The Social Cost of Carbon Revisited,” *Journal of Environmental Economics and Management* 94 (2019): 140–160.

[75] Kevin Rennert et al., “Comprehensive evidence implies a higher social cost of CO_2,” *Nature* 610 (2022): 687–692.

5.2. Avoided particulate matter emissions

In addition to GHG emissions, there are other air pollutants associated with the combustion of jet fuel, including nitrogen oxides, **particulate matter**, and sulfur oxides.[76] These pollutants emitted during aircraft travel impact the local ambient air quality and can negatively affect human health.[77] The chemical make-up of ATJ SAF has fewer contaminants than fossil jet fuel. Blending or substituting fossil jet fuel with SAF can lower the emission levels of some of these air pollutants and improve air quality, which in turn will reduce health impacts. Figure 10 visualizes this cascading effect and resulting benefit.

Figure 10. Air quality benefits from substituting fossil jet fuel with SAF



5.2.1. Reduction in aromatic content

Aromatic compounds, such as benzene and naphthalene, possess a particular chemistry that enables them to combust more slowly than other hydrocarbons found in jet fuel. Because of this, jet fuel containing higher levels of aromatics tends to emit more particulate matter than low-aromatic jet fuel.[78]

Particulate emissions negatively impact the local ambient air quality surrounding airports and has been linked to detrimental health impacts. Long-term exposure to fine particulate matter can cause chronic respiratory diseases, cardiovascular diseases, and lung cancer.[79] Recent studies have calculated a 1.29% increase in mortality for every 10 ug/m^3 increase in fine

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[76] Calvin A. Arter et al., "Air Quality and Health-Related Impacts of Traditional and Alternate Jet Fuels from Airport Aircraft Operations in the US," *Environmental International* 158 (2022).

[77] Calvin A. Arter et al., "Air Quality and Health-Related Impacts of Traditional and Alternate Jet Fuels from Airport Aircraft Operations in the US," *Environmental International* 158 (2022).

[78] Jasper Faber et al., *Potential for Reducing Aviation Non-CO2 Emissions through Cleaner Jet Fuel* (Delft, Netherlands: CE Delft, 2022).

[79] Zarashpe Z. Kapadia et al., "Impacts of Aviation Fuel Sulfur Content on Climate and Human Health," *Atmospheric Chemistry and Physics* 16 (2016).

particulates (PM 2.5, particulate matter measuring less than 2.5 micrometers in diameter).[80] In addition, particulate matter contributes to the formation of persistent contrails as they provide the seeds for ice formation to accumulate from the water vapor emitted from the engines. Contrails also produce a warming effect, although there is a wide range in estimates on the magnitude of the radiative forcing.[81]

Current regulations specify a minimum aromatic content of 8% for jet fuel because aircraft engines that have already been exposed to jet fuel containing higher levels of aromatics require a minimum aromatic content to ensure that the seals within the engine swell in the manner they are designed to.[82] There is also a maximum aromatic content of 25% by volume for Jet A due to environmental concerns.[83] Typical compositions of fossil-based jet fuel contain aromatics at concentrations of 14%–20%.[84]

The ATJ SAF production process generates jet fuel from a very pure stream of ethanol, relying on a process called oligomerization, which builds up the molecular chain needed to form the jet fuel. This process by nature produces negligible quantities of aromatic compounds like benzene and naphthalene. Studies have shown that low-aromatic SAF can reduce soot and ice crystals, and thus produce fewer contrails.[85] Given the typical fossil-based jet fuel aromatic concentrations of 14%–20%, low-aromatic SAF can be blended at significant levels without jeopardizing the 8% minimum aromatic content requirement, greatly reducing particulate matter and GHG emissions.

Another benefit of reduced aromatic content is that it produces fuels with a higher energy density. The average fossil-based Jet A fuel has an energy density of 43 MJ/kg,[86] compared to Gevo's ATJ SAF typical energy density of 44 MJ/kg.[87] Greater energy density contributes to aircraft being able to operate more efficiently and use lower volumes of fuel.

5.2.2. Reduction in sulfur content

ATJ SAF contains negligible quantities of sulfur, while fossil-based jet fuel contains sulfur content due to the composition of the crude oil feed stock. Jet A fuel specifications set a

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[80] Calvin A. Arter et al., "Air Quality and Health-Related Impacts of Traditional and Alternate Jet Fuels from Airport Aircraft Operations in the US," *Environmental International* 158 (2022).

[81] Jasper Faber et al., *Potential for Reducing Aviation Non-CO2 Emissions through Cleaner Jet Fuel* (Delft, Netherlands: CE Delft, 2022).

[82] US DOE, Alternative Fuels Data Center, "Sustainable Aviation Fuel: Review of Technical Pathways," accessed June 2024, https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html.

[83] A. Anuar et al., "Effect of Fuels, Aromatics and Preparation Methods on Seal Swell," *Aeronautical Journal* 125, no. 1291 (2021): 1–24.

[84] US DOE, Alternative Fuels Data Center, "Sustainable Aviation Fuel: Review of Technical Pathways," accessed June 2024, https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html.

[85] Christiane Voigt et al., "Cleaner Burning Aviation Fuels Can Reduce Contrail Cloudiness," *Communications Earth & Environment* 2 (2021).

[86] US DOE, Alternative Fuels Data Center, "Sustainable Aviation Fuel: Review of Technical Pathways," accessed June 2024, https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html.

[87] Gevo, "Low-Carbon, Bio-Based Sustainable Aviation Fuel," accessed June 2024, https://gevo.com/product/sustainable-aviation-fuel.

maximum sulfur content of 3,000 ppm, and typical fossil jet fuel contains ~600–800 ppm sulfur.[88]

Sulfur content in fuels leads to the emission of sulfur dioxide and contributes to an increase in particulate matter levels, which, as described above, negatively impacts human health. Sulfur dioxide emissions can cause lung and other health issues, especially in children and people with asthma.[89] The sulfate aerosols can also impact contrail formation but is thought to be much more limited compared to the impact of soot as described in the prior section.[90] By reducing sulfur emissions, SAF blending has the potential to reduce particulate matter in the atmosphere and reduce adverse health effects for populations living near airports.

5.2.3. Other combustion pollutants

Nitrogen oxide emissions occur due to the high temperature combustion occurring in contact with ambient air, which contains nitrogen. Nitrogen dioxide has been found to have negative impacts on respiratory health. Further, nitrogen oxides can react in the atmosphere, producing ozone and particulate matter. Ozone can cause respiratory issues and aggravate existing conditions such as asthma.[91]

However, because the nitrogen oxide emissions are produced from the nitrogen in the air, these pollutant levels are unchanged by switching to SAF.[92] Current technology does not have a clear path forward to reducing nitrogen oxide emissions from aircrafts. Reducing the combustion temperature does reduce nitrogen oxide emissions, but it also reduces the fuel efficiency of the aircraft and results in increases to CO_2 emissions.[93]

5.2.4. External benefit of avoided particulate matter emissions

Jet fuel produces other combustion pollutants in addition to GHGs. Among these, the most harmful to human health include NOx emissions and fine particulate matter. While the adoption of SAF jet fuel may not reduce the NOx emissions produced during combustion, it can greatly reduce the emission of particulate matter, as described in Section 5.2. To quantify the external benefits, we determine how much particulate matter emissions would be reduced by using SAF instead of fossil jet fuel (Figure 11). Based on existing research, we then estimate the resulting health impacts. We also consider avoided premature mortalities in the U.S. from reduced particulate matter emissions throughout the flight path of the aircraft. The avoided damages are then valued based on the value of statistical life (VSL), which represents additional costs that society would be willing to pay to reduce risk that in aggregate would reduce expected fatalities by one. There are other adverse health effects from air pollution exposure in addition to premature mortality, including respiratory disease, cardiovascular

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[88] Jasper Faber et al., *Potential for Reducing Aviation Non-CO2 Emissions through Cleaner Jet Fuel* (Delft, Netherlands: CE Delft, 2022).

[89] EPA, "Sulfur Dioxide Basics," January 31, 2024, https://www.epa.gov/so2-pollution/sulfur-dioxide-basics.

[90] Jasper Faber et al., *Potential for Reducing Aviation Non-CO2 Emissions through Cleaner Jet Fuel* (Delft, Netherlands: CE Delft, 2022).

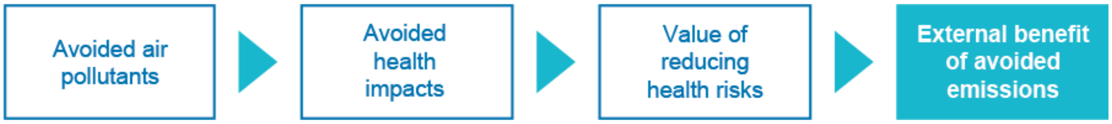
[91] EPA, "Control of Air Pollution from Aircraft and Aircraft Engines; Emission Standards and Test Procedures," *Federal Register* 77, no. 117 (2012).

[92] Calvin A. Arter et al., "Air Quality and Health-Related Impacts of Traditional and Alternate Jet Fuels from Airport Aircraft Operations in the US," *Environmental International* 158 (2022).

[93] Carla Grobler et al., "Marginal Climate and Air Quality Costs of Aviation Emissions," *Environmental Research Letters* 14, no. 11 (2019).

disease, and cancers, which can lead to reduced quality of life as well as public costs due to increased hospital admissions and lost workdays.[94] In this analysis, we do not quantify the avoided costs of these other health effects because there is less data around these statistics specific to SAF substitution.

Figure 11. Quantifying benefits from avoided air pollutants



For this analysis, we first examine the impacts from landing and take-off (LTO) operations that impact local air quality conditions for populations living near airports or downwind of airports as well as for airport workers. Improved air quality can result in improved health outcomes and reduce the number of premature mortalities.

To quantify this potential impact, we rely on analysis by Arter et al. (2022), which analyzed emissions from commercial LTO activities at airports within the United States.[95] Their research compared air quality and health outcomes from two scenarios, one using fossil jet fuel and one modeled with a 50% blend of SAF. The 50% SAF blend resulted in reduced emissions of sulfur oxides, particulate matter, and carbon monoxide. The authors used the air pollutant data to model the impact on premature mortalities and value the associated damages. The EPA guidance advises a central figure of $7.4 million (2006 dollars based on 1990 income) to be used as the VSL.[96] When adjusted for inflation and change in income, the VSL used in these calculations is $13.5 million (2024 dollars based on 2023 income).[97] We adjust the VSL used in Arter et al. to align with the EPA assumption and 2024 dollars. The total damages are divided by the total fuel burned for LTO activities in the United States as calculated by Arter et al. (~1.6 billion gallons of fuel burned in the study year).

This calculation yields $0.13/gal jet fuel burned during LTO. To account for the benefits yielded just by the gallons of SAF fuel that were blended, we adjust this benefit by a factor of 2 to yield a benefit of $0.27/gal SAF burned during LTO. To account for the benefit per gallon of SAF consumed for the entire flight, we use the consumption of jet fuel in the U.S. in the study year relative to the fuel burn during LTO. This yields a value of $0.02/gal SAF consumed.

However, air pollutants are also emitted during aviation cruising activities and result in greater overall damages, though the impact per unit of fuel burned is lower than during LTO. There is currently not a direct study measuring full-flight impact of SAF on air pollutants and human health. However, here we rely on a study on the health impacts of low sulfur jet fuel as

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[94] Zarashpe Z. Kapadia et al., “Impacts of Aviation Fuel Sulfur Content on Climate and Human Health,” *Atmospheric Chemistry and Physics* 16 (2016).

[95] Calvin A. Arter et al., “Air Quality and Health-Related Impacts of Traditional and Alternate Jet Fuels from Airport Aircraft Operations in the US,” *Environmental International* 158 (2022).

[96] EPA, Office of Air and Radiation, *The Benefits and Costs of the Clean Air Act from 1990 to 2020* (Washington, DC: EPA, 2011).

