Carbon Direct

# Sustainable Aviation Fuels Primer:

## Promising production pathways and opportunities to scale

# Introduction

Sustainable aviation fuel (SAF) has emerged as the primary means of emissions abatement for the aviation industry. Although many airlines are pursuing alternatives (including aircraft efficiency, logistics streamlining, electrification, hydrogen, and carbon dioxide [$CO_2$] removal), SAF is the cornerstone for airlines, aircraft manufacturers, and airports.

Given this level of commitment, it is imperative to address three central challenges to SAF's ability to abate aircraft emissions at scale:

- Multiple parts of the value chain must be scaled up.  SAF production is not monolithic, like aviation fuel today.  SAF includes different technology pathways with different degrees of technical readiness.
- Incumbent SAF technologies are insufficient.  The carbon abatement associated with individual production pathways ranges enormously, from very little reduction to large greenhouse gas (GHG) increases to fully carbon negative ($CO_2$ removing) fuels.
- There is not anywhere near enough supply for today's fleet, market, and demand; massive investment is needed to achieve industry-wide 2030 and 2050 goals.

To better understand the full range of fuel types, carbon intensities, market conditions, and costs associated with this landscape of options, Carbon Direct Inc. analyzed all options and all producers in the market. This was done in partnership with Apple, which provided financial support for the work as well as guidance and exchange around what would be of greatest interest from the company's perspective. The goal of the report was *to identify pathways to produce scalable volumes of sustainable aviation fuel in 2030 that achieve a >70% carbon intensity (CI) reduction beyond conventional fuels and are economically viable.* The key findings are as follows:

- Since the key purpose of SAF is climate change mitigation, the full life cycle carbon intensity (CI) must be the critical metric of value.  SAF can be made from many feedstocks through many technology pathways and details of production can significantly affect the CI.
- Carbon capture and storage (CCS), when practiced thoughtfully in a well regulated environment that prevents leakage, is a low-cost actionable way to dramatically reduce CI for many SAF pathways.
- Some SAF pathways, such as Fischer-Tropsch to Jet and Alcohol-to-Jet, appear to have actionable routes to impactful scale, particularly if they access under-utilized forestry and agricultural waste feedstocks. Others, including some of today's cheapest options such as Hydrotreated Esters and Fatty Acids (HEFA), cannot scale readily or sustainably.
- Price is critically important to purchasers of SAF. The cost of SAF is a complex function of feedstock, energy inputs, production methods, scale of production, and CI.
- Producers of SAF need long-term surety in their revenue streams to finance projects and grow supply. This confidence can be achieved through long-term offtake agreements and stable policy support such as the subsidies and credits included in the recently enacted Inflation Reduction Act (IRA).
- The Inflation Reduction Act has transformed the SAF landscape, with the inclusion or expansion of at least three significant tax credits. As a result, many low-CI pathways can become cost competitive with conventional jet fuel.

# SAF Today

Sustainable Aviation Fuel (SAF) is a promising near-term option to reduce $CO_2$ emissions from aviation, but the market is nascent and supply is limited. There is considerable uncertainty around cost, scalability, and life cycle carbon intensity (CI) of SAF, and many studies have acknowledged the challenges of scaling low-carbon and carbon-negative SAF.[1] Addressing these challenges begins with consistent analysis across the wide variety of SAF pathways. The evolution of this market is also heavily dependent on the value and stability of key subsidies and current/future supportive policies. SAF has the potential to reduce life cycle emissions to very low or net-negative, depending on the technology, feedstock, and permissible blending ratio.[2]

