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Agenda Item 1: Environmental sustainability and interdependencies

ESTIMATING LIFE CYCLE GREENHOUSE GAS EMISSIONS FROM ALTERNATIVE JET FUELS

(Presented by the United States)

SUMMARY

Alternative jet fuels produced from renewable sources have the potential to reduce aviation's impact on global climate change. However, a full accounting of the life cycle greenhouse gas (GHG) emissions, which extends from the well, field, or mine to the wake behind the aircraft, is necessary to determine whether a biofuel, or any other alternative fuel, will bring a climate benefit or detriment. This working paper presents background information on the use of life cycle analysis for estimating GHG emissions.

The conclusions for the conference are in paragraph 7 and recommendations in paragraph 8.

1. INTRODUCTION

1.1 Currently feasible, drop-in alternative fuels, if created from renewable resources, offer the potential for a reduction in aviation greenhouse gas (GHG) emissions. This is not due to a change in fuel composition nor is it due to a change in engine efficiency; instead the reduction is due to a change in the GHG emissions that result from the extraction, production and combustion of the alternative fuel. Through a life cycle accounting of the GHG emissions that starts with the well, mine, or field where the fuel feedstock is extracted, and that extends to the wake behind the aircraft, one can ascertain the change in GHG emissions that result from the use of an alternative fuel.

1.2 Synthetic Paraffinic Kerosene (SPK) fuels, which can be created via Fischer-Tropsch (F-T) synthesis or the hydroprocessing of renewable oils to a Hydroprocessed Renewable Jet, HRJ, fuel have similar molecular composition to conventional jet fuel. The combustion of SPK fuels results in about 4% lower CO_2 emissions (per unit mass of fuel) as compared to conventional jet fuel (1).

1.3 Depending on the feedstock that is used in the fuel production and the details of extraction and production, the life cycle GHG emissions from an SPK fuel can vary by two orders of magnitude. If waste products are exclusively used to create the fuel and to power the fuel production process, then the emissions could be as little as a tenth of those from conventional jet fuel; however, if the extraction and production of the fuel results in the conversion of lands with high carbon stocks, then the emissions could be eight times higher than conventional jet fuel (1). These changes could be much larger than the 4% change mentioned in the previous paragraph.

1.4 This WP introduces the key issues regarding the use of life cycle analysis for estimating GHG emissions from alternative jet fuels (2) while highlighting ongoing research being conducted in the United States and Europe to estimate the life cycle GHG emissions from alternative jet fuels.

2. ESTIMATING LIFE CYCLE GREENHOUSE GAS EMISSIONS FROM ALTERNATIVE JET FUELS

2.1 A Life Cycle Assessment (LCA) is a compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle (3, 4). Although an LCA of alternative jet fuels could involve an evaluation of the environmental impacts of resource extraction, fuel production and fuel combustion on air and water quality as well as global climate change, the focus here is on the creation of an inventory of "well-to-wake" life cycle GHG emissions.

2.2 Life cycle GHG emissions include those created from the extraction of raw materials through the combustion of the processed fuel by the aircraft. This can be described with a set of five life cycle stages: (1) *Raw Material Acquisition*, (2) *Raw Material Transport*, (3) *Fuel Production from Raw Materials*, (4) *Fuel Transport and Aircraft Fueling*, and (5) *Aircraft Operation*. Chapter 2 of ref. 2 presents details and examples of these five life cycle stages for several F-T and HRJ fuel pathways.

2.3 The emissions inventory is generally given in terms of the emissions, or the impact of the emissions, relative to some unit of productivity delivered by the fuel. To allow for an equitable comparison of SPK and conventional jet fuels, which have different energy content on both a unit mass and a unit volume basis, the emissions are given on the basis of a unit of energy delivered to the aircraft tank. To allow for an equitable comparison of carbon dioxide with other GHG emissions such as N_2O and CH_4 that may result from fuel production, Global Warming Potentials (GWP) are generally used to sum emissions into units of carbon dioxide equivalent, CO_2e. As such, life cycle GHG emissions are often given in terms of grams carbon dioxide equivalent per megajoule.

2.4 Metrics using GWP have major limitations in terms of examining the impact of non-CO_2 combustion emissions from aviation (5) As such, while non-CO_2 combustion emissions should be estimated as part of a life cycle GHG emissions inventory, an appropriate means of combining these emissions with those from life cycle stages 1 through 4 (from well-to-tank) and the CO_2 emissions from life cycle stage 5 (tank-to-wake) has not yet been defined.

2.5 Three areas meriting special consideration in regards to estimating a life cycle GHG emissions inventory, (1) *System Boundary Definition*, (2) *Emissions Allocation among Co-Products*, and (3) *Data Quality and Uncertainty*, are discussed further in the following sections.

3. SYSTEM BOUNDARY DEFINITION

3.1 Based on the ISO guidelines (2,3), a life cycle GHG emissions inventory should include a full accounting of the GHG emissions that result from the creation of all materials, energy, and activities that are related to the fuel production, not only those within the processes of the primary production chains, but also those supporting necessary input to the primary production chain. The system boundary therefore needs to be defined such that it captures all of the processes used in jet fuel creation. Chapter 3 of ref. 2 provides a discussion on various methodologies for determining system boundaries.

3.2 If sufficient quantities of agricultural products were redirected from the production of food to the production of biofuels, then indirect land use changes will result that need to be accounted for in the life cycle analysis. For example, complete domestic use of an existing agricultural product as a fuel feedstock would reduce exports of that crop, resulting in compensatory land use change elsewhere. The resulting land use change could lead to considerable GHG emissions, especially if the converted land is from high carbon sequestration systems such as rainforest or peat lands. Alternatively, use of fallow domestic agricultural land or excess production of existing crops would incur no such GHG emissions.

