CONFERENCE ON AVIATION AND ALTERNATIVE FUELS

Rio de Janeiro, Brazil, 16 to 18 November 2009

Agenda Item 1: Environmental sustainability and interdependencies

COMPARISON OF LIFE CYCLE GHG EMISSIONS FROM SELECT ALTERNATIVE JET FUELS

(Presented by the United States)

SUMMARY

Alternative jet fuels produced from renewable sources may have reduced life cycle greenhouse gas emissions (GHG) relative to jet fuel. As such, alternative fuels could play a central role in mitigating aviation's contribution to climate change. Although there are several challenges, including identifying appropriate feedstocks and processes, ensuring adequate performance, scaling production, assuring sufficient supply, and establishing life cycle GHG emission inventories, substantial progress has been recently realized. This paper summarizes the findings of an analysis undertaken by the U.S.

1. INTRODUCTION

1.1 Alternative jet fuels that are produced and created from renewable sources may have reduced life cycle greenhouse gas emissions relative to jet fuel. Researchers sponsored by the U.S. undertook a well-to-wake, life cycle analysis of potential feedstock-fuel pathways that could be used as alternative jet fuels.[1] The analysis included all GHG emission resulting from the creation of the alternative fuel—recovery, processing, and transport—as well as those resulting from its combustion.

1.2 The fuel options reviewed are considered “drop-in”. They have the potential to serve as a direct replacement for conventional jet fuel, requiring little or no modification to existing infrastructure or aircraft engines.

1.3 However, these fuels have varied life cycle GHG emissions. The fundamental reason that biofuels present the opportunity for lower GHG emissions is that biomass feedstocks absorb CO_2 for growth during photosynthesis in relatively short time scales. In general, the growth of biomass feedstocks offsets some, if not all, of the combustion CO_2 emissions, resulting in reduced life cycle GHG emissions.

[1] Stratton, R.W., Wong, H.M., and Hileman, J.I., “Life Cycle GHG Emissions from Alternative Jet Fuels,” PARTNER-COE Report, in preparation, to be posted at http://web.mit.edu/aeroastro/partner/projects/project28.html

1.4 Direct and indirect land-use changes are important aspects that must be evaluated when considering biofuels. Such changes include deforestation, conversion of grasslands to agricultural production, or diversion of agricultural production to fuel production. These may result in considerable GHG emissions, and potentially overwhelm the gains from CO_2 absorption.

2. FEEDSTOCK-TO-FUEL PATHWAYS CONSIDERED

2.1 The analysis considered multiple feedstock-to-fuel pathways. These included conventional jet fuel created from conventional petroleum resources as well as oil sands and oil shale. It included Synthetic Paraffinic Kerosene (SPK) fuels created from Fischer-Tropsch (F-T) synthesis and hydroprocessing of renewable oils to create hydroprocessed renewable jet (HRJ) fuels.

2.2 F-T fuels can be created from natural gas (GTL), coal (CTL), biomass (BTL) as well as a combination of coal and biomass (CBTL). Corn stover was considered in the analysis of BTL and CBTL in ref. 1. HRJ fuels can be created from jatropha, soybeans, palm, and algae. A route of using halophytes, a salt-water tolerant plant, to produce biomass for both BTL and HRJ production was also considered. Other feedstock options also exist (e.g., camelina), but these have not yet been considered in the ongoing research effort that is summarized in ref. 1.

2.3 GTL and CTL fuels have large production potential, but have higher emissions than conventional jet fuel. With Carbon Capture and Sequestration (CCS), GHG emissions could be comparable to jet fuel, but CCS technology is not fully mature. BTL fuels have low GHG emissions but limited fuel production potential due to the large quantities of biomass required for their production. CBTL with the use of CCS could represent a means of combining the production potential of CTL with the low GHG emissions of BTL to yield a fuel with improved GHG emissions, relative to conventional jet fuel. However, Fischer-Tropsch facilities are capital intensive. These fuels are considered in depth in Section 4 of ref. 1.

