Assessing the Prospects for Minnesota-Produced Sustainable Aviation Fuel

Humphrey School Capstone Report

The Hubert H. Humphrey School of Public Affairs
The University of Minnesota

Casidy Anderson
Meghan Anderson
Sophia Lackens

PA 8081 Capstone Workshop
Science, Technology & Environmental Policy
Instructor: Steve Kelley, Director, Master of Public Affairs

Spring 2025

Minnesota Department of Commerce

Subject Keywords (to aid searchability in the Digital Conservancy, minimum 4): **Sustainable Aviation Fuel, SAF, Decarbonization, Aviation, Transportation, Biofuel, Minnesota, HEFA, AtJ, FT, PtL**

Abstract (250 words or less):
The aviation sector contributes about 4% of global greenhouse gas (GHG) emissions (Ritchie, 2024). Sustainable Aviation Fuel (SAF) remains the only viable option for meaningful decarbonization in the near term. Minnesota is uniquely positioned to produce SAF in-state because of its existing partnership with Delta Airlines through the Minnesota SAF Hub, its thriving agricultural industry, and its proven interest in investing in decarbonization. There are four relevant pathways to produce SAF in Minnesota: Hydroprocessed Esters and Fatty Acids (HEFA), Alcohol-to-Jet (AtJ), Gasification with Fischer-Tropsch Synthetic Paraffinic Kerosene (FT), and Power to Liquid (PtL). The agricultural pathways, HEFA, AtJ, and FT, are the most technologically mature. The carbon intensity score for each pathway varies heavily by the feedstock. Soy, winter oilseeds, fats, oils, and greases (FOG), corn, forestry residue, and agricultural residues are the primary feedstocks considered for Minnesota-made SAF. Additionally, each pathway will require hydrogen, water, and land use. Energy and infrastructure considerations remain a challenge to production and will require greater investment to create the fundamental resources necessary for producing SAF in the state. Funding also remains a barrier, as SAF currently costs 2 to 10 times more than traditional jet fuel and is not expected to reach price parity at scale. Policy change, especially related to permitting processes and tax incentives, will be necessary to support SAF production in the short and long term. This report identifies seven areas for recommendation: research and development, pathway prioritization, foundational investment, funding barriers assessments, water concerns, and sustainable economy promotion.

Table of Contents

List of Figures

Glossary

ASTM-D7566	Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
Carbon Intensity (CI)	Carbon intensity is a measure of greenhouse gas emissions per unit of fuel, measured in grams of carbon dioxide equivalent per megajoule of energy (gCO2e/MJ) of the fuel. It is a complete life cycle analysis, sometimes called the “well to wake” (WtW) emissions, and includes all emissions from producing feedstocks, transporting feedstocks, the chemical conversion process, and transporting SAF to the point of use.
CI Score	A measure of carbon footprint associated with the production of fuel determined by inputting feedstock, processing, and transportation information into the 40B-SAF-GREET model developed by Argonne National Laboratory
Eutrophication	An excessive enrichment of a body of water with nutrients, primarily nitrogen and phosphorus.
Feedstock	Sources of renewable biomass for SAF fuel production.
Green hydrogen	The production of hydrogen gas using carbon-free renewable electricity.
Green tons	A green ton refers to the weight of biomass material in its original, freshly harvested state, including its natural moisture content. This contrasts with a dry ton, which refers to the biomass weight after all moisture has been removed.
Greenfield	A project located on a new site with no existing foundation.
Grey hydrogen	The production of hydrogen gas from natural gas, or methane, using steam methane reformation, but without capturing the greenhouse gases made in the process. The most common form of hydrogen in current production.
Jet-A	A kerosene-type fuel compatible with most jet aircraft, both civil and military, helicopter turbine engines, turboprops, and compression-ignition piston engines.
Megajoules (MJ)	A unit of energy measurement equivalent to one million joules (1,000,000 J). One megajoule is equal to 947.817 British thermal units (BTU).
Neat SAF	Sustainable Aviation Fuel that is entirely renewable and not blended with conventional jet fuel.
Pathway	The specific process and technologies used to convert feedstock into SAF.
Sustainable Aviation Fuel	A drop-in jet fuel replacement that achieves a 50% emissions reduction in comparison to Jet-A. Currently, SAF is only usable in aircraft when blended with Jet-A at a maximum of 50% SAF.
Tons	A ton is a unit of weight commonly used in the United States to measure biomass feedstocks. In this context, it equals 2,000 pounds.

List of Acronyms

ASTM	American Society for Testing and Materials
AtJ	Alcohol to jet
BGal	Billion gallons
BG-FT	Biomass Gasification with Fischer-Tropsch
CAF	Climate Action Framework
CAPEX	Capital expenditures
CFR	Clean Fuel Regulations
CI	Carbon intensity
CO	Carbon monoxide
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
DAC	Direct air capture
DOE	Department of Energy
ESG	Environmental, social, and governance
ETS	Emissions Trading Scheme
FOG	Fats, oils, and greases
FSC	Forest Stewardship Council
FT	Fischer-Tropsch
GHG	Greenhouse gas
GPM	Gallons per minute
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies
GW	Gigawatts
GWh	Gigawatt hours
HEFA	Hydroprocessed esters and fatty acids
IRA	Inflation Reduction Act
kWh	kilowatt hours
LCA	Life cycle assessment
LCFS	Low-carbon fuel standard
MGPY	Million gallons per year
MJ	Megajoules
MnCIFA	Minnesota Climate Innovation Finance Authority
MSP	Minneapolis-St.Paul International Airport
MW	Megawatts
NGO	Non-governmental organization
NOAK	Nth of a Kind
NREL	National Renewable Energy Lab
PTC	Production Tax Credit
PtL	Power to liquid
RD	Renewable diesel
RIN	Renewable Identification Number
SAF	Sustainable aviation fuel
SFI	Sustainable Forestry Initiative
TRL	Technological readiness level
TWh	Terawatt hours
UCO	Used cooking oil
USDA	United States Department of Agriculture
WtW	Well to wake

Executive Summary

Sustainable aviation fuel (SAF) is a lower-carbon alternative to conventional jet fuel that can be used in existing airplanes, allowing for rapid decarbonization of the aviation industry. SAF shows strong promise in Minnesota due to an established biofuels industry, available agricultural feedstocks, and a large airport hub at Minneapolis-St. Paul (MSP) Airport. SAF must reduce the lifecycle greenhouse gas emissions per unit of fuel, referred to as the carbon intensity score (CI), by at least 50% compared to conventional jet fuel.

While there are eleven approved chemical conversion processes, known as pathways, to produce SAF, the four most likely to reach large scale in Minnesota are analyzed in this report: Hydroprocessed Esters and Fatty Acids (HEFA), Alcohol to Jet (AtJ), Fischer-Tropsch (FT), and Power to Liquid (PtL). A summary of pathway comparisons is found in Figure 1 below. Each uses distinct feedstocks and offers different levels of decarbonization and environmental impacts. A summary of feedstock comparisons is found in Figure 2.

Figure 1: Summary of Pathway Comparisons

Pathway	NOAK cost (USD per gallon)	Annual Requirements for 470 MGPY*		Water Use (gallons/gallons of SAF)***	TRL
		Hydrogen (Mg)	Electricity** (GWh)		
HEFA	$4 - 11	35	1817	2-6	8-9
AtJ	$4 - 9	16	848	7-12	7
FT	$3 - 11	12	606	7-12	4
PtL	$6 - 20	447	23500	2-4	3-4

*Represents all of MSP's projected fuel demand in 2050, assuming a 50% blend with Jet-A
**Electricity requirements for HEFA, AtJ, and FT are the electricity demands for green hydrogen required for the pathway, which makes up the majority of energy needs
***Range reflects variation in feedstock type, hydrogen source, facility processing design, cooling method, and local water quality.

The Hydroprocessed Esters and Fatty Acids (HEFA) pathway is the most commercially mature of the pathways and is expected to make up the majority of domestic production through 2030. Its feedstocks include soybeans, winter camelina, rendered animal fats, and used cooking oil. While soybeans have high output in Minnesota, row crops like corn and soy provide a high CI score, and the process will require additional decarbonization (e.g., sustainable agriculture practices, on-site renewable energy) in order to meet the required 50% carbon intensity reduction threshold. Waste fats and oils provide a low CI score but face steep competition from other biofuels production. Winter camelina is an emerging crop with real promise for SAF, but has yet to reach scale. Developed by the University of Minnesota and the Forever Green Initiative, it is a winter annual oilseed that can be planted over the winter. It has been shown to reduce nitrate pollution, limit soil erosion, and support biodiversity.

Alcohol to Jet (AtJ) will be primarily produced from corn ethanol in Minnesota and benefits from Minnesota's strong ethanol industry and infrastructure. Like HEFA made from soybeans, AtJ has a high CI score and requires additional decarbonization at the farm and/or production plant. AtJ will compete with ethanol for feedstocks in the short term, but will also support the industry as ethanol use declines with transportation decarbonization over time.

The Fischer-Tropsch (FT) pathway uses agricultural and forestry residues as feedstocks, both of which are abundant in Minnesota. Though it is typically considered one of the less commercially mature pathways, the lone SAF production plant that has been announced in Minnesota (DG Fuels in Moorhead, MN) plans to use the FT pathway.

The Power to Liquid (PtL) pathway is the least commercially mature pathway, not expected to be a major producer until the 2040s, but it offers the greatest potential for decarbonization. PtL converts clean energy and captured carbon dioxide into liquid fuel and will require considerable levels of clean energy. To meet the entirety of the projected 2050 fuel demand at Minneapolis-St. Paul Airport with only the PtL pathway, 23.5 TWh/yr will be required, more than Minnesota's current annual clean energy production. Permitting reform will be critical to meeting the scale of the renewable energy buildout needed for SAF, particularly if PtL is a major component of the SAF industry.

Figure 2: Summary of Feedstock Comparisons

Pathway	Feedstock	CI Score	Carbon Abatement per Million Gallons (Mg CO_2e)	2035 Projected Capacity* (MGPY)	2050 Projected Capacity* (MGPY)
HEFA	Winter Camelina	29	4496	212	940
	Soy	47	3358	446	446
	Fats, Oils, and Greases (FOG)	14	5443	119	128
AtJ	Corn	75	1589	2390	2390
FT	Agricultural Residues	8	5822	1515	2366
	Forestry Residues	8	5822	125	146
PtL	Clean energy + CO_2	0	6328	-	-

*Based on feedstock availability. Assumes 50% blend with Jet-A

All pathways require hydrogen as a feedstock, but SAF will compete with other industries for green hydrogen. Renewable energy demand for green hydrogen for SAF will range from 606 GWh to 1870 GWh annually (excluding PtL).

While feedstock availability is typically considered a barrier to SAF, our analysis of available biomass found that Minnesota has adequate feedstocks to exceed the entirety of Minnesota's jet fuel demand. In particular, the expansion of winter camelina and the utilization of existing waste agricultural and forestry residues provide sufficient feedstocks to meet demand while avoiding competition with existing land uses and providing farmers with an additional revenue stream.

SAF is two to ten times more expensive than fossil jet fuel and is not expected to reach price parity even when scaled. Tax incentives are critical to expand the industry in the short term, and additional policy options such as a Low-Carbon Fuel Standard or SAF mandate will be necessary in the longer term.

Access to capital investment is another critical barrier for the expansion of a SAF industry. The average production facility can cost anywhere from $1 billion to $5 billion to build a greenfield facility. Providing long-term assurance to the industry through durable policies will be critical to reducing commercial risk.

Currently, state and federal tax credits are available to SAF producers and blenders. In Minnesota, a $1.50 per gallon tax credit is available to producers and blenders that meet the 50% carbon intensity reduction, with an expiration date of 2030. Legislation has been proposed this session to offer an additional $0.02 per gallon for each CI point reduction past 50%, up to a maximum of $2.00. This legislation also extends the tax credit out to 2035. Additional state policies supporting research (e.g., the Forever Green Initiative) and farmers implementing sustainable agriculture practices (e.g., the Soil Health Financial Assistance Program) indirectly support Minnesota’s SAF Industry.

Recommendations:

- Develop policies to support and promote the production of SAF, especially as it relates to permitting, low-carbon fuel standards, and tax incentives.
- Prioritize pathways that are best aligned with Minnesota’s strategic plans. This includes prioritizing low-carbon-intensity pathways, avoiding feedstocks that compete with food production or have high environmental impacts, and prioritizing efficient uses of green hydrogen.
- Invest in foundational infrastructure, including a renewable energy grid and high-voltage transmission infrastructure.
- Assess and mitigate barriers to funding by extending tax credits, promoting long-term offtake agreements, and exploring alternative funding strategies.
- Prioritize sustainable water use.
- Support greater research and development, especially as it relates to further decarbonization.
- Promote Minnesota locally and internationally as a leader in developing a decarbonized economy through storytelling and public conversations.

1. Introduction

As part of the University of Minnesota Humphrey School of Public Affairs Capstone program, we are a team of three graduate students undertaking a project sponsored by the Minnesota Department of Commerce, Division of Energy Resources. This report explores how the state of Minnesota can leverage its agricultural resources, renewable energy potential, and policy environment to support the growth of a local SAF industry.

Our work examines feedstock availability, energy generation needs, natural resource considerations, and policy frameworks, while also incorporating future market scenarios, tax incentive analyses, and lessons from international efforts. Through this research, we aim to provide actionable recommendations to support Minnesota's leadership in the emerging SAF economy and help the aviation sector meet its climate goals.

Minnesota is strategically positioned to scale the future of sustainable aviation fuel (SAF). The state boasts an established biofuels industry and expansive agriculture, as well as a large demand for jet fuel at Minneapolis-Saint Paul Airport, and proven public and private interest, clearly illustrated through the Minnesota SAF Hub.

Sustainable Aviation Fuel (SAF) has emerged as a critical solution for reducing greenhouse gas (GHG) emissions in the aviation industry. Unlike conventional jet fuel, SAF is derived from renewable sources such as waste oils, agricultural products, and synthesized hydrocarbons, leading to much lower lifecycle carbon emissions.

This opportunity is in alignment with the Minnesota Climate Action Framework (CAF). Exploring the prospects of Minnesota-produced SAF supports the highlighted CAF goals below (Climate Action Framework, 2025).

Clean transportation: Connect and serve all people through a safe, equitable, and sustainable transportation system.

Clean economy: Build a thriving carbon-neutral economy that produces goods and services with environmental benefit and equitably provides family-sustaining job opportunities.

Climate-smart natural and working lands: Enhance climate benefits by absorbing and storing carbon, reducing emissions, and sustaining resilient landscapes.

Healthy lives and communities: Protect the health and wellbeing of all Minnesotans in the face of climate change.

1.1 Discussion of the Opportunity Statement Driving this Study

Minnesota has a unique and timely opportunity to become a global leader in SAF production, leveraging its strong agricultural sector, cutting-edge research institutions, and commitment to clean energy. Currently, the Minnesota SAF Hub – an innovative public-private partnership led by Greater MSP – is at the forefront of this effort, uniting industry leaders, policymakers, environmental groups, and universities in a shared mission to build a world-class SAF industry.

The aviation industry faces a critical challenge: how to transition to low-carbon fuel at scale while maintaining economic viability. SAF is the only viable near-term solution for decarbonizing air travel, yet nowhere does there exist an industrial-scale SAF economy that meets three essential market-readiness criteria: production at scale, low carbon intensity, and cost competitiveness (Air Action Transport Group, 2023).

Building an SAF industry in Minnesota represents a generational opportunity to drive economic growth, job creation, and responsible resource management across the state. Minnesota's geographical location supports a SAF industry created from a diverse range of feedstocks, including agricultural products and residues, forestry and urban wood waste, dedicated energy crops such as winter camelina, and e-fuel potential from captured carbon dioxide (CO_2) and green hydrogen.

Each of these inputs can produce SAF that meets or exceeds the 50% carbon reduction threshold required to qualify for federal and state tax incentives, with some pathways achieving reductions of 75% or even net-zero emissions. By 2030, the Minnesota SAF Hub aims to scale production across multiple facilities statewide, ensuring that economic benefits reach both urban and rural communities (Greater MSP, 2025).

Minnesota has already taken strong steps and made progress in the initial phases of creating a robust SAF industry in the state. Achievements to date include the development of a SAF blending facility at Flint Hills refinery which will pipeline blended SAF directly to MSP Airport (Niepow, 2024), the creation of a private demand consortium that includes a commitment to purchase the first 15 million gallons of SAF at premium pricing (Delta News Hub, 2024), the completion of the first SAF-powered flight from MSP in September 2024 using Minnesota-grown winter camelina, and a $5 billion investment initiative from DG Fuels to build a SAF production facility in Moorhead, capable of producing 193 million gallons of SAF annually (International Bioenergy, 2024).

Minnesota's energy and aviation stakeholders are now focused on securing additional SAF refineries, maintaining financial incentives to keep SAF investment in Minnesota, and launching a 1-million-acre winter camelina study to scale sustainable feedstock production (Forever Green Initiative, 2025).

By aligning policy, investment, and innovation, Minnesota can establish itself as the premier SAF hub in the United States. This initiative has the potential to not only create tens of thousands of good-paying jobs and attract billions in private investment, but will also reaffirm Minnesota's reputation as a leader in solving some of the world's most pressing challenges.

1.2 References to Report Goal, Questions, and Evaluation Criteria

This report aims to identify potential SAF pathways for decision makers based on feedstock availability, production methods, GHG emissions reductions, ability to scale, possible barriers, costs, and capacity of the sector in Minnesota. The report is guided by the following research questions:

- Economic analysis: How much of the feedstocks can be produced in Minnesota for each SAF pathway, and on what timeframe, given competing resource needs (e.g., renewable energy needs for other Minnesota industries, existing feedstock uses)?
- Policy analysis: What are the current policies impacting SAF?
  - Policy recommendations: What policies could provide SAF with the best outcomes in Minnesota?
- Cost-benefit analysis: What are the costs (e.g., financial, land use) compared to the benefits (e.g., emissions, economics, job creation) of SAF in Minnesota?

Opportunities, comparisons, and recommendations are based on key evaluation criteria, chosen in partnership with the Minnesota Department of Commerce. They include carbon intensity, feasibility, cost, job creation, land and water use, and environmental impact.

1.3 Outline of the Report and Key Findings

Section 2 of this report will provide details on the four identified SAF pathways for Minnesota, along with each pathway's primary feedstocks. Section 3 provides an economic analysis of the potential for SAF in Minnesota. Section 4 will explore the policy landscape surrounding SAF, including legislation from Minnesota, the United States, and abroad, as well as relevant corporate guidelines. Section 5 will outline recommendations for the future of SAF scaling in the state. To close the report, the project team's conclusions are presented in Section 6.

Ultimately, multiple pathways have the potential to produce the quantity of SAF needed for meaningful decarbonization in Minnesota. However, by pursuing multiple pathways concurrently, Minnesota can promote diversity and reduce production risk within the industry, leading to greater economic strength. An overview of the key pathways for the state is presented in the following section.

2. Pathways and Feedstocks Overview

2.1 Overview of the Identified SAF Production Pathways

Sustainable aviation fuel is a drop-in replacement for traditional fossil-fuel-derived Jet-A fuel, meaning that it can be used in existing airplanes. The final product of each pathway must conform to fuel quality and blending standards per ASTM D7566 *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*. SAF produced and blended per ASTM D7566 standards is considered equivalent to traditional Jet-A fuel.

