ALTERNATIVE JET FUEL SCENARIO ANALYSIS REPORT

Final Report

U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
Environmental Measurement and Modeling Division, RTV-41
Cambridge, MA 02142

Version: 11/14/2012

Notice

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Notice

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

REPORT DOCUMENTATION PAGE		*Form Approved OMB No. 0704-0188*
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE November 2012	3. REPORT TYPE AND DATES COVERED Final Report, 05/2010-11/2012
4. TITLE AND SUBTITLE Alternative jet fuel scenario analysis report		5. FUNDING NUMBERS
6. AUTHOR(S) Kristin Lewis, Shuchi Mitra, Sheila Xu, Lyle Tripp, Michael Lau, Alexander Epstein, Gregg Fleming, Chris Roof		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation, Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center Environmental Measurement and Modeling Division, RVT-41, Cambridge, MA 02142		8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FAA-12-01
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Aviation Administration, Office of Environment and Energy, Washington, DC 20590		10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FAA/AEE/2011-05
11. SUPPLEMENTARY NOTES		
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, Springfield, VA 22161		12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words) -

This analysis presents a “bottom up” projection of the potential production of alternative aviation (jet) fuels in North America (United States, Canada, and Mexico) and the European Union in the next decade. The analysis is based on available plans from individual companies and considers existing and emerging fuel production technologies. The analysis also forecasts how alternative fuels might contribute to greenhouse gas goals. Based on a review of fuel production companies’ stated plans to produce jet fuel, the study incorporated company-specific data into seven scenarios varying alternative jet fuel production and expansion assumptions. This study supports the use of advanced alternative fuels as one important component of achieving emissions and environmental targets, although other additional measures and/or new technologies may also be required. The analysis suggests that the FAA goal of 1 billion gallons of alternative jet fuel use by U.S. aviation in 2018 is achievable. A combination of the most optimistic demand forecasts and the “product switch” production scenarios leads to North American aviation greenhouse gas emissions leveling off or decreasing between years by 2020. For the limited scenarios considered, additional measures would be needed to return to 2005 emissions levels in North America in 2020. In the European analysis, leveling of GHG emissions by 2020 only occurs in cases where ethanol and/or biodiesel producers switch to producing some jet fuel. As this “bottom up” projection could not account for all potential alternative fuel producers (either because public data were not available or because these companies were unknown to the authors), the results presented should be viewed as one possible range of future production levels that could occur in North America and Europe. It does not consider the amount of alternative fuels that could be produced from all potentially available feedstocks (i.e., technical potential) which would be much greater. Further, production outside of North America and Europe was not included in the analysis so actual demand for alternative jet fuels in North America and Europe could be met with alternative fuels produced outside the region. Finally, the development of new technologies, new market conditions, new participants, and improved processes for known technologies could all lead to production levels higher than shown in this analysis. In fact the technical potential of biofuels production greatly exceeds projected demand. Likewise, policies and economic conditions could lead to lower, or nonexistent production levels.

14. SUBJECT TERMS			15. NUMBER OF PAGES
alternative jet fuels, alternative fuels, biofuels, Federal Aviation Administration, scenario analysis			77
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited

NSN 7540-01-280-5500 ***Standard Form 298(Rev. 2-89)*** ***Prescribed by ANSI Std. 239-18 298-102***

Contents

Tables

Figures

EXECUTIVE SUMMARY

This analysis presents a “bottom up” projection of the potential production of alternative jet fuels in North America (the United States, Canada, and Mexico) and the European Union in the next decade. These regions were chosen because they account for approximately 70-80% of current aviation fuel use [1], and data for the alternative fuel industry are more readily accessible and available in these regions. The projections reflect publicly available individual company plans – as opposed to the underlying market forces – for production and expansion, and the role that those fuels may play in achieving carbon neutral growth goals in those regions. This approach provides a snapshot, based on available public data collected between December 2009 and March 2011, of planned production by individual companies using existing and emerging fuel production technologies, and therefore does not reflect the many changes in companies, plans, and achievements since that time. The data from approximately 15% of companies identified in North America and 5% of companies identified in Europe were acquired as a result of direct contact; the remaining data used herein were culled from publicly available databases, press releases, websites, etc. It is important to note that the analysis does not cover all possible fuel producers in North America and Europe and it does not account for any production from outside of North America and Europe. As such, there is the potential for alternative jet fuel consumption in North America and/or Europe that exceeds those given within this analysis. Additional caveats and limitations are described at the end of the introduction to the main document.

Aviation currently generates approximately two percent of global carbon dioxide emissions [2]. The aviation industry’s primary stakeholder groups have committed to substantial greenhouse gas emissions reductions. The Federal Aviation Administration (FAA) has articulated an aspirational goal of carbon neutral growth for the aviation industry at 2005 emissions levels beginning in 2020 [3] that builds on the global industry goal of carbon neutral growth starting in 2020 (at 2020 emissions levels) [4]. While projected improvements in operational and equipment efficiency can achieve some reductions in greenhouse gases by reducing fuel demand, these are unlikely to be sufficient to meet the carbon neutral growth goal within the next decade. The aviation community is pursuing low carbon, sustainable drop-in alternative jet fuels to help fill this gap, and a number of stakeholder groups are interested in tracking industry progress toward the carbon neutral growth goals.

Many analyses to date estimate future alternative fuel availability from the approach of feedstock constraints and the potential amount of fuel that could be produced from a maximum retrievable amount of feedstock [e.g., 5,6]. Existing analyses on drop-in alternative jet fuel availability and adoption in the next decade [e.g., 7,8] do not provide an encouraging picture for the role of alternative jet fuels in reaching 2020 carbon neutral growth goals; an Australia/New Zealand focused report [7] suggests minimal adoption in that region by 2020 , and a global analysis suggests that even the most optimistic scenario of global adoption by 2020 would be under 3% of aviation fuels [8]. A European initiative focused on alternative jet fuels dismisses the goal of carbon neutral growth by 2020 in Europe as infeasible [9]. It should be noted that these studies focused on fuels produced by Fischer-Tropsch (FT) processes and hydroprocessing of esters and fatty acids (HEFA); therefore, these studies cover a subset of the proposed technologies for producing alternative jet fuel. This analysis takes a different approach by examining the plans of actual alternative fuel producers over the next decade.

All of the scenarios included in this study are based on a review of limited and uncertain sources of data that were available in 2009-2011. The scenarios defined herein depend on assumptions that may not be borne out. This analysis does not account for competition among fuel production processes or other uses for feedstocks that may be available in limited quantities; it assumes that each facility will be able to acquire the feedstock required to fulfill planned capacity of production. These scenarios also assume that all companies that existed at the time of data collection will continue to exist and be able to produce fuel, and in some scenarios assumes that existing companies not currently planning to produce jet fuel will switch to making jet fuel. Additionally, the analysis does not account for potential new technologies that may add to the potential fuel production. Furthermore, many companies may not be revealing the full extent of their plans for competitive reasons; therefore, while every effort has been made to produce a complete and accurate representation of current industry status, the data presented herein should be taken as an estimate rather than a definitive evaluation of alternative jet fuel plans. It should also be noted that this analysis assesses only the role of alternative fuels in addressing the emissions gap between predicted fuel burn and carbon neutral growth goals, but does not account for measures that might also contribute to achieving these goals.

The company-specific alternative fuel data were incorporated into seven scenarios (summarized in Table ES-1 – for details see Appendix B of the document). The first four scenarios do not include any biodiesel producers nor any traditional ethanol producers.

The *Basic Jet* and *Expanded Jet* scenarios (Scenarios 1 and 2, respectively) give the range of the currently planned jet fuel production based on existing companies. The *Expanded Jet Plus Moderate Switch* (Scenario 3, later referred to as *Moderate Switch)* and *Expanded Jet Plus Optimistic Switch* (Scenario 4, later referred to as Optimistic Switch) scenarios reflect the potential for market conditions to make jet fuel production desirable and the related potential for companies that do not currently plan to produce jet fuel to transition to producing it. No specific market scenarios were implemented – rather, the *Moderate Switch* and *Optimistic Switch* scenarios assume a set fraction of the alternative fuel production will be turned into jet fuel on either a volumetric or energy basis, depending on the process.

The last three scenarios incorporate information on existing ethanol and biodiesel companies and assume that the market for jet fuel would be strong enough to trigger reallocation of some of the output of these companies to jet fuel. In the *Optimistic Switch + OECD* scenario (Scenario 5), product switching assumptions were applied to Organization for Economic Cooperation and Development (OECD) projections of future availability of biodiesel and ethanol and added to the jet fuel production projections from the *Optimistic Switch* scenario (Scenario 4) to evaluate how that might affect jet fuel production and GHG emissions. In the second additional approach, a bottom up analysis similar to that used for Scenarios 1-4was used to project biodiesel and ethanol availability. The assumption of a standard fraction of biodiesel switch to jet fuel was added to the *Moderate Switch* scenario (Scenario 3) to create Scenario 6 (*Moderate Switch + Biodiesel*). A standard fraction of product switching from both biodiesel and ethanol was added to the *Optimistic Switch* scenario (Scenario 4) to create Scenario 7 (*Optimistic Switch + Biodiesel/Ethanol*).

For North America, alternative jet fuel production in the first four scenarios was projected by 2020 to be between 2.5 billion gallons per year (BGY) in the *Basic Jet* case (Scenario 1), up to over 9 BGY in the *Optimistic Switch* scenario (Scenario 4), based on 61 companies using 18 fuel production processes. Comparing these values with International Civil Aviation Organization's Committee for Aviation and Environmental Protection (CAEP) demand forecasts of aviation fuel demand in 2020 (27.8-32.9 BGY), which include a range of technology and operational improvements, indicates that the amount of jet fuel that might be replaced by alternative fuels in 2020 ranges from approximately 7.2-8.5 % in the *Basic Jet* scenario (2.5 BGY) up to 33% of jet fuel in the *Optimistic Switch* scenario (9.2 BGY) and the lowest demand forecast.

Under the assumptions of the *Optimistic Switch + OECD* analysis, additional jet fuel that would be produced from biodiesel and ethanol facilities would expand the alternative jet fuel pool. In North America, the scenario would result in 34.4-40.8% replacement of jet fuel. Similarly, in the *Moderate Switch + Biodiesel* and *Optimistic Switch + Biodiesel/Ethanol*, jet fuel replacement in North America including product switching from biodiesel/ethanol would be 9 and 12.9 BGY, respectively (approximately 27 to 42% replacement).

In the European region, the range of results for Scenarios 1-4 is smaller, replacing between 3% and 5% of jet fuel demand in all alternative fuel scenarios and demand forecasts (800 MGY to 1 BGY) based on 18 companies and 9 processes to make advanced alternative fuels. In the *Optimistic Switch + OECD* analysis, the additional jet fuel resulting from biodiesel and ethanol facilities switching products would lead to 10.4-13.4% replacement. In the *Moderate Switch + Biodiesel* and *Optimistic Switch + Biodiesel/Ethanol*, jet fuel replacement in Europe would be 1.8 and 3.8 BGY, respectively (approximately 7.5 to 16% replacement).

In both regions, Fischer-Tropsch (FT) and hydroprocessed esters and fatty acids (HEFA) processes dominated, most likely due to their successful certification for aviation fuel use in 2009 and 2011 respectively. Other processes with noticeable contributions to the North American analysis include alcohol oligomerization and photosynthetic organisms that have been genetically modified to produce hydrocarbons.