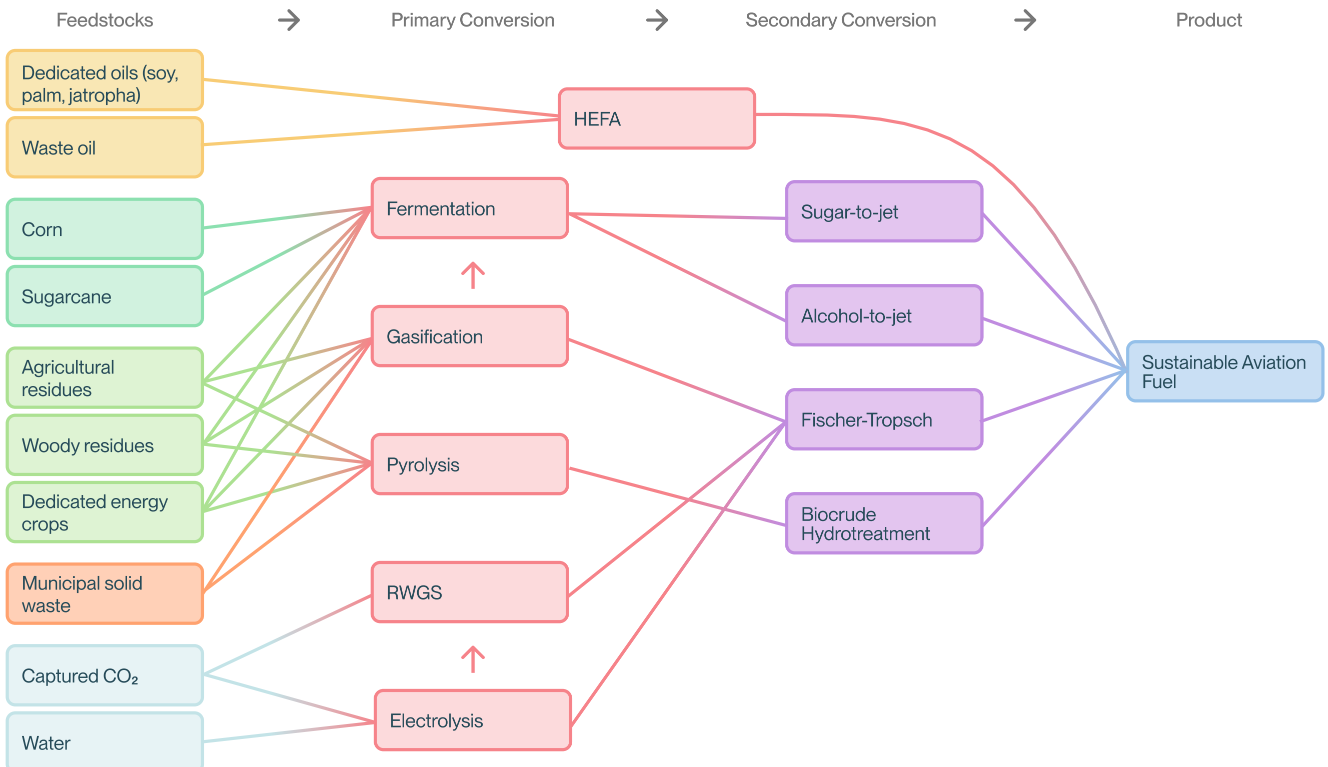


**Figure 1** SAF production pathways

Today's SAF landscape contains a variety of biofuels and low-carbon fuels (Figure 1) that are blended with conventional jet fuel. In 2019, less than 200,000 tonnes (6 million gallons) of SAF were produced globally, which corresponds to less than 0.1% of the ~300 million tonnes (90 billion gallons) of aviation fuels used.[3] The SAF share of total aviation fuel consumption needs to exceed 30% by 2040 on a global basis - greater than the total jet fuel currently consumed in the United States - to meet the International Civil Aviation Organization's (ICAO's) emissions 2040 emissions reduction targets through fuel switching alone; this accounts for the projected doubling of airline passenger volume over the next 20 years. Although offsets remain a strategy for ICAO under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) standard, what qualifies as an offset is uncertain, the standard continues to evolve in stringency, and some accepted offset providers under CORSIA have received additional recent scrutiny regarding the validity of emissions reductions and removals sold.

Purchasing fuel is a primary operating cost for airlines, a cost only exceeded by labor. Airlines are very price-sensitive because jet fuel accounts for approximately 20%–30% of their operating costs.[4] SAF today is more than double the cost of conventional aviation fuel but costs are projected to decline with further innovations and efficiencies of scale as production increases.

## SAF Pathways and Options for CCS

There are several pathways to SAF production that have been approved by the American Society for Testing and Materials (ASTM) for use as, or blending into, jet fuel. There are additional pathways that have not yet gained approval.[5] SAF pathways considered in this report are summarized in Table 1, including summaries of the technologies, their technology maturity, appropriate feedstocks, and the status of their ASTM approval for use in terms of their maximum approved blending limits. Notably, all of these processes yield not only SAF, but also a range of other products such as synthetic diesel, naphtha, biochar, or chemicals – products commercially relevant in automotive, petrochemical, and other sectors. This has secondary impacts on the cost of SAF production; while we do include the revenues from co-product sales in our model, to be conservative, we do not attempt to include additional policy revenues that may be associated with those co-products as well.

| | Technology maturity (TRL) | Technology summary | Feedstocks | Max. ASTM-approved blending limit (vol%) |
|---|---|---|---|---|
| **HEFA** | Mature (7-9) | Conversion of vegetable oils and other oil-based feedstocks (triglycerides, such as algae, to SAF through a series of hydrogenation, cracking, isomerization, deoxygenation, and distillation processes. | Oil crops (soy, jatropha, palm), Used cooking oils | 50 |
| **Alcohol-to-Jet (ATJ)** | Commercial pilot (7-8) | Alcohols, such as ethanol, undergo dehydration, oligomerization, hydrogenation, and fractionation. to produce SAF. The upstream production of ethanol can proceed via commercially available sugar fermentation technology, and syngas fermentation as an alternative ethanol production technology is under development. | Corn, Sugarcane, Cellulosic biomass* | 50 |
| **Fischer-Tropsch (FT)** | Commercial pilot (6-7) | A catalytic chemical process that yields liquid hydrocarbon fuels, including SAF, from a mixture of carbon monoxide (CO) and hydrogen ($H_2$) called synthesis gas or syngas. | Cellulosic biomass, Municipal solid waste | 50 |
| **HDCJ** | In development (5-6) | A pyrolysis-based process whereby feedstocks, such as lignocellulose, are heated in the absence of oxygen to produce biochar, biogas and bioliquids. The bio-liquids, also called pyrolysis oils or biocrude, are upgraded to liquid fuels via hydroprocessing to remove the significant oxygen content of biocrude and hydrogenate the hydrocarbons. | Cellulosic biomass, Municipal solid waste | 0 |
| **Sugar-to-Jet** | In development (5) | Aerobic fermentation, hydrogenation, and distillation processes convert sugars, such as from sugar beets, sugar cane, or lignocellulose, into liquid hydrocarbon fuel. Genetically engineered microorganisms produce farnesene in the fermentation step. Farnesene is then hydrogenated to produce farnesane, which is an iso-paraffin. | Corn, Sugarcane, Cellulosic biomass | 10 |
| **Air-to-fuels (ATF)** | In development (5-6) | Syngas is produced through a combination of: electrolysis of air-captured $CO_2$ to CO, electrolysis of water to $H_2$, and/or a reverse water gas shift reaction between $CO_2$ and $H_2$. Renewable electricity is used to generate $H_2$, making the $H_2$ green, and minimize electrolysis emissions. Syngas is then converted into hydrocarbons such as jet fuel via Fischer-Tropsch synthesis. | Carbon dioxide, Hydrogen | 50 |