3.3 The accurate estimation of GHG emissions from indirect land use change requires the use of sophisticated economic models that capture the agriculture and energy sectors of the global economy. An estimation of the life cycle GHG from soy-based HRJ (1), which extended the results from such an economic analysis (6), indicates that the indirect land use change emissions from a large-scale diversion of soy oil to biofuel production could lead to a doubling of GHG emissions relative to conventional jet fuel. This is comparable to the emissions from coal-to-liquids from F-T synthesis if no carbon capture and sequestration were being used.

4. EMISSIONS ALLOCATION AMONG CO-PRODUCTS

4.1 Some processes within a fuel production pathway result in multiple outputs. For example, a refinery outputs gasoline and diesel fuel in addition to jet fuel. Another example, exhibited by many biofuels, is the creation of meal in addition to renewable oil that is then processed to HRJ. The emissions that are created upstream of such processes must be divided, or allocated, among the products.

4.2 ISO recommends that emissions be allocated to co-products using the following methods in the following order: (1) *process disaggregation* in which the unit process is divided into two or more sub-processes, (2) *system expansion* wherein the system boundaries are expanded to include the additional functions related to the co-products, (3) *allocation* by physical properties (e.g., mass, volume, energy content) or market value.[4] Chapter 4 of ref. 2 discusses these methods in greater detail.

4.3 In the case of biofuel production, the life cycle practitioner may need to allocate emissions from biomass creation based on the relative mass, energy content, or market value of the oil and the meal that remains after oil extraction. This is because the system cannot be disaggregated further and system expansion may require a model for the entire agriculture industry. The selection of allocation strategy can significantly affect the GHG emissions from a fuel, including the potential for unrealistic emissions, which indicates the importance of this parameter (see Chapter 4 in ref. 2 and ref. 1).

5. DATA QUALITY AND UNCERTAINTY

5.1 Data quality and uncertainty depend on time frame and scale. For example, it is easier to obtain high quality data for an existing product, (e.g., conventional jet fuel from crude oil), than from an emerging or non-existent industry, (e.g., algal HRJ). High quality data are required to develop life cycle GHG inventories that can be used to inform decisions regarding alternative aviation fuels. Chapter 5 of ref. 2 provides a discussion on data quality and uncertainty.

5.2 Scenario dependent analyses have also been used to bracket emissions from fuel pathways, providing a means of evaluating uncertainty (1) The underlying data and assumptions were varied to provide three scenarios that provide a mean and an anticipated range of values.

6. ONGOING LIFE CYCLE ANALYSIS EFFORTS

6.1 Multiple research efforts are ongoing within the U.S. and Europe to estimate the life cycle GHG emissions from conventional and alternative jet fuels. These are in addition to the considerable, similar efforts to estimate the life cycle GHG emissions from ground transportation fuels.

6.2 In the U.S., the National Energy Technology Laboratory examined the GHG emissions from U.S. transportation fuels, including jet fuel, derived from conventional petroleum (7) while the Partnership for AiR Transportation Noise and Emissions Research (PARTNER) have examined a wide range of alternative jet fuel pathways (1). Boeing is sponsoring research on jatropha based jet fuels at Yale University and algae based jet fuels at University of Washington and Washington State University.

6.3 In Europe, Cambridge University in the U.K. examined algal jet fuels as part of the OMEGA consortium while ONERA in France are currently leading an evaluation of a wide range of fuel options as part of SWAFEA (Sustainable Way for Alternative Fuel and Energy in Aviation).

7. CONCLUSIONS

7.1 The conference is invited to:

a) conclude that the ability to compare the life cycle GHG emissions from alternative aviation fuels is an essential element of a global assessment of GHG emissions from international aviation;

b) acknowledge that GHG emissions associated with both direct and indirect land-use change may result from the production of alternative jet fuels;

c) acknowledge that there are multiple research efforts ongoing within the U.S., Europe and other States to estimate the life cycle GHG emissions from conventional and alternative jet fuels, as well as from ground transportation fuels; and

d) acknowledge that a peer reviewed, consistent approach to estimating life cycle GHG emissions that covers all sectors is needed.

8. RECOMMENDATIONS

8.1 The conference is invited to:

a) recommend the use of life cycle analysis as the appropriate means for comparing the relative GHG emissions from alternative jet fuels to conventional jet fuel.

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APPENDIX

REFERENCES

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.
2. Additional information on estimating life cycle GHG emissions from alternative jet fuels can be found in the report, "Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels," from the Aviation Fuel Life Cycle Assessment Working Group, a group convened by the U.S. Air Force. The report is to be published in Autumn 2009.
3. ISO 14040:2006. Environmental management — Life cycle assessment – Principals and framework. 2006.
4. ISO 14044:2006. Environmental management — Life cycle assessment — Requirements and guidelines. 2006.
5. Wuebbles, D.J., Huiguang Y., and Redina H., "Climate Metrics and Aviation: Analysis of Current Understanding and Uncertainties." U.S. Federal Aviation Administration, 2008.
6. Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., and Yu, T.-H., "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change," Science, Vol. 319. no. 5867, 2008, pp. 1238-1240. DOI:10.1126/science.1151861.
7. Skone, T.J., and Gerdes. K., "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels." U.S. Dept. of Energy, National Energy Technology Laboratory. 2008.

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