2.4 The use of excess palm and soy oils for HRJ production (excess meaning they are available after food needs are met) would lead to low GHG emissions fuels, but there is little excess supply currently available. As such, large-scale soy oil and palm oil to HRJ production would have large GHG emissions resulting from the land-use changes of expanding production. These pathways are discussed in depth in Sections 5.2 and 5.3 of ref. 1.

2.5 SPK production from algae, halophytes and jatropha hold promise for reducing aviation’s GHG emissions. These feedstocks can be grown on marginal or wasteland that is not being used for agricultural purposes. Jatropha production is mature, but the limited oil production per acre for jatropha means that it cannot meet future jet fuel demand on its own. Jatropha HRJ will likely be a regional solution to reducing emissions from transportation, including that from aviation. Jatropha also faces substantial challenges in overcoming the natural toxicity of its oil. Algae production is not technologically mature, but it has the potential for large oil production per acre. These pathways are discussed in depth in Sections 5.4 through 5.6 of ref. 1.

2.6 Algal HRJ, halophytes SPK, jatropha HRJ, and CBTL all provide aviation with a potential means of GHG reduction. This field is rapidly developing, and the U.S. will continue to examine evolving options and provide results to the international community.

3. LIFE CYCLE GREENHOUSE GAS EMISSIONS

3.1 Figure 1 presents the GHG emissions from various parts of the fuel life cycle for each of the fuels described in Section 2. It is important to note that this plot does not show cumulative totals, but rather it displays the emissions contributions from each step in the fuel life cycle. The impact of potential land use change scenarios, which are summarized in Table 1, is included in the form of four pathways for both soy oil and palm oil HRJ as well as two pathways for halophyte oil HRJ (these are described in Section 5.2, 5.3, and 5.6 on HRJ production in ref. 1).

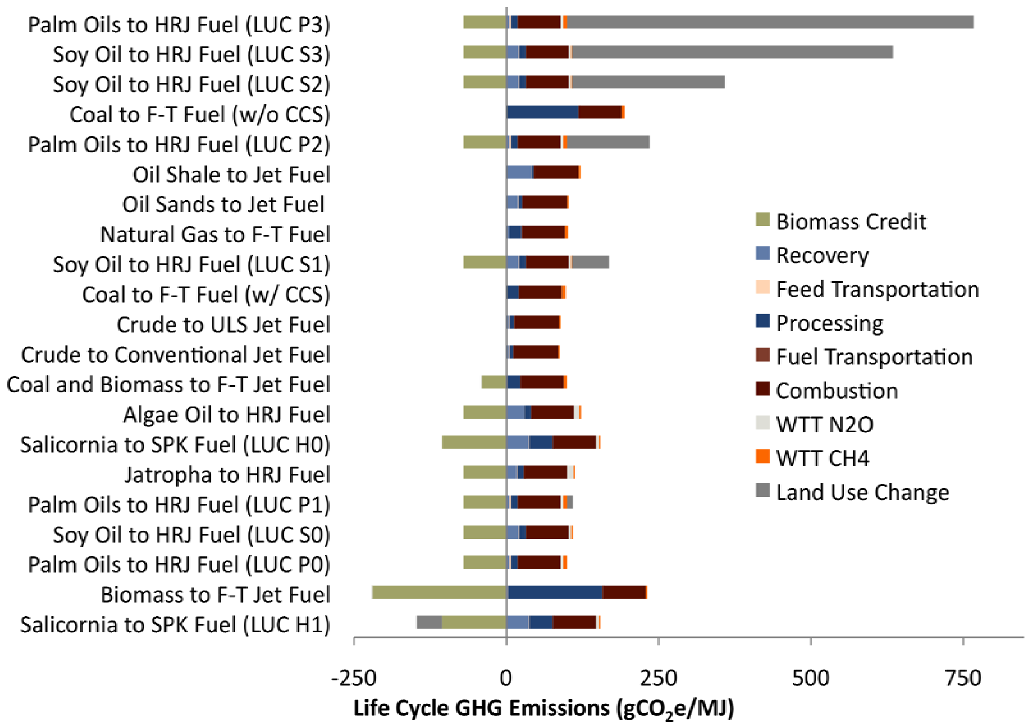


Figure 1: Life cycle GHG emissions for the alternative jet fuel pathways under consideration. Note: CCS denotes carbon capture and sequestration and the land use change (LUC) scenarios are defined in Table 1.