**Table 1** SAF pathways considered in this report.

Importantly, SAF production accesses renewable carbon. It is made by concentrating carbon that was previously in the atmosphere through biology or chemistry. Many of these processes, particularly those that refine fuels from complex biomass molecules, will return carbon to the atmosphere in the form of the $CO_2$ byproduct of the refining reactions. This potential return is an opportunity to intercept that carbon for permanent geologic storage. Put simply, many of these pathways can improve their CI through application of carbon capture and storage (CCS) at various stages of the process. The biochemical and thermochemical pathways utilize building blocks of triglyceride processing, fermentation, gasification, and/or pyrolysis, each of which provides unique opportunities for CCS.

### Hydrotreated Esters and Fatty Acids SAF (HEFA)

An opportunity for CCS may arise with HEFA for some pathways selected for deoxygenation of fatty acids. The hydrodeoxygenation and hydrodecarboxylation pathway has relatively low hydrogen demand and produces a $CO_2$ stream for possible CCS. Hydrogen production for HEFA, and possibly the hydrodecarboxylation process, generate $CO_2$ in varying concentrations, which are candidates for CCS.

### Fermentation

ATJ may utilize ethanol derived from fermentation, converting starch and sugar-based feedstocks such as corn or lignocellulosic feedstocks. Fermentation converts glucose to ethanol and carbon dioxide, where the latter is a pure stream and thus a good candidate for CCS, comprising roughly~30% of the carbon in the feedstock.

### Gasification

FT SAF upgrades syngas derived from gasification to liquid fuels, and ATJ may utilize syngas derived from gasification to produce the ethanol intermediate for the ATJ process. Gasification converts solid fuels, such as biomass or municipal solid waste (MSW), to a gaseous mixture of chiefly CO and $H_2$, plus $CO_2$, $CH_4$, and some trace gases. The $CO_2$ content of the gasifier product gas is a candidate for CCS, and the concentration of available $CO_2$ varies depending on the extent of water gas shift reaction in production.

### Pyrolysis

Pyrolysis of solid feedstocks is a thermal decomposition process that forms gases (biogases), liquids (biocrude), and solids (biochar). Pyrolytic liquids are the target product stream for hydrotreated depolymerized cellulosic jet (HDCJ) process, leaving the biogases and biochar as candidates for carbon capture and removal. The biogases are estimated to contain approximately 20% of the carbon from the feedstock in the form of carbon oxides and light hydrocarbons and could be a candidate for CCS. The biochar is also a candidate for carbon sequestration because it is a recalcitrant form of carbon which can be incorporated into durable products, stored in soil, or otherwise sequestered. Approximately 40% of the carbon in the feedstock is contained in the biochar.

## Feedstocks, Sustainability and Scalability

The carbon intensity of any given SAF production pathway begins with the carbon impact of the feedstock associated with that pathway. The range of potential SAF feedstocks is broad and complicated. At the highest level, feedstocks can be categorized into 3 "generations" (Figure 2). First generation feedstocks natively contain simple building blocks of fuels (sugars, oils), adopted in the earliest fuel production processes developed, using only a fraction of the plant conversion to fuel as feedstock, and therefore requiring significant land area to grow. Second generation feedstocks (energy crops, residues, wastes) are more challenging to convert because of their material heterogeneity but they are predicted to have much lower land use and greater sustainability. Third generation feedstocks (algae, seaweed), as well as electrochemical or thermochemical conversion of $CO_2$ directly to fuels, are still in their early stages of development.