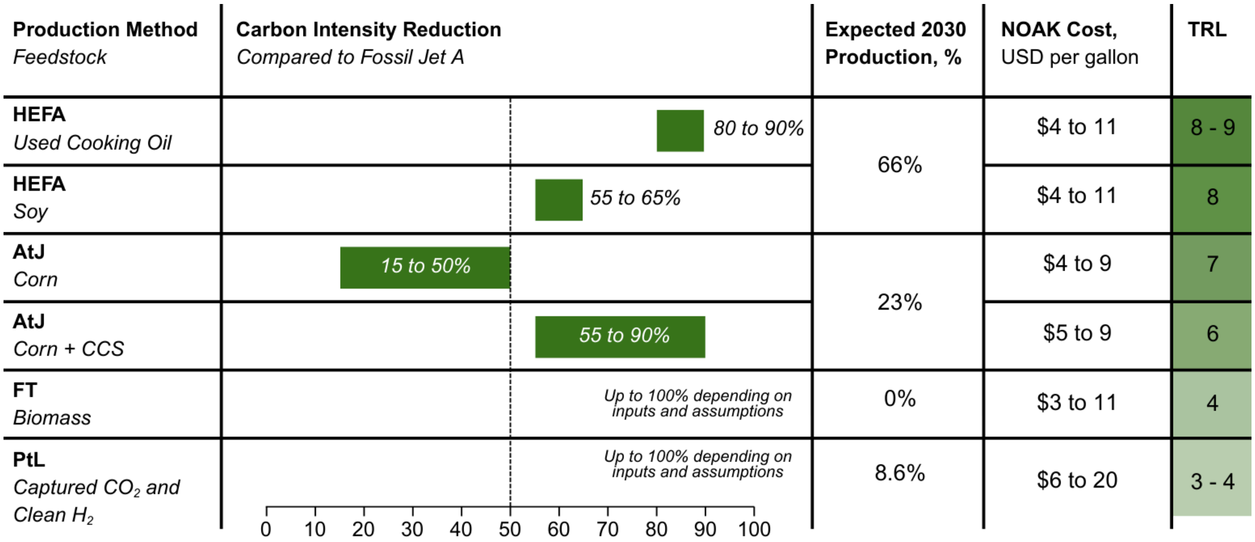
There are currently 11 ASTM-approved SAF pathways. Based on technological readiness, cost, and availability of feedstock, four pathways are likely to play the largest role in Minnesota's SAF industry: Hydroprocessed Esters and Fatty Acids (HEFA), Alcohol to Jet (AtJ), Gasification with Fischer-Tropsch (FT), and Power to Liquid (PtL).

The carbon intensity (CI) score is the main criterion for determining eligibility for SAF incentives. To be considered eligible for state and federal incentives, the sustainable aviation fuel must have a 50% reduction in carbon intensity compared to traditional jet fuel. As the CI score for Jet-A fuel is 89 gCO_2e/MJ, all SAF must have a maximum CI score of 44.5 gCO_2e/MJ to be eligible for incentives.

The four identified pathways have a range of carbon intensity scores. Figure 3 shows a range of carbon intensity reductions for the various pathways and feedstocks. Notably, each pathway's potential for carbon intensity reduction is largely based on the feedstock used. As such, an understanding and comparison of both pathways and feedstocks is necessary to examine the future of SAF in Minnesota. A summarized comparison of pathways and feedstocks can be found in Figure 13.

A key limitation to SAF for all pathways will be the cost of production. While sourcing funding for facility builds will be a challenge, the price per gallon for SAF for all production pathways is not expected to reach parity with jet fuel at scale without incentives, as described further in Section 3, Economic Analysis.

Figure 3: Carbon Intensity Reduction and Technological Readiness Level by Pathway



Production Method *Feedstock*	**Carbon Intensity Reduction** *Compared to Fossil Jet A*	**Expected 2030 Production, %**	**NOAK Cost,** USD per gallon	**TRL**
HEFA *Used Cooking Oil*	*80 to 90%*	66%	$4 to 11	8 - 9
HEFA *Soy*	*55 to 65%*		$4 to 11	8
AtJ *Corn*	*15 to 50%*	23%	$4 to 9	7
AtJ *Corn + CCS*	*55 to 90%*		$5 to 9	6
FT *Biomass*	Up to 100% depending on inputs and assumptions	0%	$3 to 11	4
PtL *Captured CO_2 and Clean H_2*	Up to 100% depending on inputs and assumptions	8.6%	$6 to 20	3 - 4

Figure Footnotes: *1. For available pathways in the 40BSAF-GREET 2024 model, carbon intensity reduction (GHG 100-year reduction) is calculated using sample inputs unless otherwise noted. Note that these sample model values are illustrative only and meant to be modified by users to calculate lifecycle carbon emissions associated with their projects. For pathways in this table that are currently unavailable in 40BSAF-GREET (FT and PtL), carbon intensity reduction is calculated based on other publicly available models and literature; ; 2. Consistent with carbon emission reduction strategies provided in 40B guidance and 40BSAF-GREET, across all available pathways, the high-end of CI reduction assumes use of renewable electricity credits (RECs) to reduce grid-related emissions, use of landfill gas-derived renewable natural gas with a counterfactual of flaring in place of fossil natural gas, and use of 45V modeled H_2 with the sample 45V modeled H_2CI (3 kg CO e/kg H) in place of fossil H_2; 3. HEFA production capacity*

is not broken out by feedstock and AtJ production capacity is not broken out by inclusion of CCS; 4. AtJ + CCS assumes 285,000 metric tons of CO_2 captured and stored as part of the ethanol production process; 5. FT is not an available pathway in 40BSAF-GREET. However, FT with certain biomass feedstocks could result in 100% carbon intensity reduction, depending on inputs and assumptions, including but not limited to available co-products, transport emissions for biomass feedstock, and inclusion of CCS; 6. PtL is not an available pathway in 40 B-SAF-GREET. However, PtL can result in 100% carbon intensity reduction depending on inputs and assumptions, including but not limited to the biogenic CO_2 source and electricity source for clean H_2 production.
Data Sources: *40BSAF GREET 2024, accessed October 2024;37 Other publicly available models and literature on carbon accounting*
Source: *Howe et al., 2024*

2.1.1 Hydroprocessed Esters and Fatty Acids (HEFA)

The United States Department of Energy Alternative Fuels Data Center describes HEFA as a process in which triglyceride feedstocks such as plant oil, animal oil, yellow or brown greases, or waste fat, oil, and greases are hydroprocessed to break apart the long chain of fatty acids, followed by hydroisomerization and hydrocracking (Alternative Fuels Data Center, 2025). It has a 50% blend limit with Jet-A as per ASTM 7566. The HEFA pathway is the most commercially mature of the SAF pathways and makes up the vast majority of announced SAF capacity in the United States, accounting for 1.7 billion gallons (Bgal) or ≈77% of the total 2.2 Bgal of announced SAF capacity by 2030 (DOE, 2025). However, there is strong competition among biodiesel industries, bioindustrial manufacturers, and food processing businesses for feedstocks.

The primary feedstocks for the HEFA pathway are vegetable oils (e.g., soybean, distillers' corn oil, canola, sunflower), oilseed cover crops such as winter camelina and pennycress, used cooking oil, and rendered animal fats. Carbon intensity scores for HEFA vary widely based on feedstock, with minor processing variations required for different feedstocks (see Figure 6).

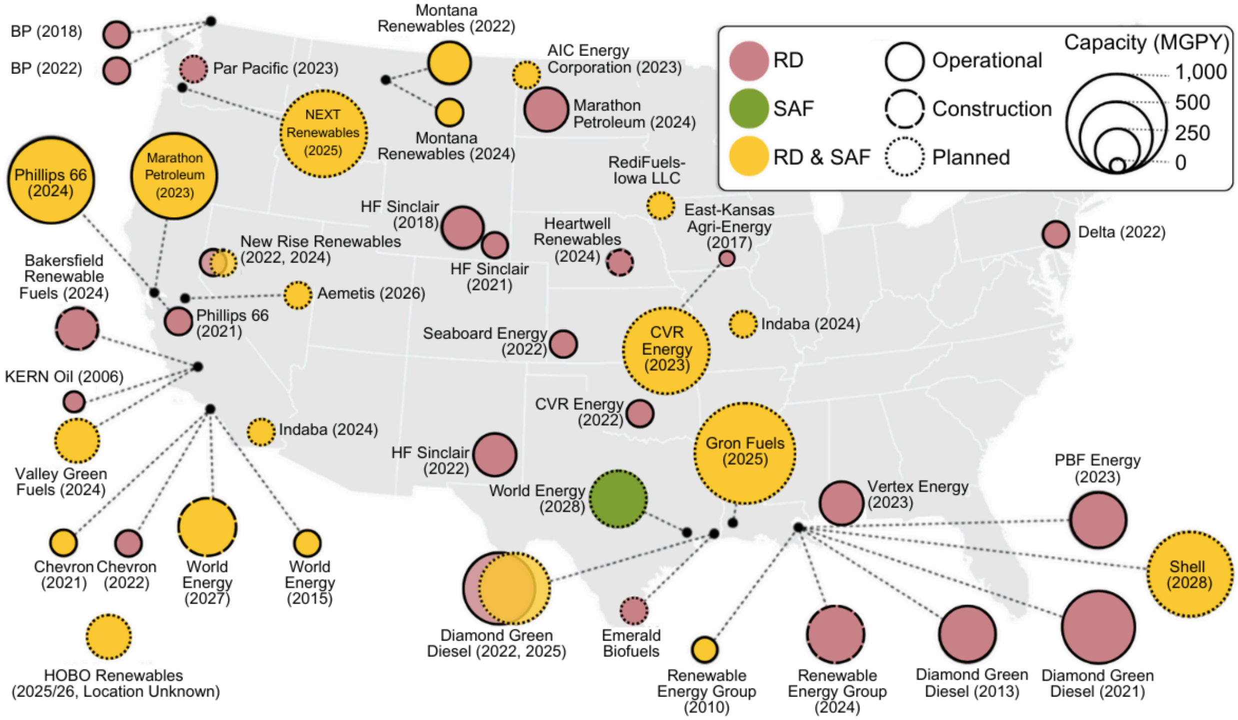
One major benefit of the HEFA pathway is its commercial readiness, or technical readiness level (TRL). HEFA SAF is the most technologically mature of the production processes (TRL 8-9, Figure 3) because of the notable overlap with other fuel production technologies, namely renewable diesel (RD) (Calderon, 2024).

The HEFA chemical conversion process can produce both RD and SAF (Calderon, 2024). As a result, many HEFA facilities produce both SAF and RD (see Figure 4), and this practice is becoming more common as the SAF industry develops.

Relatedly, it is also possible to produce SAF by coprocessing HEFA feedstocks with fossil fuels at petroleum refineries, producing both SAF and fossil fuels in the same process. Coprocessing SAF with petroleum is currently limited to 5% HEFA feedstocks, though approval of 30% coprocessing is presently under review by ASTM (Calderon, 2024). As access to capital investment is a major limitation of the SAF industry generally, coprocessing at petroleum refineries minimizes capital expenditure (CAPEX) needs and decreases operational risk.

Because of these operational similarities between petroleum refining and HEFA production, retired petroleum refineries could be retrofitted to produce HEFA SAF. As the economy transitions towards decarbonization, a decline in demand for petroleum products over time could be anticipated. Retrofitting retired petroleum refineries provides an option to lower CAPEX in comparison to a greenfield production site (Calderon, 2024). For example, the expected cost of repurposing a petroleum refinery into HEFA production was reported as $850 million for an 800 MGPY facility, compared to $1.25 billion for a 900 MGPY greenfield facility (Calderon, 2024; U.S. Department of Energy, 2025).

Figure 4: Location and Capacity of HEFA SAF and RD facilities, including expansions in operation, under construction, and planned in the United States



Source: Sustainable Aviation Fuel State-of-Industry Report: Hydroprocessed Esters and Fatty Acids Pathway (Calderon et al., 2024)

Feedstock availability is a key limitation for the HEFA pathway. Feedstocks make up 88% of the production cost for the HEFA process (Calderon, 2024), making it highly susceptible to fluctuations in prices. While Minnesota has an abundance of many of the HEFA feedstocks (e.g., vegetable oils such as soy and canola, distillers corn oil from ethanol processing, animal fats, and used cooking oil from commercial cooking operations), production of these feedstocks is not expected to keep up with increasing demand from SAF and other biofuels. Long-term national projections predict an overall increase in HEFA feedstocks (15% increase through 2034), with soybean oil and animal fats increasing in supply while other vegetable oils remain stable (USDA, 2025; Calderon, 2024).

As such, SAF will continue to compete with renewable diesel (RD) for feedstocks in the future. While SAF and RD are co-produced in the HEFA process, RD has higher profit margins than SAF, which incentivizes RD production at the expense of SAF (Alternative Fuels Data Center, 2025).

Additionally, the national RD market benefits from the Low-Carbon Fuel Standard (LCFS) in California, the largest consumer of RD. This growing demand for RD has increased the price of feedstocks for the HEFA process. While prices for soybean oil are projected to remain relatively stable (USDA, 2025), imports of fat, oil, and grease (FOG) have spiked in recent years to keep up with RD demand, leading to a corresponding increase in FOG prices (Calderon et al., 2024).

Renewable diesel is necessary for the decarbonization of medium- and heavy-duty vehicles in the present; however, as vehicle fleets turn to electric, demand for RD will likely decrease. In the future, SAF via HEFA could become more feasible due to reduced competition and mitigate stranded investment in RD.

The SAF that was used on the September 2024 flight departing from Minneapolis-St. Paul Airport was made via the HEFA process at Montana Renewables using Minnesota-grown winter camelina, demonstrating the viability and opportunity for this pathway (Fravel, 2024). Minnesota's wide availability of HEFA feedstocks makes the state well-positioned to become an early adopter of and leader in SAF via HEFA.

2.1.2 Alcohol-to-Jet (AtJ)

Alcohol to Jet (AtJ) is the process of converting alcohols into SAF. This pathway is ASTM approved and generally considered commercially ready (TRL 8, Figure 3); however, production is limited. Challenges – including economic preference for ethanol over SAF, competition with ethanol manufacturers and livestock feed producers, and a high carbon intensity score – have delayed widespread adoption.

The US DOE Alternative Fuels Data Center describes AtJ as the "conversion of cellulosic or starchy alcohol (isobutanol and ethanol) into a drop-in fuel through a series of chemical reactions—dehydration, hydrogenation, oligomerization, and hydrotreatment. The alcohols are derived from cellulosic or starchy feedstock via fermentation or gasification reactions. Ethanol and isobutanol produced from lignocellulosic biomass (e.g., corn stover) are considered favorable feedstocks, and other potential feedstocks (not yet ASTM approved) include methanol[1], isopropanol, and long-chain fatty alcohols." It has a blend limitation of 50%, currently the highest blend possible with Jet-A.

The primary feedstock for AtJ SAF is ethanol from corn, sugarcane, or cellulosic biomass. In Minnesota, the most likely feedstock for AtJ SAF will be corn ethanol. However, isobutanol (from biomass or engineered microbes) and methanol (from CO_2 + H_2 or biomass) are also viable feedstock options in the future. Again, many of the impacts from this pathway are dependent on

---

[1] Methanol is another potential feedstock for the AtJ pathway. Methanol can be produced from captured CO_2 and green hydrogen, making it a highly sustainable option. However, it has a lower energy density than ethanol, necessitating additional processing for jet fuel compatibility.

Whereas most AtJ feedstocks undergo fermentation or gasification to produce an alcohol, methanol to jet (MTJ) mainly uses methanol produced from renewable hydrogen and captured CO_2 (Lam, 2024). This technology is in its infancy(TRL) and is not ASTM-approved (Lam, 2024).

the feedstock used in production, including corn-based ethanol and methanol. A more detailed discussion of benefits and challenges is included in Section 2.2.5 Corn.

Currently, LanzaJet is the only company in the U.S. making AtJ SAF. LanzaJet's Freedom Pines Fuels facility in Soperton, Georgia, is the first commercial plant of its kind globally (LanzaJet, 2025). The facility uses low-carbon ethanol to produce SAF and renewable diesel fuel. The process uses grid electricity, natural gas, gray hydrogen, and low-carbon-intensity ethanol from Brazilian sugarcane. The facility is supported by a loan from the DOE's Bioenergy Technology Office (BETO), as well as a robust portfolio of private investors that include Airbus, All Nippon Airways, British Airways, Southwest Airlines, Groupe ADP, LanzaTech, Microsoft's Climate Innovation Fund, Mitsui & Co., Shell, and Suncor Energy (LanzaJet 2024).

Major opportunities for AtJ SAF include the potential for cellulosic ethanol, which is produced from non-edible plant materials and reduces environmental impact, and the ability to produce carbon-neutral fuel when methanol is combined with green hydrogen. Further challenges include the need for costly infrastructure upgrades and the energy-intensive nature of hydrogen production for methanol-to-jet conversion.

In Minnesota, SAF made using the AtJ pathway is expected to rely on corn as its feedstock. In this way, SAF has the potential to play a major role in the future of the state's ethanol industry, with the added benefit of incentivizing sustainable practices in corn farming.

2.1.3 Gasification with Fischer-Tropsch (FT)

The Fischer-Tropsch (FT) synthesis pathway offers a promising approach to SAF production by converting woody biomass, municipal solid waste, and other cellulosic feedstocks into syngas through gasification, followed by a catalytic reaction that synthesizes jet fuel. One of its primary advantages is its potential to achieve low lifecycle emissions, with carbon intensity (CI) scores near or below zero when utilizing waste-derived feedstocks. This makes FT an attractive option for long-term decarbonization efforts in aviation. However, several challenges hinder its near-term scalability, including technological immaturity (TRL 4, Figure 3), a lack of established infrastructure, and high production costs.

These barriers make it unlikely that FT-based SAF will reach large-scale demonstration by 2030. Nevertheless, continued research and development investments are crucial to advancing this technology, ensuring that FT can play a vital role in achieving long-term SAF production and emissions reduction goals beyond 2030.

While this pathway is typically considered one of the less technologically mature pathways, the sole SAF production plant that has been announced in Minnesota is planning to use the FT pathway. DG Fuels announced a 193 million gallon per year (MGPY) plant that will be located in Moorhead, MN (DG Fuels, 2024).

2.1.4 Power to Liquid (PtL)

Power to Liquid (PtL) is a promising synthetic fuel production pathway that harnesses renewable electricity to produce green hydrogen via electrolysis, which is then reacted with captured carbon dioxide (CO_2) to synthesize hydrocarbons for jet fuel. PtL, often called eSAF for aviation, can potentially deliver near-zero lifecycle emissions, particularly when carbon inputs are sourced through Direct Air Capture (DAC). Point-source carbon dioxide capture also holds strong promise when captured from industries with high-purity CO_2 emissions, such as ethanol, creating a synergy between PtL and AtJ SAF production.

Despite its potential, PtL is the most nascent of the approved SAF pathways, and remains in the early stages of technological maturity (TRL 3-4, Figure 3). Currently, few pilot plants exist globally; only one of which is located in the United States. Production is highly energy-intensive, requiring approximately 100 kWh of electricity per gallon of SAF (Rojas-Michaga, 2023), an order of magnitude larger than the most energy-intensive of the other pathways. Because of the high energy requirements of PtL, the pilot plants to date are located in coastal areas with access to offshore wind farms, which cover the high energy demands of these facilities (Catalyst, 2024). To meet the projected SAF demand at MSP Airport by 2050, 23.5 TWh of low-carbon electricity would be required (see Figure 10), surpassing the state's total 2024 renewable electricity output of 19.23 TWh (2025 Minnesota Energy Factsheet). Consequently, widespread PtL deployment is unlikely before the 2040s and will require considerable investments and advancements in green hydrogen and carbon capture technologies.