[97] U.S. Department of Health and Human Services, “Appendix D: Updating Value per Statistical Life (VSL) Estimates for Inflation and Changes in Real Income,” April 2021, https://aspe.hhs.gov/sites/default/files/2021-07/hhs-guidelines-appendix-d-vsl-update.pdf.

representative of the potential benefit.[98] Typical fossil-based jet fuel contains 600 ppm of sulfur, and ultra-low sulfur jet fuel contains only 15 ppm (SAF fuel would contain negligible amounts of sulfur). Barrett et al. (2012) calculated that given a global implementation of ultra-low sulfur fuel, the reduction in air pollutants during cruising activities would yield approximately 89–147 avoided mortalities in the United States (excluding LTO impacts). We rely on the high end of this estimate as SAF fuel would contain less sulfur than the modeled fuel. We calculate the benefit per unit volume of fuel burned in the United States in the study year (~22 billion gallons in the study year), and applying the VSL yields a benefit of $0.09/gal.

The avoided mortalities were not valued based on a mortality lag structure, and there would be some expected lag between the reduction in air pollution and the reduction in premature mortalities. However, a large fraction of the benefit could be assumed to be experienced over the near term based on the EPA's recommended lag structure which assumes that 80% of the avoided mortalities would occur in the first five years.[99]

The annual external benefit from avoided particulate matter emissions resulting from the adoption of SAF would be at least ~$0.12/gal SAF.

5.3. Regenerative agricultural practices

External benefits can also be realized by using corn feedstock grown at farms that use regenerative agriculture practices instead of conventional farming practices. Regenerative practices aim to improve soil health and farming sustainability by minimizing soil disturbances, increasing soil cover, and increasing crop diversity. These practices lead to cascading beneficial impacts that work to improve soil health, including increasing soil organic matter content and increasing soil moisture and soil nutrient content. More resilient soils reduce soil erosion, which decreases runoff and helps to improve surrounding air and water quality.[100] As soil health improves, this further reduces the need for additional chemical amendments. Reducing chemical application and decreasing the use of farming equipment help to reduce farming costs and also benefit the surrounding environment by improving air and water quality.[101] Importantly, these practices reduce GHG emissions from farming, which in turn helps to reduce the lifecycle GHG emission of ATJ SAF. In farming, GHGs are directly emitted from the equipment's usage of fossil fuels, fertilizer application, as well as the upstream production of fertilizer, chemicals, fuels, and other inputs.[102] Plant decomposition also contributes to GHG emissions, though this can be offset by soil carbon sequestration. Some of these sources of GHG emissions can be reduced through regenerative agricultural practices. For example, soil carbon sequestration is increased by improving the soil health, and fossil fuel consumption is also reduced by reducing equipment usage. Reduced fertilizer applications, through more precise applications and maintenance of soil nutrient content,

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[98] Steven R. H. Barrett et al., "Public Health, Climate, and Economic Impacts of Desulfurizing Jet Fuel," *Environmental Science & Technology* 46, no. 8 (2012): 4275–4282.

[99] EPA, Office of Air and Radiation, *The Benefits and Costs of the Clean Air Act from 1990 to 2020* (Washington, DC: EPA, 2011).

[100] Illinois Sustainable Ag Partnership, "An Introduction to Soil Health Practices," 2024, https://farmlandinfo.org/wp-content/uploads/sites/2/2024/01/ISAP-an-introduction-soil-health-practices.pdf.

[101] USDA, "Sustainability Grows in Healthy Soil," 2014, https://scienceforgeorgia.org/wp-content/uploads/2021/12/SoilHealth_SellSheet_rev05-02-2014.v3.pdf.

[102] Uisung Lee et al., "Retrospective Analysis of the U.S. Corn Ethanol Industry for 2005–2019: Implications for Greenhouse Gas Emission Reductions," *Biofpr* 15, no. 5 (2021): 1318–1331.

help to reduce N2O emissions, which is particularly important as this GHG has a warming potential much greater than CO_2 (265 times greater on a 100-year timescale).[103]

The physical impacts to the farmland from regenerative agricultural practices result in environmental, social, and economic benefits. Figure 12 illustrates several of these impacts, as shown in a cyclical process to demonstrate the interconnection between benefits. Environmental impacts improve not just the farmland but also the surrounding land, resulting in benefits to society and local economies. Likewise, economic impacts further bolster social benefits and drive continued environmental improvement. These social benefits reinforce the community's motivation to encourage further adoption of these practices.

Environmental benefits include improved soil quality, reduced soil erosion, improved air and water quality, enhanced biodiversity, improved crop resiliency, and reduced GHG emissions. Reduced soil erosion causes less sediment and chemicals to leave the farmland and impact the surrounding environment, resulting in improved water and air quality.[104] Biodiversity is enhanced in local habitats surrounding both the farms and the insect populations, which are vital to crop health primarily because these practices improve soil quality and reduce pesticide applications.[105] Additionally, crops grown in healthier soil are more resilient to pests, disease, and drought.[106] These stressors can become exacerbated in a future where climate change impacts continue to intensify, resulting in more extreme weather events and more drought conditions in certain regions.[107] Moreover, decreased GHG emissions contribute to lessened climate impacts, which not only benefit the environment but also yield social benefits by reducing future impacts to livelihood and the risk of damages from disasters. Improved quality of air and water also benefits the surrounding community's health and livelihood. Additionally, lessened soil erosion can yield social benefits by lessening flooding damage impacts. Many regenerative practices also result in benefits to local economics because improved soil quality leads to increasing yields and many practices also require fewer expenses than conventional practices, which increases farmers' net income.[108] If the crop is valued for these regenerative practices, then it can also produce a higher market value.

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[103] Hoyoung Kwon et al., "Greenhouse Gas Mitigation Strategies and Opportunities for Agriculture," *Agronomy Journal* 113, no. 6 (2021).

[104] Maria Bowman, Steven Wallander, and Lori Lynch, "An Economic Perspective on Soil Health," USDA, September 6, 2016, https://www.ers.usda.gov/amber-waves/2016/september/an-economic-perspective-on-soil-health/.

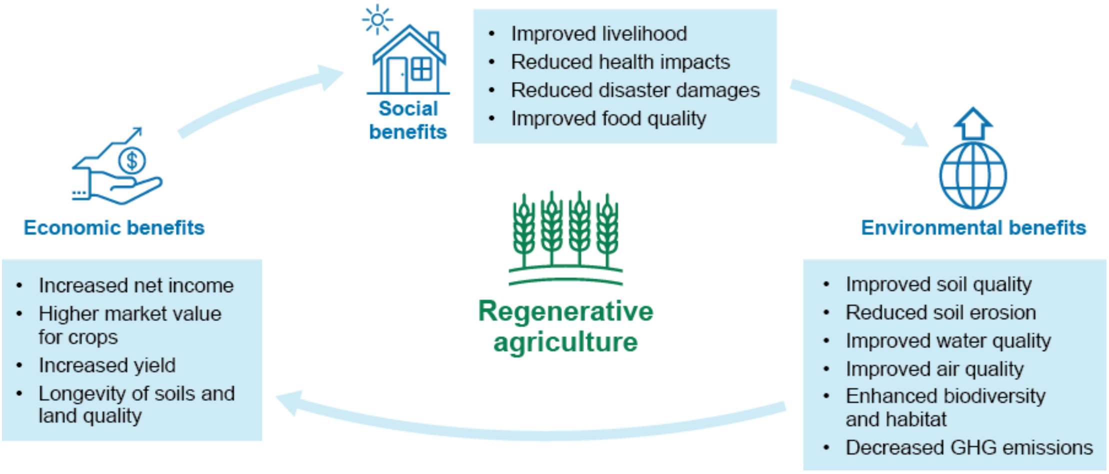
[105] Claire E. LaCanne and Jonathan G. Lundgren, "Regenerative Agriculture: Merging Farming and Natural Resource Conservation Profitably," *PeerJ* 6 (2018).

[106] USDA, "Sustainability Grows in Healthy Soil," 2014, https://scienceforgeorgia.org/wp-content/uploads/2021/12/SoilHealth_SellSheet_rev05-02-2014.v3.pdf.

[107] USDA, "The Economic Impact of Climate Change on Northwest Farms," 2021, accessed 2024, https://www.climatehubs.usda.gov/hubs/northwest/topic/economic-impact-climate-change-northwest-farms.

[108] USDA, "Sustainability Grows in Healthy Soil," 2014, https://scienceforgeorgia.org/wp-content/uploads/2021/12/SoilHealth_SellSheet_rev05-02-2014.v3.pdf.

Figure 12. Regenerative agricultural benefits



Regenerative practices include reducing tillage, planting cover crops, applying manure, and precision nutrient management. Reduced tillage is a practice that minimizes disturbances to the soil and uses plant residue as cover over the field. Benefits of this practice include increased soil organic carbon, reduced soil erosion, improved soil moisture, and reduced energy usage as the farming equipment is used less frequently.[109] Farms in South Dakota have adopted no-till practices (52%) at a rate higher than the national average (37%).[110]

However, practices that require higher up-front costs are generally implemented at lower rates. For example, cover cropping—which requires planting a vegetative cover during the season when production crops are not being propagated—requires purchasing additional seeds and soil amendments. Cover crops can provide vital benefits like reducing erosion, increasing soil organic content, improving soil moisture, suppressing weeds, and reducing soil compaction.[111] However, this practice has a lower adoption rate, at only 2% of cropland in South Dakota and 5% in the US.

Another regenerative agriculture practice is manure application, which provides a source of essential nutrients and additional organic carbon to the soil. Manure application can reduce the need for conventional fertilizer application, but unlike conventional fertilizer, there are no upstream manufacturing emissions associated with it because it is a waste byproduct of the livestock sector.[112] Precision agriculture also aims to reduce fertilizer use by reducing the application of fertilizers, pesticides, and other amendments. This practice is summarized by

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[109] NRCS, “Residue and Tillage Management, Reduced Till,” September 2016, https://www.nrcs.usda.gov/sites/default/files/2022-09/Residue_And_Tillage_Management_Reduced_Till_345_CPS.pdf.

[110] Soil Health Institute, “Economics of Soil Health Systems in South Dakota,” 2022, https://soilhealthinstitute.org/app/uploads/2022/01/Economics-of-Soil-Health-South-Dakota.pdf.

[111] NRCS, “Residue and Tillage Management, Reduced Till,” September 2016, https://www.nrcs.usda.gov/sites/default/files/2022-09/Residue_And_Tillage_Management_Reduced_Till_345_CPS.pdf.

[112] Zhangcai Qin et al., *Incorporating Agricultural Management Practices into the Assessment of Soil Carbon Change and Life-Cycle Greenhouse Gas Emissions of Corn Stover Ethanol Production* (Argonne, IL: Argonne National Lab, 2015).

the 4Rs: "right time, right place and right form and right rate." Specifically, this involves determining the optimal time to apply the amendment, analyzing the land via soil testing, calculating the rate of application, and determining the appropriate amendment and method of application. This practice can greatly reduce the costs for soil amendments (including fertilizers), and farmers on average can save $30/acre on fertilizer costs by implementing these strategies.[113] In addition, using chemicals more efficiently helps to reduce chemical runoff and improve surface water quality. More precise application of chemicals will also avoid wide-scale spraying, which can impact surrounding wildlife. Precision agriculture has been adopted by 27% of farms in the US, with higher adoption rates in South Dakota (53%).[114]

One limitation to a wider adoption of these practices is the concern that they do not yield a "measurable economic return," particularly if up-front costs are required.[115] Larger farms are more likely to adopt new techniques because they have the resources to invest in new technology and economy of scales translates to a lower cost per unit of product.[116] Incentive payments can be key to increasing the adoption of these practices. Existing federal programs provide financial incentives to farmers who adopt certain regenerative agricultural practices, but the contract period is typically only 5–10 years and program budgets are limited. While some practices require little up-front investment and may be adopted without payment (e.g., reduced tillage), other practices require more incentivization, and programs that provide ongoing premiums for these practices can yield high levels of additional adopters.[117,118]

The NZ1 facility will use a tracking program to verify the implementation of regenerative agriculture practices and to quantify the CI of the farming. NZ1 also plans to pay premium for corn that meets certain CI thresholds and has been verified as implementing regenerative practices. This ensures that the NZ1 facility is using low-carbon corn feedstock. The premium will also incentivize the adoption of these practices and, by valuing the external benefits of these practices, share that value back to farmers.

The key external benefits from regenerative agricultural practices that are quantified in this analysis include:

- Reduced soil erosion: Improved water and air quality
- Reduced GHG emissions: Reduced climate change impacts
- Improved yield and reduced farming expenses: Positive impact to farmers net income

5.3.1. External benefit of reduced soil erosion on water and air quality

The corn used in the NZ1 facility will implement regenerative agriculture practices, which help to reduce soil erosion. Loss of topsoil and a decline in soil quality can have long-term impacts

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[113] NRCS, "Nutrient Management," accessed June 2024, https://www.nrcs.usda.gov/getting-assistance/other-topics/nutrient-management.