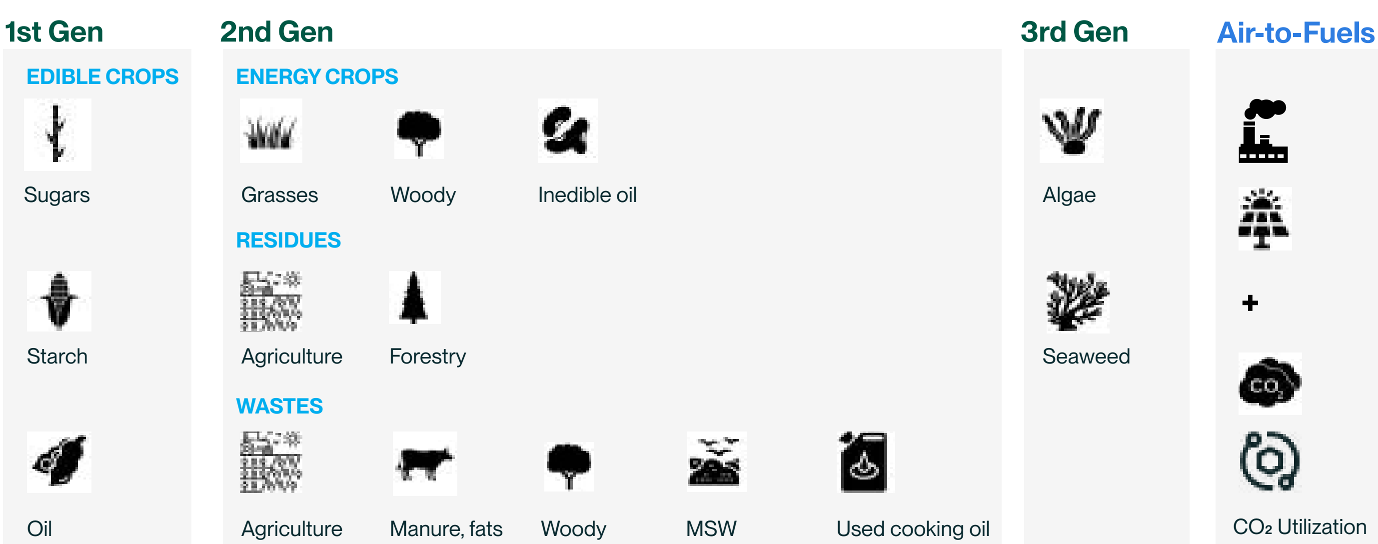


**Figure 2** Feedstock Characterization.

The sustainability of biomass-based feedstocks and fuels is largely contingent on the impact of biomass production on land and soils. These impacts are summarized in "direct land use change" (dLUC, emissions from the land onto which crop production is expanded) and "indirect land use change" (iLUC, emissions from land onto which other agriculture activities are displaced by bio-energy applications on primary lands) metrics associated with each feedstock. Figure 3 depicts a selection of dLUC and iLUC[6] values used in Carbon Direct's analysis of SAF pathways.

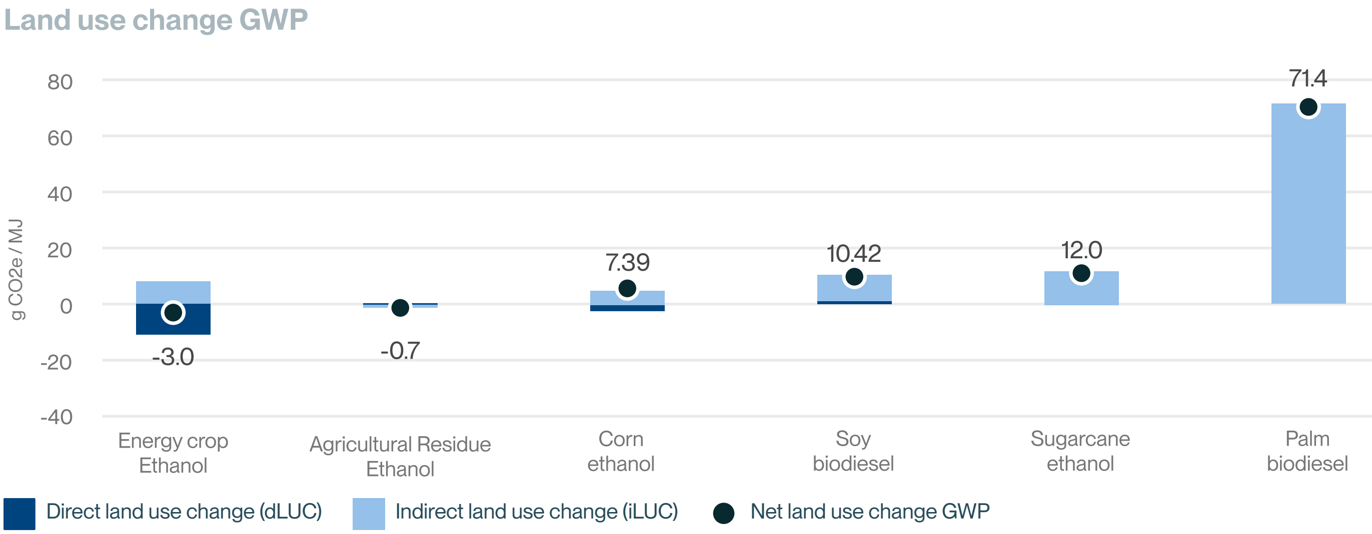


**Figure 3** Estimates of $CO_2$ emissions from direct and indirect land use change associated with six fuel production pathways. In this instance switchgrass is the energy crop and corn stover is modeled as the agricultural residue.

In general, first generation feedstocks are not suitable for SAF production at scale. Food-based feedstocks compete with alternative uses in existing commodity markets. The exception to this assessment is that in the near term, some corn ethanol-based SAF production may be viable as a stepping-stone to ethanol intermediate fuels produced from other feedstocks (cellulosic). This is especially true in the U.S. if the corn ethanol market becomes oversupplied as gasoline consumption decreases due to increasing passenger vehicle electrification.  In that scenario, excess ethanol would be available without putting pressure on food crops or land use.

In contrast, second generation feedstock supplies stand out economically and sustainably. When considering aggregate supply, cellulosic biomass in the United States is sufficient for SAF production on the scale defined in our criteria.