To determine the potential greenhouse gas benefit of alternative jet fuels, generalized GHG LCA values were selected based on previous work on aviation alternative fuels [10]. In cases where no previous work using a methodology consistent with Stratton et al. was available, a proxy value based on other processes was assigned. These values were then used with individual company plans to project potential GHG emissions reductions.

Table ES-1: Summary of included data for the seven scenarios considered in this analysis. Details on the scenarios and assumptions can be found in Appendix B of the report.

			Assumed alternative jet fuel production level or fraction of production slate					
	Included producers		**Companies with stated intent to produce jet fuel**		**Companies with stated intent to produce but no stated production levels**	**Companies without stated intent to produce**		
Scenario Short Name	**Companies that intend to produce jet fuel**	**Companies without stated intent to produce**	**Reflects starting plans**	**Reflects expansion plans**	**Reflects assumed allocation of product to jet**	**Reflects assumed switch in allocation of product to jet**		
						Biodiesel	*Ethanol*	All Other Processes
Basic Jet	✓		✓		✓			
Expanded Jet	✓		✓	✓	✓			
Expanded Plus Moderate Switch	✓	✓	✓	✓	✓			✓
Expanded Plus Optimistic Switch	✓	✓	✓	✓	✓			✓
Optimistic Switch + OECD	✓	✓	✓	✓	✓	✓	✓	✓
Moderate Switch + Biodiesel	✓	✓	✓	✓	✓	✓		✓
Optimistic Switch + Biodiesel/ Ethanol	✓	✓	✓	✓	✓	✓	✓	✓

The percent greenhouse gas emission reduction corresponding to the potential alternative jet fuel availability projections varied depending on the fuel demand forecast. In the *Moderate Switch* scenario (Scenario 3) for North America, GHG emissions are nearly the same (approaching a leveling of GHG emissions) between 2016 and 2020 in the lowest demand forecast. And in the *Optimistic Switch* scenario (Scenario 4) total GHG emissions would actually decrease from 296 to 295 Mt carbon dioxide equivalents (CO2e) from 2016 to 2020 in the lowest demand forecast (and would result in 10.7% overall reduction in GHG emissions in 2020 compared to the lowest demand forecast using all petroleum-based jet fuel).

Under the *Optimistic Switch + OECD* scenario (Scenario 5), additional jet fuel that would be produced from biodiesel and ethanol facilities would result in further North American GHG reductions (total reduction of 14.2-16.8% compared to 100% standard jet fuel). In North America, the *Moderate Switch + Biodiesel* scenario (Scenario 6) would result in 8.8-10.4% GHG reduction, and the *Optimistic Switch + Biodiesel/Ethanol* scenario (Scenario 7) would result in 14.2-16.8% GHG reduction compared to 100% standard petroleum based jet fuel, similarly to the OECD scenario estimate.

The FAA's target is to achieve carbon neutral growth of U.S. aviation at 2005 emissions levels starting in 2020. A comparison of the North American results with available data on 2006 emissions levels (a close proxy for 2005 emissions levels) indicates that emissions predicted in 2020 under Scenarios 1-4 are 16 to 50% greater than the 2006 emissions level. Even in the *Optimistic Switch+Biodiesel/Ethanol* scenario and lowest demand forecast, emissions do not return to 2005 levels in 2020. However, it should be noted that further reductions may be achieved through greater expansion of alternative fuel production or other mechanisms than alternative fuels.

In the European analysis, the total projected volume of alternative jet fuel is much lower than in North America. Given the overall lower projected replacement of jet fuel, the GHG emissions reduction is therefore less than that for North America – in the European *Optimistic Switch* scenario and lowest demand forecast, it is approximately 3% of demand. The average LCA value for the planned production in Europe is approximately 40-50% that of standard petroleum. In the European analysis none of the scenarios show a leveling off of GHG emissions between 2016 and 2020 as a result of alternative jet fuel use given the assumptions of the first four scenarios; however, as this analysis does not account for policy or market-based measures, these results do not necessarily indicate that carbon neutral growth targets cannot be met.

Under the *Optimistic Switch + OECD* scenario (Scenario 5), the GHG reduction in Europe due to alternative jet fuel would be 5.6-9.3%. In Europe, 3-3.9%, GHG reductions would result from the *Moderate Switch+Biodiesel* scenario(Scenario 6) and 6.3 to 8.2% GHG reduction would result from the *Optimistic Switch+Biodiesel/Ethanol* scenario (Scenario 7), the most optimistic case. In Scenarios 6 and 7, total GHG emissions between 2016 and in 2020 are projected to increase in the *Basic Jet* scenario and Expanded Jet scenarios, but only increase slightly (295 to 296 Mt CO2e) in the *Moderate Switch+Biodiesel* scenario, suggesting potential leveling off of emissions. In the *Optimistic Switch+Biodiesel/Ethanol* scenario total GHG emissions would decrease from 281 Mt CO2e in 2016 to 275 Mt in 2020. Thus, in this additional analysis with the *Switch* scenarios and lowest fuel demand forecasts, leveling of GHG emissions could occur between 2016 and 2020 at approximately 2016 emissions levels even without policy or market-based measures that may also contribute to GHG emissions reductions.

This analysis shows that the goal of the FAA to achieve 1 billion gallons of alternative jet fuel production by 2018 may be achievable. It also suggests that the USAF goal for replacement of 50% of its domestic jet fuel consumption, the European Biofuels Flightpath target of 600 million gallons per year by 2020, and the Air Transport Action Group (ATAG) goal of 6% replacement of jet fuel by 2020 may be possible.

However, even with optimistic assumptions, including full expansion of all companies that plan to produce jet fuel and switching to production of some jet fuel by other companies, as well as unlimited feedstock availability, the results of this analysis suggest that leveling of GHG emissions in the 2020 timeframe will be difficult to achieve except in the lowest North America demand forecast unless additional approaches, such as policy and market-based measures, are implemented. To address the emissions gap using only alternative jet fuels under the assumptions of this study, a combination of the most optimistic demand forecasts and one of the *Switch* scenarios (Scenarios 3-7) are required for North America to achieve leveling of GHG emissions in aviation by 2020, but even in these scenarios that carbon neutral growth does not occur at 2005 emissions levels, the FAA's target. Likewise, the analysis suggests that leveling of GHG emissions from aviation is unlikely to be accomplished in the European region without substantial product switching, changes in anticipated production capacity, imports of alternative fuels from outside Europe, improvement in the average GHG LCA value of the alternative fuels, changes in policies, and/or implementation of market-based measures. It is likely that both production capacity and GHG LC emissions for particular fuels will evolve and improve over time as the technology portfolio and market develops. Furthermore, the potential for alternative jet fuel production from all available feedstocks greatly exceeds the projected production by the companies identified in this study, indicating potential for industry growth. This suggests that subsequent snapshots of industry status may show improved likelihood of achieving carbon neutral growth in the targeted timeframe. Nevertheless, these results point to the potential need for additional reductions in fuel demand for the fleet, improvements in efficiency of aircraft operation through procedures and infrastructure, imports of low GHG alternative fuels from regions outside North America, and/or policy measures.

The analyses did not project alternative fuel availability beyond 2020, as very few companies had production plans beyond 2020 and as no assumptions were made about expansion beyond current planned capacity. Thus, based on the guiding rules of this analysis, in most cases the total amount of alternative jet fuel projected would not increase if the scenarios were extended beyond 2020. However, as aviation continues to grow, it is anticipated that alternative jet fuels will need to play a rapidly growing part in maintaining carbon neutral growth, and the alternative fuels industry would need to both expand substantially and reduce GHG emissions in order to achieve carbon neutral growth at 2005 levels.

The results presented here provide an example of the challenge of carbon neutral growth. However, new technologies, new market conditions that lead to new alternative jet fuel companies or shifts in production focus for existing companies, and improved processes to reduce GHG emissions may all change the actual future alternative fuel production and GHG benefits compared to what is predicted in this report. The technical potential of alternative jet fuel production (based on all potential feedstocks) provides the possibility of rapid industry expansion given appropriate conditions. Furthermore, other mechanisms could also play an important role in reducing GHG emissions from aviation, and this study may provide information on gaps that can be filled by implementing other options.

1. INTRODUCTION

Aviation currently generates approximately two percent of global carbon dioxide emissions [2]. The aviation industry's primary stakeholder groups have committed to substantial greenhouse gas emissions reductions. The Federal Aviation Administration (FAA) has articulated an aspirational goal of carbon neutral growth in the United States for the aviation industry at 2005 emissions levels beginning in 2020 [11] that builds on the global industry goal of carbon neutral growth starting in 2020 (at 2020 emissions levels) as put forth by the Airports Council International (ACI), the International Air Transport Association (IATA), the Civil Air Navigation Services Organization (CANSO) and the International Coordinating Council of Aerospace Industries Associations (ICCAIA) [12] and agreed to by the International Civil Aviation Organization (ICAO)[4].

The ICAO Committee for Aviation Environmental Protection (CAEP) and the Forecasting and Economic Analysis Support Group (FESG) have generated a set of jet fuel demand forecasts based on assumptions about aviation industry growth, fleet efficiency improvements and operational efficiency [13]. While projected improvements in operational and equipment efficiency can achieve some reductions in greenhouse gas (GHG) emissions by reducing fuel demand, these are likely to be insufficient to meet the carbon neutral growth -goal within the next decade. The aviation community is pursuing low carbon, drop-in alternative jet fuels to help fill this gap, and a number of stakeholder groups are interested in tracking industry progress toward the carbon neutral growth goals.

Many analyses to date estimate future alternative fuel availability from the approach of feedstock constraints and the potential amount of fuel that could be produced from a maximum retrievable amount of feedstock [e.g., 5,6]. For the United States, estimates of biomass availability range from 423 million [6] to over a billion tons [5] per year of various feedstocks that could be utilized to make biofuels, including agricultural and wood waste and dedicated bioenergy crops.

A few studies have investigated the potential for aviation fuels in particular to be replaced by drop-in alternative jet fuels based on "top down" analyses ("drop-in" aviation fuels are deoxygenated alternative fuels that are fungible with standard jet fuel as specified in ASTM Standard D7566). A recent report by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO [7] suggests that 4.1 billion gallons of alternative jet fuel could conceivably be produced from Australasian feedstock sources with no competition for feedstocks from other end users, and suggests that long-haul road transport and aviation are likely to be the main users of biomass for fuels in the long term due to the potential for electrification of other forms of transport. Nevertheless, their models incorporating costs and carbon price policies showed essentially no alternative jet fuel production before 2020 [7]. A study of potential global alternative jet fuel deployment by Bauen et al. [8] suggests that even without constraints on feedstock or conversion capacity availability and with a carbon price that causes alternative jet fuel to be less expensive than oil, alternative jet fuel will not reach 10% penetration of the market before 2024. Furthermore, a recent study by the European Sustainable Way for Alternative Fuels and Energy in Aviation (SWAFEA) determined that the carbon neutral growth goal starting in 2020 is infeasible in Europe due to the requirement for unrealistic expansion of alternative fuel production by that year and recommends economic/market-based measures to complement alternative jet fuel contributions to GHG emissions reductions [9]. Thus, existing research does not provide an encouraging picture for the role of alternative jet fuels in reaching 2020 carbon neutral growth goals. It should be noted that these three studies focused on fuels produced by Fischer-Tropsch (FT) processes or by hydroprocessing of esters and fatty acids (HEFA), and the E4Tech study also included limited information on synthetic hydrocarbons. Therefore, these studies cover a subset of the proposed technologies for producing alternative jet fuel. This analysis takes a different approach by examining the plans of actual alternative fuel producers over the next decade.