[114] GAO, *Technology Assessment: Precision Agriculture* (Washington, DC: GAO, 2024).

[115] Conservation Technology Information Center et al., *National Cover Crop Survey Report 2022–2023* (West Lafayette, IN: Conservation Technology Information Center, 2023).

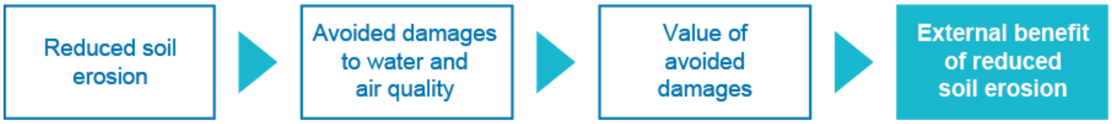
[116] GAO, *Technology Assessment: Precision Agriculture* (Washington, DC: GAO, 2024).

[117] Iowa State University, "Financial Support for Conservation Practices: EQIP and CSP," 2023, https://www.extension.iastate.edu/agdm/crops/pdf/a1-39.pdf.

[118] Roger Claassen et al., *Additionality in U.S. Agricultural Conservation and Regulatory Offset Programs* (Washington, DC: USDA, 2014).

on the surrounding environment, resulting in worsening flooding impacts and land degradation, as well as negatively impacting the farmland's longevity. Water and wind transport of sediment, chemicals, and nutrients can result in decreased air and water quality, which impacts habitat quality and can affect the livelihood and recreational uses that rely on that resource. To determine the value of the external benefits, we determine the amount of soil erosion that is avoided compared to conventional farming practices. The avoided soil erosion is then valued based on avoided damages from water and air quality. Figure 13 outlines the approach used to calculate the external benefits from reduced soil erosion.

Figure 13. Quantifying external benefits from reduced soil erosion.



Practices such as no-till and cover crops can reduce soil erosion by ~1 ton/acre/year.[119,120] When considering cropland that requires high treatment, the potential to reduce erosion can increase to as much as 2 tons/acre/year. For the purposes of this analysis, we consider the weighted average soil erosion reduction possible for high-treatment-need cropland (2.2 tons/acre/year for 49 million acres) and moderate-treatment-need cropland (0.8 tons/acre/year for 97 million acres), which equals ~1 ton/acre/year.[121] Erosion occurs through both water and wind. To account for the varying impacts that occur from these different types of erosion, we allocate the total erosion reduction between these two modes based on U.S. Department of Agriculture (USDA) reported soil erosion on cultivated cropland in 2012 via water (sheet and rill) compared to wind.[122] Approximately 44% of erosion is via wind erosion and 56% via water erosion.

To value the benefits, we apply monetary values to the changes in soil erosion. We rely on the quantification of these benefit values as calculated by the USDA, which accounts for direct economic impacts resulting from water and air quality impacts due to soil erosion from farmlands. These impacts are calculated as avoided costs (further detailed in the appendix):[123]

- Maintenance costs for irrigation ditches and canals
- Maintenance costs for road drainage ditches
- Operational costs for municipal water treatment plants

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[119] Precision Conservation Management, "The Business Case for Conservation," 2021, https://www.precisionconservation.org/wp-content/uploads/2021/06/PCM-booklet-2021-1.pdf.

[120] USDA, "Regulatory Impact Analysis for the Environmental Quality Incentives Program," September 25, 2020, https://www.nrcs.usda.gov/sites/default/files/2023-03/Regulatory_Impact_Analysis_for_the_Environmental_Quality_Incentives_Program.pdf.

[121] USDA, "Regulatory Impact Analysis for the Environmental Quality Incentives Program," September 25, 2020, https://www.nrcs.usda.gov/sites/default/files/2023-03/Regulatory_Impact_Analysis_for_the_Environmental_Quality_Incentives_Program.pdf.

[122] Roger Claassen et al., *Conservation Compliance: How Farmer Incentives Are Changing in the Crop Insurance Era* (Washington, DC: USDA, 2017).

[123] LeRoy Hansen and Marc Ribaudo, *Economic Measures of Soil Conservation Benefits: Regional Values for Policy Assessmen*t (Washington, DC: USDA, 2008).

- Flood damage costs
- Marine fisheries, freshwater fisheries, and recreational fishing catch rates
- Operational costs for municipal industrial water use equipment
- Maintenance costs for water use equipment of steam power plants
- Dust cleaning required due to wind-borne particulates

There are additional benefits from reduced erosion that are not captured here, including impacts to the ecosystem, other recreational use impacts, and potential health impacts. Therefore, this value may represent a low-end estimate of the avoided costs.

We consider the benefit values from three USDA farm production regions as shown in Figure 14:

- Northern Plains: North Dakota, South Dakota, Nebraska, and Kansas
- Lake States: Minnesota, Wisconsin, and Michigan
- Corn Belt: Iowa, Missouri, Illinois, Indiana, and Ohio

These are the main regions for corn farming in the United States, and the values are adjusted from year 2000 dollars to year 2024 dollars and adjusted to income year 2023. However, other factors may have changed with time since these values were published.[124,125,126]

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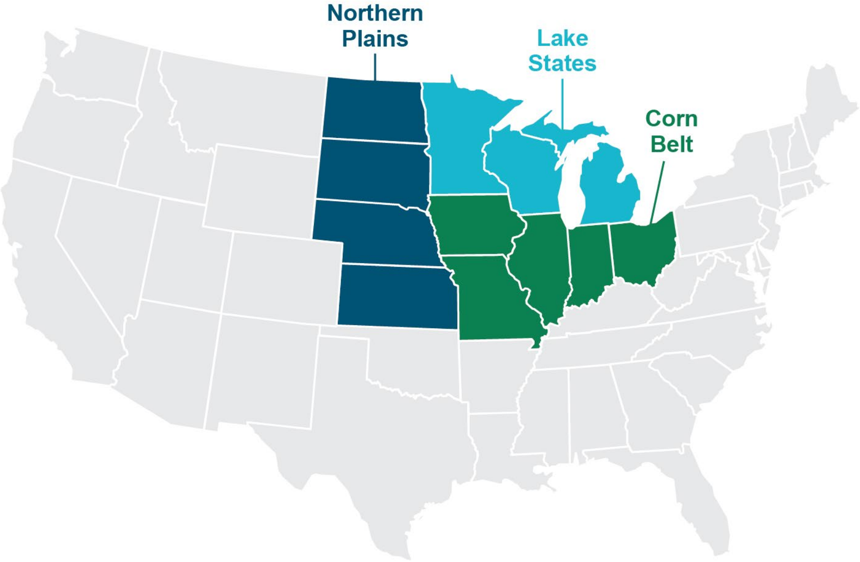
[124] U.S. Bureau of Labor Statistics, “CPI Inflation Calculator,” accessed June 2024, https://www.bls.gov/data/inflation_calculator.htm.

[125] U.S. Bureau of Labor Statistics, “Median Usual Weekly Earnings,” data extracted May 2, 2024, https://data.bls.gov/timeseries/LEU0252881600.

[126] U.S. Department of Health and Human Services, “Appendix D: Updating Value per Statistical Life (VSL) Estimates for Inflation and Changes in Real Income,” April 2021, https://aspe.hhs.gov/sites/default/files/2021-07/hhs-guidelines-appendix-d-vsl-update.pdf.

Figure 14. Agricultural regions considered for soil erosion impact analysis



The Lake States region experiences a total benefit of $7.14/ton reduced soil erosion, Corn Belt $3.62/ton, and the Northern Plains $3.56/ton. Multiplying the benefit values by the tons of reduced erosion via wind and soil in tons/acre/year yields the benefit of reduced erosion in terms of $/acre for a given year. The value per acre is then converted to $/gal SAF using the current corn crop yield of 177 bushels/acre,[127] the facility's yield factors of 1.74 gallons of hydrocarbon per bushel of corn, and 0.92 gallon of SAF per gallon of hydrocarbon. The benefit, if relying on acreage in the Lake States region, is $0.029/gal SAF; the Corn Belt region has a benefit of $0.015/gal SAF, and Northern Plains $0.01/gal SAF. Likewise, extrapolating these erosion reduction benefits across the acreage required to support the capacity at the ATJ facility yields total benefits per year of $1.7 million in the Lake States region, $875,000 in the Corn Belt, and $690,000 in the Northern Plains. The average of these annual erosion benefit values across the three regions is ~$0.018/gal SAF.

5.3.2. External benefit of reduced farming GHG emissions

Another key benefit of regenerative practices is that they enable greater soil carbon content and lower overall GHG emissions by reducing soil disturbances, using less fertilizers, and reducing fuel usage. Increased soil carbon content positively impacts crop yield and lowers the CI of farming. The value of the external benefit from other lifecycle GHG emissions reductions in Section 5.1.3 is based on conventional farming practices and does not include the GHG emissions reductions gained from implementing regenerative agricultural practices. We account for the benefit of reduced GHG emissions in corn faming here.

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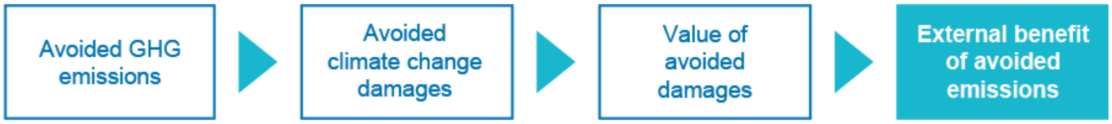
[127] USDA, "Corn Yield – United States," updated January 12, 2024, https://www.nass.usda.gov/Charts_and_Maps/Field_Crops/cornyld.php.

The external benefit is calculated by determining the GHG emissions avoided by adopting regenerative agricultural practices. These impacts are valued using estimates of the avoided climate changes damages and the value of avoided damages as outlined in Figure 15.

Figure 15. Quantifying external benefits from avoided GHG emissions



Implementing precision farming can reduce the CI of SAF by 5.5 gCO2e/MJ. Yield increases from regenerative practices can further reduce it by 3.8 gCO2e/MJ, and sustainable farming practices contribute to a 13 gCO2e/MJ reduction in CI.[128] In total, these farming practices can reduce the CI of SAF by 22 gCO2e/MJ. To value the benefit of the reduced GHG emissions, we again rely on the EPA's social cost of carbon, ~228/t CO2 (2024 dollars).[129] The resulting external benefit is $0.66/gal SAF.

5.3.3. External benefit of increased yield and reduced farming expenses

There are also direct economic benefits to be gained by farmers who adopt regenerative agricultural practices. While there are some up-front expenses such as in adopting cover crops that require purchasing additional seeds and require additional post-harvest expenses, there are also cost benefits. Improvements to soil quality and increased yield can lead to improvements in crop production. Reductions in expenses are also realized through reduced labor and fuel costs primarily from reduced tillage. In addition, these practices can lead to reduced fertilizer expenses by reducing application via precision farming and reducing nutrient loss by decreasing soil erosion. In this analysis, we value the external benefit of increased yield and improved soil quality to farmers' livelihood by measuring the impact to farmers' net income (Figure 16).

Figure 16. Quantifying the external benefit to farming income

The Soil Health Institute found that net farm income increased in farms that adopted regenerative agricultural practices. In South Dakota, corn farms increased their net income by an average of $66/acre, and nationwide corn farms' net income increased by ~$63/acre.[130,131] Based on corn yield in the U.S. in 2022 and the product yield at the facility,

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[128] Lifecycle emission estimate based on McKinsey Analysis of Gevo NZ1 SAF; GREET model.

[129] EPA, *Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* (Washington, DC: EPA, 2023).

[130] Soil Health Institute, "Economics of Soil Health Systems on 100 Farms," 2021, https://soilhealthinstitute.org/app/uploads/2022/01/100-Farm-Fact-Sheet_9-23-2021.pdf.

[131] Soil Health Institute, "Economics of Soil Health Systems in South Dakota," 2022, https://soilhealthinstitute.org/app/uploads/2022/01/Economics-of-Soil-Health-South-Dakota.pdf.

this results in a benefit of $0.23/gal SAF in South Dakota–based farms and $0.22/gal nationwide.