As efforts to combat environmental challenges advance, increasing attention is being directed toward the over 1 trillion tons of human-caused CO_2 emissions released since the Industrial Revolution (Ritchie, 2024). DAC has gained popularity as a tool that can help manage these historic emissions by removing them from the atmosphere and sequestering or repurposing them for products like SAF. Additionally, DAC presents opportunities to mitigate emissions of hard-to-decarbonize industries like cement production that are likely to rely on carbon-based fuels for decades to come.

United Airlines recently announced an agreement to purchase up to 500,000 tons of CO_2 from Heirloom Carbon, which operates a DAC facility in Tracy, California (Heirloom Carbon, 2025). One ton of captured CO_2 yields about 85 gallons of SAF (Heirloom Blog, 2025). Currently, Heirloom only captures 1,000 tons of CO_2 per year, with plans of expanding operations in Louisiana. Heirloom's second proposed location in Louisiana is estimated to cost $1 billion, with $550 million of that from DOE funding. The plant is projected to capture 17,000 tons of CO_2 per year.

There are 25 DAC facilities in operation globally, which cumulatively capture around 100,000 tons of CO_2 per year (Moniz et al., 2024). United Airlines' intention to purchase up to 500,000 tons of CO_2 represents an ambitious target based on the current global production.

Challenges of the PtL pathway in Minnesota include access to the renewable energy requirements, managing the high capital expenditure (CAPEX) of a PtL facility, particularly when integrating DAC, and the availability of green hydrogen.

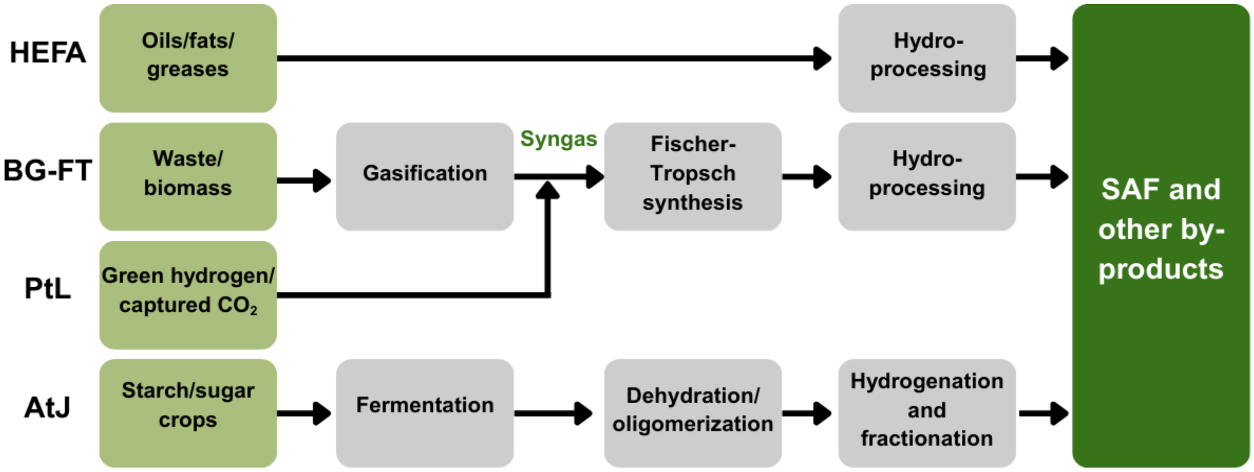
Current Minnesota state legislation only allows for biomass-based SAF, and PtL is not currently eligible for the Minnesota SAF Tax Credit (Holler, 2024). However, bills currently pending in the Minnesota state legislature would expand the definition of SAF to include PtL SAF (Minnesota Legislature, 2025).

2.2 Comparison of Necessary Feedstocks

2.2.1 Overview

A primary challenge for each SAF pathway is sourcing the necessary feedstocks. Feedstocks for the HEFA pathway consist of oilseed crops (e.g., soybean, winter camelina) and waste fats, oils, and greases (e.g., rendered animal fats and used cooking oils). AtJ is primarily created from ethanol using corn as the feedstock. The FT pathway can be produced from a wide variety of biomass sources, but typically uses agricultural and forestry residues. PtL is sourced from clean electricity and carbon dioxide. In addition, all pathways require water, hydrogen, and energy. An analysis of the feedstocks' benefits and challenges is provided in each section below.

Figure 5: Process Overview of SAF Pathways



Source: NexantECA, 2025

An analysis of the SAF capacity based on projected Minnesota feedstock availability in 2035 and 2050 is shown for the HEFA, AtJ, and FT pathways in Figure 6 below. While it is commonly stated that no pathway can provide adequate feedstock resources to produce the necessary quantities of SAF for aviation operations (Delta News Hub, 2024), our analysis shows that Minnesota does have adequate biomass resources, particularly if sufficient market demand is developed from the SAF industry. In particular, the expansion of winter camelina and the utilization of existing biomass sources such as agricultural and forestry residues have the potential to provide the necessary feedstock quantities for adequate SAF production.

Figure 6: Minnesota Projected SAF Capacity by Feedstock

Pathway	Feedstock	CI Score	2035 MN Projected Capacity (MGPY)*	2050 MN Projected Capacity (MGPY)*
HEFA	Winter Camelina	29	106	470
	Soy	47	223	223
	Soy with Sust. Ag.	42	30	60
	FOG	14	60	64
AtJ	Corn	75	1195	1195
	Corn with Sust. Ag.	65	158	316
FT	Agricultural Residues	8	758	1183
	Forestry Residues	8	62	73

*Based on feedstock availability.

Assumptions: For corn and soybeans, acreage used for food, feed, and seed is excluded; remaining acreage will compete with other biofuels. For winter camelina, projections are based on medium-scenario market pull per Ecotone Analytics, 2023. For agricultural and forestry residues, it assumes a sustainable level of harvesting and sufficient residues left in the ground for soil health per BETO, 2023. For FOG, agricultural residues, and forestry residues, 2035 projections are based on improved harvesting of current availability, and 2050 projections are based on medium-scenario market pull per BETO, 2023.

Sources: Ecotone Analytics, 2023; USDA National Agriculture Statistics Service, 2024; USDA Dept. of the Chief Economist, 2024; BETO, 2023; Zhou et al., 2022; International Civil Aviation Organization, 2024; "GREET", n.d.; Li & Mupondwa, 2014;

Hydrogen (Section 2.2.8 Hydrogen) and energy generation requirements (Section 2.2.10 Energy Generation Requirements) are analyzed for projected fuel demands at Minneapolis-St. Paul Airport in 2035 and 2050. Analysis is conducted for all of MSP in 2050 based on a projected demand of 470 million gallons per year for an assumed 50% blend fraction (currently ASTM-approved) and a hypothetical future scenario where neat SAF (not blended with Jet-A) is approved. Additionally, fuel demand for Delta is analyzed for 2035, as they are the sole airline at MSP with an announced SAF goal. Delta aims to use 50% SAF by 2035 and 100% SAF by 2050. Analysis is conducted for 2035 based on 50% of their fuel demand of 250 million gallons per year, with SAF blended 50% with conventional Jet-A fuel.

2.2.2 Soybeans

Soybeans, Minnesota's second most dominant crop, spanning 7.6 million acres, are likely to play a large role as a SAF feedstock. However, soybeans have a high carbon intensity score, and SAF production will likely face competition from other biofuels.

While soybeans have a high quantity in Minnesota, there is not a high excess of the crop due to competition from existing uses. Currently, 80% of soybeans are used for animal feed and 7% for existing biofuels like renewable diesel (Minnesota Soybean Research & Promotion Council, 2024). As discussed in Section 2.1.1, Hydroprocessed Esters and Fatty Acids (HEFA), both SAF and RD can use soybeans as a feedstock. RD is cheaper to make and has more reliable demand due to California's Low-Carbon Fuel Standard, allowing RD to outcompete SAF for feedstocks as a result. Soybean prices are expected to remain relatively flat for the next decade (U.S. Department of Agriculture, Office of the Chief Economist, 2025). A large expansion of the RD and SAF market may increase prices as demand grows. With 88% of HEFA SAF prices dependent on the cost of feedstocks (Calderon, 2024), a soybean price spike could have a considerable impact on the per-gallon price of SAF.

Using soybeans for SAF leads to too high of a carbon intensity score (CI = 47 gCO_2e/MJ) to qualify for state and federal tax incentives without pursuing additional decarbonization methods. For soy and other food crops with existing uses, diverting these feedstocks to SAF will likely cause additional land to be converted into cropland. This indirect land use change is taken into account in the carbon intensity score calculations. Based on the 40B-SAF-GREET model, use of sustainable agriculture practices such as no-till and cover crops lowers the CI score by five points, enough to reach the required threshold of 50% reduction in greenhouse gas emissions compared to Jet-A.

If sustainable agriculture practices are used to grow soybeans or other conventional crops for SAF, they have the potential to decarbonize agriculture as well as transportation. Agriculture has Minnesota's second-highest greenhouse gas emissions, constituting 25% of statewide emissions (MPCA, 2025). Sustainable agriculture practices like cover crops and no-till have demonstrated emissions reduction and environmental benefits (Ecotone Analytics, 2023), but historically have been challenging to implement in agriculture due to the associated financial cost to farmers. SAF has the potential to provide market-based incentives for farmers to implement these sustainable agriculture practices.

2.2.3 Winter Annual Oilseeds (Camelina, Pennycress)

Winter annual oilseeds like winter camelina (*Camelina sativa*) and domesticated pennycress (*Thlaspi arvense)*, developed by the Forever Green Initiative at the University of Minnesota, show strong potential for SAF but have yet to reach scale. Winter camelina is currently planted on only 2,000 acres in Minnesota, while pennycress is still in development (Vondracek, 2024).

Winter annual oilseeds are crops planted after a fall harvest, grown through the winter season, and harvested ahead of a typical spring planting. They have been specifically bred by the

University of Minnesota to withstand harsh Minnesota winters. Because they are planted on existing fields during a time when fields are usually bare, they do not result in indirect land use change and have a resulting low carbon intensity score (CI = 29 gCO_2e/MJ).

Winter annual oilseeds, called “clean water crops” by environmental NGOs, have strong environmental benefits in addition to their low carbon intensity scores. When soil is left bare without crops growing, it is vulnerable to erosion from heavy precipitation events and spring snowmelt. Soil that washes into surface waters carries fertilizer and pesticides into waterways, leading to eutrophication and subsequent decline and loss of aquatic life. By planting a winter crop during the typical fallow period, known as continuous living cover, the impacts on natural resources from bare soil are prevented. Additionally, winter annual oilseeds can take up excess nitrogen fertilizer in the soil, preventing nitrates from leaching into surface and groundwater. Winter camelina has been shown to reduce nitrate leaching by 40-70% (Ecotone Analytics, 2023). Along with benefits to water quality, winter annual oilseeds also provide critical habitats for biodiversity. These plants bloom early in the spring before most other crops, providing important nutrients for pollinators during a period of limited resources.

These crops also provide an additional revenue stream for farmers. Despite their documented environmental benefits, continuous living cover crops are only planted on 2% of Minnesota cropland at the time of writing (Minnesota Board of Water and Soil Resources, 2024). A key factor is that cover crops are not typically sold as a commercial crop, and are only used as a method of improving soil health. When surveyed, 60% of Minnesotan farmers who do not use cover crops listed expense as the main factor (Gauthier, 2023). If continuous living cover crops like winter annual oilseeds could become a source of revenue rather than an expense, this agricultural practice could be expanded across Minnesota’s 25 million acres of cropland and boost water quality, soil health, and biodiversity.

Winter camelina can fit into a small grains rotation, spanning 2.2 million acres of farmland in Minnesota (Ecotone Analytics, 2023). It does not currently fit into a typical corn/soybean rotation, which has a longer growing season. However, with continued research and development from the University of Minnesota and the Forever Green Initiative and an expanding growing season, winter camelina is expected to be suited to a corn/soybean rotation by mid-2030s (Ecotone Analytics, 2023). In a modest adoption scenario, an estimated 1.2 million acres of winter camelina are projected to be planted by 2035 and 5.5 million acres by 2050 if a SAF market develops (Ecotone Analytics, 2023).

2.2.4 Fats, Oils, and Greases (FOGs)

Fats, oils, and greases (FOGs) are a feedstock to the HEFA pathway. FOGs primarily consist of animal fats from slaughterhouses and used cooking oil (UCO) from industrial and commercial food processing. As a waste product, FOGs have a low carbon intensity score (CI = 14 gCO_2e/MJ) and are converted into commodities by rendering them at processing plants. They are commonly used in biofuels, animal feed, and pharmaceuticals, where there is high competition for the feedstock, primarily from other biofuels (Khan et al. 2024).

Minnesota is a top-ten producer of livestock in the United States (Ye, 2023) and has numerous animal rendering (Minnesota Board of Animal Health, 2025) and industrial food system operations, generating large quantities of FOGs. However, SAF faces stiff competition for FOGs from biodiesel and renewable diesel. The use of FOGs for biofuels tripled from 2019 to 2022 in the US, leading to a doubling in import quantities as well as price (Render, 2023). China is one of the main FOG exporters, making up 60% of the used cooking oil imported into the US (Economic Research Service, 2025). With new tariffs on China and China's own emerging SAF industry (Neo, 2025), the domestic supply of imported FOGs is uncertain. Nationally, about 6 million tons of FOGs are produced annually, while 7 million tons are consumed, with half being used for biofuels (Render, 2023). Domestic production of FOGs is expected to increase to 8 million tons by 2050 due to population growth and increased meat consumption (U.S. DOE Billion Ton Report, 2023). As the supply of FOGs becomes more available and additional SAF pathways mature (i.e., increased production from AtJ, FT, and PtL, reducing demand for HEFA feedstocks), prices will likely decline in future years.

While FOGs have a low carbon intensity score, imported used cooking oil poses additional environmental concerns. Minnesota state law prohibits the use of palm oil for SAF, but there are serious limitations to verification for this supply chain.

2.2.5 Corn

As discussed in Section 2.1.2 Alcohol to Jet, corn is a feedstock for the AtJ pathway to SAF. A primary advantage of using corn grain as a feedstock for SAF is the high quantity grown in Minnesota. Additionally, the abundance and well-established production of ethanol allow for short-term scalability. However, high carbon intensity scores, feedstock competition, and land use concerns present considerable challenges.

Corn grown using conventional agricultural methods (e.g., intensive use of nitrogen fertilizer and tillage) would not qualify as SAF under current federal and state tax credits due to its high carbon intensity score (CI = 75 gCO_2e/MJ). To be eligible for these tax credits, corn ethanol used for AtJ SAF must further decarbonize its process to meet the minimum carbon intensity requirements, such as through sustainable agriculture practices, on-site renewable energy generation, or carbon capture and storage. While necessary, implementing any of these practices would increase the cost of SAF. Like soybeans used for HEFA, the emergence of a SAF industry could provide potential market incentives for the production of low-carbon corn used for AtJ. To meet this demand, farmers would need to implement sustainable agriculture practices that would aid in the decarbonization of agriculture in Minnesota.

SAF will face competition for corn feedstocks from existing industries in Minnesota. As ethanol is currently profitable as a gasoline blend, expensive ethanol-based SAF production would likely remain unpopular. Currently, animal feed accounts for about 40% of domestic corn use, ethanol (the majority of which is used in gasoline blends) accounts for nearly 45%, other food, seed, and industrial uses account for an additional 15%, and human consumption accounts for less than 2% (USDA Economic Research Service, 2025; Sloat, 2022).

These competing industries present a challenge for the future of ethanol-based SAF. It also raises concerns about land use, as incentivizing ethanol-based SAF may encourage more land and water to be diverted to agriculture.

While the abundance of corn and well-established production of ethanol are key strengths of this feedstock, competition and carbon intensity present large barriers to scaling.

2.2.6 Forestry Residues

Forestry and waste-derived biomass present a locally abundant, economical, and environmentally beneficial feedstock for SAF production in Minnesota (Minnesota Forest Resources Council, 2024). This includes a variety of sources such as wood waste from mills (e.g., sawdust, bark), unused tops and limbs from logging operations, tree salvage following storm blow-downs or wildfires, and trees compromised by invasive species like the emerald ash borer, spruce budworm, and eastern larch beetle.

In 2022, an estimated 2.6 million green tons of forest waste were available in the state. After subtracting 1.5 million green tons already claimed by industries like particleboard, wood chip, and animal bedding production, approximately 1.1 million tons remain potentially available for SAF without disrupting these existing markets. Additionally, vast swaths of forested land – 660,000 acres of balsam fir in the Arrowhead region and 1 million acres of tamarack – are dead or dying from invasive pests, presenting a unique opportunity (Minnesota Forest Resources Council Biennial Report, 2024) (see Figures 21 and 22 in Appendix). These compromised stands currently have no viable commercial market, and SAF production offers a promising solution that also enhances forest health, reduces wildfire risk, and supports biodiversity.

The use of wood fiber for SAF offers substantial climate benefits. With carbon intensity scores as low as 8 gCO_2e/MJ, forestry-based SAF can reduce lifecycle emissions by up to 80% compared to conventional jet fuel. Forests themselves are carbon sinks, converting atmospheric carbon into biomass through photosynthesis and storing it long-term unless disturbed by decomposition or fire. In Minnesota, forests absorb approximately 15% of the state’s total emissions (MPCA, 2025), making the forest sector the only carbon-neutral economic industry in the state.

Most forested lands in Minnesota are enrolled in third-party certification programs such as the Sustainable Forestry Initiative (SFI) and the Forest Stewardship Council (FSC), which require that harvesting practices meet high environmental standards. These certifications require that sufficient biomass is left behind to maintain ecosystem functions such as wildlife habitat, soil health, and water retention.

However, there are logistical and infrastructural barriers to scaling this pathway. Biomass feedstocks are bulky and have low energy density, making transport to SAF production facilities a critical challenge. Without rail access or centralized preprocessing hubs, biomass would need to be trucked in large volumes. A single SAF facility producing 60 million gallons per year would require a large fuel tanker truck arriving or departing every two minutes, placing strain on rural roads and increasing emissions from transportation (Calderon, 2024).

Despite these challenges, the forestry sector remains a cornerstone of Minnesota’s economy, ranked as the fifth-largest industry in the state, employing 68,000 people and generating $7.3 billion in economic output (Division of Forestry, 2025). SAF development offers a new value stream for this industry, particularly for underutilized wood waste and diseased or damaged trees, while complementing existing forest management goals. If implemented strategically, forestry-based SAF can strengthen climate resilience, support rural economies, and enhance the ecological integrity of Minnesota’s forests.

2.2.7 Agricultural Residues

Like forestry waste, agricultural residues such as corn stover and wheat chaff are an abundant and underutilized resource in Minnesota. Corn stover is Minnesota's most plentiful agricultural residue (BETO, 2023), and its use for fuel avoids direct competition with food crops, unlike corn grain used in ethanol production. As a residue, corn stover is relatively inexpensive compared to purpose-grown energy crops, and its proximity to existing transportation infrastructure can offset collection costs.

Agricultural residues offer favorable CI scores; when used in FT pathways, they can yield low lifecycle CI scores (CI = 8 gCO_2e/MJ) due to their waste status.

The use of agricultural residues as a SAF feedstock does not come without challenges. These feedstocks are available only after the fall harvest, and their seasonality would require large-scale storage or blending with other feedstocks at a continuous biorefinery. Collection, baling, and transportation are labor- and energy-intensive; their low bulk density makes storage and transport expensive. Typically, 30-50% of agricultural residues are left in the field to break down into soil, improving soil health (BETO, 2023). Excessive removal of residues can degrade soil, require additional fertilizer application in the following seasons, and increase erosion. As such, some level of these agricultural residues must remain in the field, reducing overall feedstock availability and increasing harvest complexity.