Scope and Objectives

The goal of this analysis was to use a “bottom up” approach to estimating future alternative jet fuel availability and GHG impacts out to 2020 based on existing and planned conversion (production) facilities, as identified through data on specific companies. The analysis is restricted to North America (the US, Canada, and Mexico) and Europe. The European analysis covers the contribution of European Union (EU27) countries’ alternative fuel production to meeting jet fuel demand in the ICAO-defined European region [14]. These restrictions are due to the difficulty in collecting data on individual companies beyond these regions. North America and Europe account for approximately 70-80% of current aviation fuel use [1]. The European Union accounts for approximately 89% of the total current and anticipated jet fuel demand in the ICAO European region. However, the proportion of aviation fuel demand due to Asia and the Middle East is expected to expand substantially, and Asia is investing heavily in alternative energy. Further, other regions of the world, such as South America, have the potential to not only meet their domestic needs but also export alternative jet fuels to North America and Europe. Therefore, it is crucial that future analyses address similar questions for these regions and other developing regions in which aviation is expanding.

The projections described in this report reflect individual company plans – as opposed to the underlying market forces – for production and expansion, and the role that those plans may play in achieving carbon neutral growth goals in the two target regions. The data from approximately 15% of companies identified in North America and 5% of companies identified in Europe were acquired as a result of direct contact; the remaining data were culled from publicly available databases, press releases, websites, etc. Due to the short-term nature of most alternative fuel company plans, no data were collected beyond 2020. Detailed information collected on individual companies was used to generate scenarios for alternative jet fuel production (Chapter 2). These projections are presented by processing type and are based on existing and incipient technologies for producing jet fuel and the aspirational plans of individual companies. Projecting alternative jet fuel availability from these plans is optimistic, but reflects expectations by active players within the industry at the time of data collection.

The resulting projections for alternative fuel production were compared with the existing CAEP forecasts of aviation fuel demand in the corresponding regions for the next decade (Chapter 3) to determine the possible replacement of petroleum-based jet fuel with alternative jet fuels. General GHG life cycle analysis (LCA) values for each process were used to estimate the GHG emissions associated with each scenario, and these emissions were compared with the baseline petroleum-only case for each CAEP forecast to estimate the potential GHG savings associated with alternative fuels (Chapter 4).

Due to the current dominance of ethanol and biodiesel producers in the biofuels industry, the last analysis chapter (Chapter 5) utilizes projected ethanol and biodiesel production from both existing predictions (from the Organization for Economic Cooperation and Development) and the "bottom up" (equivalent to the data collection in the first part of the analysis) to provide expanded scenarios in which ethanol and biodiesel producers switch a portion of their production to jet fuel, to assess how far such a change would move the industry toward the achievement of carbon neutral growth at 2020 or 2005 emissions levels in 2020.

Limitations and Caveats

The analysis presented herein depends on a "bottom up" projection of the potential production of alternative jet fuels that is based on a review of fuel production companies' stated plans to produce jet fuel. This review was conducted in 2010 and 2011. All of the scenarios included in this study, even the *Basic Jet* scenario, are thus based on a limited and uncertain source of data and could be seen to have incomplete data thus under-predicting future production and/or optimistic assumptions thus over-predicting future production.

The *Basic Jet* scenario assumes that all companies that are planning to produce alternative jet fuel will survive and successfully produce jet fuel in their anticipated timeframes. The "Expanded Jet" case assumes all jet fuel companies will succeed and that they will be able to fully expand to their aspirational production targets. The *Moderate* and *Optimistic Switch* scenarios assume that all identified companies of various conversion process types will decide to produce jet fuel starting in 2015 at the level indicated in the scenario descriptions above. However, in general, most start-up companies do not survive and achieve their initial plans, and many companies are cannibalized to produce products for a particular market and are not nimble in response to market shifts.

However, the analysis also does not include plans that companies have not made public or plans of companies not identified in the review. Therefore, it is possible that additional planned capacity will come online beyond that anticipated in this analysis. As plans were only obtained through direct contact for approximately 15% and 5% of companies in North American and Europe, respectively, these data may also lag behind actual plans as they are mainly captured from publicly available sources such as internet websites and press releases. It is also important to note that this study only evaluates the potential role of alternative jet fuels in addressing the gap in emissions between predicted fuel demand (incorporating technology and operational improvements) and carbon neutral growth goals. It does not address policy options or market-based measures that may result in further GHG emissions reductions.

For the European analysis, the production data focus on the EU27 countries due to accessibility of information, and the effects of that production on ICAO's European region fuel demand is evaluated. However, additional advanced alternative fuel production may be planned in other ICAO "Europe" countries (e.g., Russia, Turkey, Switzerland) that may substantially increase the availability of alternative aviation fuels and potential GHG emissions reductions.

The data in this study provide a "snapshot" in time of alternative jet fuel producer plans. The data were collected in 2010 and early 2011. No new information was added after March of 2011. Assumptions and scenario rules were applied to all data provided unless the producer actually published or provided year-by-year production plans for jet fuel specifically. Thus, even in cases where some data were available, assumptions about lag times and linear ramp up or fraction of production being turned into jet fuel may not accurately reflect individual company plans, but provide a general basis for annualized production projection over the next decade in order to compare alternative fuel production with the various GHG and alternative fuel targets.

This analysis does not include any import or export of fuels, but assumes fuels produced domestically will be consumed domestically.

No aspects of environmental benefit or detriment other than GHG emissions are considered in this analysis. However, particulate matter (PM) emissions benefits and issues such as water and land use, biodiversity, invasive species, and air and water pollutants will also need to be evaluated in order to fully assess the sustainability of any alternative fuels.

Finally, it should be very clear to the user that the GHG LCA values utilized herein are general estimates for each process and are rounded to fractions in order to emphasize the approximate nature of these values. Individual processes and, in particular, individual facilities may vary widely from these values depending on the details of their processing, location, and power options. This could change the GHG emissions reductions estimates substantially.

These caveats should be carefully considered.

2. ALTERNATIVE JET FUEL PRODUCTION PROJECTIONS

Approach

Alternative fuel companies were identified based on web searches, industry knowledge, previous studies [15], media database resources such as the Biofuels Digest (see Appendix A for a list of media sources), news articles and press releases. Individual companies from the United States, Mexico, Canada, and from the European Union were researched on the internet, and asked through direct contact about their plans for total alternative fuel production and in particular for total alternative jet fuel production. The data from approximately 15% of companies identified in North America and 5% of companies identified in Europe were acquired as a result of direct contact; the remaining data were culled from publicly available databases, press releases, websites, etc. The dataset also incorporates and expands upon previously collected data utilized for the United States Department of Transportation (DOT) Report entitled "Aviation Biofuel Potential to Meet Carbon Emissions Goals" [16], which focused solely on the United States and a narrower set of companies. Where possible, partnerships and company name changes were identified to eliminate double-counting of production amounts. Each company was categorized based on conversion process and feedstock, and the principal steps of the conversion were identified in order to facilitate assignment of estimated greenhouse gas (GHG) life-cycle assessment (LCA) values for each company.

This approach provides a snapshot of planned production by companies using existing and emerging fuel production technologies. It does not account for competition among these processes for feedstocks that may be available in limited quantities; it assumes that each facility will be able to acquire the feedstock required to fulfill planned capacity of production. It should be noted that the scenarios defined herein are optimistic by nature, as they assume that all companies that currently exist will continue to exist and be able to produce fuel, regardless of feedstock availability, or land use change caused as a result of feedstock production. Some scenarios also account for potential entrants into the alternative jet fuel market from other companies using existing fuel production technologies. However, this study does not attempt to predict the development of new technologies or the entry of entirely new companies into the industry. It should also be assumed that many companies are not revealing the full extent of their production plans for competitive reasons or due to non-disclosure agreements. Thus, although every effort has been made to accurately represent the current plans of the industry, this study should be treated as an estimate rather than a definitive evaluation.

Scenarios

The company-specific alternative fuel data were incorporated into four scenarios (see Tables in Appendix B for a summary of scenarios and assumptions). The data were extrapolated or interpolated according to the rules outlined in Appendix B to provide data for each year of the study (2012-2020). The *Basic Jet* and *Expanded Jet* scenarios give the range of the currently planned jet fuel production based on existing companies. In the *Basic Jet* scenario, all companies that plan to produce jet fuel were assumed to start production, but not to expand beyond their initial planned commercial facility (>1 MGY). In the *Expanded Jet* scenario, all companies that plan to produce jet were assumed to expand to their full planned production. The

Expanded Jet Plus Moderate Switch and *Expanded Jet Plus Optimistic Switch* scenarios reflect the potential for market conditions to make jet fuel production desirable and the related potential for companies that do not currently plant to produce jet fuel to transition to producing it. The latter two scenarios inherently assume that it is possible to switch products relatively easily – i.e., that companies using genetically modified organisms to make hydrocarbons directly can tune their production to make some amount of jet fuel, or that biobutanol companies can convert their product to jet fuel through alcohol oligomerization. No specific market scenarios were implemented – rather, the *Moderate Switch* and *Optimistic Switch* scenarios assume a set fraction of the production will be turned into jet fuel on either a volumetric or energy basis, depending on the process. In the *Moderate Switch* case, all processes switch 10% of their production to jet, except for pyrolysis/liquefaction, which yield a bio-crude that is somewhat difficult to refine and therefore is assumed to result in 5% jet fuel. In the *Optimistic Switch*, all processes switch 25% of their production into jet fuel except for pyrolysis and liquefaction, which produce 10% jet fuel. No economic factors (carbon price, fuels prices, etc.) were incorporated; the study focuses entirely on the fuels produced, the processes that produce them, and their corresponding GHG emissions. Details of the fuel production, capacity and jet fuel allocation assumptions, as well as process inclusion in each scenario, can be found in Appendix B.

Results

Per the methodology described in this chapter, predictions of jet fuel production by each individual company were generated for each of the scenarios described. The results are divided into North American and European subsets.

North America (U.S., Mexico, Canada)

The following table shows, by scenario, the estimated total North American production of alternative jet fuel out to 2020.

