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The impact of advanced biofuels on aviation emissions and operations in the U.S.

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ABSTRACT

We analyze the economic and emissions impacts on U.S. commercial aviation of the Federal Aviation Administration's renewable jet fuel goal when met using advanced fermentation (AF) fuel from perennial grasses. These fuels have recently been certified for use in aircraft and could potentially provide greater environmental benefits than aviation biofuels approved previously. Due to uncertainties in the commercialization of AF technologies, we consider a range of assumptions concerning capital costs, energy conversion efficiencies and product slates. In 2030, estimates of the implicit subsidy required to induce consumption of AF jet fuel range from \$0.45 to \$20.85 per gallon. These correspond to a reference jet fuel price of \$3.23 per gallon and AF jet fuel costs ranging from \$4.01 to \$24.41 per gallon. In all cases, as renewable jet fuel represents around 1.4% of total fuel consumed by commercial aviation, the goal has a small impact on aviation operations and emissions relative to a case without the renewable jet fuel target, and emissions continue to grow relative to those in 2005. Costs per metric ton of carbon dioxide equivalent abated by using biofuels range from \$42 to \$652.

1. Introduction

Recent estimates indicate that aviation currently accounts for approximately 5% of total anthropogenic radiative forcing (Dessens et al., 2014; Lee et al., 2009). Furthermore, the International Civil Aviation Organization (ICAO, 2013) predicts that in the absence of mitigation measures, driven by a sevenfold increase in air traffic, total greenhouse gas (GHG) emissions associated with aviation will be 400–600% higher in 2050 than in 2010.

To address these concerns, in 2009 the International Air Transport Association (IATA) announced that it aimed to achieve carbon-neutral growth in global airline operations from 2020 onward, and to reduce aviation GHG emissions in 2050 by 50% relative to 2005 (IATA, 2009). The industry's strategy for meeting these goals rests upon improvements in operations, airport and air traffic management, airframe and engine technologies, as well as large-scale introduction of aviation biofuels that have significantly lower GHG emissions on a lifecycle basis than petroleum-derived jet fuel (IATA, 2009). Hileman et al. (2013) quantify the reduction in lifecycle GHG emissions intensity required to achieve the 2050 IATA goal in the U.S. They find that, after accounting for predicted growth in airline operations and fuel-efficiency improvements, aviation GHG intensity would need to decrease from 1.37 g of carbon dioxide equivalent (CO_2e) per kilogram-kilometer in 2005 to 0.22 g in 2050; a decrease of 84%.

Motivated by energy security and climate concerns, the U.S. Federal Aviation Administration (FAA) has established a voluntary goal that one billion gallons (~3.8 billion liters) of alternative jet fuel is consumed annually from 2018 onward in the U.S. (FAA, 2011). This goal includes renewable fuel targets set by the U.S. Air Force and Navy, so the biofuel goal for commercial aviation is a fraction of this amount.

Operating concurrently with the FAA's biofuel goal, the National Renewable Fuel Standard (RFS2) regulates biofuels used in ground transportation in the U.S. RFS2 sets mandates for biomass-based diesel, cellulosic biofuel, undifferentiated advanced biofuels and the total quantity of biofuels. The U.S. Environmental Protection Agency ensures that the RFS2 mandates are met by issuing a renewable identification number (RIN) for each gallon of biofuel produced, and requiring refineries to purchase a certain amount of RINs for each gallon of fuel sold for ground transportation (U.S. GAO, 2014). Separate RINs and turn-in targets are issued for each biofuel category. Aviation biofuels qualify for RINs, which have a monetary value, and therefore reduce the cost of renewable jet fuel to airlines.

Almost all biofuel currently produced is ethanol or biodiesel which, due to contamination and safety concerns, cannot be used in aircraft engines (Hileman et al., 2009; Waterland et al., 2003). Therefore, additional biofuel technologies need to be developed that are compatible with existing infrastructure and aircraft (Hileman et al., 2009).