Table 1: Land use change scenarios explored for HRJ pathways

Land use change	**Soy oil to HRJ pathway**	**Palm oil to HRJ pathway**	**Salicornia to HRJ and F-T Jet pathway**
Scenario 0	None	None	None
Scenario 1	Grassland conversion to soybean field	Logged over forest conversion to palm plantation field	Desert land converted to salicornia cultivation field
Scenario 2	World wide conversion of non-cropland	Tropical rainforest conversion to palm plantation field	n/a
Scenario 3	Tropical rainforest conversion to soybean field	Peatland rainforest conversion to palm plantation field	n/a

3.2 The results from Figure 1 highlight the need to avoid land usage changes that result in GHG emissions. As discussed in Section 4.4 of ref. 1, the particular biomass types used in this analysis of BTL and CBTL should not lead to land use changes, (e.g., waste biomass or biomass grown on marginal land).

3.3 The method of presentation of Figure 1 includes 'biomass credits' that are given to biofuels because of the CO_2 that is absorbed during biomass growth; biomass credits are largely the reason why these fuels offer the potential for reduced GHG emissions. With the exception of BTL and CBTL, the biofuel pathways all have similar 'biomass credits' and the magnitude of these credits is approximately the magnitude of the combustion emissions. The 'biomass credit' for CBTL is smaller because the fuel is created from a combination of coal and biomass. The 'biomass credit' for BTL is larger because biomass is used to power the entire fuel production process.

3.4 Scenario dependent analyses have also been used to bracket emissions from fuel pathways, providing a means of evaluating uncertainty. The underlying data and assumptions were varied to provide three scenarios that provide a mean and an anticipated range of values. This concept is described in Section 2.4 of ref. 1. The scenario dependent life cycle GHG emissions are presented in Figure 2. The uncertainty bars represent the range of emissions as given by the low and high emissions cases; the baseline value is the summation of the emissions presented in Figure 1. Both CBTL and algal HRJ have baseline life cycle GHG emissions that are lower than conventional jet fuel but these pathways also have the potential to have GHG emissions that are higher than conventional jet fuel. For this reason, it is essential not to simply assume that biofuels are environmentally beneficial without knowing the specifics of how the fuel is produced.