Based on feedstock availability (in 2022 and projected in 2030), we estimate the quantity of SAF that could be produced (Figure 4) if that entire supply were converted to fuel.  This exercise, while theoretical, provides some context for the proposed goal of procuring 1 billion gallons/year in 2030 and scaling to 10 billion gallons. Notably, use of all second generation feedstocks at $50 per bone dry ton (bdt)[7] could supply 10 billion gallons of SAF in 2030.

Of first generation feedstocks, only existing corn ethanol supply is sufficient to produce even 1 billion gallons of SAF without taking on sustainability risk. Considering the low supply, land use impacts, and interaction with global commodity markets of oil-based feedstocks, **we recommend disqualification of other (non-corn) first generation feedstocks from further consideration as a source of SAF**. Nevertheless, we retained these feedstocks and their conversion pathway, HEFA, in our analyses due to the commercial availability (i.e., relevance) of HEFA-derived SAF.

*Air-to-Fuels* is in its own category. While water and CO2 feedstocks are theoretically limitless, the critical component of this pathway is carbon-free energy. Here, we present the percentage (%) of existing global renewable electricity capacity that would need to be dedicated to SAF to achieve 1 billion and 10 billion gallons of SAF, which is an analogous, if imperfect proxy for "feedstock supply".

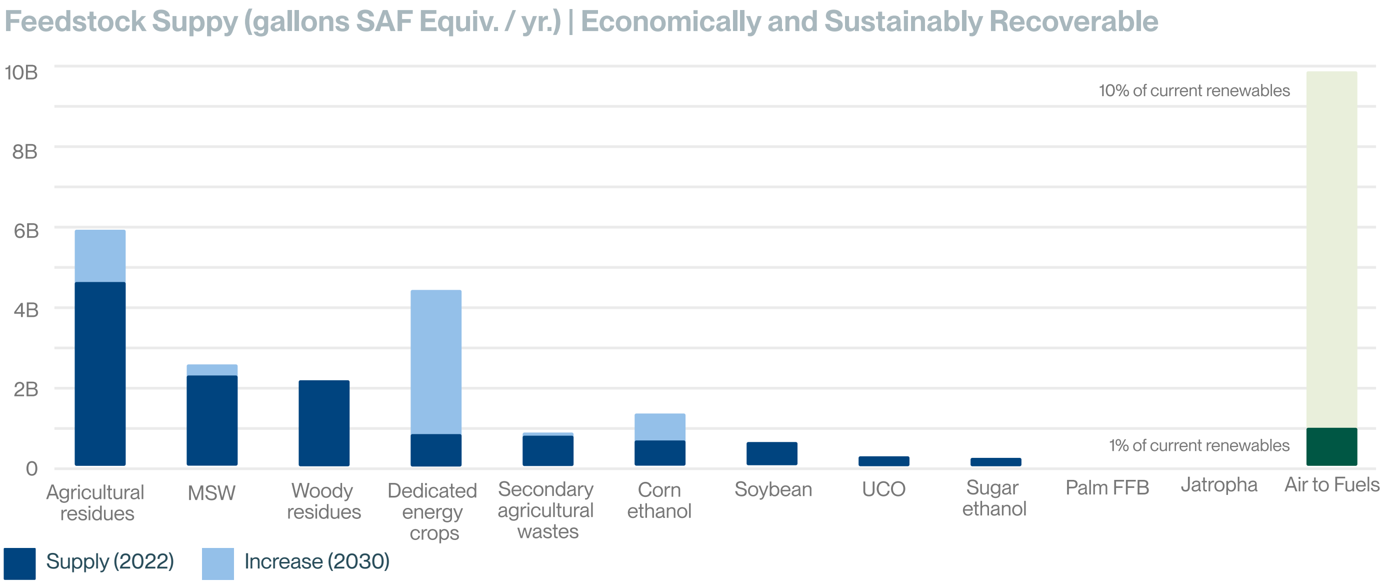


**Figure 4** Annual feedstock supply converted to SAF equivalence.

Based on the analysis, we rank the sustainability of SAF feedstocks as follows:

### 01. Agricultural residues (and secondary agricultural wastes)

These feedstocks represent the largest near-term recoverable supply. Production inputs, land use concerns, and sustainability risks are negligible relative to alternatives.

### 02. Woody residues

These feedstocks share most of the supply and sustainability benefits of agricultural residues, with added logistical challenges for some potential sources (e.g., forest residues).

### 03. Corn starch

While the long-term sustainability of this feedstock is unlikely, there is existing sustainable supply, infrastructure, and commercially-proven technologies for conversion to SAF. This feedstock could serve as a near-term bridge to cellulosic ethanol.

### 04. Municipal solid waste

There is ready supply of this feedstock at low-cost to no-cost. There are significant sustainability advantages (e.g., avoided methane emissions) to using these feedstocks. However, the heterogeneous nature of feedstocks currently represents a technical and logistical challenge.

### 05. Dedicated energy crops

These feedstocks have significant potential on a cost and sustainability basis, but there is limited evidence of near-term supply.

### 06. Used cooking oil

While promising from a cost and sustainability perspective, there is very little supply and competition for what supply exists.

### 07. Sugarcane and oil crops

These are the least desirable biomass feedstocks both from a supply and sustainability perspective. Sustainable supply of sugar, palm, and soy would be difficult to verify. Scaling these feedstocks to industry-relevant volumes would carry significant cost and sustainability risks, Next-generation oil crops like jatropha may avoid some of these risks, but there is no evidence of commercial supply in the near-term.

