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Aviation CO_2 emissions reductions from the use of alternative jet fuels

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ABSTRACT

Although a relatively small contributor to annual anthropogenic CO_2 emissions (~2.6%), commercial aviation activity is growing at ~5% per annum. As a result, alternative jet fuel (AJF) technologies have garnered interest as a means to achieve large, near-term emissions reductions for the industry. This analysis quantifies the potential for AJF to reduce aviation's CO_2 emissions by assessing: the availability of AJF feedstock; AJF volumes that could be produced from that feedstock; the lifecycle emissions of AJF compared to petroleum-derived jet fuel; and the number of bio-refineries and capital investment required to achieve the calculated emission reductions. We find that, if the use of AJF is to reduce aviation's lifecycle GHG emissions by 50% or more by 2050, prices or policies will have to significantly incentivize the production of bioenergy and waste feedstocks, and AJF production will need to be prioritized over other potential uses of these resources. Reductions of 15% by 2050 would require construction of ~60 new bio-refineries annually (similar to growth in global biofuel production capacity in the early 2000s), and capital investment of ~12 billion USD_{2015} per year (~1/5 of annual capital investment in petroleum refining).

1. Introduction

Commercial aviation currently accounts for approximately 2.6% of annual global carbon dioxide (CO_2) emissions from fossil fuel combustion (ICAO, 2016a; IEA, 2016), and ~3.5% of total anthropogenic radiative forcing (Lee et al., 2009). Aviation activity is expected to grow by an annual average of approximately 4.5–4.8% in the coming decades (Airbus, 2016; Boeing, 2016), and as a result aviation's contribution to global fossil fuel CO_2 emissions could grow to 4.6–20.2% by mid-century.

Policies in a number of jurisdictions aim to address aviation's climate impact. For example, in the United States (US) the goal of the Continuous Lower Energy, Emissions and Noise program is to accelerate reductions in aircraft fuel burn and emissions, and aviation has been included in the European Union Emissions Trading Scheme since 2012 (EC, 2017; US FAA, 2016). At the intergovernmental level, the International Civil Aviation Organization (ICAO), a specialized agency of the United Nations (UN), has adopted a goal of carbon neutral growth of international aviation from 2020 (ICAO, 2013). The International Air Transport Association (IATA), an airline industry group, has a further goal of a 50% reduction in CO_2 emissions by 2050 (IATA, 2017). To facilitate these international goals, member states to ICAO's Committee for Aviation Environmental Protection recently agreed to a global market-based mechanism to address international aviation emissions, called the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) ICAO (2016b). Under CORSIA, the aviation sector will be required to offset international aviation CO_2 emissions in excess of average emissions during 2019 and 2020. This requirement may be satisfied by the purchase of offset credits from crediting mechanisms, or allowances from emissions trading schemes, such as the UN Clean Development Mechanism (CDM) or the Reducing Emissions from Deforestation and forest Degradation (REDD+) programme (ICAO, 2017). The implementation of this policy means there is financial incentive for airlines to reduce their international CO_2 emissions.

In order to mitigate the cost of offsetting CO_2 emissions to comply with sectoral climate policies such as CORSIA, the aviation industry may reduce its CO_2 emissions directly through improvements in airframe and engine technologies (Graham et al., 2014; Cansino and Román, 2017; Schäfer et al., 2016), more efficient aircraft and ground operations (Linke et al., 2017; Niklaß et al., 2017), and the use of sustainable alternative jet fuels (AJF). Hileman et al. (2013) found that, in order to achieve a 50% reduction in CO_2 emissions by 2050 without

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purchasing offset credits or emissions allowances, an 84% reduction in the lifecycle greenhouse gas (GHG) emissions intensity of aviation is required in the US context. Dray et al. (2010) and Sgouridis et al. (2011) used partial-equilibrium and system dynamics modeling approaches to assess the potential for reductions in aviation CO_2 emissions. All three of these studies indicate that keeping annual aviation CO_2 emissions at or below 2020 levels is only possible with a combination of technological, operational, and policy measures, together with the large-scale use of AJF. The International Energy Agency (IEA) (2015) found that, without the purchase of offsets or emission allowances from other sectors, post-2020 carbon neutral growth is out of reach for the aviation industry. Notably, the IEA (2015) analysis did not consider the use of AJF. Finally, Wise et al. (2017) showed that, in the absence of AJF, aviation CO_2 emissions mitigation potential is limited and would likely be at the expense of growth in demand for aviation services.

While these previous analyses have found that achieving the aviation industry's CO_2 emissions goals will require the use of AJF, no peer-reviewed work to date has addressed the implications of industrial-scale AJF use for commercial aviation. In this paper, we quantify the global potential for AJF production on the basis of feedstock availability, and the associated lifecycle CO_2-equivalent (CO_2e) emissions benefit of AJF compared to petroleum-derived fuels, under a number of scenarios out to 2050. We estimate the number of fuel production facilities and associated capital expenditures required for the calculated AJF production volumes, and derive practical and policy implications from our findings. The remainder of the paper proceeds as follows: in Section 2 the overarching modeling approach is outlined; the detailed methods as well as data are presented in Section 3; results are presented and discussed in Section 4; and Section 5 concludes and summarizes the policy implications.