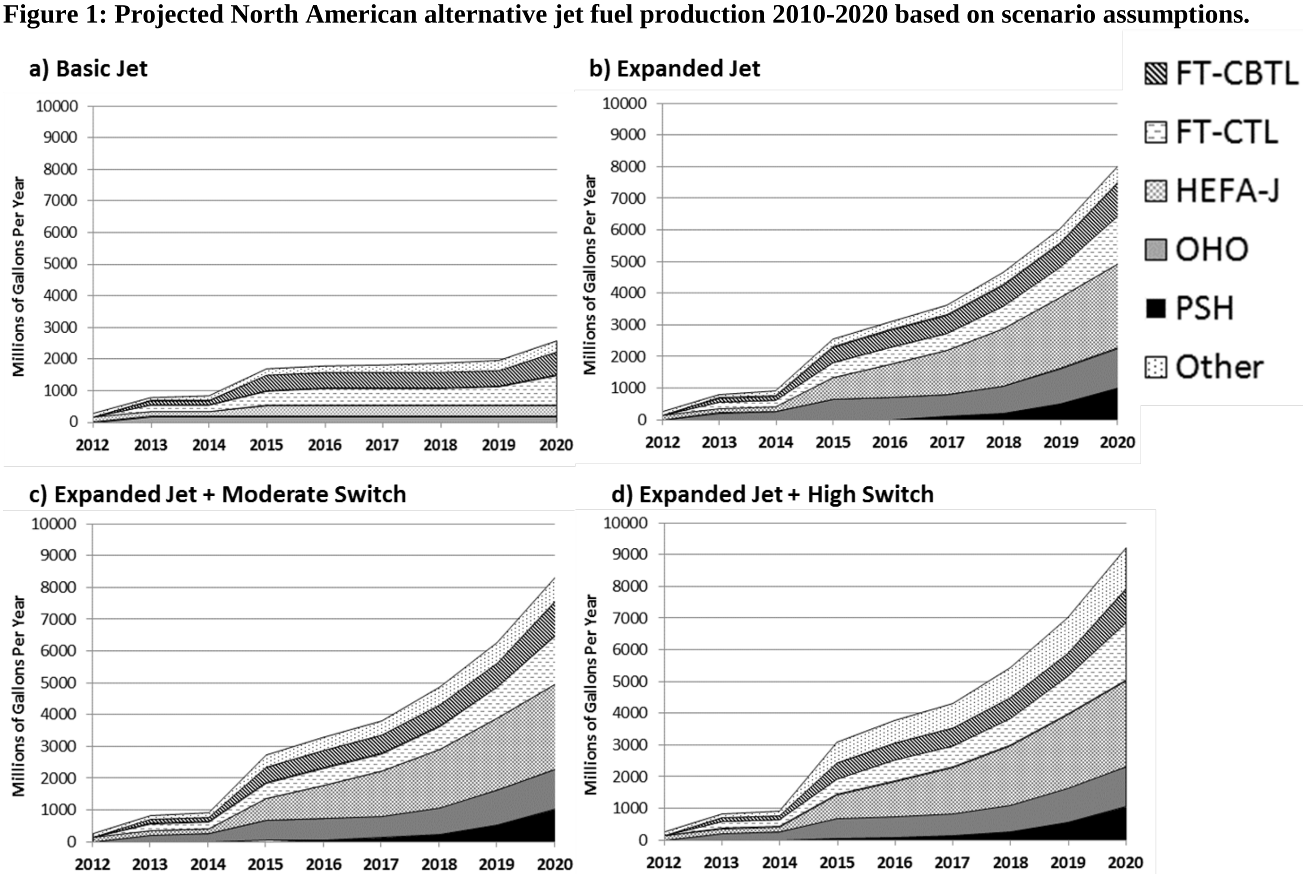
Table 1: Total projected North American alternative jet fuel production based on scenario assumptions in millions of gallons per year (MGY) and megatonnes per year (MT)

Case / MGY	2012	2013	2014	2015	2016	2017	2018	2019	2020
Basic Jet	254	756	809	1665	1770	1799	1859	1950	2584
Expanded Jet	254	796	901	2528	3089	3608	4639	6008	8032
Expanded Plus Moderate Switch	254	796	901	2719	3279	3799	4865	6268	8328
Expanded Plus Optimistic Switch	256	803	911	3063	3755	4292	5434	6999	9221

Case/ MT	2012	2013	2014	2015	2016	2017	2018	2019	2020
Basic Jet	0.7	2.2	2.3	4.8	5.1	5.2	5.3	5.6	7.4
Expanded Jet	0.7	2.3	2.6	7.2	8.9	10.3	13.3	17.2	23.0
Expanded Plus Moderate Switch	0.7	2.3	2.6	7.8	9.4	10.9	13.9	18.0	23.9
Expanded Plus Optimistic Switch	0.7	2.3	2.6	8.8	10.8	12.3	15.6	20.1	26.4

The results reflect the projected output of sixty-one companies and 18 production processes – defined in Appendix C – to produce alternative fuels. Of the 61 companies, 34 intend to produce jet fuel and were included in the *Basic* and *Expanded Jet Only* scenarios. The other 27 companies were incorporated into the *Moderate* and *Optimistic Switch* scenarios in addition to the companies that plan to produce jet fuel. Figure 1 shows the production of alternative jet fuel by conversion process. Only the dominant five processes are shown individually in the graphic, with the remaining 13 processes grouped into the "other" category; all the identified processes are distinguished in the list in Appendix C and the data tables showing future jet fuel production predictions in Appendix D.

Figure 1: Projected North American alternative jet fuel production 2010-2020 based on scenario assumptions.



Based on these data, the dominant processes for producing alternative jet fuels in the next decade are likely to be Fischer-Tropsch (FT) facilities, specifically coal-to-liquid (abbreviated FT-CTL and corresponds to blue area in Figure 1) and coal/biomass-to-liquid (FT-CBTL; pink), hydroprocessed esters and fatty acids (HEFA; green), also known as hydroprocessed renewable jet (HRJ), alcohol oligomerization (OHO, orange) and genetically modified (GM) photosynthetic organisms that produce hydrocarbons (photosynthesis-to-hydrocarbons (PSH; dark purple). In the *Basic Jet* scenario, which includes only the initial planned production of companies that specifically intend to produce jet fuel, the FT facilities are most dominant, most likely because

the initial plant size of these facilities tends to be quite large; thus by constraining the scenario such that no companies expand beyond the first initial facility, these companies will be the largest producers. In the remaining three scenarios, these five processes (FT-CTL, FT-CBTL, HEFA, OHO, and PSH) dominate throughout the analysis. By 2020, FT-CTL production ranges from approximately 970 million to 1.5 billion gallons per year in the *Basic Jet* and remaining cases, respectively, FT-CBTL ranges from approximately 727 million to 1.05 billion gallons, and HEFA ranges from approximately 330 million to approximately 2.75 billion gallons. Alcohol oligomerization (OHO), also called alcohols-to-jet, is estimated at approximately 183 million gallons per year in the *Basic Jet* case, expanding to up to 1.28 billion gallons by 2020 in the *Optimistic Switch* case. The PSH category ranges from approximately 2 million to just over 1 billion gallons by 2020 (see Appendix D for projected production details by process).
The dominance of these processes in the projected fuel mix is most likely due to the status of current technologies. Fischer-Tropsch and HEFA fuels have been certified for jet fuel production through ASTM International (Specification D7566 and annexes). Therefore many of the companies that plan to produce alternative jet fuel in the near term are utilizing these processes (there are 10 HEFA companies and 15 FT companies). The alcohol oligomerization pathway is still in the early stages of commercialization, but there are five companies in the dataset that plan to produce hydrocarbons from oligomerization, and there is a working group focused on getting jet fuels from these alcohol oligomerization processes through the ASTM certification process. In addition, unlike production of jet fuel from Fischer-Tropsch or hydroprocessing, in which longer carbon chain molecules must be broken down into jet fuel and lower value naphtha as a by-product, there may not be a production penalty for making jet fuel instead of diesel using alcohol oligomerization or photosynthesis-to-hydrocarbon organisms. Thus, companies using these processes may be more likely to plan to produce alternative jet fuel in the near term than other novel processes.

The *Expanded Plus Moderate* and *Optimistic Switch* scenarios in which companies that do not currently plan to produce alternative jet fuel are assumed to switch to jet fuel production show over a three-fold increase in alternative jet fuel projections compared to the basic case, but only a small increase over the expanded jet case, indicating that if the 34 companies (55%) that plan to produce jet fuel are able to expand as they intend, they would supply over 85% of the alternative jet fuel in the market even if the other companies were to switch 10 to 25% of their production to jet fuel as defined in the scenarios above.

European Union

The following table shows the amount of alternative jet fuel projected to be produced in the European Union based on the scenarios and the available data.

Table 2: Total projected European Union alternative jet fuel production based on scenario assumptions in millions of gallons per year (MGY) and megatonnes per year (MT)

Case / MGY	2012	2013	2014	2015	2016	2017	2018	2019	2020
Basic Jet	698	698	698	789	801	801	801	801	801
Expanded Jet	698	698	698	789	801	801	841	881	921
Expanded Plus Moderate Switch	698	698	698	845	860	861	913	965	1017

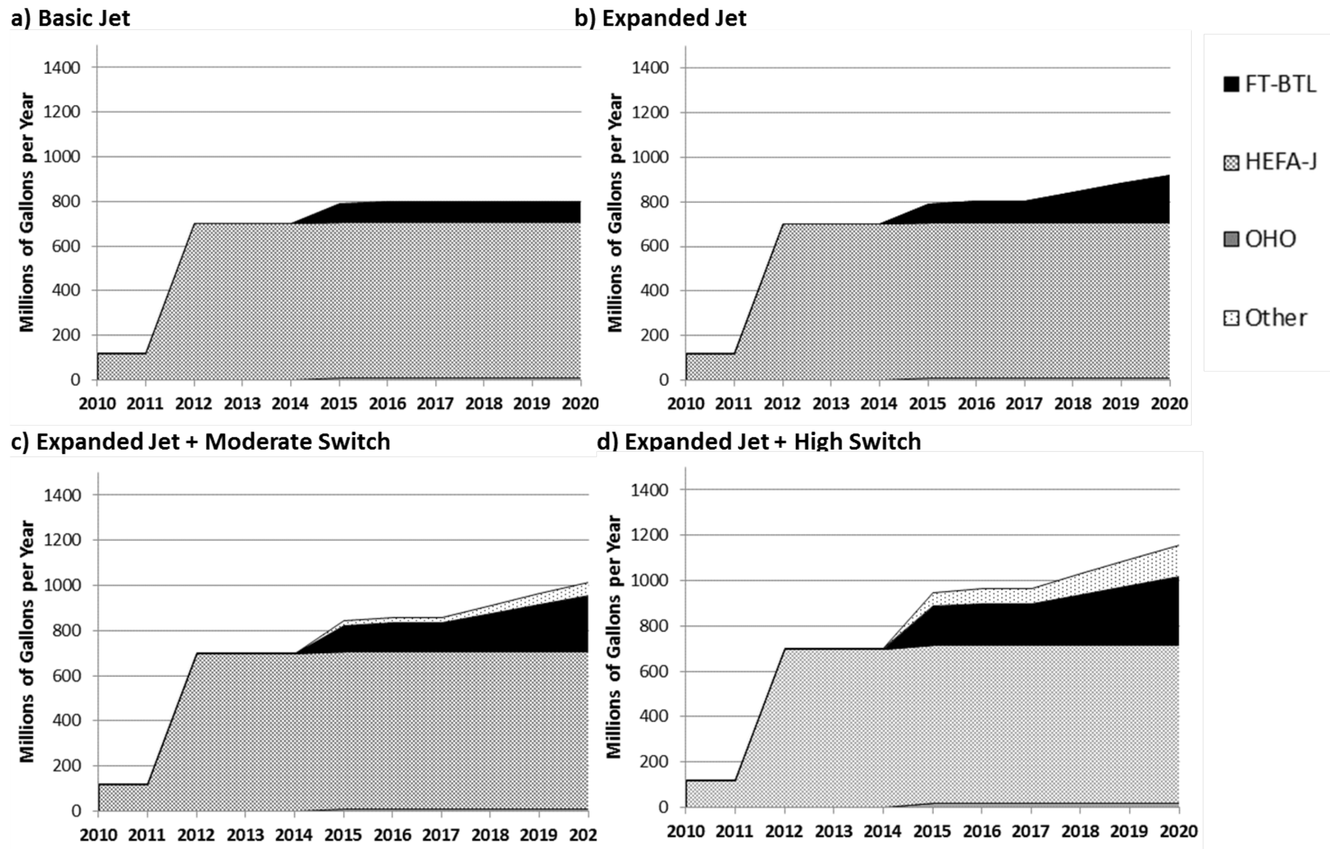
Expanded Plus Optimistic Switch	698	698	698	943	962	964	1028	1093	1157