5.3.4. Other external benefits

The benefits we could quantify on a monetary basis total $0.90/gal SAF and are based on impacts from the NZ1 facility on an annual basis. However, there are other benefits to society and the environment that also provide value but are less easily quantified as a dollar value.

One key benefit of regenerative agriculture is an increase in the biodiversity of wildlife due to reduced pesticide and insecticide applications. In fact, corn fields treated with insecticide have a higher insect pest population than untreated farms that implement regenerative practices. These farms benefit from the greater insect diversity that develops without insecticides, and the healthier biodiversity along with protective regenerative practices serves to manage pest populations more effectively.[132]

Further, the long-term impacts to society and the environment are difficult to quantify but can be incredibly meaningful. Improving the soil health also increases the soil's resilience, which can serve to provide ongoing benefits. Healthy soils sequester carbon more readily and have improved water infiltration and nutrient cycling, which ensures a healthier, more diverse microbe and insect population. This biodiversity, as previously mentioned, helps to maintain the health of the soil.[133] More resilient soil can also reduce soil erosion, which impacts water and air quality, as detailed in the earlier section. Though we measured some of the impacts from improved water quality, we did not quantify the more pervasive ecosystem-level improvements and long-term benefits to the environment of not degrading the soils. Nor did we measure benefits to the environment from more efficient uses of water, which could be particularly important in areas of water scarcity. Crops grown in healthy soils benefit from the soil's nutrients, which leads to better crop yields. While we quantified this impact on annual farming income, we did not quantify the long-term benefits of maintaining the soil on the farm for the livelihood of future generations of farmers. Degradation of the soil can negatively impact not only the farmland but also the larger food supply chain and the industries and communities that rely on it. Sustainable practices that also enhance the soil's resiliency ensure the longevity of the farmland, ecosystem services, food supply, and health of the environment.

5.4. Land use

Land use change (LUC) occurs when changes to land use occur either directly to a specific unit of land or indirectly due to induced changes from market impacts. LUC can result in potential carbon impacts from changes in soil conditions that occur when land is converted to different uses. In the context of corn-based ethanol, direct LUC can occur if additional land is converted from grasslands to croplands, which can result in reduced soil organic carbon storage for a given region. However, corn farming in the U.S. has consistently increased its yield, generating more corn per acre annually. This has resulted in greater corn production

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[132] Claire E. LaCanne and Jonathan G. Lundgren, "Regenerative Agriculture: Merging Farming and Natural Resource Conservation Profitably," *PeerJ* 6 (2018).

[133] USDA, "Sustainability Grows in Healthy Soil," 2014, https://scienceforgeorgia.org/wp-content/uploads/2021/12/SoilHealth_SellSheet_rev05-02-2014.v3.pdf.

without substantially increasing cropland acreage. Figure 17 highlights the change in average corn yield in the U.S.

Further, as detailed in Section 5.3, regenerative agriculture practices can increase crop yield and reduce farming GHG emissions. The Gevo NZ1 facility will offer a premium for corn grown via regenerative practices, which will encourage the adoption of these practices and reduce LUC and its impacts.

Figure 17. United States average corn yield (bushels per acre)[134]

However, SAF production has limited means to directly impact indirect LUC, which can be influenced by complex global markets impacting land around the world. This metric cannot be directly observed and so is typically modeled to assess the estimated impact to GHG emissions. These models aim to determine the change in CI due to ILUC that impacts the soil sequestration of a unit of land. Typically, the lifecycle GHG emissions for biofuel production will be assigned a fixed carbon penalty for each MJ of fuel to account for the soil carbon impacts of ILUC change associated with that feedstock.

A wide range of studies have been conducted to estimate the ILUC CI value of corn-based ethanol, with widely varying results. Given high levels of uncertainty around soil carbon estimates and sourcing techniques, variation will likely continue to exist between studies. However, over the past decade, the research community has generally converged around lower CI values than previously modeled. Before 2010, multiple studies estimated an ILUC value of >30 gCO2e/MJ to roughly 7 gCO2e/MJ.[135] ICAO's framework for emissions calculations (Carbon Offsetting and Reduction Scheme for International Aviation) for SAFs

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[134] USDA, "Quick States, 2000–2023," accessed June 2024, https://quickstats.nass.usda.gov/results/DA61C33B-E971-3192-A0AE-DE265F82F46E?pivot=short_desc.

[135] Melissa J. Scully et al., "Carbon Intensity of Corn Ethanol in the US: State of the Science," *Environmental Research Letters* 16 (2021).

estimates ~25 gCO_2e/MJ CI for LUC in corn ethanol to jet fuel pathways.[136] However, the CORSIA model does not account for increased crop yield unique to the U.S. bioethanol industry and recent research incorporating cropland switching.

The ANL GREET model calculated more recent estimates of ~7 gCO_2e/MJ for ethanol and an adjusted value of 9 gCO_2e/MJ for ATJ SAF production.[137] On April 30, 2024, the Treasury made an announcement allowing SAF producers to use ANL's GREET model for SAF tax credit qualification, which uses a value of 9 gCO_2e/MJ for ATJ SAF ILUC.[138]

Several key drivers have improved the state of the science and led to reductions in emissions estimates for ILUC. These key drivers include the following:

1. Reduced assumptions that ethanol production increases corn prices
2. Improved research surrounding yield per acre, reflecting higher-efficiency land use
3. Improved data on historical land use to correctly account for grassland to cropland LUC[139]

The GHG lifecycle emissions calculations detailed in Section 5.1 include a measure of the CI resulting from indirect LUC associated with corn-based ethanol production. We rely on the GREET ILUC metric for ATJ SAF of 9 gCO2e/MJ.[140] However, as shown in Sections 5.1 and 5.3, ATJ SAF still has a significantly lower GHG lifecycle emissions intensity than convention fossil jet fuel (~107% reduction).

5.5. Technological spillover benefit to SAF industry

As the ATJ SAF industry scales, it is poised to benefit from significant learnings as production experience accumulates, driving costs down. Future ATJ SAF production facilities will benefit from the first movers on commercial investments like NZ1. This development contributes to the progress of foundational technologies, advancing biofuel technologies that rely on sugar/starch feedstocks as well as cellulosic feeds (inedible vegetation). Cellulosic biofuels use a sustainable feedstock, but this technology currently requires further advancement to become commercially viable.[141] The learnings gained in developing the ATJ SAF technology can also benefit the development of cellulosic biofuel production. Figure 18 presents the benefits and impacts that first movers can have on a nascent industry. As the industry continues to grow, it will continue to increase its experience and learnings, which will lead to efficiency gains and

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[136] ICAO, "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels," June 2022, /https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20June%202022.pdf.

[137] Eunji Yoo, Uisung Lee, and Michael Wang, "Life-Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel through a Net-Zero Carbon Biofuel Plant Design," *ACS Sustainable Chemical Engineering* 10, no. 27 (2022): 8725–8732.

[138] U.S. Department of Treasury, "U.S. Department of the Treasury, IRS Release Guidance to Drive American Innovation, Cut Aviation Sector Emissions," April 30, 2024, https://home.treasury.gov/news/press-releases/jy2307.

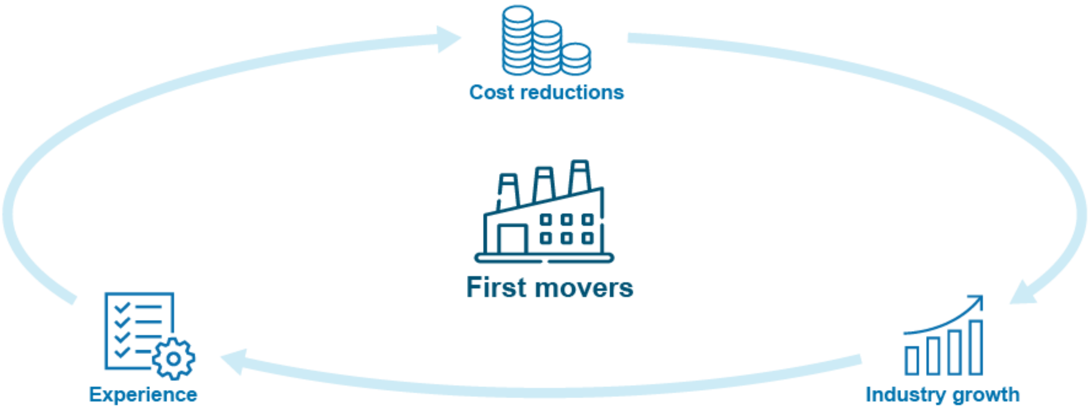
[139] Kenneth Copenhaver and Steffen Mueller, "Considering Historical Land Use When Estimating Soil Carbon Stock Changes of Transitional Croplands," *Sustainability* 16, no. 2 (2024).

[140] Lifecycle emission estimate based on McKinsey Analysis of Gevo NZ1 SAF.

[141] EIA, "Biofuels Explained," February 23, 2024, https://www.eia.gov/energyexplained/biofuels/ethanol.php.

subsequent reductions in cost. The reduced cost will grow demand for the industry and contribute to its continued growth.

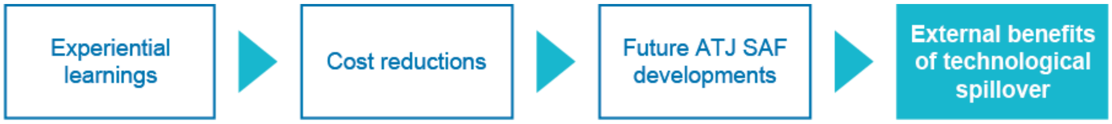
Figure 18. Benefits initiated by the first movers in a nascent industry



Learning curves, also known as experience curves, are rooted in the empirical observation that unit costs often decline as production experience increases. This concept has been well-documented in various industries, including the energy sector, where it has been applied to understand cost reductions in ethanol production and electricity generation methods like nuclear, coal, hydropower, wind, and solar PVs. The learning curve represents how production costs tend to decline with a fixed percentage over each doubling in cumulative production. This concept also connects developments in production costs or prices with cumulative production, reflecting the accumulated experience of production.

We calculate a value for the external benefit of technology spillover by first quantifying the technological learnings as a production cost reduction. The reduced cost is then applied to future ATJ SAF developments via an estimated spillover factor to determine the external benefit as outlined in Figure 19.

Figure 19. Quantifying benefits from technological spillover

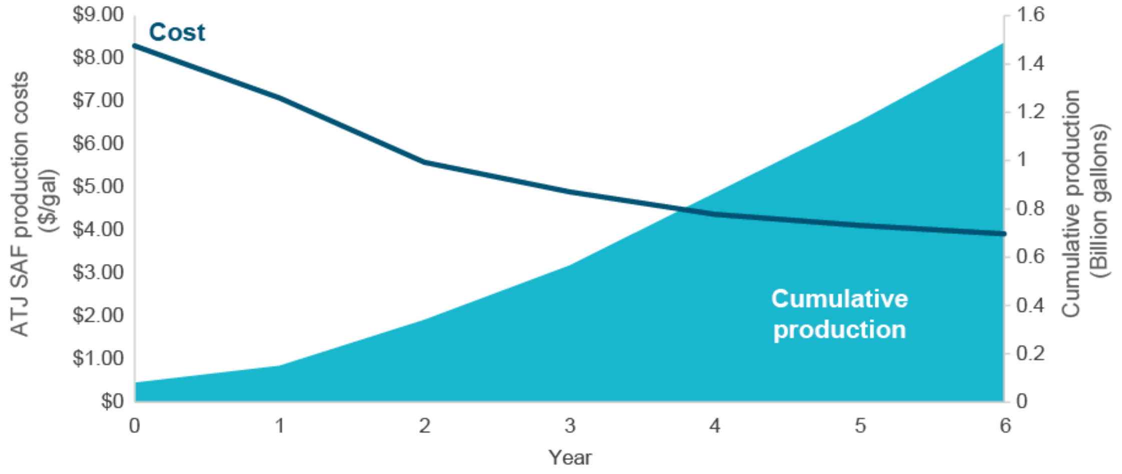


We model the learning curve for ATJ SAF on that of ethanol production. Based on historical prices and cumulative production, the learning curve measures the progress ratio with a lower value indicating faster development and greater cost reductions. A progress ratio of 80% implies that unit costs are reduced by 20% over each doubling of cumulative production. Sugarcane ethanol production in Brazil showed progress ratios of 93% from 1980 to 1985 and 71% from 1985 to 2002. Similarly, wind energy exhibited progress ratios of 99% between 1981 and 1985, and 88% from 1985 to 2000, while solar PVs showed a progress ratio of 77% from

1981 to 2000.[142] We assess the ATJ SAF cost reductions based on a progress ratio of 80%. This rate aligns with early-stage biofuel production learning rates.[143] Since part of the process relies upon ethanol production, which is a more mature industry, we consider the share of the production cost allocated for ethanol production separately and apply a progress ratio of 90%. The cost of ethanol production is not anticipated to decline at the rate of the SAF production process, which is in the early stages of its commercial development.