*Air to fuels*, which could certainly be sustainable and suitable, are different enough from biomass based pathways that we simply acknowledge the limited supply of feedstock today.

# Carbon Intensities

Carbon Direct calculated the carbon intensity (in grams of $CO_2$-equivalent per megajoule) of 22 distinct SAF production pathways using a consistent life cycle assessment framework. The results are depicted in Figure 5.

### SAF Pathway LCA Results

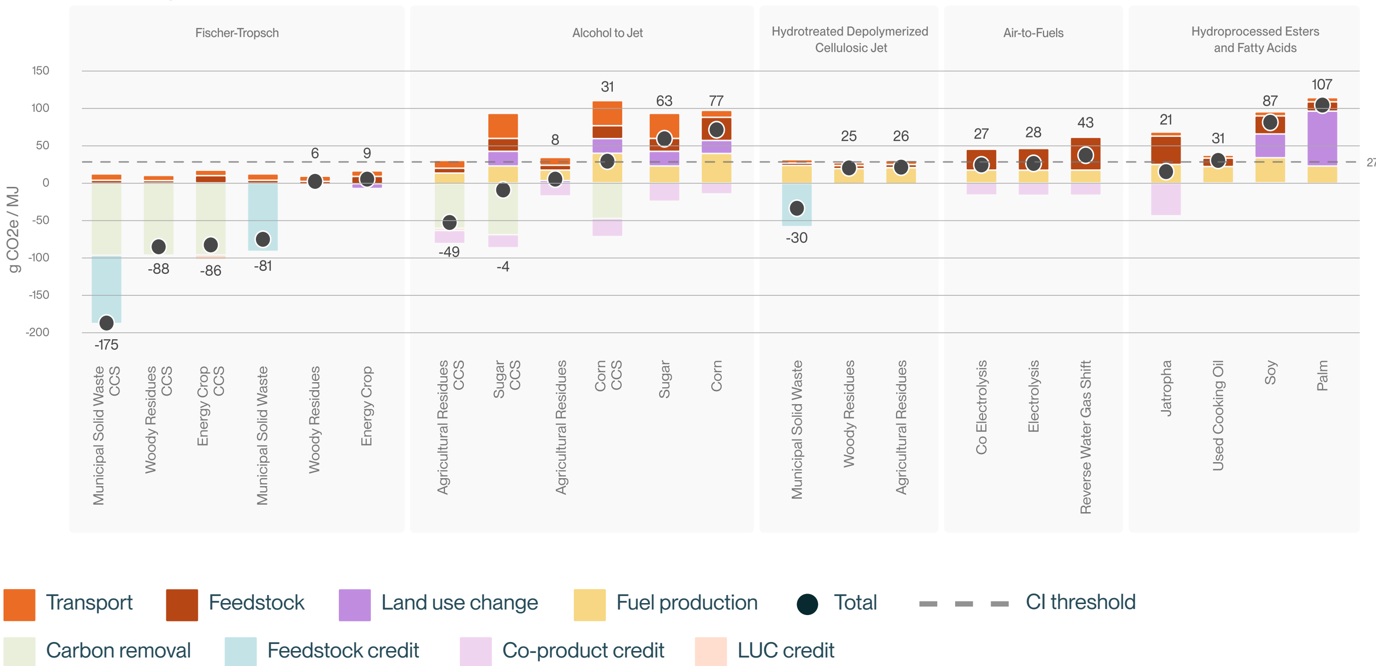


**Figure 5** Process contributions and total carbon intensities of 22 SAF pathways.

A target >70% reduction life cycle CI from Jet-A translates to a maximum SAF life cycle CI of 27 $gCO_2e/MJ$ (dashed "CI Threshold" line). This criterion removes most food-based feedstocks from consideration (with the notable exception of sugar ATJ+CCS). All pathways with CCS as an option (the green bars) provide substantial opportunities for $CO_2$ reduction and CI improvement. Corn ATJ with CCS is close to the cutoff at 31 $gCO_2e/MJ$. While this ATJ pathway does not meet our threshold criteria, it could do so with improvements to its life cycle CI such as reductions in fertilizer use or increases in soil carbon sequestration. This would further strengthen the case for corn ethanol as a bridge to cellulosic ATJ.

Use of MSW and the pairing of cellulosic feedstocks with CCS can result in negative CI values for SAF, indicating net carbon removal. The greatest potential for carbon negativity is found in Fischer-Tropsch pathways combined with CCS or FT pathways that utilize MSW as feedstock, with the most carbon-negative SAF fuel arising from the combination of FT with CCS and MSW as feedstock. The ATJ+CCS pathway also removes carbon when corn stover or sugarcane are used as feedstock.[8] **Negative CI fuels could garner larger CI-based subsidies, offset emissions from higher CI pathways, and/or contribute to corporate carbon removal goals.**

# Projected Costs

Unsubsidized SAF costs are plotted against pathway CIs in Figure 6.1. In the absence of subsidies, SAF prices range from approximately \$3-15/gal and none are at or below the price of Jet-A (lower right of graph). All of the pathways that meet cost and emissions criteria (below the dashed horizontal line and to the left of the dashed vertical line) without subsidy face technology readiness challenges (e.g., HDCJ) or feedstock sourcing/supply challenges (e.g., sugarcane ATJ, jatropha HEFA). The implication is that policy support will be essential to meet SAF cost criteria. The projected impacts of existing subsidies such as the Low Carbon Fuel Standard (LCFS), some of which are tied to the fuels' CI, are depicted in Figure 6.2[9]. Lower CI pathways exhibit greater movement downward, surpassing our target price in many cases.