Case/ MT	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Basic Jet	2.0	2.0	2.0	2.3	2.3	2.3	2.3	2.3	2.3
Expanded Jet	2.0	2.0	2.0	2.3	2.3	2.3	2.4	2.5	2.6
Expanded Plus Moderate Switch	2.0	2.0	2.0	2.4	2.5	2.5	2.6	2.8	2.9
Expanded Plus Optimistic Switch	2.0	2.0	2.0	2.7	2.8	2.8	2.9	3.1	3.3

In the European analysis there were far fewer companies producing alternative fuels other than ethanol and biodiesel (18 in the European Union versus 61 in North America). Only five of these companies specifically plan to produce jet fuel (28%). This is reflected in the difference in total estimated production – in the *Basic Jet Fuel* case, the data indicate approximately 800 million gallons would be produced in Europe in 2020, compared to approximately 2.5 billion gallons in North America, and in the *Expanded Jet Plus Optimistic Switch* case, production in 2020 is projected to be approximately 1.1 billion gallons in Europe compared to approximately 9 billion gallons per year in North America. In addition, only nine processes were identified. Fischer-Tropsch and HEFA were the dominant sources (Figure 2), as was the case in the North American analysis. By 2020, FT-BTL production capacity was estimated at approximately 94 to 300 million gallons per year depending on the scenario, and HEFA production capacity was estimated at 700 million gallons (see Appendix D for projected production details by process).

Because there are fewer companies in this analysis, the two *Switch* scenarios do not show as great an increase in absolute terms over the *Basic* and *Expanded Jet* cases as was identified in the North American analysis. However, similarly to the North American results, approximately 85% of the jet fuel that would be produced would come from the 28% of companies that already plan to produce jet fuel currently, even in the most optimistic scenario.

Figure 2: Projected European Union alternative jet fuel production 2010-2020 based on scenario assumptions



3. Alternative Jet Fuel Replacement of Petroleum-Based Jet Fuel

Baseline Information from Existing Fuel Demand Forecasts

To understand the impact of the potential alternative jet fuel production volumes, those volumes must be compared to the expected demand for jet fuel in the two regions. The CAEP forecasts of jet fuel demand take into account operational and equipment efficiency gains in various combinations ("consensus" forecasts) as well as applying the same gains to projections accounting for the recent dip in demand due to the 2008-2009 economic downturn ("low" forecasts). These forecasts of total jet fuel demand provide a range of possible baselines of petroleum-based jet fuel use that can be used to identify the greenhouse gas emissions reductions desired from alternative jet fuels as well as to compare the relative contributions of efficiency, operations, and fuels. The CAEP forecasts were used to generate the predicted fuel burn demand for 2010, 2016 and 2020 for North America, the ICAO European region, and the European Union (EU 27). Five fuel demand forecasts were generated for both the consensus and low assumptions (Forecast 1 is the highest demand forecast within each set, while Forecast 5 is the lowest). The demand forecasts are defined in Appendix F.

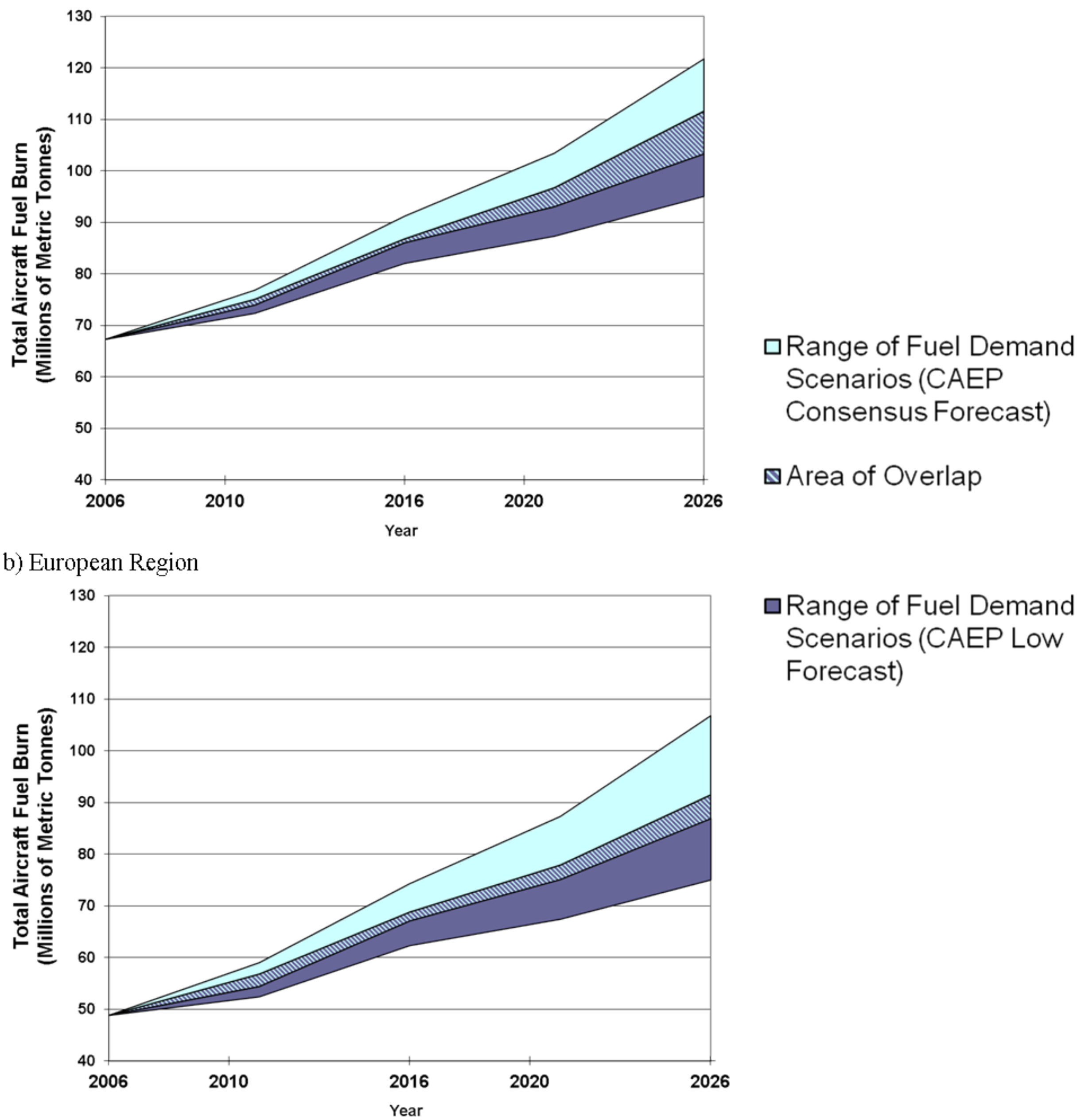
These fuel burn trends scenarios were extracted from existing data using the Volpe Aviation Fuel Query Tool (AFQT Version 1.0.0.0), which allows the user to define geographic extent, year of forecast, extent of operational improvements, and extent of equipment efficiency improvements, as well as allowing the entry of aggregate volume and average LCA value for alternative fuels for a given year and the resulting GHG emissions reduction. The tool also allows the processing of detailed alternative fuel scenarios such as those presented here (see Appendix G for details of AFQT capabilities). The AFQT data are generated using the Aviation Environmental Design Tool (AEDT) currently under development at the Volpe Center for the FAA Office of Environment and Energy. AEDT is an aviation-specific model that can analyze fuel burn and associated emissions and noise at the airport, regional, or global level.

Replacement of Jet Fuel Based on Demand Forecasts

The range of fuel demand predictions that result from the applications of the various CAEP assumptions, including increased flight projections as well as changes in operational and equipment efficiency, to North America and ICAO's European Region are shown in Figure 3 (detailed information on technology and operational improvements and tables of forecast values can be found in Appendix D). The CAEP forecasts were originally generated in 10 year increments (2006, 2016, and 2026). Therefore, the Volpe AFQT was used to interpolate demand forecasts for the start (2010) and end (2020) of the decade spanned by this scenario analysis, with 2006 providing the baseline year and 2016 an interim year. Linear interpolation is shown on the graphs between calculated years. North American demand in 2020 is estimated at 34 billion gallons per year, varying as low as 28.7 BGY depending on the forecast. For Europe the range is 28.8 to 22.2 BGY. EU27 demand is anticipated to comprise approximately 89% of the ICAO "European region" demand. According to the forecasts, fuel demand for North America can be reduced by as much as 10% in 2020 by fuel efficiency and operational measures compared to the baseline case. In the European region, the fuel demand can be reduced by approximately 14% in 2020 through these measures. These reductions are consistent in both the consensus and low forecast sets within each region. However, in neither of these regions would fuel burn level off starting in 2020. Even in the best case for North America (Low Forecast 5, shown by the lowest line on Figure 3a), fuel demand in 2026 is 6.5% higher than in 2020, and in the European region (Figure 3b) the best case is 11.3% higher in 2026 than in 2020. Demand stasis would be required in order to achieve carbon neutral growth using only petroleum-based fuels. To achieve carbon neutral growth at 2005 emissions levels will require reductions in demand rather than growth. As demand is not anticipated to level off nor decrease, the resulting gap in required greenhouse gas emissions reductions is proposed to be filled by alternative jet fuels to achieve carbon neutral growth at 2020 (the international aviation industry goal) or 2005 (FAA goal) levels. Given the jet fuel demand forecasts, 23-35% of 2020 fuel demand in North America and 20-40% of fuel demand in the European region would have to be replaced with zero-carbon fuels in order to achieve 2005/2006 emissions levels as the baseline for carbon neutral growth.