Figure 20 outlines the predicted decline in the production cost of ATJ SAF that will result from production experience (i.e., cumulative production capacity). Gevo's contributions to these cost reductions were allocated based on NZ1's contribution to cumulative production, which was estimated using SAF and ATJ production forecasts. Figure 3 details the SAF production forecast that we used to make these calculations.

Figure 20. ATJ SAF learning curve



To determine what fraction of these benefits will impact future developments, we rely on research on spillover effects. The spillover effect in R&D plays a crucial role in technological progression and future cost reductions. Spillovers occur when a firm's R&D investment reduces production costs for rival firms, thereby enhancing the industry-wide cost-reduction effect of R&D investment. Studies have shown sizable R&D spillover effects at both the firm and industry levels, with average spillover benefits of ~50%.[144] Thus, as the ATJ industry scales, subsequent ATJ plants are set to benefit from the R&D investments made in early-stage plants.

Subsequently, we apply the spillover effects to determine the dollar-per-gallon ($/gal) benefit. We assume a 50% spillover factor, indicating that half of the cost reduction for additional near-

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[142] José Goldemberg et al., "Ethanol Learning Curve: The Brazilian Experience," *Biomass and Bioenergy* 26, no. 3 (2004): 301–304.

[143] Laura J. Vimmerstedt and Brian W. Bush, "Dynamic Modeling of Learning in Emerging Energy Industries: The Example of Advanced Biofuels in the United States," National Renewable Energy Laboratory, 2015, https://www.nrel.gov/docs/fy15osti/60984.pdf.

[144] M. Ishaq Nadiri, "Innovations and Technological Spillovers," NBER Working Paper No. w4423, August 1993, https://www.nber.org/papers/w4423.

term plants is attributable to the NZ1 plant. As the foundational plant, the R&D efforts invested in NZ1 are expected to benefit subsequent plants in the industry.

The future benefits from the cost reduction are applied to the forecasted capacity in the years 2030 and 2050 to yield a total potential benefit and are then divided by the capacity of the NZ1 facility. The future benefits are discounted to the present year using a discount rate of 5%. The spillover factor for benefits in year 2050 is also discounted to represent the lessened impact of technological spillover over the longer-term horizon for each additional unit of production. We use a discounting rate of 15% to calculate a reduced spillover factor for 2050. The spillover benefits total $1.60/gal when considering the impacts to capacity in year 2030 (near term) and an additional $2.30/gal when considering 2030–2050 (long term).

5.6. Energy security benefits

Ensuring a stable supply of energy at an affordable price is essential to the U.S. economy. This includes protecting existing energy assets and reducing exposure to volatile prices. SAF can increase energy security and energy independence because it reduces reliance on crude oil imports and its production has a greater geographical distribution than petroleum refinery plants.

While the U.S. has become a net petroleum exporter in recent years, as evident in Figure 21, it remains a net importer of crude oil.[145] Following advances in fracking and shale oil production, the U.S. was able to greatly increase its domestic crude oil production. However, most this new oil production has been light oil, and many refineries have invested heavily in production processes that rely on heavy oil to produce a wider variety of petroleum products.[146] U.S. refineries currently rely on a feedstock made up of 40% imported crude oil.[147] U.S. crude oil exports have increased in recent years as there is a higher production of light crude oil than U.S. refineries can process.

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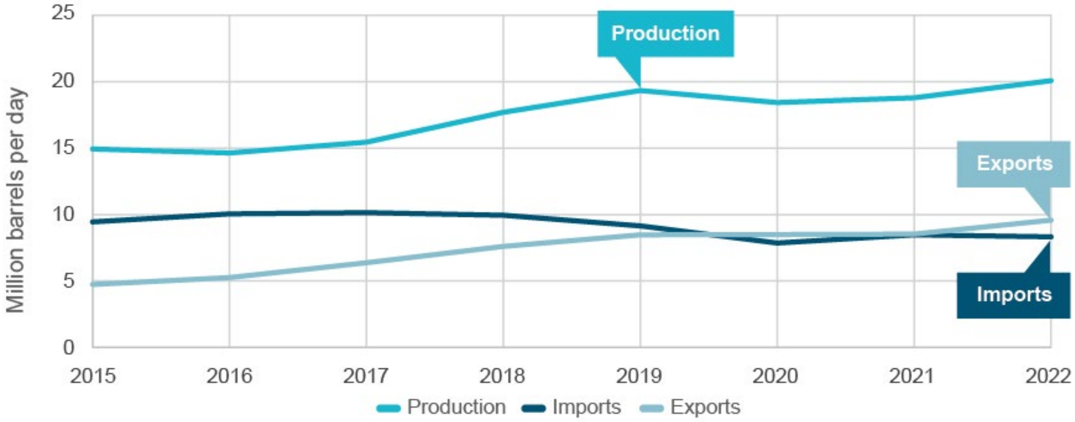
[145] EIA, "Oil Imports and Exports," 2022. Link.

[146] Dean Foreman, "Why the U.S. Must Import and Export Oil," American Petroleum Institute, June 14, 2018, https://www.api.org/news-policy-and-issues/blog/2018/06/14/why-the-us-must-import-and-export-oil.

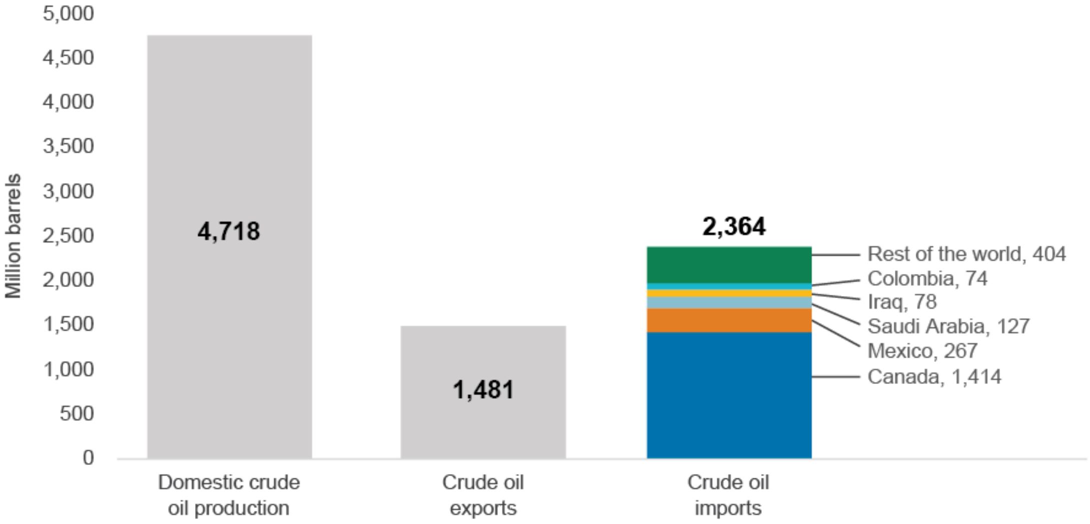
[147] Renewable Fuels Association, "Ethanol Promotes Energy Independence," 2023, https://ethanolrfa.org/ethanol-101/energy-independence.

Figure 21. U.S. total petroleum production, imports, and exports



Total U.S. oil consumption is also projected to continue to increase.[148] In 2023, the U.S. imported ~2 billion barrels of crude oil and ~1 billion barrels of petroleum products. While the U.S. produced ~4.7 billion barrels of crude oil and exported 1.4 billion barrels, it still imported a total of ~2.4 billion barrels of crude oil. Sixty percent of imports came from Canada; however, the remainder is spread across 37 different countries, including 11% from Mexico, 5% from Saudi Arabia, 3% from Iraq, and 3% from Colombia.[149] Relying on foreign sources of oil carries the risk of supply disruption due to any regional instabilities or geopolitical conflict.

Figure 22. Total U.S. crude oil production, total exports and imports (by country)



The disruption of oil import supplies can cause a spike in oil import prices and can cause economic disruption as the price of oil has cascading impacts throughout the economy. The

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[148] EPA, *Draft Regulatory Impact Analysis: RFS Standard for 2023–2025 and Other Changes* (Washington, DC: EPA, 2023).

[149] EIA, “U.S. Total Crude Oil and Products Imports,” 2023, https://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_a.htm.

risk of economic damages from imported oil supply shocks could be avoided by increasing the domestic production of biofuels such as SAF.

Additionally, there are the costs of existing U.S. energy security policies, which could be reduced if the economy relied less on imported oil. Currently, the U.S. maintains the largest government-owned reserve in the world. While the strategic petroleum reserve is one lever that the country can use to stabilize the oil supply, there are costs to maintaining this reserve. In addition, there are military expenses to secure or stabilize regions with oil supply; however, these are difficult to quantify and attribute to energy security activities specifically.

SAF also has a greater geographic distribution across the U.S. than current fossil jet fuel production. For example, 53% of U.S. fossil jet fuel production capacity is located in the Gulf Coast region, and four out of the five largest petroleum refineries by jet fuel production capacity are located in the Gulf Coast. U.S. ethanol production is geographically more distributed, with half of production capacity located across three different states: Iowa, Nebraska, and Illinois. In addition, ethanol plants on average have a lower production capacity. The largest ethanol production plant only contributes ~2% of total ethanol production capacity, and the top five largest ethanol plants make up only 9% of total ethanol production capacity. Meanwhile, the petroleum refinery with the greatest jet fuel production capacity makes up 8% of the U.S. total capacity (the five largest make up ~30% of total jet fuel production capacity).

While these energy security benefits are not quantified, the value they would provide is beneficial to the energy security, and energy independence of the U.S. SAF would reduce dependence on imported oil, reduce economic disruption from oil, reduce costs for energy security policies, and enable a more distributed domestic jet fuel production.

6. External benefits and incentive costs results

Totaling only the external benefits that were quantified in this analysis yields a value of $4.83-7.13 per gallon of SAF. More than three to four times greater than existing federal incentive costs.

Net federal incentive costs do not include the value of RFS RINs which are not a U.S. federal government cost for SAF. The low end of the external benefits calculation considers only the near-term benefits of technological spillover, and the high end considers both the near- and long-term impacts from technological spillover. The cost-benefit analysis shows that external benefits outweigh the incentive costs.

Figure 23 demonstrates the value of externalities that we can quantify on a monetary basis and includes both the near- and long-term technological spillover benefits.

Considering the total impact of the NZ1 operations that produce 60 million gallons of SAF annually yields total external benefits of between ~$290 and $428 million.

We also consider the total external benefits that could result from the entire ATJ SAF industry if SAF production capacity were properly incentivized to scale up. We apply the forecasted production volumes detailed in Figure 3 and use the same valuation per gallon of SAF for the external benefits. First, we consider potential impacts based on the ATJ SAF production volume of 325 million gallons as forecasted in our scenario for 2030 and consider only the near-term technological spillover benefits. This forecasted results for total annual external benefits of ~$1.6 billion. The ATJ SAF volume forecasted for 2050 of 28 billion gallons would result in total annual external benefits of ~$200 billion (inclusive of near-and long-term technological spillover effects).[150]

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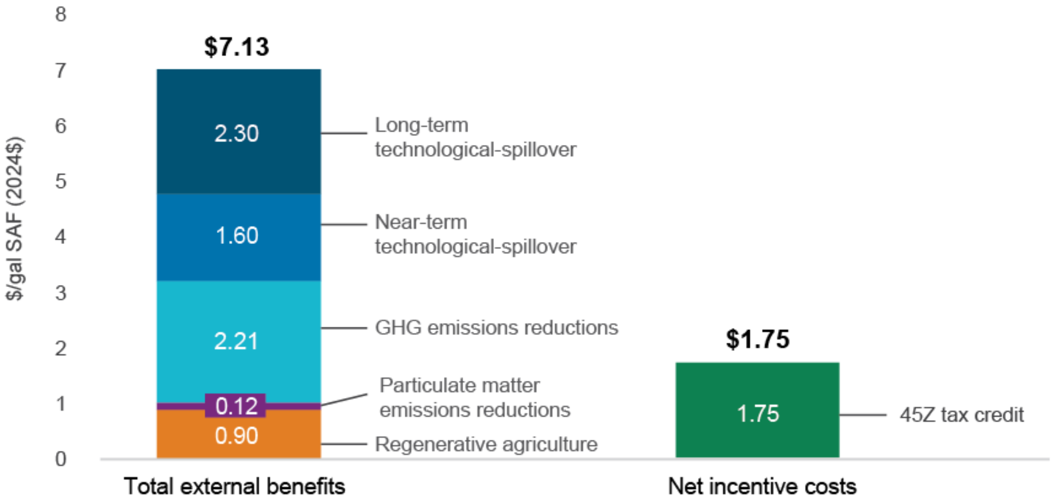
[150] These calculations for external benefit use the future production volumes but rely upon the valuation of the external benefits for the current year, as detailed in the methodologies in Section 5.