2.2.8 Hydrogen

Jet fuel is composed of hydrogen and carbon (“hydrocarbons”), with a ratio of about 2H:1C (two hydrogen atoms for every 1 carbon atom). Hydrogen plays a critical role as a feedstock across all the SAF production pathways, with pathways requiring different amounts of hydrogen, as shown in Figure 7. Hydrogen is primarily used to deoxygenate biomass feedstocks, to saturate carbon bonds, and to modify the hydrocarbon chain into drop-in jet fuel that meets strict aviation specifications. Bio-based renewable feedstocks are complex and require processing to achieve the strict chemical formula of ASTM-approved jet fuel.

Most renewable feedstocks – such as fats, oils, greases, agricultural residues, and forestry waste – contain high amounts of oxygen, which must be removed to produce energy-dense, hydrocarbon-saturated jet fuel. In the HEFA process, for example, hydroprocessing uses hydrogen for the purpose of stripping away oxygen atoms, converting triglycerides and free fatty acids into saturated hydrocarbons.

Many bio-based feedstocks, such as vegetable oils, contain unsaturated carbon-carbon double bonds. Hydrogen is used to saturate these bonds in a process called hydrogenation. The biomass used in FT or HEFA comprises hydrocarbon chains that are too long for use in jet engines. Hydrogen assists in hydrocracking, a process in which long hydrocarbon chains are broken into shorter-range molecules (C8-C16) typical of jet fuel.

In the case of PtL, hydrogen is a foundational input and main building block for SAF. Renewable hydrogen is produced via electrolysis and is then combined with CO or CO_2 (e.g., from DAC) to synthesize hydrocarbons via FT or another thermocatalytic route.

Hydrogen production is a major energy cost driver in SAF. Green hydrogen requires 50.6-52.5 kWh of electricity per kilogram (Cathcart et al., 2024), which contributes to the high price and energy intensity of SAF, especially in PtL pathways.

Figure 7: Annual H_2 Demand for SAF Production by Pathway

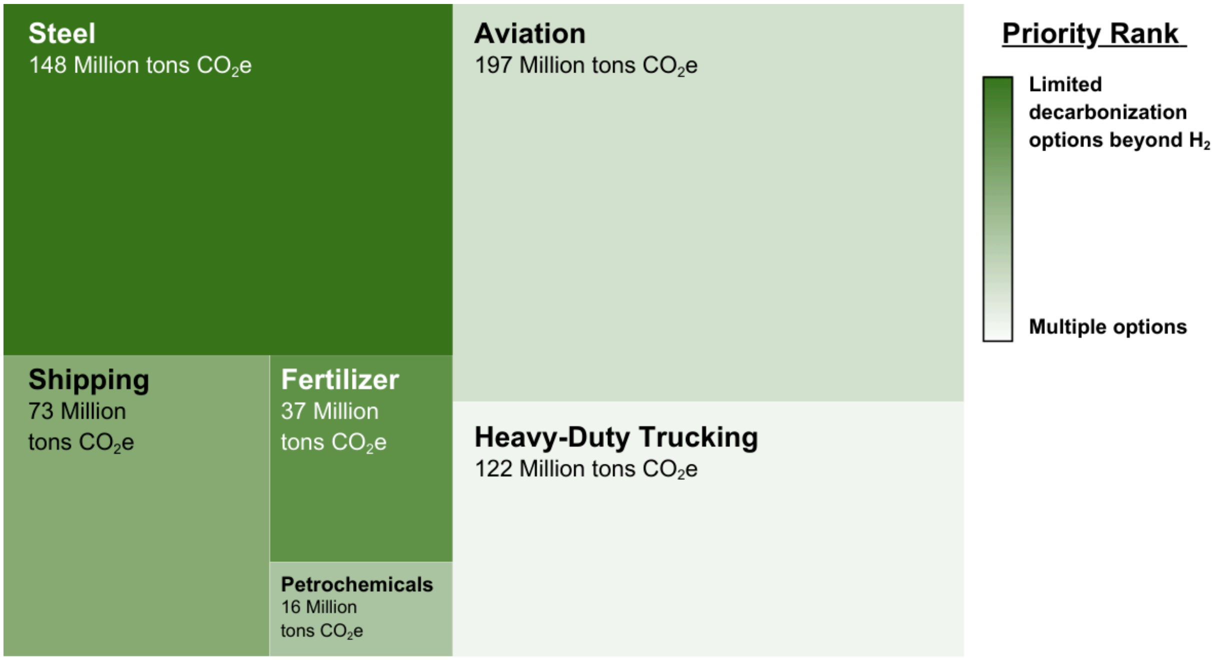
	Pathway Hydrogen requirement (kg H_2/ gal SAF)	H_2 demand for SAF Pathways (Mg H_2 per year)		
		Delta Demand	MSP Projected Fuel Demand	
		125 MGPY* (2035)	470 MGPY* (2050)	470 MGPY, Neat SAF (2050)
HEFA	0.15	9.4	35.25	70.5
AtJ	0.07	4.4	16.45	32.9
FT	0.05	3.1	11.75	23.5
PtL	1.9	118.8	446.5	893

*Assumes 50% blend with Jet-A

Sources: Cathcart et al., 2024; Delta News Hub, 2024; Department of Energy, 2021; Linde, 2025

Many industry sectors will compete for green hydrogen resources as they move towards decarbonization. As shown in Figure 8 below, SAF provides the greatest carbon abatement for the use of green hydrogen, with a reduction of 197 $MtCO_2$ nationwide. However, industries such as green steel and green fertilizer have fewer alternative methods for decarbonization.

Figure 8: Hydrogen-Enabled Abatement Potential by Sector



Source: Mills, 2024

2.2.9 Water

Water is a critical input for sustainable aviation fuel. Depending on the SAF pathway, water requirements range from 2 to over 10 gallons per gallon of SAF produced (Figure 9), adding up to potentially millions of gallons per day. Because of potential environmental and regulatory concerns, water requirements related to SAF must be considered.

Figure 9: Water Demand for SAF Pathways

	Water Use (gallons/gallon SAF)*	Water demand for SAF Pathways (Million gallons of water per year)		
		Delta Demand	MSP Projected Fuel Demand	
		125 MGPY** (2035)	470 MGPY** (2050)	470 MGPY, Neat SAF (2050)
HEFA	2 - 6	125 - 375	470 - 1410	940 - 2820
AtJ	7 - 12	438 - 750	1645 - 2820	3290 - 5640
FT	7 - 12	438 - 750	1645 - 2820	3290 - 5640
PtL	2 - 4	125 - 250	470 - 940	940 - 1880

*Range reflects variation in feedstock type, hydrogen source, facility processing design, cooling method, and local water quality

**Assumes 50% blend with Jet-A

Sources: Delta News Hub, 2024; Department of Energy, 2021; Wu, 2024; Rojas-Michaga et al., 2023; Lau et al., 2024

Agricultural and forest biomass feedstocks require water to grow. In case of insufficient rain, mechanical irrigation, pulling water from local water sources, is required. The production process for biomass feedstocks requires substantial amounts of water, creating a complex problem that includes both water sourcing and wastewater disposal.

DG Fuels, the proposed SAF plant in Moorhead, MN, has been granted permits to draw up to 6,600 gallons of water per minute (GPM) (J. Frischman, personal communication, April 08, 2025), equal to 1.5 million gallons per day, and more than 500 million gallons annually. These permits allow DG Fuels to draw water from all three water sources that serve the Moorhead region: the Buffalo and Moorhead aquifers, and the Red River. The amount of water permitted to DG Fuels represents roughly 80% of the city's total groundwater consumption, raising serious environmental, equity, and regulatory concerns. The water permits only cover processing requirements; they do not cover any feedstock irrigation needs (e.g., poplar plantations), though such forests could require large quantities of additional water.

In addition to feedstock irrigation and processing requirements, wastewater management poses an additional issue. Water is used in cleaning, cooling, pre-treatment, and in catalytic conversion processes, leading to waste streams of up to hundreds of thousands of gallons per day. The water treatment and disposal capacity often lags behind production permitting, leading to interim trucking or disposal solutions. Montana Renewables illustrates this exact challenge. As of early 2025, Montana Renewable was producing approximately 80,000 gallons of wastewater per day. The facility has not been permitted to dispose of wastewater in the state of Montana. Their interim solution is transporting 50 truckloads of wastewater daily out of state, primarily to Idaho, Wyoming, and Texas, to dispose of the wastewater in their permitted injection wells. In addition, Montana Renewables produces up to 75 tons of sludge per day, which is hauled off to a nearby landfill (Hudson, 2025). Residents and environmental groups have voiced concerns over the lack of prioritization for onsite treatment, volumes of truck traffic, and the uncertainty around long-term wastewater disposal.

Water usage is a major factor in determining the sustainability of SAF production. While technologies like PtL and FT offer low-carbon options, they may come with steep water footprints, especially when combined with green hydrogen or irrigated biomass. If not managed thoughtfully, large-scale SAF deployment could strain regional water resources, particularly in aquifer-dependent areas.

2.2.10. Energy Generation Requirements

The establishment of a SAF industry in MN will demand substantial energy generation. Following the newly signed Minnesota's Carbon Free 2040 law (HF 7, 2024). SAF will require extensive build-out of renewable energy and transmission.

The Power to Liquid pathway is the most energy-intensive of the four pathways analyzed. Current PtL technology requires 100 kWh per gallon of SAF (Pathways to Commercial Liftoff, 2025), though this is expected to decrease as technology continues to mature. Figure 10 below shows the amount of electricity needed for different levels of PtL SAF production per year with current technology. If PtL SAF produced all of MSP's projected fuel demand, it would require up to 23.5 TWh of renewable energy per year; in comparison, Minnesota had a total of 19 TWh of electricity generated from renewable sources in 2023 (2024 Minnesota Energy Factsheet). This 100% carbon-free energy requirement for PtL SAF equates to 67 new 200 MW solar farms or 40 new 200 MW wind farms (U.S. EIA, 2023). While PtL is not expected to be a major SAF producer until the 2040s, the large scale of the required renewable energy generation and transmission necessitates immediate and concerted action. Permitting reform will be critical to the scaling of PtL, discussed further in Section 4.2.4 Permitting in Minnesota.

Figure 10: Annual Electricity Demand for PtL SAF

	Electricity demand for PtL SAF (GWh)		
	Delta Demand	MSP Projected Fuel Demand	
	125 MGPY* (2035)	470 MGPY* (2050)	470 MGPY, Neat SAF (2050)
PtL	6250	23500	47000

*Assumes 50% blend with Jet-A

Sources: Delta News Hub, 2024; Department of Energy, 2021; Braun et al, 2024

For the agricultural pathways (HEFA, AtJ, and FT), the energy requirements will depend largely on the type of hydrogen used. If green hydrogen is used, large amounts of renewable energy will be necessary. With current green hydrogen technology, 50.6-52.5 kWh are required to produce one kilogram of green hydrogen (Cathcart et al., 2024). Figure 11 below shows the electricity required to produce the green hydrogen for each pathway for different quantities of SAF production, given current green hydrogen technology. The renewable energy demand if green hydrogen is used for the agricultural pathways will require additional renewable energy buildout. For MSP to meet their 2050 fuel projections using SAF made with green hydrogen, it would require two to six new 200 MW solar farms or one to four new 200 MW wind farms.

However, SAF production without green hydrogen will require considerably less energy, with the energy requirements similar to other biofuels plants such as ethanol. The largest ethanol production facilities in Minnesota consume approximately 56 GWh per year (I Percher, personal communication, May 3, 2025) and produce over 100 MGal of ethanol (Smith, n.d.). Typical HEFA plants producing 150 MGal annually require 50 MW of electricity (L Hughes, personal communication, May 2, 2025), or approximately 160 GWh.

Figure 11: Annual Electricity Demand for SAF, Agricultural Pathways

	Electricity demand for only the green hydrogen used for SAF pathways (GWh)			Renewable Energy Buildout Needed for 470 MGPY* (number of 200 MW facilities)	
	Delta Demand	MSP Projected Fuel Demand		Solar	Wind
	125 MGPY* (2035)	470 MGPY* (2050)	470 MGPY, Neat SAF (2050)		
HEFA	483	1817	3634	5.2	3.1
AtJ	226	848	1696	2.4	1.4
FT	161	606	1211	1.7	1.0

*Assumes 50% blend with Jet-A

Sources: Cathcart et al., 2024; Delta News Hub, 2024; Department of Energy, 2021; US EIA, 2023

SAF will face strong competition for renewable energy resources in Minnesota as existing industries decarbonize and new industries emerge. The continued increase in electric vehicles (EVs) and the decarbonization of industries such as steel and fertilizer production will increase the demand for renewable energy. Moreover, multiple data centers have also proposed siting facilities in Minnesota, with electric utility companies Xcel Energy and Great River Energy each estimating additional demand in the range of 1,000 MW (Orenstein, 2025).

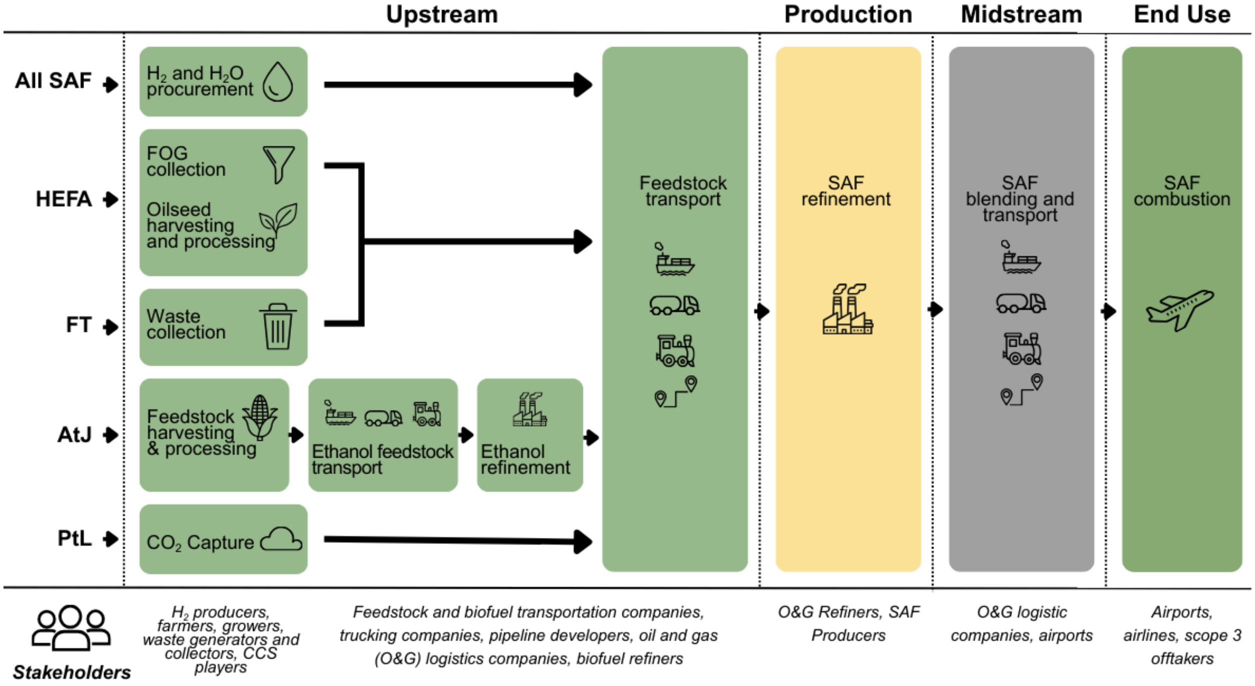
With a large-scale build-out of renewable energy comes land use conflicts, particularly as large-scale solar and wind projects require large acreage. On average, utility-scale solar farms need approximately 10,000 acres to generate 1,000 MW of electricity—roughly 10 acres per MW—due to the spacing and layout needed for optimal sun exposure (Wyatt et al., 2021). Wind energy, while often compatible with agricultural use, still requires about 1.5 to 2 acres per MW of installed capacity for turbine pads, access roads, and infrastructure, though the entire wind farm footprint can span hundreds of acres (Center for Sustainable Systems, 2024). These land demands can compete with agriculture, conservation, and housing, especially in regions with limited open space or contested land ownership.

2.3 Supply Chain and Infrastructure Considerations

2.3.1 Supply Chain

The supply chain for SAF, shown in Figure 12 below, consists of feedstock production, SAF production, blending with conventional jet fuel, use at airports, and transportation between each phase.

Figure 12: SAF Supply Chain by Pathway



Source: Howe et al., 2024

Feedstock production is dispersed throughout the state (see figures in the Appendix for infrastructure and feedstock locations). Agricultural feedstocks (e.g., corn, soy, winter camelina, and agricultural residues) are primarily concentrated in the state's southern, central, and western parts. These areas have extensive rail networks established for the transport of these crops. Forestry feedstocks are primarily located in northern Minnesota and require more truck transport than agricultural feedstocks due to limited railroad infrastructure, which would result in higher transportation emissions compared to rail. Fats, oils, and greases are available from a limited number of rendering facilities located primarily in southern Minnesota. All feedstocks would require transport via truck or rail to SAF production facilities. To minimize GHG emissions from feedstock transportation, SAF facilities would be best located along existing rail lines.

SAF production plants could be greenfield, co-located, or retrofitted from existing ethanol production sites or oil and gas refineries. Minnesota has 19 current ethanol refineries, primarily located in southern Minnesota (see Figure 18 in the Appendix). To facilitate feedstock delivery, these facilities are located on rail lines. Minnesota has two oil and gas refineries: Pine Bend Refinery, operated by Flint Hills Resources in Rosemount, and St. Paul Park Refinery, operated by Marathon Petroleum in St. Paul Park (see Figure 18 in the Appendix). DG Fuels announced a planned SAF production facility in Moorhead.

Neat SAF (not blended with fossil jet fuel) is not currently ASTM certified as a stand-alone fuel. It must be blended with conventional jet fuel (Jet-A or Jet-A1) and then recertified under ASTM D1655 to be considered a suitable drop-in fuel for existing aircraft engines and infrastructure. Because of these limitations, neat SAF is not currently approved for pipeline transmission, and transportation of SAF from production facilities to blenders would require truck or rail transport if production and blending are not co-located. However, neat SAF is expected to gain approval for pipeline transmission in the coming years as further research demonstrates its safety (Calderon et al., 2024). As transportation throughout the production pathway is calculated into CI scores, pipelines would be the lowest emission option. These pipelines would need to be built between SAF production and blending facilities and may encounter community pushback.

Neat SAF and petroleum jet fuel are combined at blending facilities to create SAF. Each pathway has specific ASTM-approved blend fractions, but all four pathways discussed in this paper are approved at a blending fraction of up to 50%. Pine Bend Refinery in Rosemount is currently the only announced blending facility in the state and is scheduled to come online in late 2025 with a 30 MGal/year capacity, about 12% of Delta’s 250 MGal/year jet fuel demand at MSP. Pine Bend currently transports jet fuel to MSP via pipeline, which could be used for SAF. Once neat SAF is blended with jet fuel, its process is the same as conventional jet fuel.