Figure 3: Projected range of jet fuel demand in the next 15 years based on CAEP forecasts

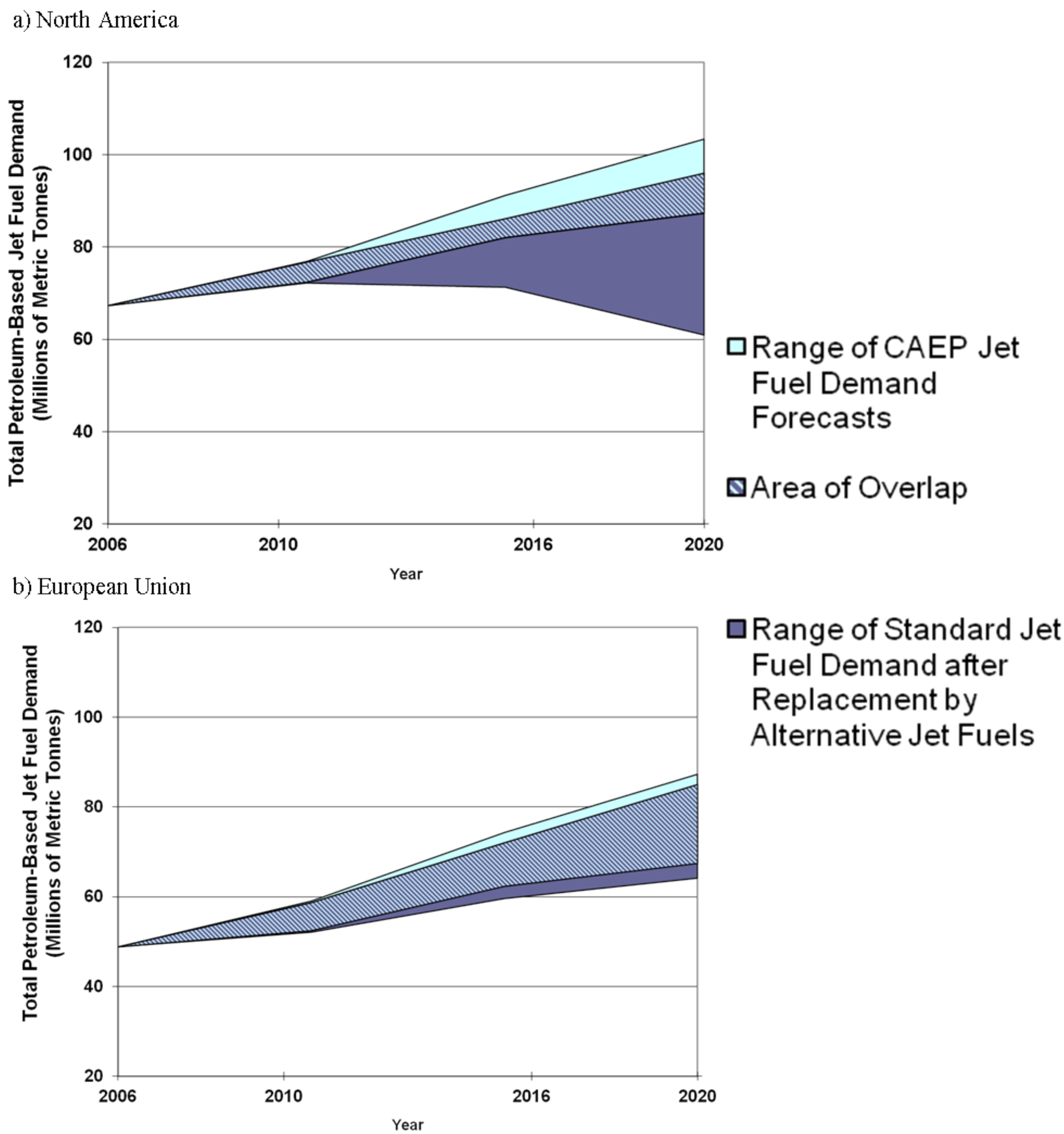
a) North America



Alternative Fuel Replacement of Petroleum-based Jet Fuel

The data from the alternative fuels production estimates were compared with CAEP "Consensus" and "Low" Forecasts for jet fuel demand for North America and the European region to determine the percentage of demand that would be replaced by the projected volumes of alternative jet fuels under various assumptions about equipment and operational efficiency (see Appendix D for details of these assumptions). The range of reduction in standard petroleum-based jet fuel due to replacement by alternative fuels is shown in Figure 4. The percent of each forecast that would be replaced by alternative fuels in each scenario are shown in detail in Appendix D,

Figure 4: Potential reduction in standard petroleum-based jet fuel demand based on scenario assumptions compared to petroleum-only baseline CAEP forecasts due to replacement by alternative fuels in the production scenarios.



For North America, the percentage of jet fuel that might be replaced by alternative fuels in 2020 ranges from approximately 7.2-8.5 % (7.4 MT or 2.5 BGY) in the *Basic Jet* scenario, depending on the demand forecast to which it is compared, up to 27% (23 MT or 8 BGY) in the *Expanded Jet Fuel* scenario for the lowest demand forecast, and up to nearly a third of jet fuel (26 MT or 9.2 BGY) in the *Expanded Jet Plus Optimistic Switch* scenario and the lowest demand forecast. In the European region, the range is much smaller, replacing between 3 and 5% (800 MGY to 1 BGY) of jet fuel demand in all alternative fuel scenarios and demand forecasts. Thus, the North American analysis suggests that the replacement of jet fuel could be within the range that would enable carbon neutral growth at 2005 emissions levels (20-35%), depending on the GHG LCA value of the fuels, even without additional market-based measures and policies to reduce fuel demand and GHG emissions. For the European region, even if the maximum replacement level identified (5%) were to be achieved using zero carbon fuels, meeting the international goal of carbon neutral growth goal at 2020 emissions levels through EU27 alternative jet fuel production without additional policy and market-based measures is unlikely.

The next section addresses whether the scenarios described provide a sufficient carbon benefit to bring aviation to carbon neutral growth and how close emissions will be to the desired 2005 baseline for North American emissions.

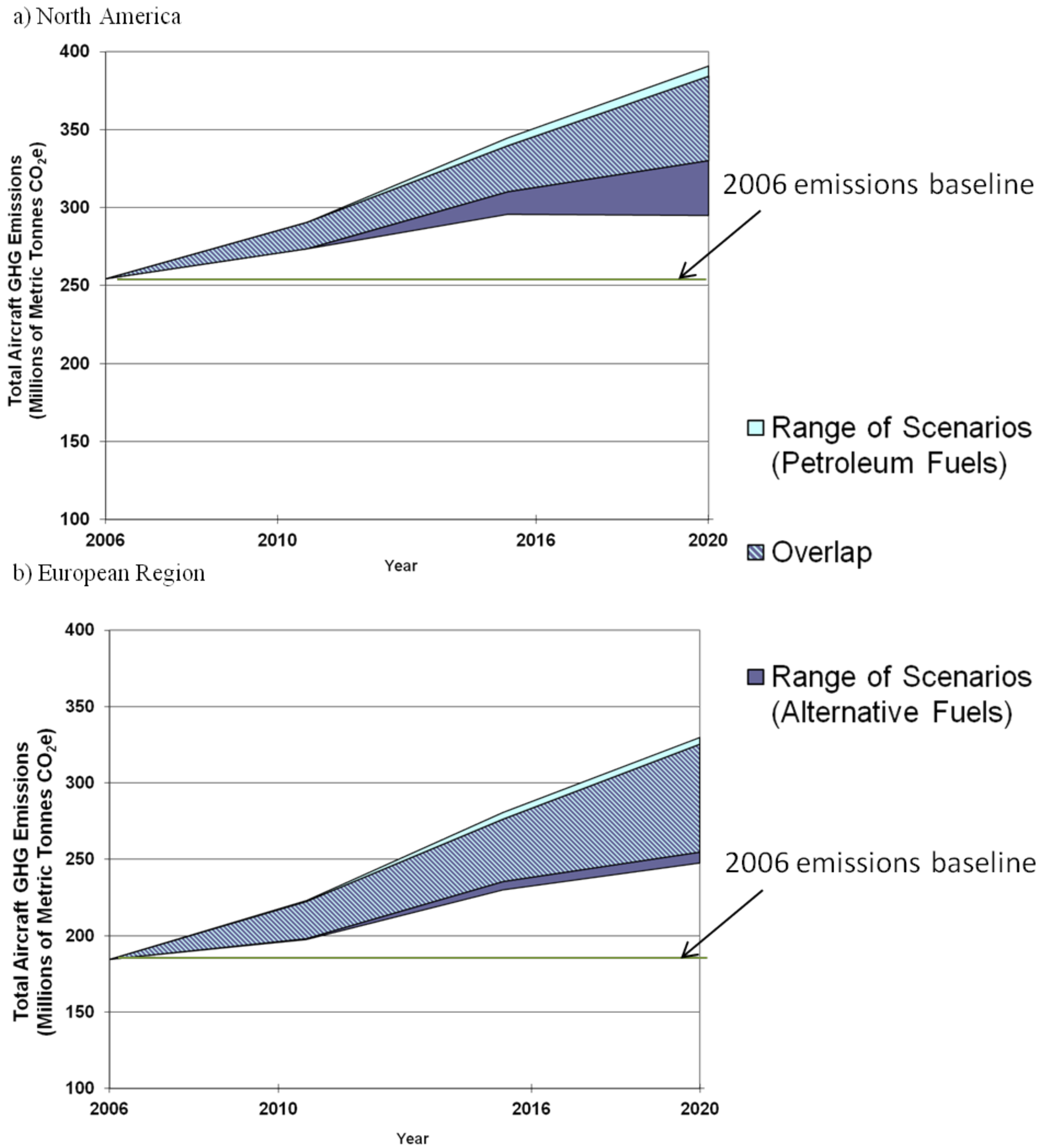
4. GREENHOUSE GAS EMISSIONS REDUCTION AND CARBON NEUTRAL GROWTH

The previous sections on jet fuel production provide an overview of the potential growth of the alternative jet fuel industry out to 2020 given current technology and plans. These data can be used to evaluate the potential GHG benefit of alternative jet fuel in these scenarios, whether the aviation community may be able to achieve the international goal of carbon neutral growth starting in 2020 based on these plans without additional policy and market-based measures, and how close these projections would bring aviation to the FAA goal of carbon neutral growth at 2005 emissions levels starting in 2020.

As indicated in Chapter 3, in order to achieve carbon neutral growth in 2020 at 2005 emissions levels, 20-40% of projected 2020 fuel demand would need to be fulfilled using zero-carbon alternative fuels. In North America, the identified, existing alternative fuels production plans suggest that it may be possible to achieve this level of jet fuel replacement, assuming the lowest fuel demand forecast and full expansion by the companies that plan to produce jet fuel, some product switching by other companies, or both. In the European region the desired level of jet fuel demand replacement to achieve carbon neutral growth does not appear likely based on identified plans, at least within the EU27. Furthermore, on a life cycle basis, alternative fuels are not necessarily zero carbon fuels. Therefore, the achievement of GHG reductions and carbon neutral growth are dependent on the estimation of life cycle GHG emissions for individual fuel processes and the resulting aggregate effect on emissions when the alternative fuels are inserted into the fuel pool.

The projected production values for each individual fuel process were used in conjunction with estimated GHG LCA values (grams of carbon dioxide equivalent emissions per megajoule of fuel (gCO_2e/MJ)) to calculate estimated GHG emissions reductions for each year and scenario. The GHG LCA values are general estimates for each process based on the range of values calculated for the process with variation in feedstock and process parameters as detailed in Stratton et al. 2010 [10]. Because of the uncertainty of process/feedstock details inherent in such a broad overview of companies, and because of the need for consistent, comparable values for each process, the LCA values were binned into fractions of standard petroleum baseline LCA of 87.5 gCO_2e/MJ. The smallest increment of binning was 1/8. For processes where no LCA value has been calculated using the methodology of Stratton et al., a proxy value or modified proxy value from one of the other processes was assigned based on general process knowledge. The fractions used for each process and the assignment of proxies are detailed in Appendix D. Using these fractions, the GHG emissions due to the alternative fuels were calculated and incorporated into future projections based on replacement of standard petroleum-based jet fuel. The 2016 and 2020 values were compared with estimated fleet-wide GHG emissions for petroleum-based jet fuel only for the CAEP fuel demand scenarios. Figure 5 shows the potential GHG emissions reductions of the alternative fuels scenarios compared with the petroleum-only emissions associated with each CAEP forecast. Detailed tables of GHG reductions by forecast, year, and alternative fuels scenario can be found in Table 9 in Appendix D.