Figure 23. Total annual external benefits and federal incentive costs[151]



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[151] Note: Net federal incentive costs do not include the value of RFS RINs which are not a U.S. federal government cost for SAF. Programmatic costs are also excluded.

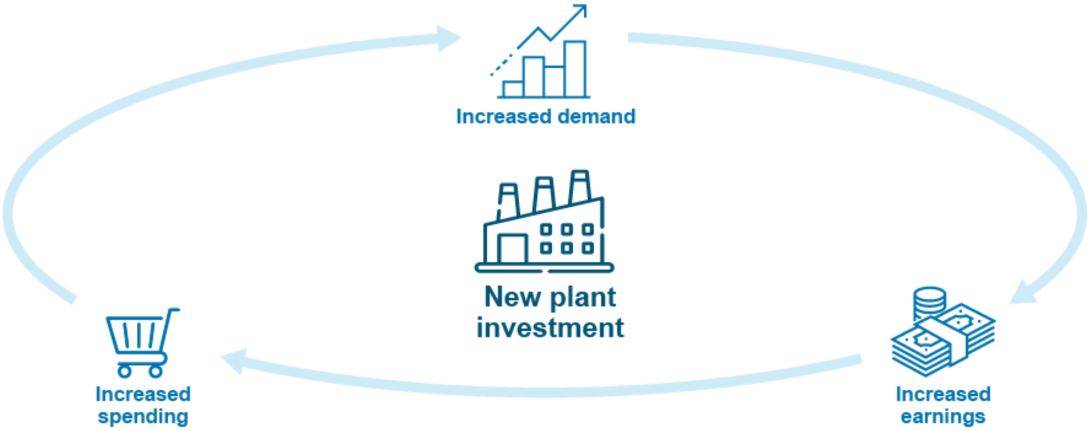
7. Local and state economic impacts

In addition to the external benefits quantified above, which have broad impacts across the United States, there are also local and state economic benefits. The NZ1 facility investment and operations in a rural region of South Dakota will provide economic benefits to the local and state economy. The relative economic impact will be particularly pronounced for this region as the majority of inputs are sourced locally and this region typically receives lower levels of economic investment and development. The economic impact measured includes direct, indirect and induced effects. Increased revenue generated from the NZ1 facility will have a **direct economic impact** from inputs purchased by the plant and an **indirect** effect from purchases from supporting industries. Additionally, the increase in earnings for employees in these industries will trigger **induced impacts** for other regional industries. Figure 24 outlines how these components result in a measure of benefits to the **local economy**.

Figure 24. Quantifying benefits to the local economy

While the initial construction phase will have a temporary impact on the local economy, the ongoing operations will foster long-term increases in economic value. Due to the differences in these phases, we analyze them separately. Figure 25 shows the chain of benefits resulting from the new plant investment and its ongoing operations. The plant will increase demand for goods and materials that are needed for its operations as well as produce indirect economic impacts resulting from inputs purchased by supporting industries. Employees will be supported by this investment both directly for those employed in the NZ1 facility and indirectly for those now supported to meet the increased demand for input products. Increased earnings for these employees provide additional economic impact as they will use their earnings on spending within the local region, creating an induced impact for even more businesses.

Figure 25. Local and state economic impacts



7.1.1. Operational impacts

The new ATJ SAF production facility will produce 60 million gallons of SAF annually as well as 0.6 million tonnes of animal feed & corn oil. The ongoing production will generate new revenue in these industries of approximately $226 million annually in SAF and $64 million in animal feed (2024 dollars). The product revenue is representative of the value spent on inputs to generate these products. To estimate the impact to the local economy, we use the Regional Input-Output Modeling System (RIMS II).[152] RIMS II is a regional economic model that uses multipliers to estimate the impact of economic activity in one industry on other industries. We use Type II multipliers, which encompass the direct, indirect, and induced impact resulting from the initial economic activity. Direct impacts are those resulting from inputs purchased directly by the plant, while indirect impacts occur due to inputs purchased by the supporting industries. Induced impacts are related to the personal spending by employees from all the direct and indirect industries.

RIMS multipliers from 2022 are applied from Kingsbury County, South Dakota to reflect the impact to the local economy where the NZ1 facility will be built. We define the local area as including this county and surrounding counties. Supporting industries and household spending will likely extend beyond just one county and we did not have sufficient data to account for all potential leakages of economic impact. The following industries are used to calculate the economic impact from the NZ1 facility: “Other basic organic chemical manufacturing” (a proxy for SAF) and “Wet corn milling.” The annual revenue for each industry was first converted into 2021 dollars to align with the dollar year of the RIMs II multipliers, and then the dollar value outputs were converted to 2024 dollars. The results indicate that the increase in revenue could support approximately 836 jobs and will add $116 million in value to the GDP of the local economy. A significant share of the economic impact is realized in the agricultural sector. However, it should be noted that if the agricultural inputs do not come from new corn plantings, they may not result in new jobs but rather support existing employment in the agriculture sector.

The **value-added** includes earnings, returns on investment, and taxes on production and imports less subsidies. Total value-added is $116 million, and earnings make up $65 million of this total.

To estimate the contribution of the local economy’s value-added to federal tax revenue, we consider that the value-added calculated here represents the addition to the GDP. The federal tax to GDP ratio in the United States was reported to be 19.6% in 2022.[153] We estimate that the tax revenue resulting from the NZ1 operations total value-added is $23 million. The value-added is already inclusive of taxes on production and imports, which includes general sales and property taxes including federal excise taxes on goods and services. In the United States taxes on goods and services as well as property taxes have historically made up 29% of total U.S. federal tax revenue.[154] **The total tax revenue contribution per gallon of SAF is $0.38/gal SAF, while the value-added (excluding any tax revenue) is ~$1.82/gal SAF.** Figure 26 details how these benefits could accumulate with the value of the other external

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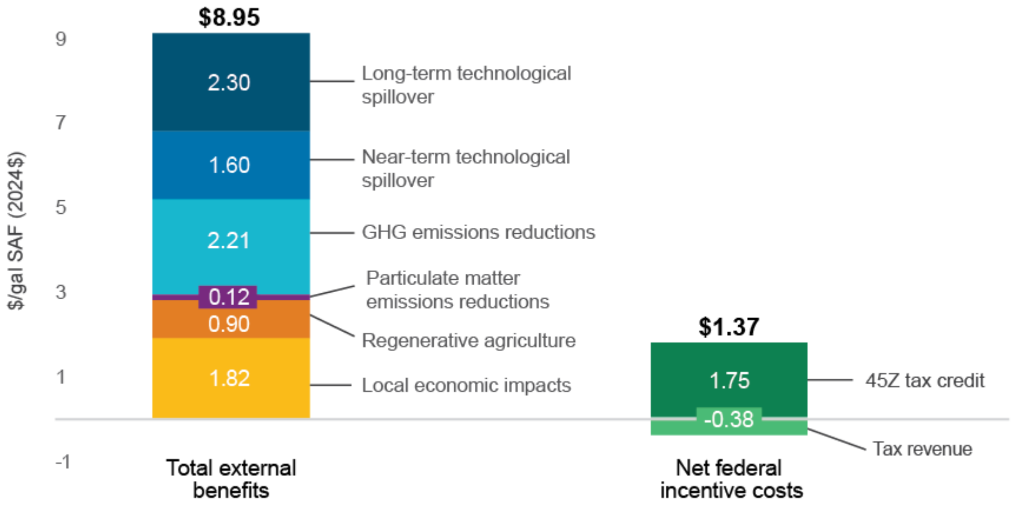
[152] Bureau of Economic Analysis, “RIMS II,” https://apps.bea.gov.

[153] Congressional Budget Office, “The Budget and Economic Outlook: 2023 to 2033,” February 2023, https://www.cbo.gov/publication/58946#_idTextAnchor024.

[154] OECD, “Revenue Statistics 2023 – The United States,” 2023, https://www.oecd.org/tax/revenue-statistics-united-states.pdf.

benefits. The government incentives represent costs to the government, and in this figure the total cost to the government is reduced by the additional federal tax revenue gained through the SAF operations.

Figure 26. Total annual benefits and net incentive costs[155]



7.1.2. Construction impacts

To determine the temporary impacts of the SAF facility's construction, we use the National Renewable Energy Laboratory's (NREL) Jobs and Economic Development Impact Model (JEDI), which uses state-level multipliers derived from IMPLAN data.[156] The corn ethanol plant model serves as a proxy for the ATJ SAF plant, and we model based on a production capacity of 65 million gallons of ethanol, a 25-month construction period, and construction costs (installed, land, and soft costs) of ~$1.3 billion. The construction phase results in a total impact of supporting ~1,266 jobs and value-added of ~$184 million over the construction phase.

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[155] Note: Net federal incentive costs do not include the value of RFS RINs which are not a U.S. federal government cost for SAF. Programmatic costs are also excluded.

[156] NREL, "JEDI Biofuels Models," accessed June 2024, https://www.nrel.gov.

8. Scenario analysis

8.1. Benefits to agriculture and rural economies

The U.S. is the largest producer of corn with an average production of 13.9 billion bushels per year for the last decade. Fuel ethanol is the most significant use, consuming 38% of total domestic corn.[157] In 2023, 15.6 billion gallons of ethanol were produced, consuming 5.2 billion bushels of corn.[158] There are currently over 180 ethanol production plants in the US, with the majority sited in rural regions, particularly in the Midwest. In 2023, ethanol's contribution to the U.S. GDP amounted to $54.2 billion, directly and indirectly supporting almost 400,000 jobs across multiple sectors and adding $10.4 billion in tax revenue ($5.6 billion in federal taxes and $4.8 billion in state/local taxes).[159] Agriculture communities in particular benefit from the current demand for ethanol. Unused ethanol-production capacity would represent a loss in potential economic value and a loss in jobs that are essential to these rural communities.

As the nation moves toward a future where EVs gain a larger market share, there will be a decrease in demand for gasoline and likewise a reduced demand for ethanol for fuel blending. This presents an opportunity for another end use for ethanol to develop and provide continued support for the many jobs in agriculture and other supporting industries. International demand for ethanol could provide one offtake of U.S. ethanol production; however, that would limit the domestic economic benefit. Domestic nonfuel uses for ethanol would provide one valuable use for ethanol, which would also contribute to additional domestic investment. ATJ SAF represents a promising growing demand for ethanol. If the ATJ SAF industry is incentivized to fully develop, the increase in demand for ethanol would help to offset the declining demand from other industries. This would provide continued support for the rural economies and, importantly, make use of the corn crop production that continues to increase its yield. In addition, as outlined in Section 7, the ATJ SAF production will bring more investment and value to rural communities. In this section, we focus only on the impact on rural communities from the ethanol production, assessing the value along its supply chain and most importantly its impact on agricultural communities.

We base this scenario analysis on a rapid decarbonization of light-duty vehicles (LDVs) to align with the ATJ SAF forecast, which is also based on a rapid decarbonization (the scenario approaches net zero by 2050). The scenario forecasts that most LDVs in the U.S. will be electrified by 2050 (with EVs and hybrid EVs making up 75% of LDVs). This scenario relies on assumptions that an accelerated adoption of EVs will be possible due to technological advancements, robust policy support, and increased consumer demand. The analysis relies primarily on NREL forecasts for EV adoption and EV efficiency.[160,161]

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[157] USDA, "Feed Grains Yearbook," June 17, 2024, ers.usda.gov/data-products/feed-grains-database/feed-grains-yearbook-tables.