## SAF Pathway Comparison - Unsubsidized


**Figure 6.1** Unsubsidized costs, CI, and feedstock availability (marker size) for pathways.

## SAF Pathway Comparison - Subsidized

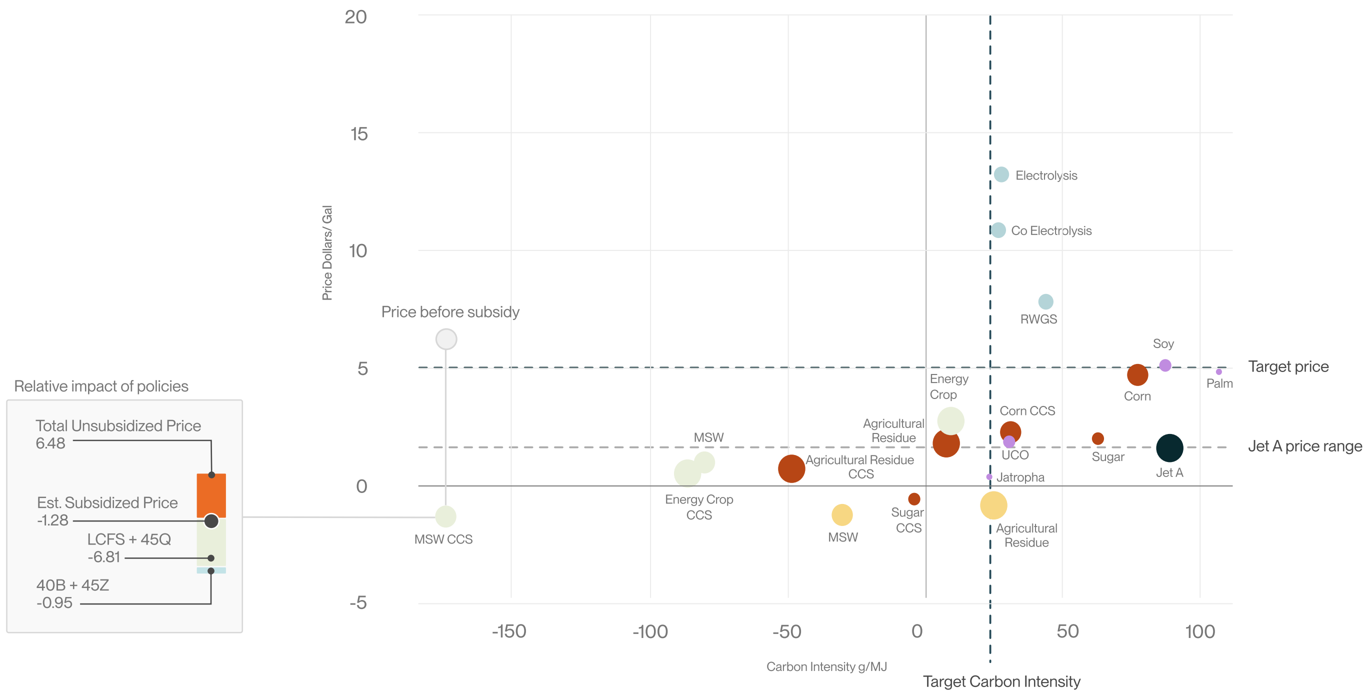


**Figure 6.2** Subsidized costs, CI and feedstock availability. The impacts of LCFS, 45Q, 40B and 45Z subsidies on fuel price are depicted at left for a single example.

Realistically, no SAF is price competitive without subsidies. Historically (2018 and 2019), Jet-A prices were roughly $2/gallon. In 2021, the prices for jet fuel were lower, largely due to price collapse associated with the COVID-19 pandemic. Prices rebounded as airline demand recovered and spiked during the energy crisis linked to the war in Eastern Europe. Our analysis shows that HDCJ from MSW and cellulosic feedstock pyrolysis appear relatively promising, although they are limited today by low technical readiness (TRL 5). Subsidies tied to blending of SAF, feedstock or intermediate production, carbon capture and sequestration, and/or capital expenditure will move various pathways downward on this graph, pushing them into the target cost zone.

## SAF Following IRA Enactment

The recent passage of the landmark Inflation Reduction Act (IRA) has greatly improved the economic outlook for the SAF industry and adjacent sectors. In part, this is because there are a stack of new and expanded incentives that would greatly subsidize the production of low-cost, low CI fuels, including SAF. Three tax credits in particular stand out for their potential in reducing SAF cost and CI:

- **SAF Blenders Credit (40B, 2023-2024):**
  This new, 2-year $1.25/gal SAF blending credit applies toward SAF that reduces emissions by at least 50% compared to standard jet fuel. An additional 1 cent/gal will be given for each percentage point over 50% to a max of $1.75/gal[10]. The SAF needs to be dispensed in the US to qualify. Notably, the SAF cannot be derived from palm fatty acid distillates or petroleum.

- **Clean Fuel Production Credit (45Z, 2025-2027)**
  The 3-year Clean Fuel Production credit replaces 40B for an additional three years with a $1.75/gallon credit for fuels that reduce CI by at least 50%.