Figure 5: Potential reduction in GHG emissions based on alternative jet fuel production scenario assumptions compared to petroleum-only CAEP forecasts.



Same-Year Comparison with Petroleum-Only Jet Fuel Emissions

North America (U.S., Mexico, Canada)

Figure 5a shows the potential GHG emissions reductions over the petroleum-only baseline for each North American fuel burn and alternative fuel production scenario. The results suggest that in 2020, in the most optimistic case (lowest fuel burn demand and *Optimistic Switch* alternative fuel scenario) GHG emissions will be reduced by approximately 11%, a result of the fact that the average LCA value for the pool of alternative fuels represented in the data is approximately two-thirds that of standard petroleum. In the *Expanded Jet* and *Moderate Switch* scenarios, there is a slight increase in total GHG emissions between 2016 and in 2020 in the lowest demand forecast (299 to 301 and 298 to 299 Mt CO_2e, respectively), suggesting the possibility of leveling off of emissions that might result in carbon neutral growth beyond 2020. In the *Optimistic Switch* GHG total GHG emissions would actually decrease from 296 to 295 Mt from 2016 to 2020 in the lowest demand forecast (Low Forecast 5). Carbon neutral growth is not achieved in any other demand forecasts regardless of alternative fuel scenario, although this does not preclude achieving carbon neutral growth with additional policy and/or market-based measures. If CTL fuels (including carbon capture and sequestration), which carry a slight GHG penalty compared to standard petroleum fuels, are removed from the alternative fuel pool, the results are essentially the same: there is an approximate leveling off of GHG emissions in the *Expanded Jet* (299 Mt) and *Moderate Switch* (297 Mt) scenarios and reduction between 2016 and 2020 in the *Optimistic Switch* scenario (295 to 292 Mt). Total GHG emissions reduction in the best case (*Optimistic Switch* and lowest demand forecast) is approximately 11.5%.

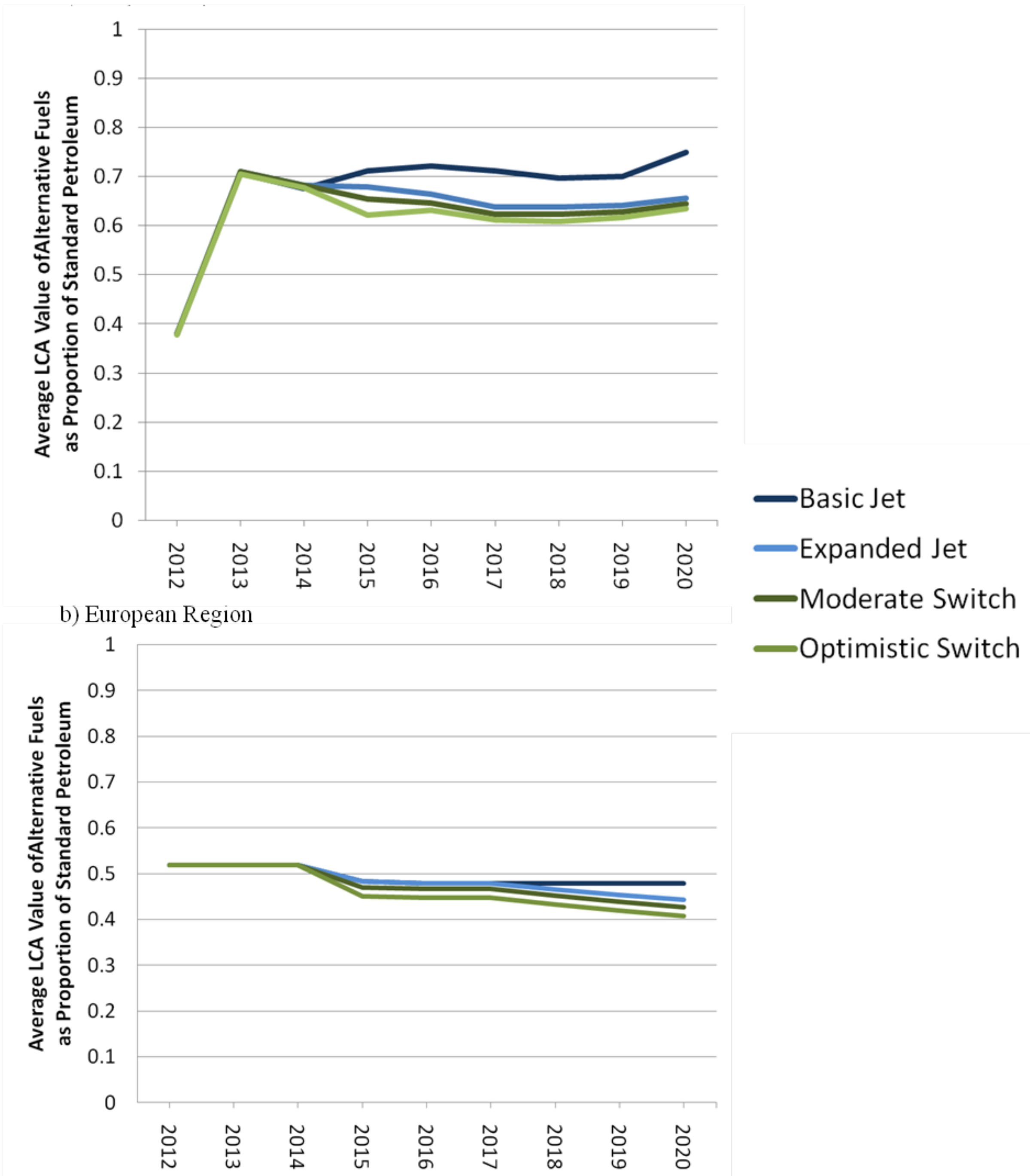
European Region

Similarly, Figure 5b shows the potential GHG emission reductions associated with the projected alternative jet fuel production in the various scenarios compared with the CAEP forecasts. Given the overall lower projected replacement of jet fuel, the GHG emissions reduction is less than for North America – in the *Optimistic Switch* scenario and the lowest CAEP demand forecast, it is approximately 3%. This reflects that the average LCA value for the planned production in Europe in the *Optimistic Switch* scenario is approximately 40% that of standard petroleum (5% fuel demand replacement leads to 3% reduction in GHG emissions). However, the total projected volume of alternative jet fuel is much lower in Europe than in North America, and thus the reduction in GHG emissions is concomitantly smaller. Therefore, unlike in the North American analysis, in the European analysis none of the scenarios show a leveling off of GHG emissions between 2016 and 2020 based on alternative jet fuel use, although this does not preclude further GHG emissions reductions resulting from policies or market-based measures.

Alternative Fuel Portfolio Average LCA Value

Based on the aggregated data for all processes, the total GHG emissions associated with the alternative fuels production for each year were divided by the total MJ of alternative fuel produced and compared to standard petroleum to provide an average LCA value (as a fraction of the standard petroleum baseline of 87.5 gCO2e/MJ) for the entire alternative fuel palette for each year. These averages can be seen in Figure 6. At the start, the North American fuels have an average LCA value less than 50% that of standard petroleum due to the dominance of HEFA (generalized LCA value estimated at half of standard petroleum GHG emissions) and consolidated bioprocessing, which has a generalized LCA value estimated at 1/8 that of standard petroleum. As various fuel processes begin production, the average LCA value for the North American alternative fuels portfolio increases above 50% of standard petroleum. This is due to the effects of FT-CTL fuels, which have a GHG LCA value above standard petroleum even with carbon capture and sequestration technology, and alcohol oligomerization processes using corn as a feedstock (assigned LCA value ¾ that of standard petroleum). If CTL fuels are excluded, the average LCA values for the alternative fuels in North America are between 51 and 55% that of standard petroleum in 2020. In Europe, LCA values do not deviate much from 50% of standard petroleum, although in the *Optimistic Switch* scenario, the average fuel LCA value approaches 40% of standard petroleum. Overall, the results indicate a lower average LCA value in the European projections than in the North American projections beyond 2013. The contribution of coal-to-liquid FT fuels to the total volume of alternative fuels in North America (approximately 1 – 1.8 billion gallons per year in 2020) is substantially different from the contribution of fossil based fuels in the European dataset (no FT-CTL plants were identified in Europe) and likely affects the difference between the average fuel LCA value of the fuel pools. However, the lower average LCA value estimate for Europe may also reflect the presence of more processes in the North American analysis that have not been extensively analyzed for GHG emissions. It is possible that the assigned proxy LCA values for these processes are too conservative. As these processes are better defined and LCA values comparable to those for more established fuels become available, these numbers may shift.

Figure 6: Average LCA value for the projected alternative fuels portfolio normalized to standard petroleum based on the scenario assumptions.



Comparison of Projected Year with Petroleum-Only Jet Fuel Emissions in 2006

The carbon neutral growth goal articulated by FAA is to achieve carbon neutral growth starting in 2020 at 2005 emissions levels [11]**.** While the AFQT does not go back to 2005, the 2006 jet fuel demand (65.3 MT or 21.5 BGY) was very close to 2005 levels. Therefore, this study used 2006 jet fuel burn and emissions levels as the benchmark to assess whether any of the scenarios approach the 2005 baseline carbon neutral growth goal. The 2006 fuel burn and emissions levels were slightly higher than 2005; therefore, using 2006 as a baseline is somewhat generous. The difference between the projected GHG emissions with the 2006 baseline can be seen in Figure 5.

Even in the most optimistic cases with the lowest projected fuel demand, none of the scenarios reach 2006 emissions levels in 2020. In North America, the best case (low demand and *Optimistic Switch* scenario) is within 16% of the baseline, but the *Basic Jet* alternative fuels scenario is 27% above 2005 levels even in the lowest demand scenario. Even if CTL fuels (which have a higher GHG LC value than standard petroleum) are removed from the analysis, the best case is still 15% above 2006 levels. In Europe, the industry would still be emitting approximately 35% more GHGs in 2020 than were emitted in 2006 even in the *Optimistic Switch* scenario in the lowest demand forecast, and approximately 75% above 2006 levels in the most conservative demand forecast (Consensus Forecast 1). The comparison of the percent of jet fuel replaced and the GHG emissions reductions shows that on average the alternative fuels identified do not have a zero carbon value, and that in fact, it will take a much larger replacement of jet fuel with these technologies to reduce GHGs to achieve carbon neutral growth at 2005 levels using alternative jet fuels, and even lower carbon fuels or larger replacement amounts to maintain that carbon emissions level in the face of anticipated industry growth. However, additional GHG emissions reductions may be achieved through other means that alternative jet fuel (i.e., policy changes and market-based measures).

5. ADDITION OF ETHANOL AND BIODIESEL PRODUCERS

The scenarios defined in the preceding chapters do not include companies that already make or plan to make ethanol via standard fermentation techniques (sugar/starch or cellulosic with standard fermentation processes) nor biodiesel from fatty acid methyl esterification. These industries are already well-established and markets are in place to utilize the fuel produced by these companies. Thus, the preceding analysis assumed that established production facilities focused on these industries would not readily switch to jet fuel. In addition, biodiesel (from plant and animal oils) and ethanol (from sugar, starches, or cellulosics) may compete with other processes for feedstocks, and therefore the production capacity of novel fuel types may not be additive with biodiesel and ethanol production. However, if feedstocks are not limiting, and if market conditions were to drastically favor production of jet fuel, then switching by well-established industries (biodiesel/ethanol) would greatly increase the potential availability of alternative jet fuel.