Figure 13: Comparison of Pathways and Feedstocks

Pathway	Feedstock	CI Score	Carbon Abatement per Million Gallons, 50% blend (Mg CO_2e)	Gallons SAF/Acre	Gallons SAF/dry ton feedstock	Feedstock Availability*	Competition for Feedstocks*	Water Quality Impacts*	Land Use Change Impacts*	Biodiversity Impacts*
HEFA	Winter Camelina	29	4496	69**	-	- -	+ +	+ +	+ +	+ +
	Soy	47	3358	75	-	+	- -	- -	- -	- -
	Soy with Sust. Ag.	42	3674	72***	-	-	- -	+	- -	+
	FOG	14	5443	-	302	+	- -	0	0	0
AtJ	Corn	75	1589	299	-	+	-	- -	- -	- -
	Corn with Sust. Ag.	65	2221	282***	-	-	-	+	- -	+
FT	Agricultural Residues	8	5822	-	51	+ +	+ +	0	0	0
	Forestry Residues	8	5822	-	66	+ +	+ +	0	0	+
PtL	Clean energy + CO_2	0	6328	-	-	- -	- -	0	- -	0

* Indicated criteria are qualitative assessments ranging from "- -" (very negative impact) to "+ +" (very positive impact)

** Winter Camelina would be planted as a second crop over the winter and does not require additional acreage for crop production

*** Cover crops (a sustainable agriculture practice) are known to reduce crop yields in the first years of implementation, though crop yields typically return to baseline after 3-5 years. A yield reduction of 3.5% for soybeans and 5.5% for corn is used as a conservative estimate (Zhou et al., 2022)

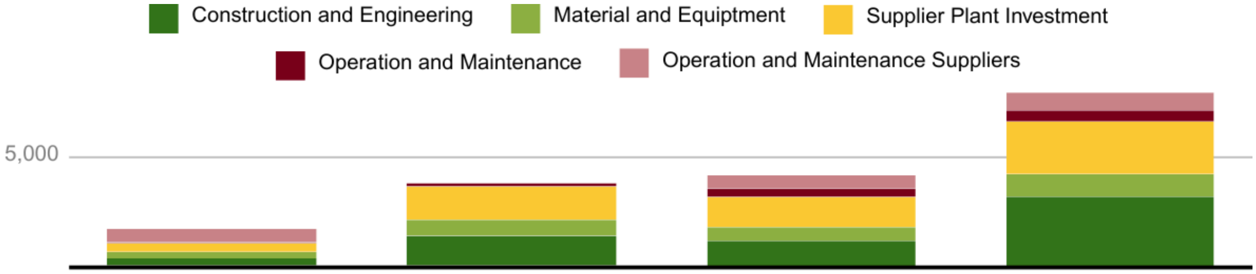
Sources: Ecotone Analytics, 2023; USDA National Agriculture Statistics Service, 2024; International Civil Aviation Organization, 2024; "GREET", n.d.; Howe et al., 2024; Li & Mupondwa, 2014; ICAO, n.d.; Zhou et al., 2022

3. Economic Analysis

The growth of a SAF industry in Minnesota provides strong economic benefits for the state, industries, and feedstock producers, particularly farmers.

The operation and construction of SAF production facilities have the potential to provide thousands of well-paying jobs to the state. Minnesota is well-positioned for a SAF industry in terms of workforce development, with a biorefinery employment rate twice the national average (Soloman, 2023), particularly due to the ethanol industry. While the state has many employees with an existing knowledge base in biorefining, a wide-scale expansion of a new industry will need to draw new talent to the state, particularly in Greater Minnesota. The announced DG Fuels plant in Moorhead (a FT production facility with a 193 MGPY capacity) is expected to create 650 jobs and deliver over $50 billion of economic impact to the state (DG Fuels, 2024). Job creation will vary by pathway, with projected job creation for a simulated 50 MGPY SAF plant shown in Figure 14 below.

Figure 14: Projected job creation depending on SAF plant design and delineated by support sector*



*Job figures for a simulated 50 million gallons/year SAF plant by value chain stakeholder
Source: Solomon et al., 2023

A burgeoning SAF industry would provide considerable benefits to the agricultural sector in Minnesota. Net farm income is projected to decline 6.5% over the next decade (U.S. Department of Agriculture, Department of the Chief Economist, 2025), and providing farmers with a new market opportunity has the potential to mitigate this decline. SAF can support corn growers as the ethanol industry declines over time, as well as soybean growers as the renewable diesel and biodiesel industries decline in future decades. Using winter camelina and agricultural residues shows particular promise to support agricultural producers, as these can be a new source of revenue for farmers without impacting their current outputs.

Minimum fuel selling price (MFSP) for SAF is 2-10 times more expensive than conventional jet fuel without incentives, even once production reaches scale. A comparison of projected fuel prices for Nth of a Kind (NOAK) production facilities for the four pathways is shown in Figure 15 below. Policies besides direct tax incentives, such as a Clean Transportation Standard, will be required to provide long-term demand assurance to a SAF market.

Figure 15: SAF Cost Estimates by Pathway, USD per Gallon

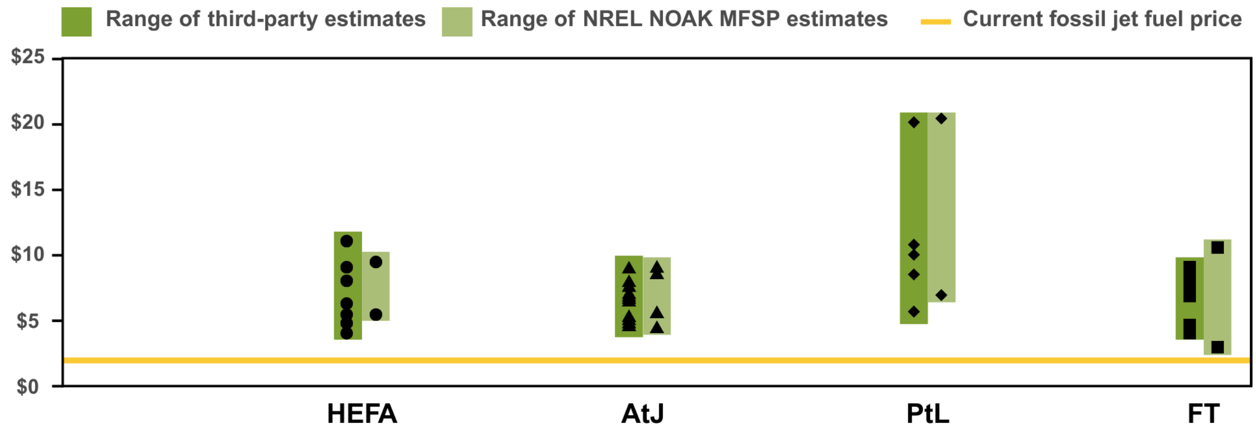


Figure Footnotes: *1. Prices are based on a range of production facility designs, inputs, and assumptions, including year, inflation, and NOAK vs. FOAK deployment. Delivered cost, or the price of SAF to airlines, includes blending, transportation and storage costs, which vary; 2. Minimum fuel selling price (MFSP) is the lowest possible price a producer could sell at to financially support operations; these estimates assume NOAK deployment;*
4. Estimates pull multiple feedstocks, including FOGs (lower end of range) and virgin oils and crops (higher end of range); 5. Estimates pull both starch and cellulosic feedstocks. The high end of the cellulosic AtJ range ($9.6 per gallon) exceeds the high end of the starch-based range ($8.60 per gallon) although the low ends of these ranges are similar ($4.50-4.60 per gallon); 6. Although FT prices appear lower than HEFA and AtJ, the gasification technology of these feedstocks is nascent and will require more time (e.g., after 2030) to validate these estimated ranges.

Source: Howe et al., 2024

3.1 Funding Pathways

As with all new technologies, securing capital is a major challenge. Traditional funding strategies, such as private, public, and government grants, are available. Alternative sources of capital, such as farmer cooperatives, could disperse the cost burden while promoting community equity. In addition, cost-saving options such as retrofitting existing fuel plants could markedly reduce upfront capital expenditures, accelerate project timelines, and leverage existing infrastructure, making the transition to new fuel production methods more financially viable.

For private investments to succeed, Minnesota will need a solid business case for the production of SAF within the state. Currently, the price of entry is extremely high, and the return on investment is uncertain. Most SAF plants will cost an estimated $1 billion to $3 billion and will take years to become profitable (Jones, 2025). Long-term offtake agreements can put production into motion as investors are assured there will be a market for their product.

In Minnesota, the Minnesota Climate Innovation Finance Authority (MnCIFA) serves as a publicly accountable financing authority. The MnCIFA, which was established by the Minnesota Legislature during the 2023 Session (Minnesota Statutes, 2023), could provide loans and access to funding for SAF initiatives working to reduce greenhouse gas emissions and support underserved communities.

In the agricultural industry, cooperative models have helped farmers navigate market volatility, global demand, and rising costs. Extending this model to sustainable aviation fuel could create new biofuels market access for farmers by distributing cost and risk. In Minnesota and Wisconsin, existing cooperatives include Farm First Dairy Cooperative, Land O’Lakes, Riverland Energy Cooperative, Basin Electric Power Cooperative, Organic Valley, and more, illustrating the impact and potential for success.

Cost reduction is another general strategy to mitigate funding costs. Retrofitting existing plants can cut costs by hundreds of millions of dollars. In Minnesota, ethanol plants, coal plants (such as Sherco), and decommissioned petroleum refining plants present opportunities for retrofitting existing technology to produce SAF.

4. Current Policy Landscape:

The transition to SAF will require policy and regulation changes to incentivize production and adoption. Globally, guidelines exist at the municipal, provincial, federal, and regional levels. In the United States, federal policy is in flux and insufficient to catalyze the necessary industry movement. Minnesota can create state-level legislation to promote the SAF economy. Moreover, key players in the airlines and related industries are developing corporate guidelines that will influence the demand for SAF.

This section examines SAF policies from around the globe, within the United States and Minnesota, as well as SAF-specific corporate guidelines from U.S.-based airlines. Minnesota SAF policies are categorized as tax credits, permitting, and indirect support.

4.1 Overview of US-based SAF Policies

The U.S. government has adopted incentive-based policies to promote SAF production and consumption. The SAF Grand Challenge, launched by the Biden Administration in 2021, sets ambitious production targets to reach three billion gallons of SAF by 2030 (10% of U.S. jet fuel demand) and thirty-five billion gallons by 2050, covering 100% of projected U.S. jet fuel demand (Department of Energy, 2021).

Federal policies have played a crucial role in shaping the SAF market. The Inflation Reduction Act of 2022 introduced the SAF Production Tax Credit (40B), which offered up to $1.75 per gallon for SAF achieving at least a fifty percent GHG reduction (Alternative Fuels Data Center, 2022) but expired at the end of 2024. It was replaced by the Clean Fuel Production Credit (45Z), which provides a tax credit of $0.35 - $1.75 per gallon, depending on carbon intensity score (Alternative Fuels Data Center, 2025). The 45Z tax credit expires in 2027, providing SAF investors with a lack of long-term assurance for the future of the industry. Other incentives, such as the Renewable Fuel Standard (RFS) and Renewable Identification Numbers (RINs), allow SAF producers to generate credits, helping offset production costs.

Additional financial support is provided through state-based programs like the Low-Carbon Fuel Standard (LCFS) in California and Oregon, which allow SAF to earn credits if it meets carbon intensity thresholds. Grants and loan guarantees from the Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) further supplement federal initiatives.

Despite these policies, critical challenges remain. The expiration of IRA tax credits creates uncertainty, discouraging long-term investment. The high cost of SAF, which remains two to ten times more expensive than conventional jet fuel, limits its competitiveness. Unlike the European Union and the United Kingdom, the U.S. lacks a federal SAF blending mandate, further constraining demand certainty.

4.2 Overview of Minnesota-based SAF Policies

Minnesota has taken proactive steps to integrate SAF into its energy landscape by leveraging its strong agricultural sector and policy initiatives. The Minnesota SAF Hub, established by Greater MSP in collaboration with Bank of America, Delta Air Lines, Ecolab, and Xcel Energy, seeks to build the first large-scale SAF production ecosystem in the United States.

Minnesota currently provides a SAF-specific tax credit of $1.50 per gallon for SAF producers and blenders, which is intended to stack with federal tax incentives. Additional policies support scaling SAF production by supporting the sustainable agriculture initiatives that allow agricultural feedstocks to reduce their carbon intensity, such as funding for the Forever Green Initiative.

While Minnesota has blending mandates for biofuels in road transportation, there is no dedicated SAF mandate at the state level.

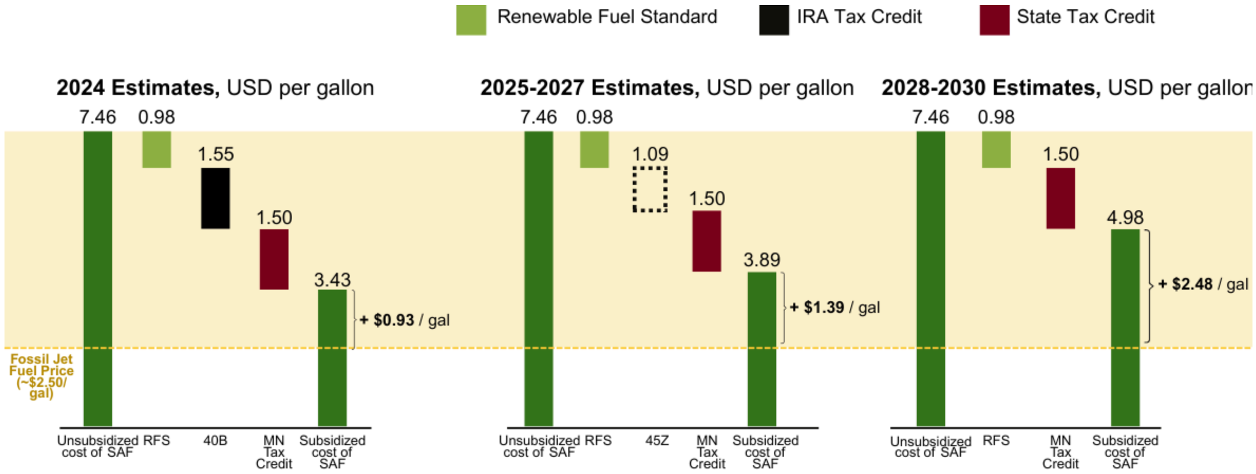
Feedstock availability and scalability remain concerns, as current production volumes are insufficient to meet large-scale SAF demand. Infrastructure gaps also persist, requiring further state and federal support to build the necessary production and distribution facilities.

4.2.2 Tax Credits in Minnesota

Minnesota’s primary supportive policy is the Sustainable Aviation Fuel Tax Credit. This policy provides a tax credit of $1.50 per gallon for companies in Minnesota who blend or produce SAF that is used in an aircraft departing from a Minnesota airport. This tax credit has a total cap of $7.4 million in 2025 and $2.1 million annually thereafter until its expiration in 2030.

Legislators in the 2025 session have proposed an additional tax credit to incentivize the production of SAF with the lowest possible carbon intensity score. The $1.50 per gallon tax credit would increase an additional $0.02 per gallon for each whole percentage carbon intensity reduction beyond the minimum requirement of 50%, with a maximum additional tax credit of $0.50. With the passage of this bill, producers and blenders of SAF with a carbon intensity score of 20 or lower would receive a tax credit of $2.00 per gallon. This proposed bill would also extend the tax credit out to 2035 and increase the total cap to $7.4 million until 2027.

Figure 16: Estimated SAF Cost Reduction with Minnesota's Tax Credits Over Time*



*The impact of state and federal incentives on SAF unit production costs from an illustrative NOAK HEFA facility with a CI score of 18 (80% reduction compared to fossil jet) located in Minnesota
Source: Howe et al., 2024

4.2.3 Minnesota Policies Providing Indirect SAF Support

Minnesota has additional policies that provide indirect support to the SAF industry for agricultural feedstocks. Maintaining these programs is critical to scaling SAF in future years.

The Forever Green Initiative is an essential partner for expanding winter annual oilseeds such as winter camelina and pennycress. These crops were developed by a partnership between Forever Green and the University of Minnesota, and ongoing research and development seek to increase yield through selective breeding. Forever Green is also the primary driver for developing a market and scaling winter camelina.

Because many of the agricultural feedstocks for SAF (particularly corn and soy) will require additional decarbonization, programs that support farmers implementing sustainable agriculture practices that reduce the carbon intensity of feedstocks will be critical. The Soil Health Financial Assistance Program offers grants for purchasing farming equipment necessary for conservation practices, and has already been used by farmers to grow winter camelina for SAF. Additionally, the Minnesota Agricultural Water Quality Certification Program and the Agricultural Best Management Practices Loan Program both provide funding for farmers implementing practices like no-till farming and cover crops.

4.2.4 Permitting in Minnesota

Permits strike a balance between prohibiting damaging development and promoting economic growth. Permitting can mitigate negative externalities of business development or disincentivize local business investment. In Minnesota, there are many environmental and community interests worth protecting. To scale state-wide SAF production, the permitting process needs to balance these concerns with industry opportunities.

Leaders in the biofuels industry see Minnesota's permitting process as "lengthy and complex" with uncertain timelines (Connelly, 2023). Many groups, including the Minnesota Pollution Control Agency, have expressed an interest in amending permitting processes (Minnesota Pollution Control Agency, 2025). Businesses will not choose to invest in production in Minnesota if they are concerned that the permitting process will drag out, potentially making them miss out on tax incentives for early adopters (AURI, 2023). At the time of writing, Minnesota House File 8 (HF8, 2025)–with support among Republicans, biofuels industry leaders, and opposition from environmental groups–is pending in the state legislature. The bill would reduce permitting barriers.

Difficult permitting processes with uncertain timelines will keep SAF investment out of Minnesota, regardless of feedstock availability, the tax incentives, and other local benefits. In addition to reform, Minnesota can work to speed up permit processing within local departments, such as the Minnesota Pollution Control Agency, and share success stories with industry partners.

4.3 Overview of US-based Airlines' ESG Goals and Publicly Announced Decarbonization Initiatives

Major airlines in the United States have made strong commitments toward SAF adoption as part of their broader environmental, social, and governance (ESG) goals. Delta Air Lines has pledged to replace ten percent of its fuel with SAF by 2030 and participated in the first SAF-powered flight from Minneapolis. United Airlines has launched the Eco-Skies Alliance, partnering with corporations to purchase SAF credits and support new production capacity. American Airlines has collaborated with Gevo and Neste to secure SAF supply contracts, aiming to cut emissions by fifty percent by 2035. Southwest Airlines has invested in SAF innovation through partnerships with the National Renewable Energy Laboratory (NREL) and the DOE.

Despite these efforts, high SAF costs continue to limit widespread adoption, leading airlines to rely on corporate buyers through SAF credit programs. Blending limits further constrain progress, as current regulations only allow up to 50% SAF blending, restricting potential emissions reductions. Additionally, SAF delivery to major airports remains a logistical challenge, complicating large-scale integration into airline fuel supply chains.

For production to grow at scale, airlines will need to go beyond their existing commitments and sign on to long-term offtake agreements.

4.4 Overview of Global SAF Policies

Globally, the European Union has implemented one of the most aggressive SAF policies through the ReFuelEU Aviation Initiative, which requires airlines to use at least two percent SAF by 2025, rising to seventy percent by 2050. The EU Emissions Trading Scheme (ETS) mandates that airlines purchase carbon credits for emissions, incentivizing the transition to SAF. The EU ETS prohibits the use of food or feed crops as feedstocks (with the exception of camelina) and primarily uses used cooking oil as a feedstock, further driving up demand for imported used cooking oil. The United Kingdom has established its own SAF blending mandate, targeting ten percent SAF use by 2030, supported by financial incentives for new production facilities.

Other countries are also advancing their SAF strategies. Canada's Clean Fuel Regulations (CFR) set carbon intensity reduction requirements for aviation fuel, similar to California's LCFS. Japan has set a target for ten percent SAF use by 2030 and is investing considerably in biomass-to-SAF pathways. Singapore has developed a national SAF framework, positioning itself as a regional hub for SAF production and distribution.

While U.S. SAF policy has progressed, challenges remain in securing long-term financial incentives, infrastructure development, and demand certainty. Minnesota is well-positioned to play a leading role in SAF production, but it requires dedicated state-level SAF incentives that can stack with federal policies. Airlines are driving demand through ESG commitments, but high costs and limited supply continue to hinder large-scale adoption. The European Union and the United Kingdom have taken more aggressive steps, putting pressure on the U.S. to enhance its SAF policies to remain competitive.