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Large-scale deployment of aviation biofuels from pathways suited for aviation face significant challenges. These include high production costs and lack of integration of aviation biofuels into regulatory frameworks (Carriquiry et al., 2011; Carter et al., 2011; Gegg et al., 2014), limits in scale-up due to feedstock availability (Seber et al., 2014; U.S. DOE, 2011), environmental and socio-economic consequences of large-scale land-use change and competition with food and feed needs (Kretschmer et al., 2009; Searchinger et al., 2008; Serra and Zilberman, 2013), water consumption associated with biomass cultivation (Scown et al., 2011; Staples et al., 2013), and the time required for scaling-up biomass cultivation and conversion facilities (Richard, 2010).

This paper deals with the impact of large-scale deployment of advanced aviation biofuels from perennial grasses such as switchgrass or miscanthus using a set of technologies known as fermentation and advanced fermentation (AF). Our modeling approach relies on an economy-wide model of economic activity and energy systems to quantify the additional cost of advanced renewable jet fuel relative to its conventional counterpart, and the impact of achieving the FAA's goal on aviation operations and emissions.

We focus on biofuels from AF technologies since they are commonly regarded as one class of next-generation biofuels that face smaller environmental and economic challenges compared to traditional biofuels from oily crops or grains (Tilman et al., 2009). AF technologies can not only use sugary crops (such as sugarcane) and starchy crops (such as corn grain), but also convert non-edible lignocellulosic biomass from agricultural residues or perennial grasses. Energy grasses have high water, light and nitrogen use efficiency (Somerville et al., 2010), are suited for a broad range of climatic and soil conditions, and can be grown on land not suitable for food crops (McLaughlin et al., 2002). This potentially reduces competition for scarce land with food or feed purposes compared to growing oily crops or grains for fuel production. Moreover, due to relatively high conversion efficiencies and low fossil fuel input requirements during processing, lifecycle GHG emissions can be significantly lower than emissions for other biofuels such as those from oily crops or grains (Staples et al., 2014). This increases the potential for emissions reductions from using aviation biofuels. Additionally, biofuels from lignocellulosic biomass that have associated lifecycle GHG emissions of at least 60% below those of their conventional counterpart qualify for the (currently) most stringent RFS2 biofuel sub-mandate and can therefore yield higher RIN prices, which makes production of these fuels, ceteris paribus, more viable from a business perspective compared to other biofuels.

While there is a wide body of literature that deals with CO_2 abatement in the airline industry through market-based measures (e.g., Hofer et al., 2010; Malina et al., 2012; Winchester et al., 2013b), only a few archival studies, as discussed below, have been published that quantify the environmental and economic impact of large-scale aviation biofuel adoption. Moreover, none of the existing papers on aviation biofuels examine the impact of advanced biofuels on aviation emissions and economic activity. In addition, no study to date has incorporated the interactions between an aviation-specific renewable fuel goal fulfilled with advanced biofuels and the corresponding biofuel RIN markets under RFS2 system for transportation fuels. Finally, most existing studies either do not address production costs of aviation biofuels, or simply assume that they will converge to the price of petroleum-derived jet fuel at some assumed point in time (e.g., Sgouridis et al., 2011).

Hileman et al. (2013) assess a portfolio of mitigation options in terms of their potential contribution to meeting the air transport industry's goal of a 50% reduction in absolute GHG emissions by 2050 relative to 2005 levels. Their results indicate that in order to achieve the industry goal, a relatively rapid adoption of new, more efficient aircraft designs would be necessary as well as the large-scale introduction of alternative fuels with low lifecycle GHG emissions compared to conventional jet fuel. In particular, in order to meet the IATA goal, they find that under the assumption that the aircraft fleet in 2050 is 116% more efficient in terms of fuel burn per kilogram-kilometer compared to current-generation narrow body aircraft, 30% of jet fuel consumed would have to come from renewable sources at a lifecycle GHG footprint of 10% of that of conventional jet fuel per unit of energy consumed.