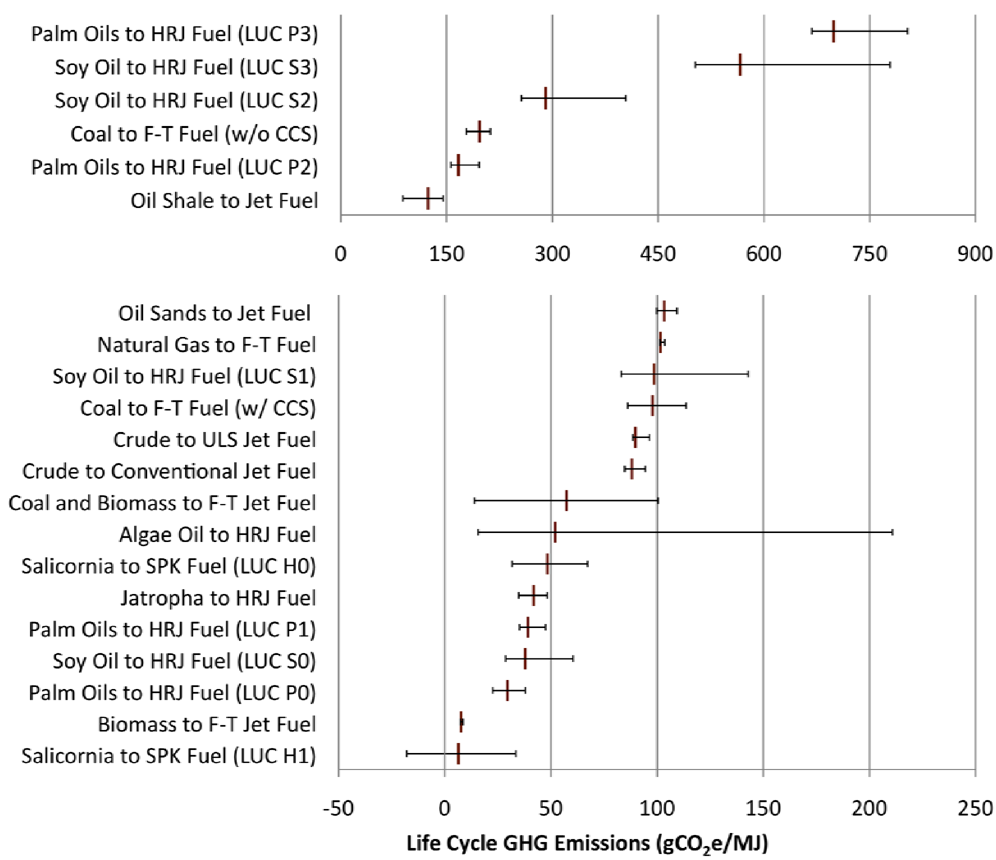
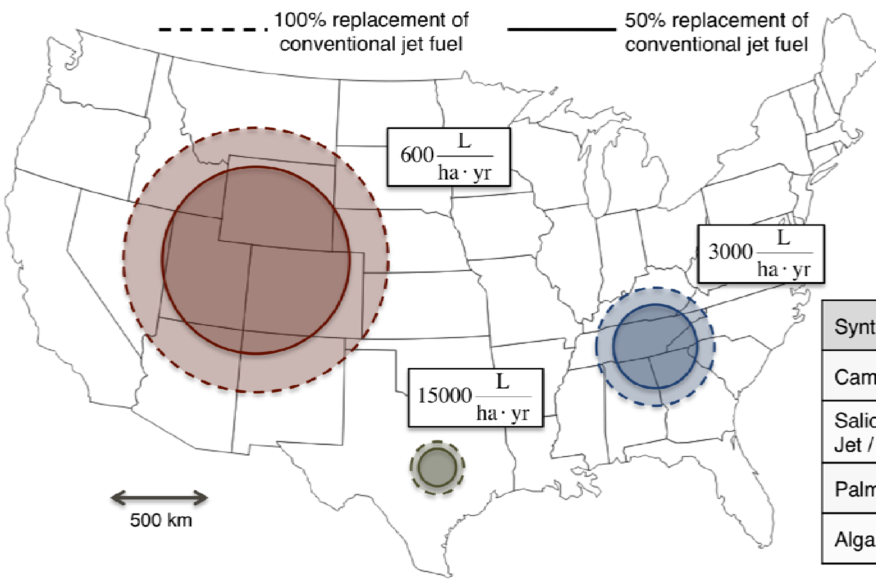


Figure 2: Life cycle GHG emissions for various alternative jet fuel pathways. Uncertainty bars represent low emissions, baseline, and high emissions scenarios. Please note the different scales for the top and bottom portions of the figure. Note: CCS denotes Carbon Capture and Storage and Land Use Change (LUC) scenarios are defined in Table 1.

4. CONSTRAINTS ON BIOFUEL AVAILABILITY

4.1 Although Figures 1 and 2 show that biofuels have the potential to reduce aviation GHG emissions; these figures do not convey the constraints on biomass production. Within ref. 1, these constraints are expressed in terms of land and water availability as well as the potential harm that could result from the introduction of invasive plant species. These are discussed in terms of U.S. biofuel production, but the implications are applicable on a wider scale. There are other constraints, such as economic cost of fuel production, that are being considered as part of ongoing research.

4.2 Within Section 6.3 of ref. 1, biofuel yields (volume of biofuel per land area per year) were created for a range of biofuel pathways. A select group of these are presented in the table within Figure 3, which also presents the land acreage that would be required to replace 50% and 100% of the current U.S. jet fuel usage of 1.4 million bpd (EIA, 2009) for various biofuel yields. The yields chosen in the figure roughly correspond to various types of biofuels.