To sustain progress in the SAF industry, the U.S. must extend federal tax credits, invest in production infrastructure, and consider a blending mandate similar to other foreign nations. With the right policies in place, SAF can play a pivotal role in the decarbonization of aviation, supporting both economic growth and environmental sustainability

5. Policy Recommendations:

The most resilient SAF economy will be one that utilizes multiple pathways and feedstocks, ensuring that disruption to a single feedstock will not prevent SAF production at scale. Additionally, future decarbonization efforts, including SAF production, will require immense energy resources, funding, and continued innovation. The following recommendations assume that Minnesota desires to play a leading role in SAF production.

Recommendations for the state of Minnesota include, (1) advancing policy to promote SAF production, (2) prioritizing the most efficient and impactful pathways, (3) investing in foundational infrastructure, (4) assessing barriers to funding, (5) supporting further research and development, (6) mitigating water-related concerns, and (7) narrating a sustainable economy. At present, these are among the most impactful steps the state can take to promote a future economy with lower greenhouse gas emissions, improved natural resource management, and more equitable health outcomes for Minnesota.

5.1 Policy Change

Policy change will be a necessary tool to overcome barriers to SAF production, especially as it relates to permitting and tax incentives. Recommendations for policy change include:

- Modify the permitting process to increase the speed at which SAF production facilities and renewable energy can be built.
- Implement a Low-Carbon Fuel Standard to support long-term SAF scaling.

Additional policy recommendations related to tax credits are explored in Section 5.4, Assessing Barriers to Funding.

5.2 Pathway Prioritization

Minnesota will need to prioritize investment and research in the most efficient pathways for the current climate. Recommendations for prioritization include the following:

- Prioritize feedstocks with the lowest carbon intensity that do not cause indirect land use change or associated environmental harms, such as agricultural and forestry wastes (FT), winter annual oilseeds (HEFA), FOG (HEFA), and PtL.
- Avoid feedstocks that are used as food crops (corn and soy) as they have higher carbon intensities due to their negative environmental impacts and require additional decarbonization in order to qualify for SAF tax credits. Where possible, promote lowering carbon intensity for these feedstocks through the promotion of sustainable agricultural practices, such as cover crops, no-till farming, and enhanced efficiency fertilizers to reduce the impacts to water quality, soil health, and biodiversity.
- Prioritize the most efficient uses of green hydrogen. All pathways require hydrogen, and there will be critical competition for green hydrogen resources beyond use in SAF. Green hydrogen may be more beneficial for green steel and green ammonia production in the short term. Green ammonia fertilizer can be used to reduce the carbon intensity of crop-based SAF (corn for AtJ, soy/vegetable oils, and winter annual oilseeds for HEFA). Within SAF, green hydrogen should be prioritized for feedstocks with higher CI scores (corn for AtJ and soybeans for HEFA).

5.3 Investing in the Foundation

Beyond the SAF-specific technology, additional resources will be needed to promote the scale-up of SAF production and a decarbonized economy in Minnesota. Specifically, recommendations for state-wide investment include the following:

- Prioritize expanding the renewable energy grid and electric capacity.
- Prioritize the build-out of high-voltage transmission infrastructure to efficiently transport electricity from renewable sources to areas of high demand.
- Prioritize permitting reform for both SAF production facilities and the renewable energy buildout for green hydrogen production.

5.4 Assessing Barriers to Funding

Funding remains a major obstacle. Recommendations include the following:

- Extend and expand the SAF Tax Credit to ensure long-term financial stability beyond 2035.
- Reward lower carbon intensity fuels with higher incentives, such as the proposed bill that provides additional tax credits for greater carbon intensity reductions.
- Consider alternative funding pathways that provide direct community benefits, such as mimicking the Green Fertilizer Grant Program that supports the cooperative model.
- Incentivize long-term offtake agreements.
- Provide support for feasibility and funding studies.

5.5 Research and Development

All SAF pathways still require additional research to push carbon intensity scores even lower, promote sustainable agricultural practices, and understand the resources needed to scale. Continued support of the University of Minnesota's Forever Green, the Department of Agriculture's Soil Health Financial Assistance Program, and other initiatives will ensure Minnesota is a leader of sustainable fuel innovation. Special attention should be paid to support for scaling winter camelina and other winter annual oilseeds throughout the state.

5.6 Mitigate Water-Related Concerns

Several strategies are recommended to mitigate water-related concerns in SAF production:

- Prioritize feedstocks that do not require irrigation, such as waste FOGs and agricultural residues.
- Incentivize water-efficient technologies, such as closed-loop water systems, advanced cooling methods, and onsite wastewater treatment.
- Establish water use reporting and lifecycle modeling requirements as part of permitting, similar to greenhouse gas LCAs.
- SAF facilities should be built in regions with resilient water infrastructure and an abundant supply, avoiding areas with known aquifer stress or limited recharge.

5.7 Narrating a Sustainable Economy

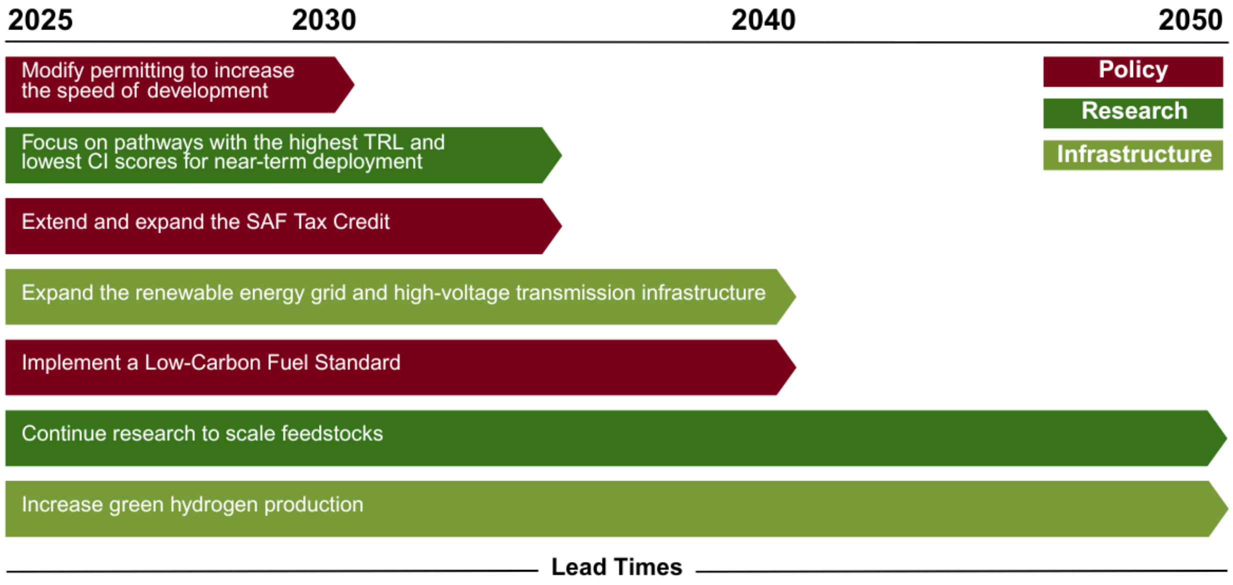
The future of Minnesota's sustainable fuels industry and other decarbonized economies will also rely on ample state-led commitment to change.

In September 2025, the North American SAF Conference and Expo is coming to Minneapolis, exemplifying the state's existing reputation as a leader within this space. The conference also serves as an opportunity for Minnesota to further establish itself as the premier location for SAF investment in the United States. Recommendations related to narrative-building include the following:

- Use the conference coming up to promote SAF production in Minnesota
- Prioritize the reputation of local government as helpful and easy to work with, especially surrounding permitting

A diverse SAF economy can create industry strength, ensuring that the viability of SAF is not dependent on a single feedstock. By taking an “all of the above” approach while prioritizing low-carbon-intensity pathways, Minnesota can become a national leader in domestic SAF production.

Figure 17: Timeline of Recommendations to Reach SAF Readiness by 2050



6. Conclusion

Minnesota is well-positioned to lead the future of sustainable aviation fuel in the United States. With its strong agricultural base, advanced research institutions, growing clean energy infrastructure, and proactive policy environment, the state is uniquely positioned to become a national leader in SAF production. This report demonstrates that Minnesota has the capacity, resources, and institutional momentum to support SAF development across multiple viable pathways, particularly HEFA, AtJ, and FT, with PtL as a long-term option.

A diversified, multi-pathway approach to SAF production can ensure resilience, scalability, and sustainability. Feedstock availability – especially winter camelina, agricultural residues, and forestry waste – offers a robust supply foundation with co-benefits for soil health, water quality, and rural economic development. However, realistic challenges remain, including high production costs, intensive energy and water requirements, hydrogen supply constraints, and limited infrastructure.

Minnesota’s energy infrastructure and electricity demand present some of the most critical barriers to SAF deployment. All SAF pathways require hydrogen, and producing green hydrogen at scale will demand between 606 and 1,817 GWh of renewable electricity annually, excluding the PtL pathway, which on its own could require 23.5 TWh per year to meet the projected demand at MSP Airport. The energy demand of the SAF industry in Minnesota will require a significant build-out of wind, solar, and transmission infrastructure.

Achieving Minnesota's SAF potential will require coordination across the private and public sectors. Permitting reform, tax credit extensions, and the establishment of long-term carbon standards can catalyze and accelerate a Minnesota SAF economy. Additionally, continued investment in research, infrastructure, and rural capacity building will be necessary to support a robust, equitable, and competitive SAF industry in the state.

By advancing the six core recommendations identified in this report – (1) advancing policy to promote SAF production, (2) prioritizing the most efficient and impactful pathways, (3) investing in foundational infrastructure, (4) assessing barriers to funding, (5) supporting further research and development, (6) mitigating water-related concerns, and (7) narrating a sustainable economy – Minnesota can build a diversified SAF industry that is both economically viable and environmentally sustainable, serving as a national model for how to decarbonize aviation while driving rural development, clean energy expansion, and effective natural resource management.

7. References

2024 Minnesota Energy Factsheet. Business Council for Sustainable Energy, 2024, https://www.cleanenergyeconomymn.org/wp-content/uploads/2024/04-MN-Factsheet-Infographic-2024.pdf

2025 Minnesota Energy Factsheet. Business Council for Sustainable Energy, 2025, https://www.cleanenergyeconomymn.org/wp-content/uploads/2025/04/2025-Minnesota-Energy-Factsheet.pdf.

Air Transport Action Group. *Beginner's Guide to Sustainable Aviation Fuel*. 4 Apr. 2023, www.atag.org.

Alternative Fuels Data Center: Ethanol Benefits and Considerations. https://afdc.energy.gov/fuels/ethanol-benefits. Accessed 29 Apr. 2025.

Alternative Fuels Data Center: Ethanol Laws and Incentives in Federal. https://afdc.energy.gov/fuels/laws/ETH?state=US Accessed 29 Apr. 2025.
.
Alternative Fuels Data Center: Sustainable Aviation Fuel. https://afdc.energy.gov/fuels/sustainable-aviation-fuel. Accessed 29 Apr. 2025.

AURI, "A Sustainable Aviation Fuel Hub Set For Take Off in Minnesota." https://auri.org/ag-innovation-news/nov-2023-jan-2024/a-sustainable-aviation-fuel-hub-set-for-take-off-in-minnesota/. Accessed 6 May 2025.

BETO: Billion-Ton 2023. https://www.energy.gov/eere/bioenergy/2023-billion-ton-report-assessment-us-renewable-carbon-resources. Accessed 29 Apr. 2025.

Braun, Matthias, et al. "Pathway to Net Zero: Reviewing Sustainable Aviation Fuels, Environmental Impacts and Pricing." *Journal of Air Transport Management*, vol. 117, May 2024, p. 102580. *DOI.org (Crossref)*, https://doi.org/10.1016/j.jairtraman.2024.102580.

Calderon, Oscar, et al. *Sustainable Aviation Fuel (SAF) State-of-Industry Report: State of SAF Production Process*. National Renewable Energy Laboratory, July 2024.

Calderon, Oscar, et al. *Sustainable Aviation Fuel State-of-Industry Report: Hydroprocessed Esters and Fatty Acids Pathway*. National Renewable Energy Laboratory, July 2024, https://www.nrel.gov/docs/fy24osti/87803.pdf.

Carcass Disposal. https://bah.state.mn.us/emergency-carcass-resources. Accessed 4 May 2025.

Catalyst. "How Twelve Makes Jet Fuel From Air." *Twelve | A World Made from Air*, 1 Oct. 2024, https://www.twelve.co/post/how-twelve-makes-jet-fuel-without-oil.

Cathcart, Joey, et al. *Fueling Up Sustainable Aviation: A Roadmap for SAF in the Rocky Mountain Region*. Rocky Mountain Institute, 2024, https://rmi.org/wp-content/uploads/dlm_uploads/2024/06/fueling_up_sustainable_aviation.pdf.

Center for Sustainable Systems, University of Michigan. 2024. "Wind Energy Factsheet." Pub. No. CSS07-09.

Clean fuel production credit. (2025). Alternative Fuels Data Center. https://afdc.energy.gov/laws/13321

Climate Action Framework | *Our Minnesota Climate*. https://climate.state.mn.us/minnesotas-climate-action-framework.

Climate change trends and data | *Minnesota Pollution Control Agency. (2025). MPCA. https://www.pca.state.mn.us/air-water-land-climate/climate-change-trends-and-data*

Connelly, Tiffanie. “Minnesota’s Path to a Cleaner Aviation Future.” *Clean Energy Economy Minnesota*, 4 Aug. 2023, https://www.cleanenergyeconomymn.org/blog/cleaner-aviation-future.

Corn and Other Feed Grains - Feed Grains Sector at a Glance | *Economic Research Service*. https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance . Accessed 4 May 2025.

Cover Crop Demonstration Grants Initiative | *MN Board of Water, Soil Resources*. https://bwsr.state.mn.us/cover-crop-demonstration-grants-initiative. Accessed 4 May 2025.

Decarbonizing Aviation: Executing on Net-Zero Goals | *McKinsey*. https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/decarbonizing-aviation-executing-on-net-zero-goals. Accessed 29 Apr. 2025.

Delta’s Industry Leading Full-Court Press on Sustainable Aviation Fuel Continues at Midwest Hubs | *Delta News Hub*. 24 Oct. 2024, https://news.delta.com/deltas-industry-leading-full-court-press-sustainable-aviation-fuel-continues-midwest-hubs.

DG Fuels. “DG Fuels to Launch SAF Plant in Moorhead, Minnesota, Converting Biomass into High-Value Fuel.” *DGFuels*, 30 Oct. 2024, https://dgfuels.com/2024/10/30/dg-fuels-to-launch-saf-plant-in-moorhead-minnesota-converting-biomass-into-high-value-fuel/.

Division of Forestry. *Minnesota Forest Products Industry at a Glance*. Minnesota Department of Natural Resources, Apr. 2025, https://files.dnr.state.mn.us/forestry/um/mn-forest-industry-fact-sheet.pdf.

“DOE Makes $3B Commitment to Two Sustainable Aviation Fuel Projects.” *Canary Media*, 16 Oct. 2024, https://www.canarymedia.com/articles/air-travel/doe-makes-3b-commitment-to-two-sustainable-aviation-fuel-projects.

Ecotone Analytics, Forever Green Partnership, & Friends of the Mississippi River. (2023). *Putting Down Roots: Analyzing the economic and environmental benefits of* *continuous living cover for Minnesota's farmers, water and climate.* *https://www.fmr.org/CLC-Report*

Electrolysis for Green Hydrogen Production. Linde. https://www.linde.com/clean-energy/our-h2-technology/electrolysis-for-green-hydrogen-production. Accessed 4 May 2025.

"European and US Used Cooking Oil Demand Increasingly Unsustainable -…." *T&E*, 9 Apr. 2025, https://www.transportenvironment.org/articles/european-and-us-used-cooking-oil-demand-increasingly-unsustainable-analysis.

Forever Green Initiative Receives $75,000 Grant | Forever Green. https://forevergreen.umn.edu/forever-green-initiative-receives-75000-grant. Accessed 4 May 2025.

Fravel, Caleb. *Delta Sends off First Flight from MSP Using Minnesota-Grown Sustainable Fuel*. 25 Sept. 2024, https://www.startribune.com/delta-cargill-msp-sustainable-aviation-jet-fuel-first-flight/601151365.

"Freedom Pines Fuels." *LanzaJet*, https://www.lanzajet.com/freedom-pines. Accessed 29 Apr. 2025.

Frischmann, Jay. *Minnesota Department of Natural Resources*. Telephone interview. 9 Apr. 2025.

Gauthier, Vincent. *Cover Crop Costs Vary Significantly: New Data from 83 Minnesota Farms Shows | EDF*. 26 July 2023, https://blogs.edf.org/growingreturns/2023/07/26/minnesota-farms-cover-crop/.

"GREET." *Energy.Gov*, https://www.energy.gov/eere/greet. Accessed 29 Apr. 2025.

Heirloom Blog - Working with United Sustainable Flight Fund to Accelerate Aviation's Path to True Net Zero. https://www.heirloomcarbon.com/news/accelerating-aviations-path-to-true-net-zero-with-united-sustainable-flight-fund. Accessed 29 Apr. 2025.

HF 7 Status in the House for the 93rd Legislature (2023 - 2024). https://www.revisor.mn.gov/bills/bill.php?f=HF7&y=2023&ssn=0&b=house. Accessed 4 May 2025.

HF 8 status in the house for the 94th legislature (2025—2026). (2025). https://www.revisor.mn.gov/bills/bill.php?b=House&f=HF0008&ssn=0&y=2025

HF 1208 Status in the House for the 94th Legislature (2025 - 2026). https://www.revisor.mn.gov/bills/bill.php?f=HF1208&y=2025&ssn=0&b=house. Accessed 6 May 2025.

Holler, John. *Fueling a Low-Carbon Biofuel Future in Minnesota*. Center for Climate and Energy Solutions, May 2024, www.c2es.org.

Howe, Campbell, et al. *Pathways to Commercial Liftoff: Sustainable Aviation Fuel*. U.S. Department of Energy, Nov. 2024, https://liftoff.energy.gov/wp-content/uploads/2024/12/LIFTOFF_-Sustainable-Aviation-Fuel_Updated-2.6.25.pdf.

Hudson, Matt. "Pause Lifted on Biofuel Facility Loan." *Montana Free Press*, 17 Feb. 2025, http://montanafreepress.org/2025/02/17/pause-lifted-on-biodiesel-facility-loan/.

Hughes, Lisa. *Minnesota Department of Employment and Economic Development*. Zoom interview. 24 Jan. 2025.

International, Bioenergy. "DG Fuels to Launch SAF Plant in Minnesota." *Bioenergy International*, 11 Nov. 2024, https://bioenergyinternational.com/dg-fuels-to-launch-saf-plant-in-minnesota/.

International Civil Aviation Organization. *CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels*. International Civil Aviation Organization, Mar. 2024, https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20March%202024.pdf.

Jones, Florence. *'Tens of Billions' Needed to Scale up Sustainable Aviation Fuel Ahead of 2030*. https://www.sustainableviews.com/tens-of-billions-needed-to-scale-up-sustainable-aviation-fuel-ahead-of-2030-5e93a083/. Accessed 4 May 2025.

Lam, Edmund. "Alcohol-to-Jet: Fueling the Future of SAF." *ADI Analytics*, 25 June 2024, https://adi-analytics.com/2024/06/25/alcohol-to-jet-fueling-the-future-of-saf/.

"LanzaJet Announces Strategic Investment from Airbus - Pioneering…." *LanzaJet*, 24 July 2024, https://www.lanzajet.com/news-insights/airbus.