[158] Renewable Fuels Association, "EIA Data Indicate Ethanol Volumes Rose, Blend Rate Hit a Record High in 2023," February 29, 2024, https://ethanolrfa.org/media-and-news/category/news-releases/article/2023/02/eia-data-indicate-ethanol-blend-rate-hit-a-record-high-in-2022.

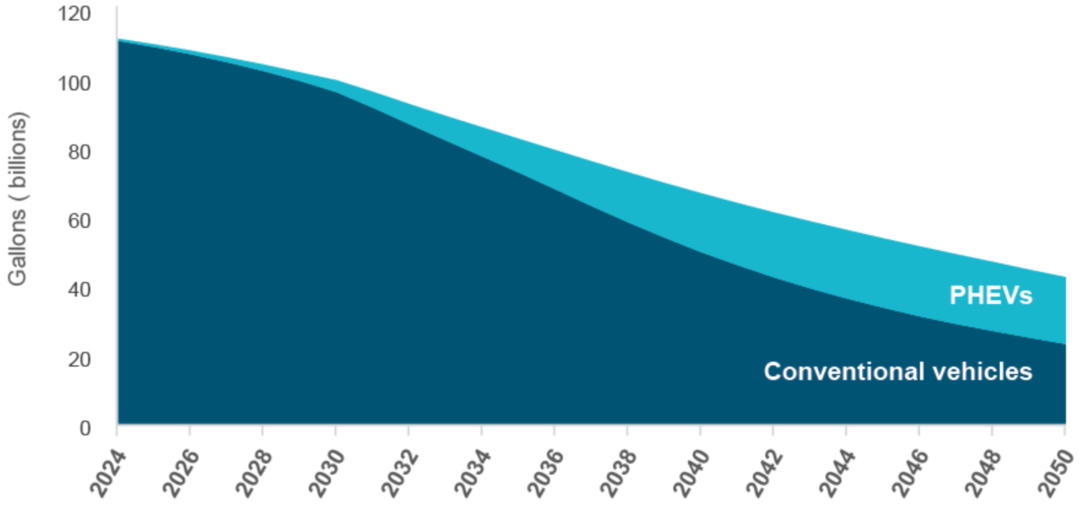
[159] Renewable Fuels Association, "Contribution of the Ethanol Industry to the Economy of the United States in 2023," 2024, https://d35t1syewk4d42.cloudfront.net/file/2659/RFA%202023%20Economic%20Impact%20Final.pdf.

[160] Trieu Mai et al., *Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States* (Golden, CO: NREL, 2018).

[161] NREL, "2022 Transportation Annual Technology Baseline," 2022, https://atb.nrel.gov/transportation/2022/index.

Figure 27 illustrates how the rapid electrification of LDVs leads to decreased gasoline consumption. By 2050, plug-in hybrid EVs will take up a greater share of gasoline consumption than conventional vehicles. The decline in gasoline consumption will also lead to a decline in ethanol for fuel blending. More aggressive scenarios than this would only result in even more ethanol production capacity being available and more agricultural income being at risk. We use this scenario as a conservative assessment of the impact to rural communities, and the potential of ATJ SAF to offset some of these losses and bring economic benefit to the agricultural communities.

Figure 27. Gasoline consumption forecast



In 2023, the United States had an ethanol production capacity of 17.6 billion gallons per year and produced 15.5 billion gallons.[162,163] Of that total production, approximately 11.4 billion gallons of ethanol were blended for use in LDVs in 2023. Figure 28 highlights the decline in ethanol consumption for gasoline fuel blending under this decarbonization scenario. This forecast is based on projected gasoline consumption and assumes a gradual transition from the current blending ratio of 10.4% ethanol to an anticipated 15% ethanol content.[164] This increase in ethanol blending would be driven by increasing decarbonization policy mandates.

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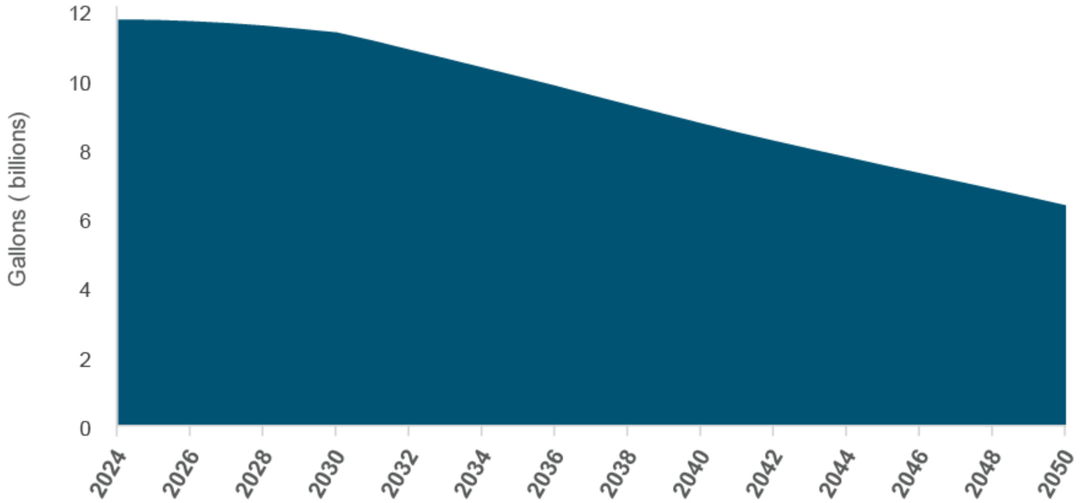
[162] EPA, "U.S. Fuel Ethanol Plant Production Capacity," August 7, 2023, https://www.eia.gov/petroleum/ethanolcapacity/.

[163] Renewable Fuels Association, "Annual Industry Outlook," accessed June 2024, https://ethanolrfa.org/resources/annual-industry-outlook.

[164] CRA Analysis, 2024.

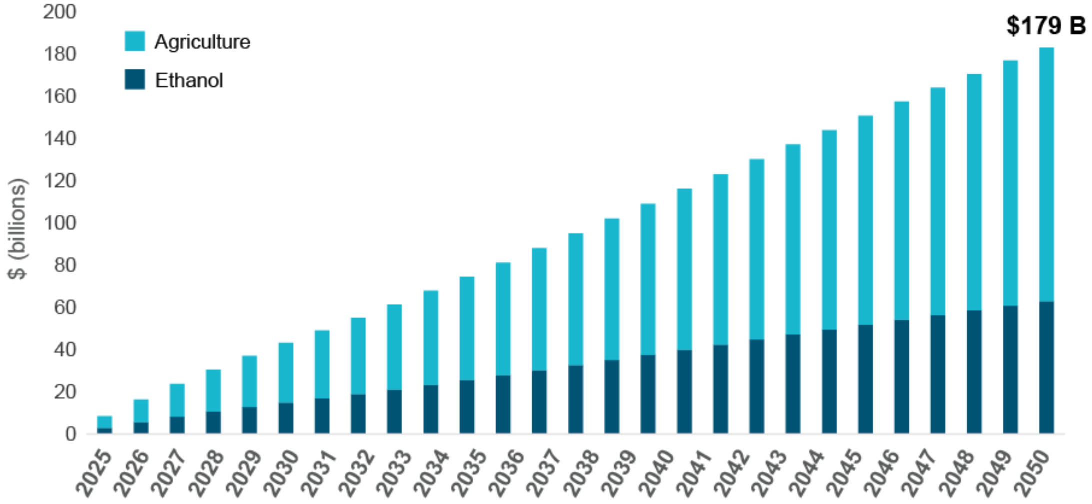
Figure 28. Ethanol consumption for gasoline fuel blending



Potential surplus ethanol projections were derived by comparing forecasted ethanol demand to current production volumes in 2024. Economic losses were then determined by assessing the economic impact on the U.S. ethanol industry's footprint, encompassing direct, indirect, and induced effects. Finally, these projected losses were adjusted to present value, reflecting their economic significance in 2024 dollars.

This decline in ethanol demand could result in a cumulative lost economic value of ~$179 billion (2024 dollars) to the U.S. GDP by 2050. The majority of the lost economic value, approximately $118 billion, would be due to lost value from the agriculture industry and $61 billion of the lost value from ethanol production (these economic impacts encompass the industry itself, other industries along its supply chain, and induced impacts). Additionally, an estimated 178,000 jobs would be lost as a result, as well as a total cumulative tax revenue loss of ~$34 billion. As highlighted in Figure 29, the loss in economic value will largely impact the agricultural industry and therefore the rural communities that depend upon it. Given that corn farming constitutes a significant component of the ethanol production process, over 65% of the lost economic value is related to the agricultural industry.

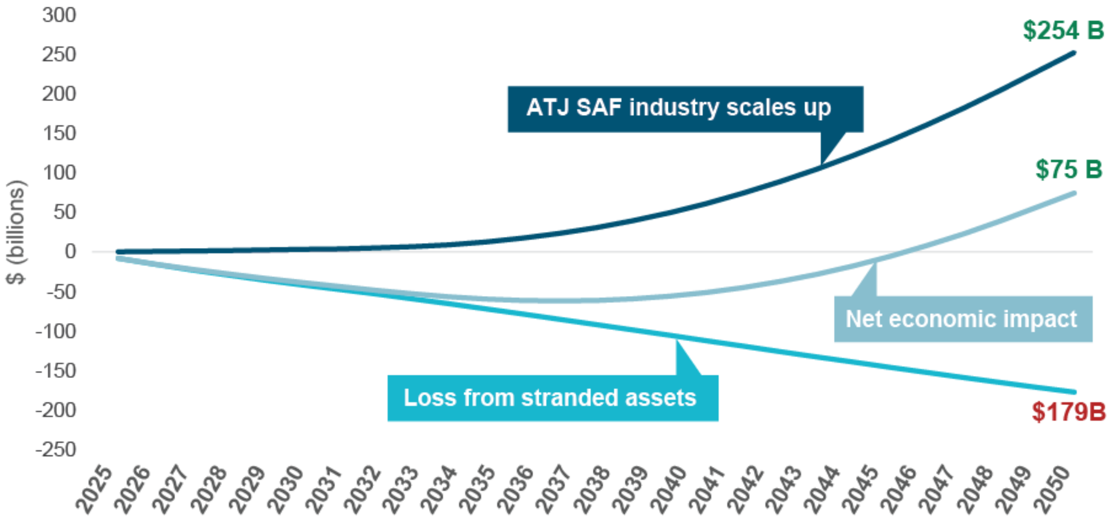
Figure 29. Cumulative lost economic value in 2024 dollars



Scaling the SAF industry to meet the goals set by the U.S. SAF Grand Challenge could yield benefits to rural agricultural communities. Figure 30 shows the potential economic loss if ethanol assets are stranded without an increase in another offtake source. As highlighted earlier, the cumulative loss from stranded ethanol assets could total approximately $179 billion by 2050. The figure also includes the economic impact of increased demand for ethanol by a growing ATJ SAF industry. The measured economic impact focuses on the effects of ethanol production on the ethanol industry and its supporting industries. Additionally, the analysis assumes that ATJ SAF consumes stranded ethanol to the extent that its production capacity allows. Under these scenario assumptions, the total cumulative potential benefit from ATJ SAF demand for ethanol could be approximately $254 billion. The economic impact represents the ethanol industry's direct, indirect, and induced economic impact under the scenario where ATJ SAF scales up to increase ethanol demand.

In the initial years the net economic impact is negative because the ATJ SAF production is limited so some excess ethanol remains unused leading to stranded assets. However, as ATJ SAF scales up over time, the increasing use of ethanol will result in a positive net economic benefit. By 2039 the ATJ SAF industry consumes all excess ethanol production and then begins to increase ethanol production beyond current levels. Scaling up the ATJ SAF industry would ensure there are no stranded ethanol assets and provide a net economic benefit of $75 billion.

