

Greenhouse Gas Implications of Processing Biomass into Aviation Fuels

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Introduction

Standard aviation fuel (Jet A or JP-8) begins with a petroleum feedstock and is then refined into a finished product using processes which fall into three basic categories:

- **Separation processes** – Separates the fuel components based on physical properties. Separation using the boiling point (“distillation”) is the most common separation process.
- **Upgrading processes** – Improve the quality of the fuel by using chemical reactions to remove undesirable compounds such as sulfur, sugar, nitrogen compounds, and undesirable hydrocarbon classes.
- **Conversion processes** - Change the molecular structure by “cracking” large molecules into smaller ones at elevated temperatures and pressures in the presence of catalysts, and often hydrogen.

Most of the resulting hydrocarbons are paraffins (alkanes), naphthenes, or aromatics. Kerosene-type jet fuels range from 8 to 16 carbon atoms; wide cut fuels range between 5 and 15 carbon numbers. At the middle of the distillation range for kerosene-type fuels, the composition is typically C₁₀ aromatics, C₁₁ naphthenes and C₁₂ paraffins. The hydrocarbon base for Jet A is quite similar to that for JP-8; the primary difference is that JP-8 requires three additional additives: a corrosion inhibitor/lubricity enhancer, a fuel system icing inhibitor, and a static dissipater additive.

When aviation fuel is refined from biofuels, the primary feedstock consists of triacylglycerols (TAGs, also – triglycerides). The primary refining processes are:

- **Hydrolytic conversion** – separates TAGs into free fatty acids + glycerol
- **Decarboxylation** – Converts free fatty acids into alkanes
- **Conversion** – Reduces long-chain alkanes into shorter branched alkanes and ring structures through the use of a catalyst, heat, pressure, and hydrogen. May involve isomerization / hydroisomerization, hydrocracking, and hydrocyclization.

Greenhouse Gas Implications

Estimates of the energy utilized for conversion of TAGs to Jet A vary widely. In order to get an approximate relative value of energy cost and greenhouse gas production, the GREET fuel-cycle model (version 1.8c) compiled by Argonne National Lab was consulted. It should be noted that GREET does not support aviation fuels directly, so diesel fuel production was

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used as a surrogate. The model shows the “energy cost” to produce diesel fuel from petroleum to be 12.6%, (0.126 MJ Energy Consumed / MJ Energy Produced) and the energy cost to produce “renewable diesel” (produced by similar process of hydrolytic conversion, decarboxylation, isomerization) to be 70.9%. The increased energy required for renewable diesel is largely due to the higher amounts of hydrogen required for hydrocracking; hydrogen production is an energy intensive process. Refining schemes which involve transesterification before decarboxylation incur an energy cost of over 130%; this is largely due to the energy cost of methanol, neutralization and fuel processing, and then the decarboxylation/conversion steps. It should be noted that the energy costs reported by GREET for biofuel conversion are significantly higher than those estimated by industrial fuel processors. The GREET model does include the energy costs of various inputs such as methanol and hydrogen (production from natural gas was assumed in the numbers just cited). Commonly cited values from the industrial community are 25%-35% as the energy cost to convert TAGs to Jet A. Thus, the range of “energy costs” for refining varies from 25%-130%, depending on the process. A higher energy cost for processing nominally corresponds to a higher production of greenhouse gas emissions. It should be noted that the co-products from biofuel extraction and refining have significant offset value. Co-products include both glycerol from the TAG processing and meal/cake from the soy / canola / algae from which the TAGs were extracted.

Emerging Technologies

Several emerging technologies have the potential to alter the energy cost of fuel processing. New technologies being considered include:

- **Direct production of hydrocarbons** – Large focus on genetic modification of algae to produce alkanes and terpenes directly. This could significantly reduce the energy cost of processing.
- **Fisher-Tropsch** – Produces synthesis gas ($H_2 + CO$) from the gasification of biomass, then uses a catalyst at high temperature and pressure to “stitch” together C and H atoms to make long chain alkanes. Ideally, this provides a very wide range of feedstocks, but the energy cost of production can be quite high.
- **Pyrolysis processing** – Analogous to Fischer-Tropsch, but uses very rapid heating of biomass to produce long chain tars which are then “cracked” to produce a finished fuel. Potentially much greater leeway on feedstock, but significantly higher energy cost for processing, with commensurate greenhouse gas penalties. System modeling required to confirm whether the increased greenhouse gas production from processing offsets potentially lower greenhouse gas production from feedstock production.
- **Enzymatic** – Utilizes enzymes (or potentially bacteria and/or yeasts) to transform sugars, cellulosic feedstocks, and/or TAGs to fuel. This may require additional processing, but the assumption is that the enzymatic approach will significantly reduce the overall energy cost. It should be noted that production of TAGs from sugar is currently feasible (primarily using heterotrophic algae), but production from cellulosic materials is still an emerging science.

Feedstock / Fuel Processing Interactions

Very significant interactions exist between feedstocks and fuel processing. In the previous section, the interaction energy utilization for feedstock production vs. fuel processing was discussed for Fischer-Tropsch and pyrolysis fuels. There are also significant impacts even with respect to TAG production. The following two items are meant to be illustrative, not to be an exhaustive list:

- **TAG variations** – There are significant differences in the free fatty acids in the TAGs from various fuel crops. For example, the FFAs from algae may contain 5%-20% long-chain highly unsaturated compounds, including eicosapentaenoic acid (EPA, 20:5[n-3]) and docosahexaenoic acid (DHA, 22:6[n-3]). These compounds have high value for human nutrition, but their long-chain, highly unsaturated structure increases the amount of hydrogen and energy required for processing. It should be noted that different species produce different amounts of these compounds; their concentration can be influenced by species/strain selection and by cultivation conditions.
- **Extraction technique** – Solvents are commonly used to increase the oil extraction from the feedstock. The choice of solvent can have a significant impact on the content of the resulting product. I will use lipid extraction from microalgae to illustrate. The use of a relatively neutral solvent like hexane will primarily extract neutral lipids – chiefly the triglycerides that occur as storage lipids in eukaryotic microalgae. The use of more polar solvents like methanol will extract more polar lipids such as the diglycerides which make up cell membranes. It should be noted that these cell membranes are phospholipids and the phosphorous must be removed, which requires additional energy and incurs additional costs.