Synthetic Fuel	L / ha / yr
Camelina Jet	751
Salicornia Jet / Diesel	1,200 / 1,721
Palm Jet	3,311
Algae Jet	16,969

Figure 3: Land areas requirements to replace current U.S. annual jet fuel consumption for varied biofuel yields. Biofuel yields are given for select fuel feedstocks. Additional yield information is available in Section 6.3 of Ref. 1.

4.3 As can be deduced from Figure 3 and the data in Section 6.3 of ref. 1, many fuel feedstocks, such as soybeans, jatropha, and camelina, do not have sufficient biomass production per unit of land to replace an appreciable quantity of jet fuel. This does not mean that they should not be cultivated for biofuel production; it simply indicates that these feedstocks cannot replace petroleum as a source of jet fuel. For example, camelina could be grown without irrigation in rotation with other crops in the upper plains of the U.S. and Canada, thus benefiting local farmers; further, the lessons learned in converting camelina oil to biofuels could be valuable if a higher yield crop, such as algae, becomes commercially available.

4.4 Palm oil is the second highest yielding oil crop analyzed in ref. 1; it is included in Figure 3 for comparison purposes. Increasing palm production would result in the conversion of high carbon stock land to palm plantations. Therefore, increased production will result in considerable GHG emissions from land use changes.

4.5 The use of CBTL could lead to a 25% reduction in GHG emissions from aviation and considerable production of reduced GHG diesel fuel (the volume of diesel fuel is roughly twice the volume of jet fuel produced). Many feedstocks could be used for CBTL production such as agricultural residues like corn stover, forestry waste, or dedicated energy crops like salicornia biomass or grasses; however, these feedstocks could also be used for cogeneration of heat and power where their use may lead to greater carbon mitigation.

4.6 Water plays an essential role in developing and utilizing energy resources. Generally speaking, it is used in energy-resource extraction, refining and processing, and transportation. The dependence of biofuels on water extends even further to include water used for feedstock growth. Water requirements and regional availability could serve as an additional constraint on biofuel development.

4.7 The expansion of biofuel use within the U.S. will require a significant increase in crop and feedstock production and this presents the possibility that non-indigenous species will be introduced. Ironically, the impact of these invasives could be to inhibit crop production, which could then hurt the industry that was responsible for their introduction. As an example, the financial burden of losses and control due to invasive plants and microbes has been estimated as being in excess of $75 billion per year (Pimentel, 2000). This $75 billion annual loss in agricultural output could pay for enough Jet A to power the U.S. fleet for 1.75 years.[2]

5. **CONCLUSION**

5.1 Given their reduced life-cycle GHG emissions relative to conventional jet fuel, some alternative fuels could play a central role in mitigating aviation's contribution to climate change, including helping aviation to achieve carbon-neutral growth, particularly when combined with improved technology and more efficient operations. If appropriate renewable feedstocks were used, both Fischer-Tropsch (F-T) fuels and Hydroprocessed Renewable Jet (HRJ) fuel could provide aviation with modest (~10%) to large (~50%) reductions in emissions that contribute to global climate change. If projections of soil carbon sequestration prove valid a halophyte-based biofuel could have a 100% reduction in life cycle GHG emissions.

5.2 A key factor in evaluating the benefits of feedstocks for alternative fuels includes the GHG emissions impacts of land used to produce them. The feedstocks will need to be grown in a sustainable manner that does not compete with food production, incurs no adverse land use impacts or results in the depletion of our fresh water resources. Since the growing conditions vary from feedstock to feedstock, there is a need for a balanced solution that uses multiple feedstocks.

5.3 The most significant challenge is not in developing viable alternative fuels that could reduce aviation's GHG emissions -- the technology exists; rather, the challenge lies in developing and commercializing the next generation of biomass feedstocks that could be grown in a sustainable manner to make these fuels.

— END —

[2] The crop loss figure is from Pimentel (2000), which is referenced in Ref. 1. The estimated annual cost of Jet A of ~$43 billion per year is derived from a Jet-A consumption of 1.4 million bbl/day at ~$70/bbl for crude oil and a 20% crack spread between crude oil and jet yielding a cost of jet fuel of $84/bbl.