Sgouridis et al. (2011) also assess strategies for mitigating CO_2 emissions from air transportation. They find that if aviation biofuels can be offered at price parity to conventional jet fuel, between 15.5% and 30.5% of total jet fuel consumption in 2024 could be from renewable fuels, which would decrease cumulative CO_2 emissions from aviation between 2004 and 2024 by 5.5% to 9.5% relative to their reference case.

Krammer et al. (2013) use a systems model for the aviation industry to simulate aviation biofuel adoption under different socio-economic and policy assumptions. Like Sgouridis et al. (2011), they assume that biofuel usage does not incur a price premium compared to conventional jet fuel, and that market uptake is only limited by fuel availability. Under these assumptions, they find that 50% of global jet fuel burn could be satisfied by biofuels by 2041, and that global GHG emissions attributable to aviation would be 48–53% lower than in a baseline (no-biofuels) case.

Using a numerical general equilibrium approach, Winchester et al. (2013a) quantify the economy-wide and aviation-specific impact of using one class of aviation biofuels derived from oily crops. To our knowledge, this is the only study that models price differences between aviation biofuels and conventional jet fuel with the associated market impacts. Winchester et al. (2013a) find that if the FAA alternative fuels goal described above were to be met with these fuels exclusively, an implicit subsidy would have to be paid ranging from $0.35 to $2.69 per gallon of renewable jet fuel. The lower estimate assumes that all feedstock demand can be satisfied through rotation crops grown on fallow land that do not directly compete with food or feed crops, while the higher estimate assumes soybeans on existing agricultural land to be used as feedstock. Abatement costs are calculated at approximately $400 per metric ton of CO2e abated in the soybean case, and approximately $50 per metric ton for optimistic assumptions on the availability of oilseed rotation crops. Total abatement of GHG emissions due to the use of biofuels is calculated at approximately 1% compared to the baseline case in the year 2020.

The remainder of this paper proceeds as follows: In Section 2 we outline aviation biofuel pathways, focusing on the technology sets and feedstock considered in this paper. Section 3 presents a stylized analysis of the interaction between aviation biofuel goals and RFS2 mandates in a simplified setting. Our modeling framework and scenarios are explained in Section 4. We present results and discuss them in Section 5. The final section concludes.

2. Advanced fermentation biofuels

Jet fuels are certified for use in commercial aviation through ASTM, a global standard setting organization. The first two biofuels to be certified in 2009 and 2011, respectively, were synthetic paraffinic kerosene (SPK) from biomass using a Fischer-Tropsch process, and SPK consisting of Hydroprocessed Esters and Fatty Acids (HEFA) jet fuel, also known as Hydrotreated Renewable Jet fuel (ASTM, 2011). This certification allows these fuels to be used in existing aircraft engines and fuel infrastructure up to a blending percentage by volume of 50% (ASTM, 2011). While these fuels have not been deployed at large scale, some airlines are using blends on selected routes. For example, in summer 2013, United Airlines executed a purchasing agreement with Alt Air Fuels for 15 million gallons of HEFA jet fuel from animal fats and non-edible oils to use on routes from Los Angeles International Airport (United Airlines, 2013). In South Africa, Sasol is providing SPK jet fuel using a Fischer-Tropsch technology and coal as a feedstock to airlines operating at O.R. Tambo International Airport in Johannesburg (Sasol, 2011).

In June 2014, ASTM revised D7566, the aviation fuel standard concerning synthesized hydrocarbons, to include a type of biofuel called "Synthesized Iso-Paraffinic" (SIP) fuel from hydroprocessed fermented sugars. The SIP fuel is produced by the fermentation of biomass derived sugars into Farnesene, followed by hydrotreatment and fractionation of