Figure 30. Economic impacts of ethanol production industry



9. Conclusion

Aviation is currently responsible for about 2.7% of domestic GHG emissions in the US, and aviation activity is only forecasted to continue to increase. SAF presents the most promising pathway to decarbonize aviation, a key component of the American and broader global economy. Gevo's planned NZ1 ATJ SAF facility will advance the commercial development of the nascent ATJ SAF industry while also yielding total benefits that outweigh net federal incentive costs. If properly incentivized, the SAF industry can continue to develop to meet U.S. decarbonization goals while also ensuring that the aviation industry continues to thrive and net benefits are positive.

Although external benefits from SAF are not reflected in pure market prices, they still produce real impacts. This analysis quantified some of these external benefits including avoided GHG reductions, avoided particulate matter emissions, regenerative agricultural practices, technological spillover, and energy security. The analysis also accounted for benefits to local and state economies. Not all benefits could be quantified. Additional benefits from SAF which were considered qualitatively in this analysis include benefits to energy security and to the future competitiveness of the agriculture, ethanol, and aviation industries under a rapid decarbonization scenario. The total benefit value makes ATJ SAF more valuable than fossil jet fuel.

Annually, the value of total benefits of ATJ SAF is estimated to be more than four to six times the cost of current federal incentives. On a unitized basis, every $1.00 of federal incentive costs for ATJ SAF yields an estimated $4.85-$6.53 of total quantified benefits. Total benefits are comprised of 73%-80% from **external benefits** and 20% from **local economic benefits**. The low end of the external benefits estimate includes near-term benefits of the technological spillover, and the high end includes long-term benefits of the technological spillover.

The total benefits on a per-gallon basis, the value of SAF's benefits (as extrapolated from NZ1) are **estimated at $6.65–$8.95 per gallon** versus a net incentive cost of $1.37 per gallon ($1.75 per gallon less $0.38 per gallon of incremental federal tax benefits flowing back to the government), as shown in Figure 2. Net federal incentive costs do not include the value of RFS RINs which are not a U.S. federal government cost for SAF. Federal programmatic costs are also excluded. The low end of the estimate considers near-term benefits of the technological spillover, and the high end includes long-term benefits of the technological spillover.

This would result in **total dollar benefits from the NZ1 facility estimated at $399–$537 million per year**.

- Total dollar external benefits from the NZ1 facility are $290–$428 million per year.
- Total dollar local economic benefits from the operations of the NZ1 facility are estimated at $116 million from direct, indirect, and induced impacts. Additionally, NZ1 is estimated to generate 836 jobs (100 at the plant and 736 in other local jobs). We estimate the federal tax revenue generated from the economic value-added at approximately $23 million annually.

- The annual federal net incentive cost from the NZ1 facility is estimated at $82 million.

Incentivizing the SAF industry to produce the volumes needed to meet the U.S. SAF Challenge goals will require additional incentives to SAF or a decrease in the subsidies that fossil jet fuel currently benefits from. Even though ATJ SAF cash production cost is on par with the commodity price of fossil jet fuel, the levelized cost of ATJ SAF includes return of and on capital and is currently higher. The price of fossil jet fuel also benefits from legacy capital investment and long-term subsidies. Leveraging the current federal incentives narrows but does not eliminate this difference. Leveraging both the 45Z tax credit and RFS RINS credit values, the price differential between the price of fossil jet fuel and the levelized cost of ATJ SAF is estimated at $1.24/gal. However, the 45Z tax credit will expire after 2027 under current law. Leveraging only the RFS RIN results in the ATJ SAF being $2.99/gal greater than the fossil jet price. State incentive programs could also contribute to reducing this difference. However, none of the current state programs result in a total incentive value that exceeds $2.99/gallon, leaving a gap in the near-term with the pending expiration of the federal 45Z credit. The next generation of ATJ SAF will benefit from the cumulative experiential learnings of the first generation of production facilities. These future production facilities could realize production costs that are 53% lower by 2030. However, this decrease in production costs will only be realized if the private sector and government work together to rapidly scale production to meet the U.S. SAF Grand Challenge goals.

In addition, we assessed the potential benefit that ATJ SAF could bring to offsetting the risk of potential economic loss in **rural agricultural communities.** The agriculture industry in particular benefits from the current demand for ethanol. Unused ethanol-production capacity would represent a loss in potential economic value and a loss in jobs that are essential to these rural communities. Additionally, as the nation moves toward a future where EVs gain a larger market share, there will be a decrease in demand for gasoline and likewise a reduced demand for ethanol for fuel blending. This presents an opportunity for another end use for ethanol to develop and provide continued support for the many jobs in agriculture and other supporting industries. If the ATJ SAF industry is incentivized to fully develop, the increase in demand for ethanol would help to offset the declining demand from other industries. This would provide continued support for rural economies and importantly make use of the corn crop production that continues to increase its yield.

We estimate that the ATJ industry's scale-up could generate a cumulative economic benefit of about $254 billion by 2050. The net economic benefit, representing the overall gain after recovering from stranded assets, is estimated to reach approximately $75 billion by 2050.

The aviation industry benefits from investments in foundational low-carbon technologies such as ATJ SAF. In the absence of scaling effective decarbonization pathways such as SAF, the aviation industry and the broader economy would be negatively impacted under a more rapid-decarbonization scenario such as net zero by 2050. Federal tax incentives don't need to be permanent. However, near-term investment to build a SAF production facility will be based on current technology, current production costs and currently available incentives. Extension of the 45Z tax credit will support these needed investments.

10. Glossary

Alcohol-to-jet sustainable aviation fuel (ATJ SAF): A sustainable aviation fuel production pathway that converts alcohols such as ethanol or isobutanol into hydrocarbons suitable for jet fuel blending. The process can use starch/sugar feedstocks (e.g., corn, sugarcane) as well as cellulosic crops (nonfood-based sources including crop residues, industrial wastes and energy crops like grasses, woody plants and algae).

Animal feed: A coproduct of the NZ1 facility. The animal feed produced has lower sugar content and carbon intensity than conventionally produced animal feed, thus reducing the overall carbon intensity of the animal farming supply chain.

Avoided emissions: Emissions that would otherwise be produced based on a reference scenario.

Biogenic CO_2 emissions: CO_2 emissions originating from a carbon source that is part of the natural carbon cycle and occurs on a policy relevant timeline.

Carbon capture and storage (CCS): To sequester carbon dioxide from a process or emission point and confine to long-term storage.

Corn oil: A coproduct of the NZ1 facility. This corn oil has a lower carbon intensity than conventionally produced corn oil. End uses include feedstock for low-carbon biodiesels or as a supplement in animal feed.[165]

Corn milling: The first step of the NZ1 process entails grinding the corn kernels and liquefying the corn flour into a slurry. This slurry mix is then fed into the fermentation process.

Direct economic impact: Economic impact resulting from the inputs purchased by the plant directly.

Economic benefits: Value-added to the economy through increased revenue, increased earnings, and generation of new jobs.

Energy independence: Decreasing reliance on foreign energy sources.

Energy security: Ensuring available energy at affordable price.

External benefits (positive externalities): Positive impacts to third parties that are not directly producing or consuming a product, so the value of external benefits is not captured in the product price.

Fermentation: Process that converts sugars to ethanol and CO_2. In the NZ1 process the CO_2 produced is captured. The outputs of the process are ethanol, animal feed, and corn oil.

Foundational technologies: A key technology whose development can produce advances in several pivotal areas.

Greenhouse gas (GHG): Gases that contribute to atmospheric warming.

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[165] U.S. Grains Council, “Ch. 3: Dry-grind production of ethanol, distillers corn oil and corn co-products”, 2018, https://grains.org/wp-content/uploads/2018/06/Chapter-3.pdf

Gross domestic product (GDP): A measure of the value of the final output of the goods/services produced within a country or region's borders.

Hydroprocessed esters and fatty acids (HEFA): A SAF production pathway that converts vegetable oils, waste oils, or fats into a blend of hydrocarbons suitable for mixing with conventional jet fuel.

Indirect economic impact: Economic impacts resulting from inputs purchased by the supporting industries.

Induced economic impact: Economic impacts resulting from the earnings spent by workers in the local region.

Land use change: Changes to land use occur either directly to a specific unit of land (LUC) or indirectly due to induced changes from market impacts (ILUC). The changes can impact the soil conditions and affect the soil carbon sequestration.

Levelized production cost: A measure of the average net present cost of production for a production facility over its lifetime, taking into account returns of and on all investment capital and all operating costs.

Lifecycle greenhouse gas emissions: A lifecycle accounting of all GHG emissions produced in making and consuming a product. The boundaries of this assessment begin with emissions from farming and soil sequestration related to the biomass feedstock and end with the aircraft's combustion of the fuel.

Local economic impact: Economic impact to the region of Kingsbury County, South Dakota and the surrounding counties/region.

Other fuel coproducts: The NZ1 process also yields lesser quantities of renewable diesel and naphtha, which have a lower carbon intensity than conventional fuels. End uses include industrial and fuel applications.

Particulate matter: Fine airborne particles emitted from numerous air pollution sources.

- PM 2.5: Particulate matter measuring less than 2.5 micrometers in diameter.

Regenerative agriculture: Practices that aim to improve soil health and farming sustainability by minimizing soil disturbances, increasing soil cover and increasing crop diversity.

Sustainable aviation fuel (SAF): renewable jet fuels derived from renewable feedstocks such as agriculture crops, vegetable and other oils and fats, and forestry and municipal wastes. SAF can be used in existing infrastructure and aircraft today as a drop-in substitute for fossil jet fuel and has significantly lower lifecycle GHG emissions.

Technological spillover: Spillovers occur when a firm's investment reduces production costs for other firms, thereby enhancing the industry-wide cost-reduction effect. The next generation of plants reap the benefits of the experiential learnings that have accumulated from the prior generations.

- Long-term: In this analysis, defined as the period between 2030-2050. The spillover effects from the initial NZ1 plant diminish over time as other advancements contribute to future developments.

- Near-term: In this analysis, defined as the period up to 2030. The spillover effects from the initial NZ1 plant are more pronounced in the near-term, as this period more directly benefits from these contributions.

Value-added economic benefit: The gross output less intermediates to capture the contribution to the gross domestic product (GDP).

Zero-carbon hydrogen: The hydrogen used for SAF production at NZ1 will be zero-carbon hydrogen. Hydrogen produced via electrolysis powered by renewable energy, a process which that does not produce direct GHG emissions.

11. Appendix

Table 1. ASTM-approved SAF[166]

SAF pathway	Possible feedstocks	Approved maximum blend ratio
Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	Coal, natural gas, biomass	50%
Synthesized kerosene with aromatics derived by alkylation of light aromatics from nonpetroleum sources	Coal, natural gas, biomass	50%
Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA)	Vegetable oils, animal fats, used cooking oils	50%
Synthesized paraffinic kerosene from hydrocarbon HEFA	Algae	10%
Synthesized isoparaffins from hydroprocessed fermented sugars	Biomass used for sugar production	10%
Alcohol-to-jet synthetic paraffinic kerosene	Ethanol, isobutanol, and isobutene from biomass	50%
Catalytic hydrothermolysis jet fuel	Vegetable oils, animal fats, used cooking oils	50%
Synthetic paraffinic kerosene with aromatics	C2–C5 alcohols from biomass	50%[167]

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[166] ICAO, “Approved Conversion Processes,” July 2023, https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx.

[167] Commercial Aviation Alternative Fuels Initiative, “Fuel Qualification,” 2023, https://www.caafi.org/focus_areas/fuel_qualification.html#approved.

Table 2. USDA soil erosion reduction impacts[168]

Impact	Description
Irrigation ditches and canals	Reduced erosion decreases costs to maintain ditches and canals due to decreased build-up of sediment and nutrients
Road drainage ditches	Reduced erosion decreases costs to maintain roads because of decreased build-up of sediment
Municipal water treatment	Reduced sediment in water, decreased municipal water treatment plant costs
Flood damages	Reduced sediment related to flood damages
Marine fisheries	Improved catch rates at fisheries due to decreased sediment and nutrient effluent
Freshwater fisheries	
Marine recreational fishing	
Municipal and industrial use	Reduced water use equipment damage from reduced sediment
Steam power plants	Reduced maintenance costs from reduced sediment and nutrient loading
Dust cleaning	Household cleaning costs due to wind-borne particulates

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[168] LeRoy Hansen and Marc Ribaudo, *Economic Measures of Soil Conservation Benefits: Regional Values for Policy Assessmen*t (Washington, DC: USDA, 2008).