Lashof, Dan, and Audrey Denvir. *Under New Guidance, "Sustainable" Aviation Fuel in the US Could Be Anything But*. May 2024. *www.wri.org*, https://www.wri.org/insights/us-sustainable-aviation-fuel-emissions-impacts.

Lau, Jason Ik Cheng, et al. "Emerging Technologies, Policies and Challenges toward Implementing Sustainable Aviation Fuel (SAF)." *Biomass and Bioenergy*, vol. 186, July 2024, p. 107277. *DOI.org (Crossref)*, https://doi.org/10.1016/j.biombioe.2024.107277.

Leavitt, Matt. (2024, October 2). *Winter camelina: A new oilseed crop for Minnesota*. University of Minnesota Extension. https://blog-crop-news.extension.umn.edu/2024/10/winter-camelina-new-oilseed-crop-for.htmlMinnesota Crop News

Li, X., & Mupondwa, E. (2014). Life cycle assessment of camelina oil derived biodiesel and jet fuel in the Canadian Prairies. *Science of The Total Environment*, *481*, 17–26. https://doi.org/10.1016/j.scitotenv.2014.02.003

"Methanol-to-Jet: Pioneering the Future of Sustainable Aviation Fuel Powered by the Methanol Economy." *NexantECA*, 27 Feb. 2025, https://www.nexanteca.com/blog/202502/methanol-jet-pioneering-future-sustainable-aviation-fuel-powered-methanol-economy.

Mills, R. (2024, June 14). *The five dimensions of hydrogen*. RMI. https://rmi.org/the-five-dimensions-of-hydrogen/

Minnesota Forest Resources Council. *Wheels Up With Wood*. Minnesota Forest Resources Council, 2024, https://mn.gov/frc/.

Minnesota Forest Resources Council 2023-2024 Biennial Report. p. 40, https://www.lrl.mn.gov/docs/2025/mandated/250360.pdf.

Minnesota House of Representatives. https://www.house.mn.gov/hjvid/94/899096. Accessed 29 Apr. 2025.

Minnesota Legislature. (2025). *Senate File 1515: A bill for an act relating to agriculture; modifying the definition of sustainable aviation fuel*. SF 1515, 94th Legislature. https://www.revisor.mn.gov/bills/text.php?number=SF1515&session=ls94&session_number=0&session_year=2025&version=0

Minnesota Pollution Control Agency. *2025 Legislative Recommendations: Permitting Reform*. Minnesota Pollution Control Agency, 2025, https://www.house.mn.gov/comm/docs/1KLzshOSLEiWIoxWtwS8bQ.pdf.

Minnesota Pollution Control Agency. *MPCA Budget Recommendations*. Minnesota Pollution Control Agency, 2025, www.pca.state.mn.us/sites/default/files/leg-sy25-01.pdf.

Minnesota Statutes § 216C.441. (2023). *Minnesota Climate Innovation Finance Authority*. Retrieved from https://www.revisor.mn.gov/statutes/cite/216C.441MN Revisor's Office

Minnesota Sustainable Aviation Fuel Hub - Minneapolis Saint Paul Economic Development | Greater MSP. https://www.greatermsp.org/pages/saf/. Accessed 29 Apr. 2025.

Moniz, Ernest, et al. *Direct Air Capture: A Rapidly Expanding Landscape from Kiloton to Megaton Scale*. EFI Foundation, Nov. 2024.

Neo, Rongwei. “China Begins SAF Pilot with Commercial Flights, Airports; to Ramp up in 2025.” *S&P Global*, 19 Sept. 2024, https://www.spglobal.com/commodity-insights/en/news-research/latest-news/agriculture/091924-china-begins-saf-pilot-with-commercial-flights-airports-to-ramp-up-in-2025.

New Laws - Minnesota House Public Information Services - Minnesota House of Representatives. https://www.house.mn.gov/NewLaws/story/2023/5473. Accessed 4 May 2025.

Niepow, Dan. “Airbus to Invest in Minnesota Sustainable Aviation Fuel Hub.” *Twin Cities Business*, 9 Jan. 2025, https://tcbmag.com/airbus-to-invest-in-minnesota-sustainable-aviation-fuel-hub/.

Orenstein, W. (2025, January 10). *The staggering power needs of Minnesota data centers*. https://www.startribune.com/mega-data-centers-are-coming-to-minnesota-their-power-needs-are-staggering/601204129

"Pathways to Commercial Liftoff." *Pathways to Commercial Liftoff*, https://liftoff.energy.gov/. Accessed 29 Apr. 2025.

"Press Release: Sustainable Aviation Fuels: How We Can Get It Right." *Friends of the Mississippi River*, 17 July 2022, https://fmr.org/updates/general/press-release-sustainable-aviation-fuels-how-we-can-get-it-right.

Render Apr.23. https://pubs.rendermagazine.com/2023-04/. Accessed 4 May 2025.

Ritchie, Hannah. "What Share of Global CO_2 Emissions Come from Aviation?" *Our World in Data*, Apr. 2024. *ourworldindata.org*, https://ourworldindata.org/global-aviation-emissions.

Rojas-Michaga, Maria Fernanda, et al. "Sustainable Aviation Fuel (SAF) Production through Power-to-Liquid (PtL): A Combined Techno-Economic and Life Cycle Assessment." *Energy Conversion and Management*, vol. 292, Sept. 2023, p. 117427. *DOI.org (Crossref)*, https://doi.org/10.1016/j.enconman.2023.117427.

SAF rules of thumb. (n.d.). ICAO. Retrieved May 7, 2025, from https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

SF 2833 Status in the Senate for the 94th Legislature (2025 - 2026). https://www.revisor.mn.gov/bills/bill.php?b=Senate&f=SF2833&ssn=0&y=2025. Accessed 6 May 2025.

Sloat, Lindsey, et al. *The World Is Growing More Crops — but Not for Food*. Dec. 2022. *www.wri.org*, https://www.wri.org/insights/crop-expansion-food-security-trends.

Smith, Alan. *Production in Minnesota*. https://www.mnbiofuels.org/resources/production-in-minnesota. Accessed 4 May 2025.

Solomon, Matt. "Sustainable Aviation Fuel Targeted Opportunity Region – Great Lakes Region." *RMI*, 26 Sept. 2023, https://rmi.org/sustainable-aviation-fuel-targeted-opportunity-region-great-lakes-region/.

"Some Pondera County Citizens Concerned about Proposed Injection Well Plan." *KRTV NEWS Great Falls*, 3 June 2024, https://www.krtv.com/news/montana-ag-network/pondera-county-citizens-concerned-over-proposed-injection-well-plan.

Soy Product Innovations: Building on Current Market Trends to Support Minnesota Soybean Farmers. Minnesota Soybean Research and Promotion Council, 2024, https://mnsoybean.org/wp-content/uploads/2024/05/SoyProductsOnePager-1.pdf.

"Sustainable Aviation Fuel Facility Coming to Rosemount." *Twin Cities Business*, 10 Sept. 2024, https://tcbmag.com/sustainable-aviation-fuel-facility-coming-to-rosemount/.

Sustainable aviation fuel (SAF) tax credit. (2022). Alternative Fuels Data Center. https://afdc.energy.gov/laws/13160

Sustainable aviation fuel grand challenge. (2021). Energy.Gov; Department of Energy. https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge

The Electric. 18 June 2017, https://theelectricgf.com/.

University of Minnesota Awarded $726K for Hydrogen Production Research Project. https://citizenportal.ai/articles/2293065/Minnesota/University-of-Minnesota-awarded-726K-for-hydrogen-production-research-project. Accessed 29 Apr. 2025.

Unlocking the Potential of Sustainable Aviation Fuel through Meaningful Advocacy | Delta News Hub. 18 Apr. 2024, https://news.delta.com/unlocking-potential-sustainable-aviation-fuel-through-meaningful-advocacy.

US Corn Acres Planted Yearly Analysis: USDA Farm Price Received | YCharts. https://ycharts.com/indicators/us_corn_acres_planted#:~:text=US%20Corn%20Acres%20Planted%20is,5.22%25%20from%20one%20year%20ago. Accessed 4 May 2025.

U.S. Department of Agriculture, Department of the Chief Economist. *USDA Agricultural Projections to 2034*. Feb. 2025, https://ers.usda.gov/sites/default/files/_laserfiche/outlooks/110966/OCE-2025-1.pdf.

U.S. Department of Agriculture, Economic Research Service. (2024). *USDA Agricultural Projections to 2033*. https://www.ers.usda.gov/publications/pub-details/?pubid=106343.

U.S. Department of Energy. *2023 Billion-Ton Report: An Assessment of U.S. Renewable Carbon Sources*. Mar. 2024.

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_cf.html&sid=MN. Accessed 4 May 2025.

U.S. Imports of Animal Fats, Greases, and Processed Oils Surge to Meet Demand from Biomass-Based Diesel Production | Economic Research Service. https://www.ers.usda.gov/data-products/charts-of-note/chart-detail?chartId=109758. Accessed 4 May 2025.

USDA National Agriculture Statistics Service. *Minnesota Ag News Crop Production*. USDA, 11 Oct. 2024, https://data.nass.usda.gov/Statistics_by_State/Minnesota/Publications/Crops_Press_Releases/2024/MN-Crop-Production-10-24.pdf.

Vondracek, Christopher. *Camelina Is the Crop of Jet Fuels and Cleaner Waters. But Will Farmers Grow It?* 10 July 2024, https://www.startribune.com/camelina-sustainable-jet-fuel-water-farm-minnesota/600379667.

Werner, Brian. *Low Carbon Biofuels: A Pathway to Reward Climate Smart Agriculture*.
---. *Minnesota Biofuels Association*. 4 Mar. 2025.

Winter Camelina | Forever Green. https://forevergreen.umn.edu/crops/winter-camelina. Accessed 29 Apr. 2025.

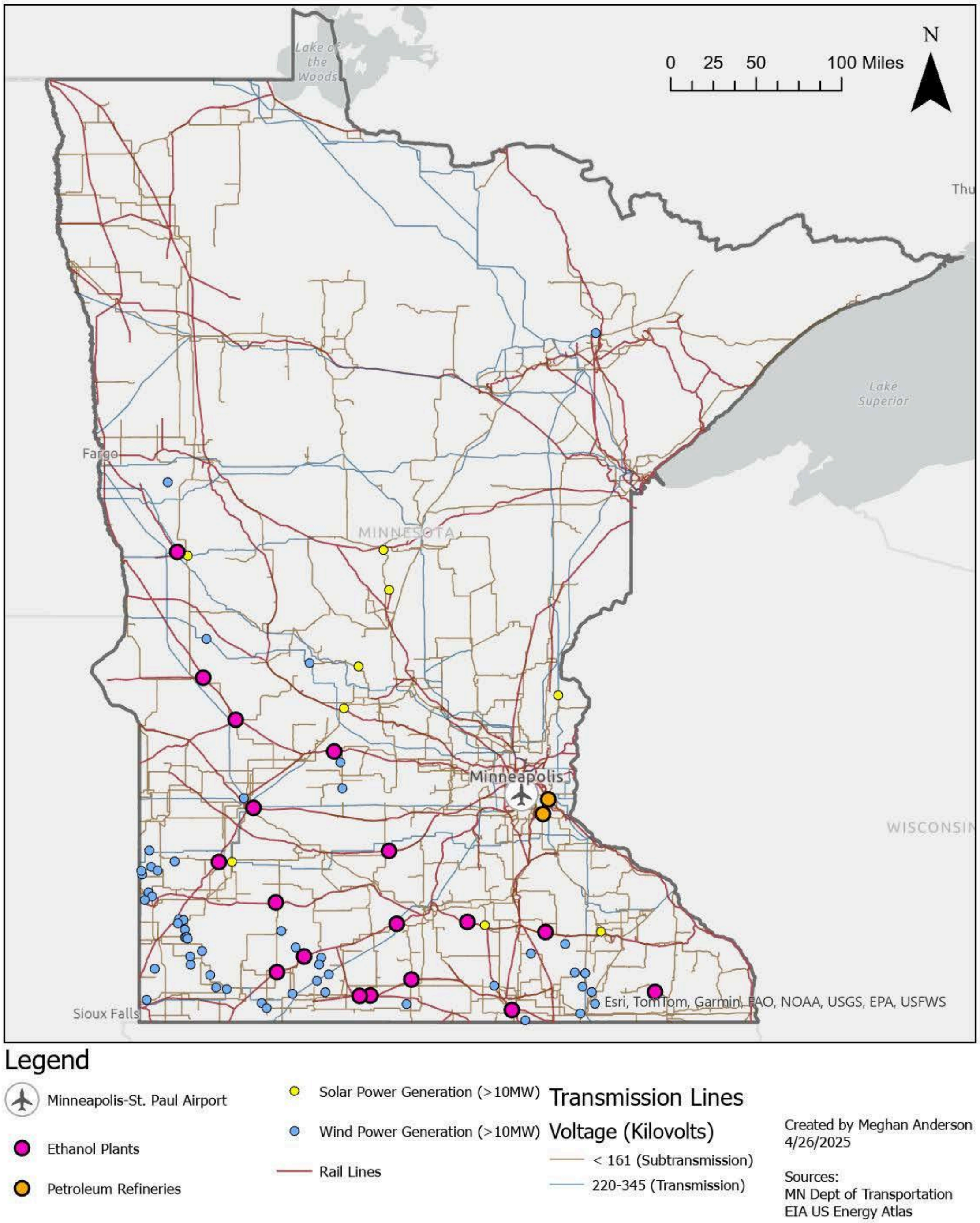
Wu, May. “Water Reuse in Sustainable Aviation Fuel Production.” *Proceedings of the Water Environment Federation*, Water Environment Federation, 2024. *DOI.org (Crossref)*, https://doi.org/10.2175/193864718825159517.

Ye, Su. *Minnesota Agricultural Facts and Stats*. Minnesota Department of Agriculture, 2023, https://www.mda.state.mn.us/sites/default/files/docs/2023-11/MN%20Ag%20Facts%20%26%20Stats%2011-1-2023.pdf.

Zhou, Qu, et al. “Recent Rapid Increase of Cover Crop Adoption Across the U.S. Midwest Detected by Fusing Multi-Source Satellite Data.” *Geophysical Research Letters*, vol. 49, no. 22, Nov. 2022, p. e2022GL100249. *DOI.org (Crossref)*, https://doi.org/10.1029/2022GL100249.

8. Appendix: Infrastructure and Biomass Availability Maps

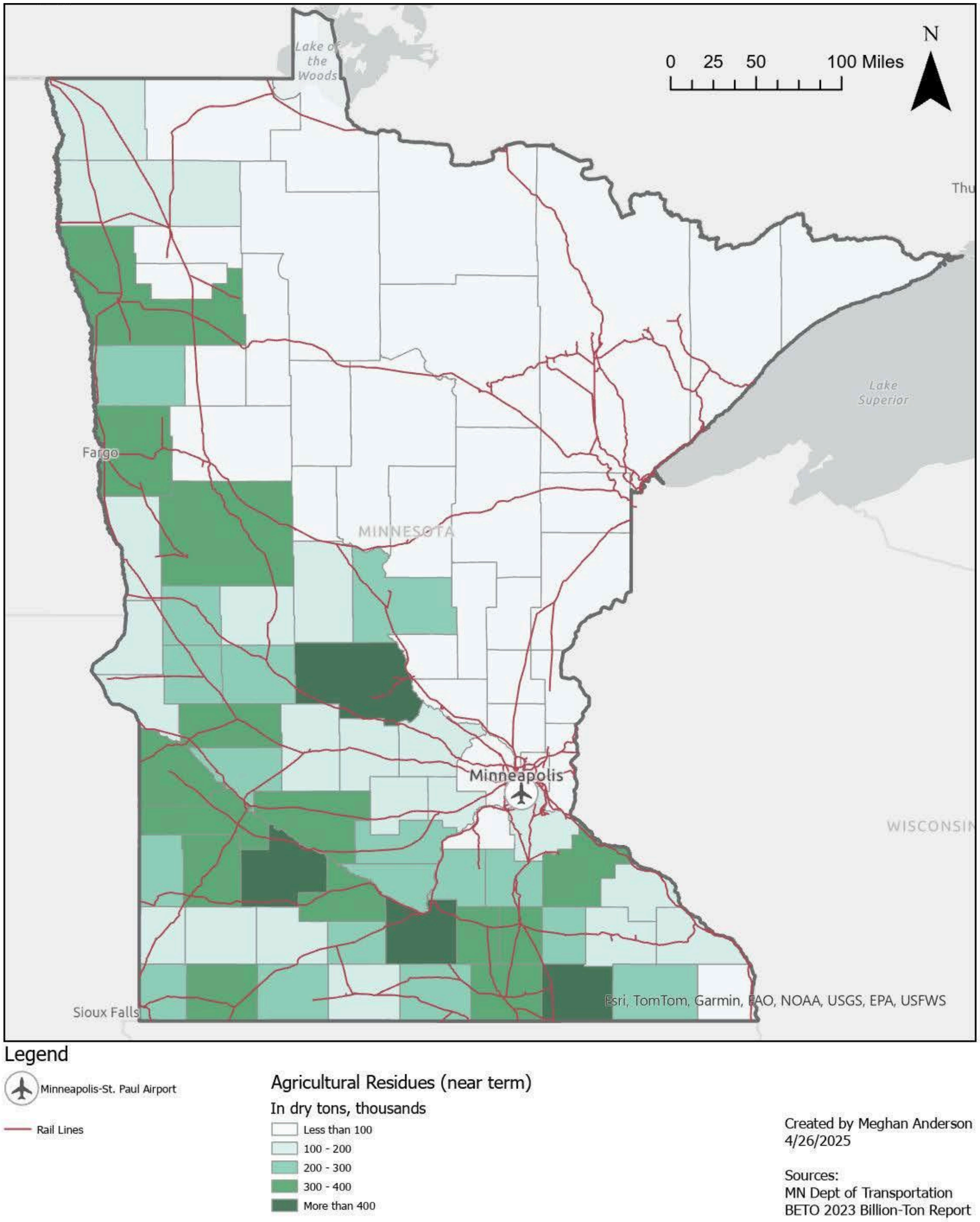
Figure 18: Map of Minnesota's Existing SAF Infrastructure



Created by Meghan Anderson
4/26/2025

Sources:
MN Dept of Transportation
EIA US Energy Atlas

Figure 19: Map of Minnesota's Near-Term Agricultural Residues



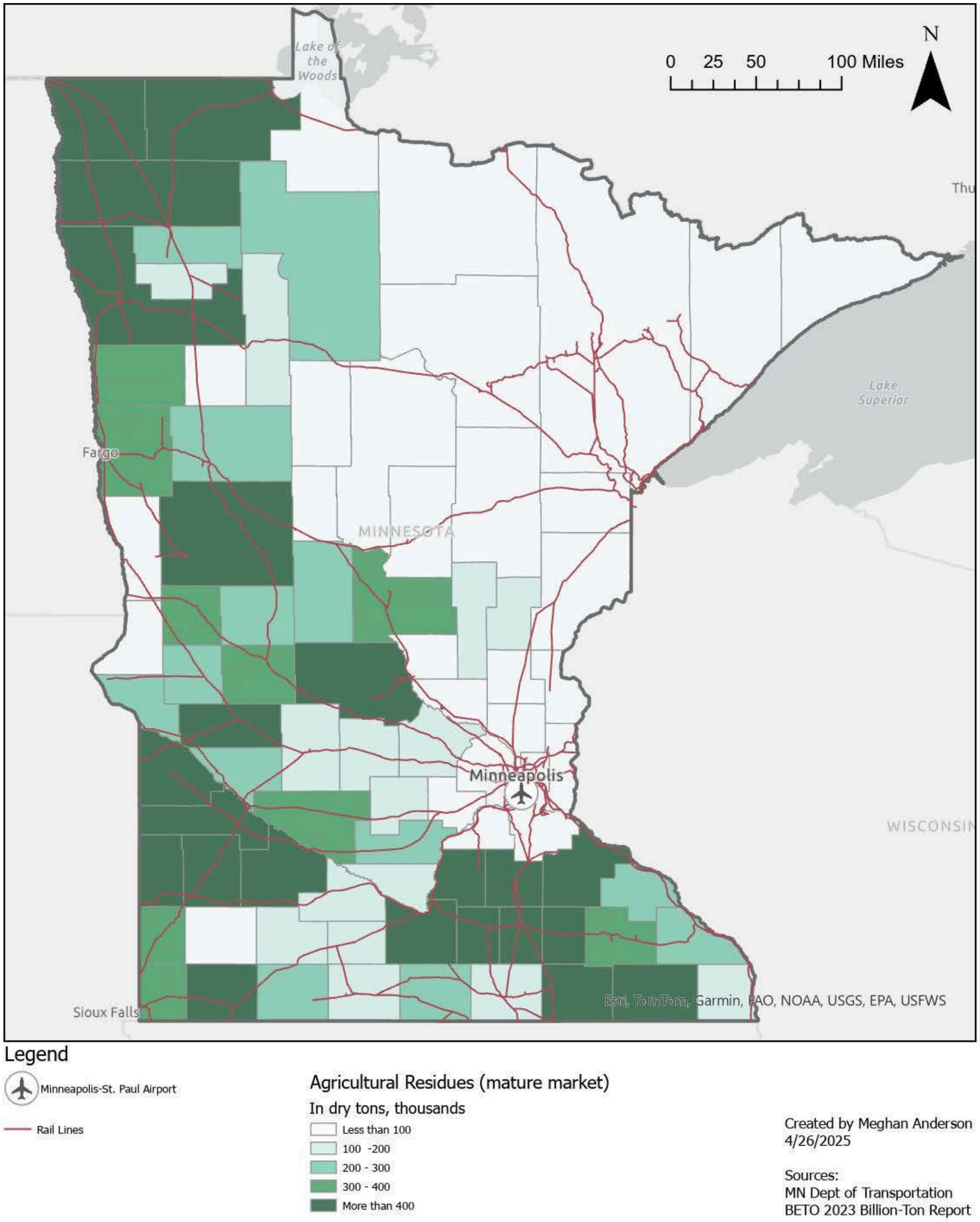
Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, USFWS

Created by Meghan Anderson
4/26/2025

Sources:
MN Dept of Transportation
BETO 2023 Billion-Ton Report

Near term (per Department of Energy Bioenergy Technology Office Billion-Ton 2023 Report): Resources that are currently available and can be used in the next 5-10 years, in addition to current uses. Assumes modeling year 2030 within county-level soil conservation constraints.