Note that this analysis is limited to CO_2 combustion emissions from aviation, as well as CO_2, CH_4 and N_2O emissions from upstream processes in the fuel production supply chain. Non-CO_2 aviation combustion emissions, aviation-induced contrails and cloudiness, and the climate impacts of surface albedo due to land use change (LUC) are outside of the scope of this analysis (for more information on these topics see Caiazzo et al., 2014 and Lee et al., 2009).

2. Modeling approach

The scope of this analysis is limited to “drop-in” AJF, defined as hydrocarbon fuels that have properties similar to those of petroleum-derived jet fuels, such that they are fully compatible with existing aircraft and infrastructure and do not inhibit aircraft performance or operation. Additionally, we focus on AJF pathways that could reduce lifecycle GHG emissions compared to petroleum-derived fuels, meaning that synthetic fuels derived from coal or natural gas are not included. The AJF pathways considered in this work are derived from either biomass or waste feedstocks (such as fats, oils and greases, or municipal solid waste).

This analysis includes three components, the first of which quantifies the potential global availability of AJF by 2050. Primary bioenergy and waste resources are quantified under assumed physical constraints (such as arable land availability, crop yields), socio-economic conditions (such as global population, gross domestic product (GDP)) and future environmental policies. The share of primary energy available for use as AJF feedstock is then calculated as a function of assumed market prices that incentivize feedstock production to varying degrees. Finally, AJF volumes are calculated based on the proportion of available feedstock converted to AJF, as opposed to other potential end uses for the feedstock.

The second component of the analysis quantifies the lifecycle GHG emissions associated with AJF. CO_2e emissions from feedstock production, transportation, and fuel production for the AJF pathways of interest, and petroleum-derived jet fuel, are taken from the peer-reviewed literature. These lifecycle assessment (LCA) data are augmented to reflect the impact on lifecycle emissions of anticipated changes in agricultural yields, nutrient application rates, farming energy requirements, process efficiencies, and the emissions associated with electricity and hydrogen requirements for fuel production to 2050, where relevant. In addition, LUC emissions are accounted for based on the land requirements, feedstock crop yields, and changes in soil and biomass carbon stocks associated with bioenergy from cultivated feedstock crops, calculated in the first component of the analysis described above.

In the third component of the analysis, the scenarios previously discussed are combined to calculate the potential for reductions in aviation's lifecycle GHG emissions to 2050. The number of production facilities and associated capital investment required to meet the resulting emissions reductions are also calculated in order to assess the feasibility of our findings.

3. Methods and data

This analysis uses a scenario-based approach to quantify the potential for reductions in aviation-attributable CO_2 emissions from the use of AJF. The following sections describe the methods and data sources used to carry out the analysis, as well as the scenario definitions employed to quantify the sensitivity of the results to key assumptions and parameters.

3.1. Primary bioenergy and waste resources

This component of the analysis concerns the quantity of primary energy from biomass and waste resources, as constrained by physical limits (such as arable land area, crop yields, and agricultural residue generation) and socio-economic factors (such as environmental policies, population, and GDP). The feedstock scope includes cultivated feedstock crops, agricultural residues from food and feedstock crop production, MSW, waste FOG, and forest and wood processing residues. Three scenarios are defined in order to explore the range of results, where S1 and S3 correspond to the combination of assumptions that lead to the largest and smallest calculated global primary energy resource, respectively. The following sections describe the methods and data used to calculate primary energy from each of the feedstock categories.

3.1.1. Cultivated feedstock crops

Data from the Land Use Harmonization (LUH) project[1] is used to estimate the arable land area for feedstock crop cultivation in 2050, where land use is described in terms of five categories: crop, pasture, urban, primary, and secondary lands. Primary land is defined as land undisturbed by human activities since 1700 CE, and secondary land is defined as land disturbed by human activities since 1700 CE and in the process of recovery (Hurtt et al., 2011). Land area data for these categories is given for the four Representative Concentration Pathway (RCP) scenarios from IPCC. In order to avoid competition for food, feed, and other projected future land use demands, this analysis considers crop and urban land areas from the LUH data to be unavailable for feedstock crop cultivation. Primary forested and protected land areas are also assumed to be unavailable for feedstock crop cultivation on the basis of ecosystem conservation, and are identified by overlaying data from the Global Agro-Ecological Zones (GAEZ) model[2] (IIASA/FAO, 2012).

The pasture, non-forested primary, and secondary land categories are considered for feedstock crop cultivation in this analysis, however the areas that are available depends on parameter assumptions that

[1] Data, documentation and project description available at hhttp://luh.umd.edu.

[2] Data, documentation and model available at http://www.fao.org/nr/gaez/en/.