- **Carbon Capture, Utilization and Sequestration Credit (45Q, 2022-2033):**
  This tax credit provides payment for storage of $CO_2$ in geological formations or for use of qualifying oxides (CO or $CO_2$) in enhanced oil recovery (EOR) or commercial products. For facilities built between 2026 and 2033, the IRA increased the credit from $50 to $85 for storage and from $35 to $60 for use. It also increased the credit for direct air capture from $50 to $180 for storage or $130 for use - a big incentive for air-to-jet.

- **Clean Hydrogen Production Credit (45V, 2023-2033):**
  This is a new production tax credit for low carbon hydrogen, including all feedstocks and upstream emissions in the production of hydrogen. For the lowest CI hydrogen, $3/kg is provided. Green and bio-hydrogen, and some very clean blue-hydrogen, projects could receive this credit.

Importantly, some of these credits can stack together while others cannot. For example, the existing wind production tax credit, 45V, and the SAF blenders credit could stack together, providing very large subsidies for SAF producers. In contrast, the clean fuel production credit cannot be stacked with 45Q, providing a smaller, but still substantial subsidy.

The implications of these credits and subsidies, depicted in Figure 6.2, are profound. Effectively, all low-CI pathways reach the target price and many pathways would produce SAF at costs fully subsidized by a combination of existing policies.[11]

## Procurement

Much of the transition from conventional jet fuel to SAF lies in the hands of commercial buyers. Commercial buyers will be responsible for procurement of SAF (in both forward purchase agreements and on the spot market), and they will require certification of the fuel's attributes to show that they are meeting emissions reduction targets. In addition, commercial buyers could play a critical role in advocating for policies that would help accelerate their ability to transition to sustainable aviation fuels.

In particular, SAF procurement is an essential element to supporting development of supply as well as a necessary component of many net-zero commitments. In that context, a portfolio approach to fuel procurement might be of particular value to a commercial SAF buyer. By establishing long-term, fixed price contracts for low-CI SAF, buyers can help suppliers secure investment to finance the delivery of new production facilities or modifications that improve CI at existing or prospective sites.

# Key Recommendations

The new technology and policy landscape for SAF looks promising and exciting, especially in the U.S. We recommend that decision makers in both policy and procurement roles consider these matters first and foremost when considering the near-term landscape (i.e., before 2030) for SAF.

### Focus on carbon intensity

Not all SAF is created equal, and SAF supplies can vary tremendously on carbon intensity, sustainability, scalability, and technical readiness. Take the time to understand supply chains, feedstocks, and energy inputs.

### CCS is a big enabler of low-CI sustainable aviation fuels

The growth of infrastructure for $CO_2$ transportation and storage and the improvements in $CO_2$ capture technology that develop alongside SAF can greatly affect final CI and price.

### Several pathways appear most promising

These are FT-to-jet, especially from agricultural, forestry, and municipal solid wastes, and ATJ. In contrast, HEFA looks difficult to scale sustainably, in part due to land-use change concerns.

### Long-term purchases are a key enabler

Producers of SAF need long-term offtake agreements to finance projects and grow supply. Given current policy frameworks, including IRA enactment, the risk of severe price shocks or escalation is minimal over a 5-10 year period. Long-term procurement could prove essential to grow dedicated supply of low-CI SAF for individual users and the industry as a whole.

## Acronym Glossary

| | |
|---|---|
| **ATF** | Air-to-Fuels |
| **ATJ** | Alcohol to Jet |
| **C** | Corn |
| **CCS** | Carbon Capture and Sequestration |
| **CI** | Carbon Intensity |
| **COEL** | Co-Electrolysis |
| **ELEC** | Electrolysis |
| **FR** | Forest Residues |
| **FT** | Fischer-Tropsch |
| **HEFA** | Hydroprocessed Esters and Fatty Acids |
| **HCDJ** | Hydrotreated Depolymerized Cellulosic Jet (pyrolysis biocrude) |
| **JAT** | Jatropha Oil |
| **MSW** | Municipal Solid Waste |
| **PAL** | Palm Oil |
| **RWGS** | Reverse Water Gas Shift |
| **S** | Sugar |
| **SG** | Switchgrass |
| **SY** | Soy Oil |
| **UCO** | Used Cooking Oil |

# Endnotes


1 Energy Transition Commission, 2022, Making Net-Zero Aviation Possible https://www.energy-transitions.org/publications/making-net-zero-aviation-possible/ ; Clean Air Task Force, 2022, Decarbonizing Aviation: Challenges and Opportunities for Emerging Fuels, https://www.catf.us/resource/decarbonizing-aviation-challenges-and-opportunities-for-emerging-fuels/

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7 U.S. Department of Energy, "2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks," 2016, https://doi.org/10.1089/ind.2016.29051.doe.


8 A credit for avoided methane emissions comprises a significant portion of the "negative emissions" for MSW pathways. While all FT+CCS pathways remain carbon-negative and superior to the other pathways without the credit, the methane component is not true carbon removal.

9 This analysis was performed assuming LCFS prices corresponding to $150/tonne.

10 The life cycle GHG emissions reduction shall be defined in accordance with CORSIA or "any similar methodology" which satisfies the criteria of the Clean Air Act.

11 This analysis was performed prior to the passage of the IRA. The policy cost reductions were amended based on Carbon Direct's carbon intensity analysis which may differ from recently released default values under the CORSIA methodology.

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