Figure 20: Map of Minnesota's Mature Market Agricultural Residues



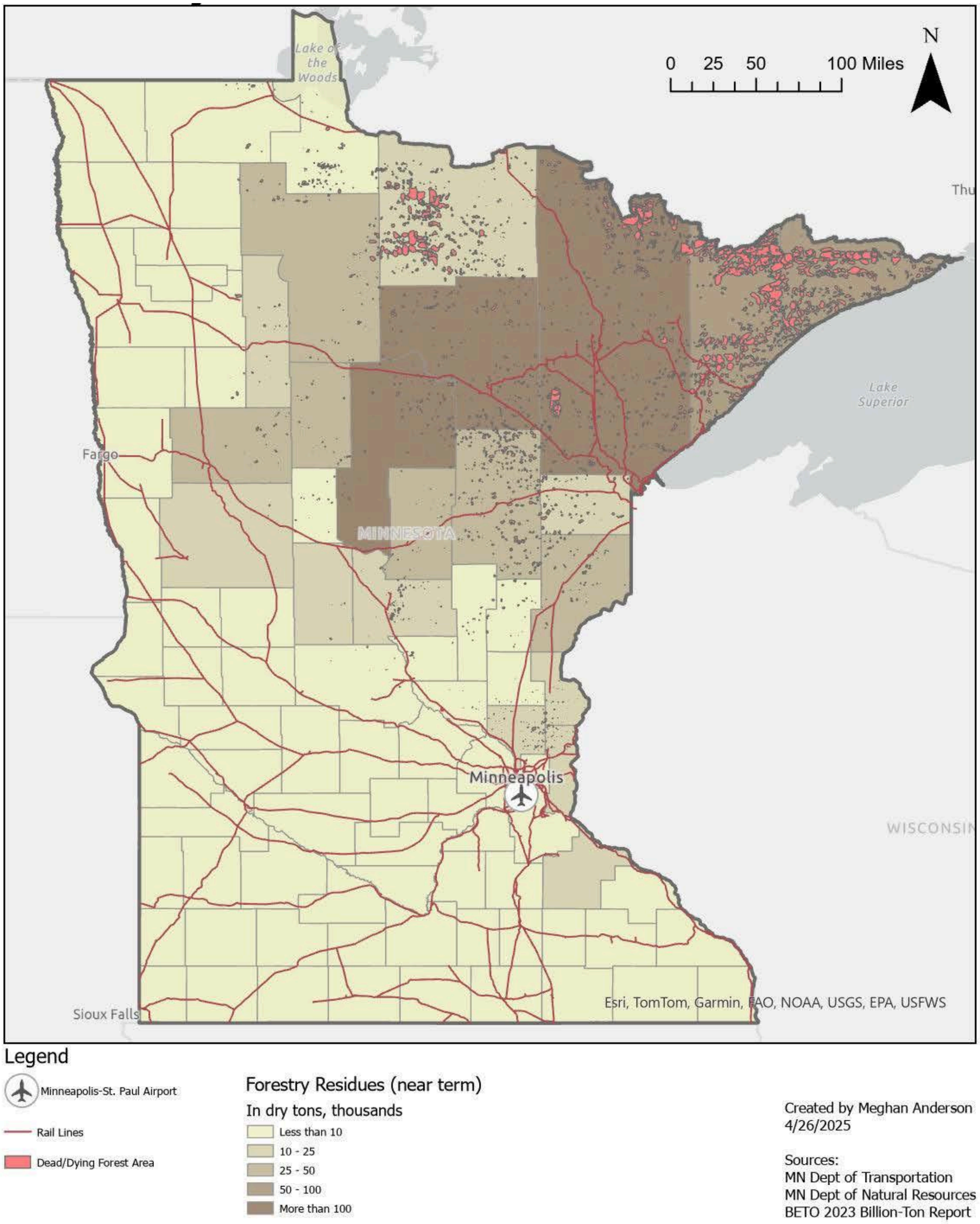
Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, USFWS

Created by Meghan Anderson
4/26/2025

Sources:
MN Dept of Transportation
BETO 2023 Billion-Ton Report

Mature Market (per Department of Energy Bioenergy Technology Office Billion-Ton 2023 Report): Assumes modeling year 2041; residue harvest technology improves from 50% to 90% potential, but within county-level soil conservation constraints. Assumes moderate market pull, moderate supply push.

Figure 21: Map of Minnesota’s Near Term Forestry Residues

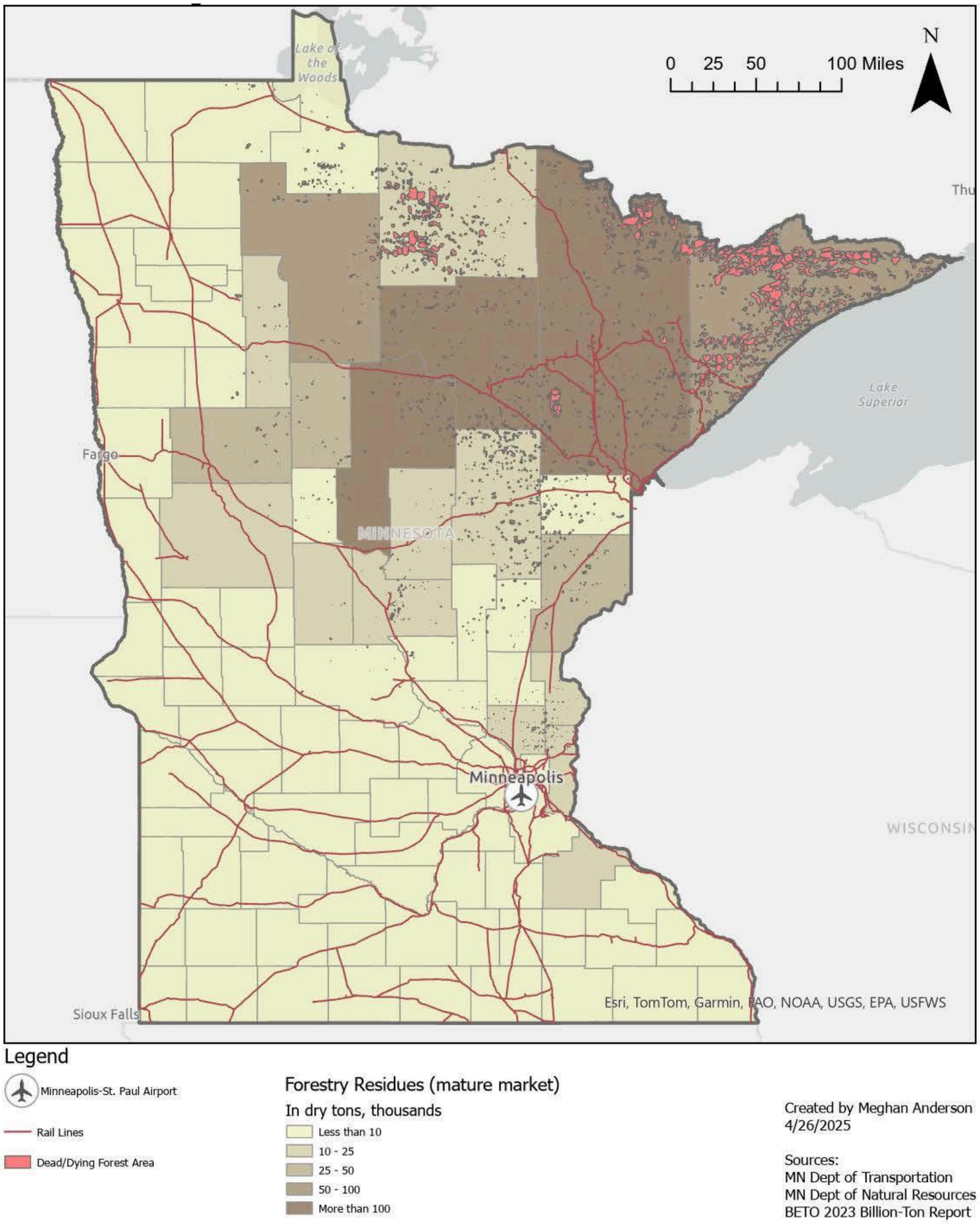


Created by Meghan Anderson
4/26/2025

Sources:
MN Dept of Transportation
MN Dept of Natural Resources
BETO 2023 Billion-Ton Report

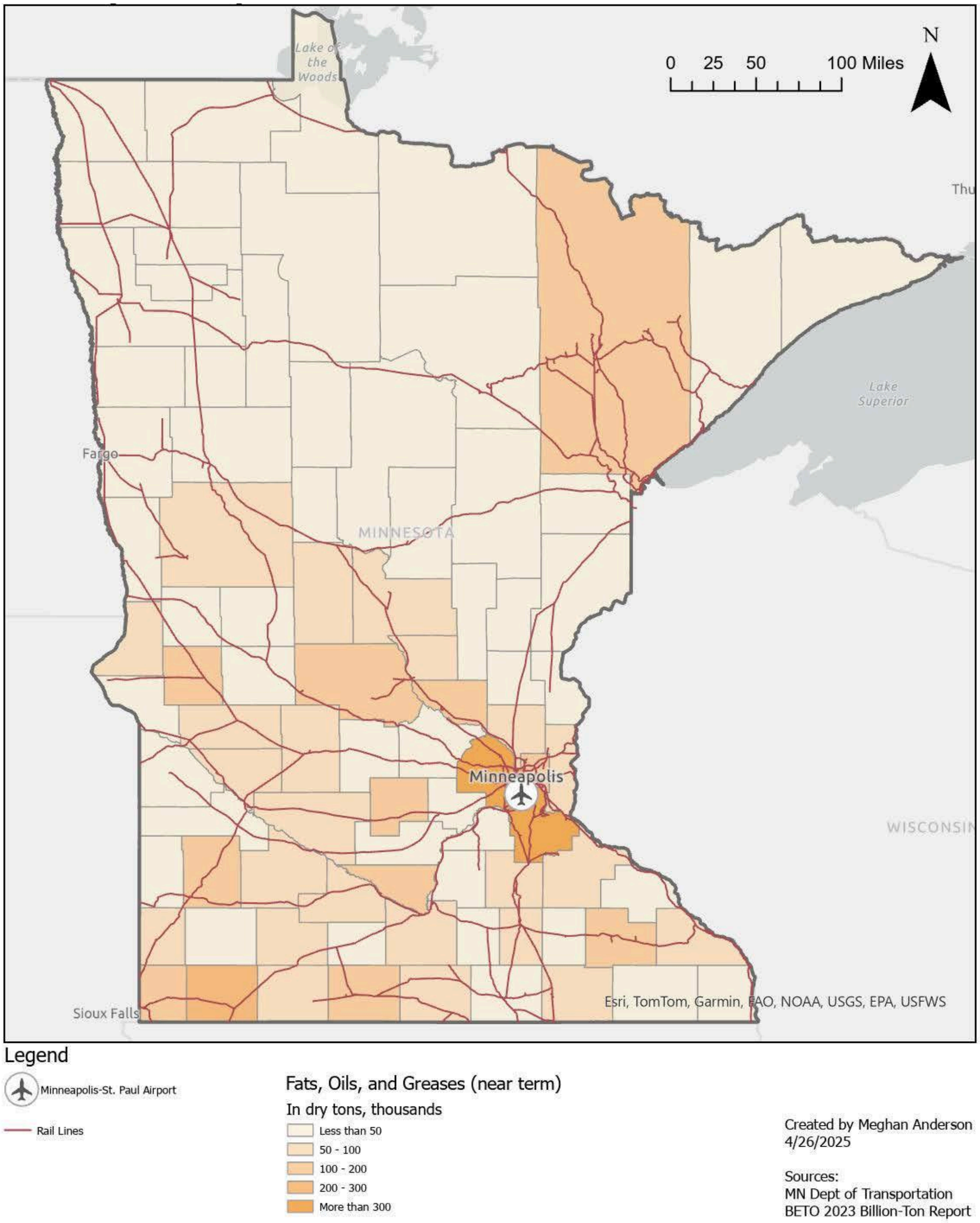
Near term (per Department of Energy Bioenergy Technology Office Billion-Ton 2023 Report): Resources that are currently available and can be used in the next 5-10 years, in addition to current uses.

Figure 22: Map of Minnesota's Mature Market Forestry Residues



Mature Market (per Department of Energy Bioenergy Technology Office Billion-Ton 2023 Report): Assumes modeling year 2050, BAU projections, moderate market pull, and moderate supply push.

Figure 23: Map of Minnesota's Near Term Fats, Oils, and Greases

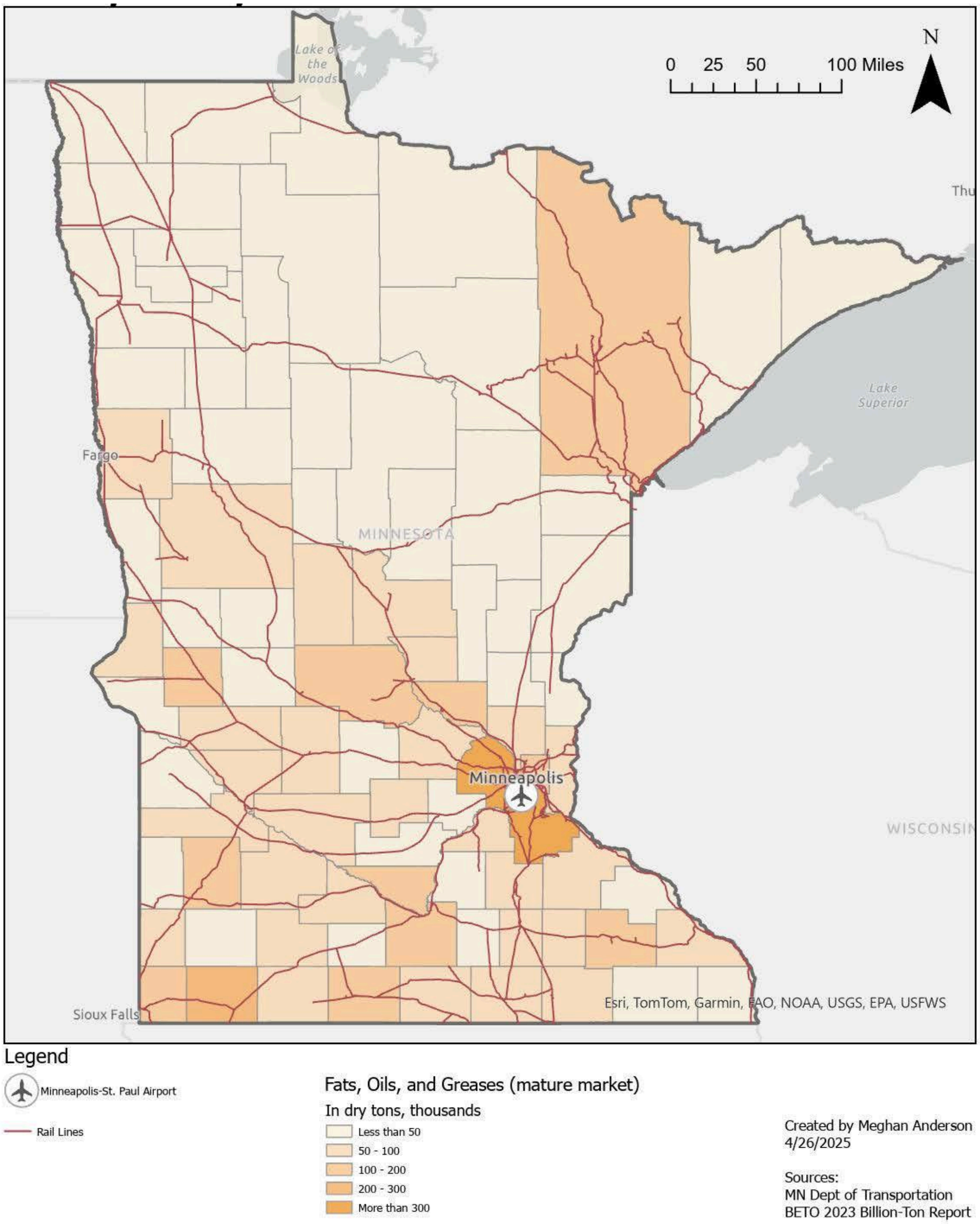


Created by Meghan Anderson
4/26/2025

Sources:
MN Dept of Transportation
BETO 2023 Billion-Ton Report

Near term (per Department of Energy Bioenergy Technology Office Billion-Ton 2023 Report): Resources that are currently available and can be used in the next 5-10 years, in addition to current uses.

Figure 24: Map of Minnesota’s Mature Market Fats, Oils, and Greases



Created by Meghan Anderson
4/26/2025

Sources:
MN Dept of Transportation
BETO 2023 Billion-Ton Report

Mature Market (per Department of Energy Bioenergy Technology Office Billion-Ton 2023 Report): Assumes BAU projections adjusted to 2050 population estimates, moderate market pull, and moderate supply push.