There are two ways of incorporating information about these two sectors that can inform the "outer bounds" of potential jet fuel production under current technology. The first is a "top down" approach utilizing broad-scale predictions of biofuel production from these two sectors and assuming that instead of being used as ethanol or biodiesel *per se*, a certain portion of that production could possibly be turned into jet fuel (e.g., by alcohol oligomerization or hydroprocessing and cracking, respectively). The conversion of these fuels to jet fuel would be added to the scenarios above to increase the replacement of jet fuel by bio-based alternative fuels and to improve the greenhouse gas emissions reductions. This approach is utilized below with projections from the Organization for Economic Cooperation and Development (OECD) for North America and the EU27 countries.

The second approach is to utilize collected data on individual companies and facilities in a "bottom up" approach as employed for the main scenario analysis. This approach utilizes the same calculations and strategy as was used in Chapters 2-4. However, due to the breadth of these two industries and the fact that it is always changing, it is difficult to ascertain how exhaustive the data are. Furthermore, few companies provide future expansion plans; thus, the data collected are based mainly on current production capacity. Therefore, these two methodologies may provide different estimates of the possible contribution of ethanol and biodiesel to alternative jet fuel production in the future.

It should be noted, however, that both of these methods run the risk of "double counting" the contribution of biodiesel and ethanol, as these products can provide the raw material for hydroprocessing to jet fuel (HEFA) or alcohol oligomerization processes, and as such at least part of the conversion capacity to transform these molecules to jet fuel may already be accounted for in the production estimates for those two processes, both of which contribute substantially to the anticipated jet fuel production in the original scenario analysis above.

Using General Predictions of Ethanol and Biodiesel Production Capacity

The OECD country statistics (www.stats.oecd.org) estimate future production for biodiesel and ethanol out to 2019. Assuming that the production value in 2019 would closely reflect available product for conversion to jet fuel in 2020, these projections can be used to estimate how much jet fuel could be produced from these fuels and what the impact would be on the aviation community GHG goals.

Current capacity for ethanol production is approximately 13.5 billion gallons per year in the US alone, with an additional 0.5 billion gallons under construction/expansion [17]. The OECD [18] predicts that production of ethanol in North America in 2019 will be approximately 18.5 billion gallons in 2019. If 25% of this were converted, on an energy equivalent basis, to jet fuel, that would add 2.9 billion gallons of jet fuel to the estimates for 2020. Biodiesel production is estimated by OECD to be 1.1 billion gallons per year. If 25% of this is converted to jet fuel on an energy equivalent basis this would add 278 million gallons per year to the 2020 estimates. Thus, the jet fuel replacement would be increased overall by approximately 3.2 billion gallons (9 Mt) per year. Added to the *Optimistic Switch* scenario, this brings the total to nearly 36 Mt of alternative jet fuel in 2020 (**Table 3**). Assuming a general LCA value of half of standard petroleum for biodiesel production, and a general LCA value of 40% of standard petroleum for ethanol producers (the approximate average of sugar, starch and cellulosic ethanol), this would result in GHG emissions reductions ranging from approximately 14 to 17% compared with the consensus and low fuel demand forecasts (5.4-6.4% of which would be due to the switch to jet fuel by ethanol and biodiesel producers).

In the European Union, the estimates from OECD are for 4.75 billion gallons of ethanol, of which 25% on an energy equivalent basis is 754 million gallons of jet fuel per year. OECD predicts 5.4 billion gallons of biodiesel, which at 25% energy equivalent would provide 1.3 billion gallons of additional jet fuel. Thus, the jet fuel replacement would be increased overall by 2 billion gallons (5.6 Mt) per year, bringing the total alternative jet fuel production in 2020 to 9 Mt (Table 3). This would result in GHG emissions reductions ranging from 5.6 to 9.3% compared with the consensus and low fuel demand forecasts (approximately 5-7% of which would be due to the switch to jet fuel by ethanol and biodiesel producers).

Table 3: *Scenario 5: Optimistic Switch +OECD* including biodiesel and ethanol product switching (25% energy equivalent) in 2020 based on the OECD production estimates and scenario assumptions

a) North America

Forecast	Mt alternative fuel in 2020	% Replacement 2020	% GHG Reduction 2020
Consensus 1	35.59	34.4%	14.2%
Consensus 2	35.59	36.0%	14.8%
Consensus 3	35.59	36.3%	14.9%
Consensus 4	35.59	37.6%	15.5%
Consensus 5	35.59	38.2%	15.8%
Low 1	35.59	36.8%	15.2%
Low 2	35.59	38.4%	15.8%
Low 3	35.59	38.7%	15.9%
Low 4	35.59	40.1%	16.5%
Low 5	35.59	40.8%	16.8%

b) European Region

Forecast	Mt alternative fuel in 2020	% Replacement 2020	% GHG Reduction 2020
Consensus 1	9.05	10.4%	5.6%
Consensus 2	9.05	11.1%	7.7%
Consensus 3	9.05	11.2%	7.8%
Consensus 4	9.05	11.8%	8.2%
Consensus 5	9.05	12.0%	8.3%
Low 1	9.05	11.6%	8.0%
Low 2	9.05	12.4%	8.6%
Low 3	9.05	12.5%	8.7%
Low 4	9.05	13.2%	9.1%

Low 5	9.05	13.4%	9.3%

Using "Bottom Up" Approach to Estimating Ethanol and Biodiesel Production Capacity

In addition to the data on companies used in the scenarios in Chapters 2-4, data were collected on biodiesel and ethanol companies. In the North American analysis, twenty standard ethanol ventures and one standard ethanol technology licenser that conveniently listed over seventy facilities they had developed were identified in the data collection. In addition, 27 cellulosic ethanol ventures, and 54 biodiesel ventures were identified. In the European data collection, 58 standard ethanol ventures, 16 cellulosic ethanol ventures, and 109 biodiesel ventures were identified. Many of these have multiple facilities and/or multiple partnerships; every effort was made to avoid double counting facilities that might be listed under two companies due to partnerships. Data were found for a few companies from neighboring countries to the EU27, including Republic of Macedonia (1 biodiesel), Ukraine (1 ethanol), and Norway (3 ethanol). Fuel from these countries was included to maximize the contribution possible from ethanol and biodiesel switching to jet fuel. The data collected in this analysis on ethanol and biodiesel production are not necessarily exhaustive due to the extensive and ever-changing nature of the industry. To incorporate the data collected in this analysis from the individual companies' planned production capacity, assumptions were added to Scenarios 3 and 4 to create two new scenarios. The Scenarios and their additions are with:

Scenario 6: Moderate Market-Based Switch + Biodiesel

Biodiesel companies switch 10% of total fuel to jet fuel production (based on net energy equivalence)

Scenario 7: Optimistic Market-Based Switch + Biodiesel/Ethanol

Biodiesel companies switch to 25% jet fuel production (energy equivalence - net)
Ethanol companies switch to 25% jet fuel production (energy equivalence – net)

This data collection utilized nameplate capacity of the facilities rather than actual current production, as the conversion capacity is a better estimate of the ability to turn feedstock into fuels. However, this does not account for market conditions or feedstock limitations. **Table 4** below shows the amount of alternative jet fuel that would be available when combining data collected on existing ethanol and biodiesel producers with the scenarios presented previously and the assumptions described above. In both Europe and North America, potential jet fuel production is greatly augmented if biodiesel and/or ethanol producers choose to transform a portion of their product into jet fuel.

Table 4: Total projected alternative jet fuel production for the *Moderate Switch + Biodiesel* and *Optimistic Switch + Biodiesel/Ethanol* scenarios) compared to the *Basic* and *Expanded Jet* scenarios. Projections are based on scenario assumptions and presented in millions of gallons per year (MGY) and megatonnes per year (MT)

a) North America

Case / MGY	2012	2013	2014	2015	2016	2017	2018	2019	2020

Scenario 1 (Basic Jet)	254	887	939	1807	1912	1941	2002	2092	2726
Scenario 2 (Expanded Jet)	254	942	1055	2700	3261	3780	4811	6180	8204
Scenario 6 (Mod. Switch + Biodiesel)	254	942	1055	3317	3886	4412	5481	6894	8964
Scenario 7 (Opt. Switch + Biodiesel / Ethanol)	256	949	1065	5897	6767	7458	8745	10524	12961

Case/ MT	2012	2013	2014	2015	2016	2017	2018	2019	2020
Scenario 1 (Basic Jet)	0.7	2.5	2.7	5.2	5.5	5.6	5.7	6.0	7.8
Scenario 2 (Expanded Jet)	0.7	2.7	3.0	7.7	9.3	10.8	13.8	17.7	23.5
Scenario 6 (Moderate Switch + Biodiesel)	0.7	2.7	3.0	9.5	11.1	12.6	15.7	19.8	25.7
Scenario 7 (Opt. Switch + Biodiesel and Ethanol)	0.7	2.7	3.1	16.9	19.4	21.4	25.1	30.2	37.1

b) European Region

Case / MGY	2012	2013	2014	2015	2016	2017	2018	2019	2020
Scenario 1 (Basic Jet)	698	698	698	789	801	801	801	801	801
Scenario 2 (Expanded Jet)	698	698	698	789	801	801	841	881	921
Scenario 6 (Moderate Switch + Biodiesel)	698	698	698	1558	1576	1581	1640	1698	1757
Scenario 7 (Opt. Switch + Biodiesel and Ethanol)	698	698	698	3288	3436	3342	3573	3595	3826

Case/ MT	2012	2013	2014	2015	2016	2017	2018	2019	2020
Scenario 1 (Basic Jet)	2.0	2.0	2.0	2.3	2.3	2.3	2.3	2.3	2.3
Scenario 2 (Expanded Jet)	2.0	2.0	2.0	2.3	2.3	2.3	2.4	2.5	2.6
Scenario 6 (Moderate Switch + Biodiesel)	2.0	2.0	2.0	4.5	4.5	4.5	4.7	4.9	5.0
Scenario 7 (Opt. Switch + Biodiesel and Ethanol)	2.0	2.0	2.0	9.4	9.8	9.6	10.2	10.3	11.0

The addition of ethanol and biodiesel conversion to jet fuel in North America (approximately 3.7 billion gallons in 2020) is similar to but slightly higher than the estimate generated from the projections provided by the OECD (3.2 billion gallons). For Europe, the additional volume amounts to approximately 2.7 billion gallons in increase, also similar to but slightly higher than that predicted using the OECD estimates (2 billion gallons). OECD estimates are for production rather than capacity. Thus, the higher values for the potential contribution of ethanol and biodiesel product switching from this “bottom up” analysis may be related to the use of conversion capacity in the present study, as opposed to actual production, which tends to be lower than capacity.

Figure 7 below show the percent replacement of jet fuel that would be achieved in each scenario for demand and alternative fuels given the additional contribution of a 25% switch from ethanol and biodiesel to jet fuel. If the lowest demand scenario were to occur, and the aviation community were able to draw from the ethanol and biodiesel industries, it would be possible to replace over 40% of petroleum-based jet fuel demand in North America, but only 16% of jet fuel demand in Europe.

Figure 7: Potential reduction in standard petroleum-based jet fuel demand due to replacement by alternative fuels based on the *Optimistic Switch+Biodiesel/Ethanol* scenario (25% product switching from biodiesel and ethanol companies).

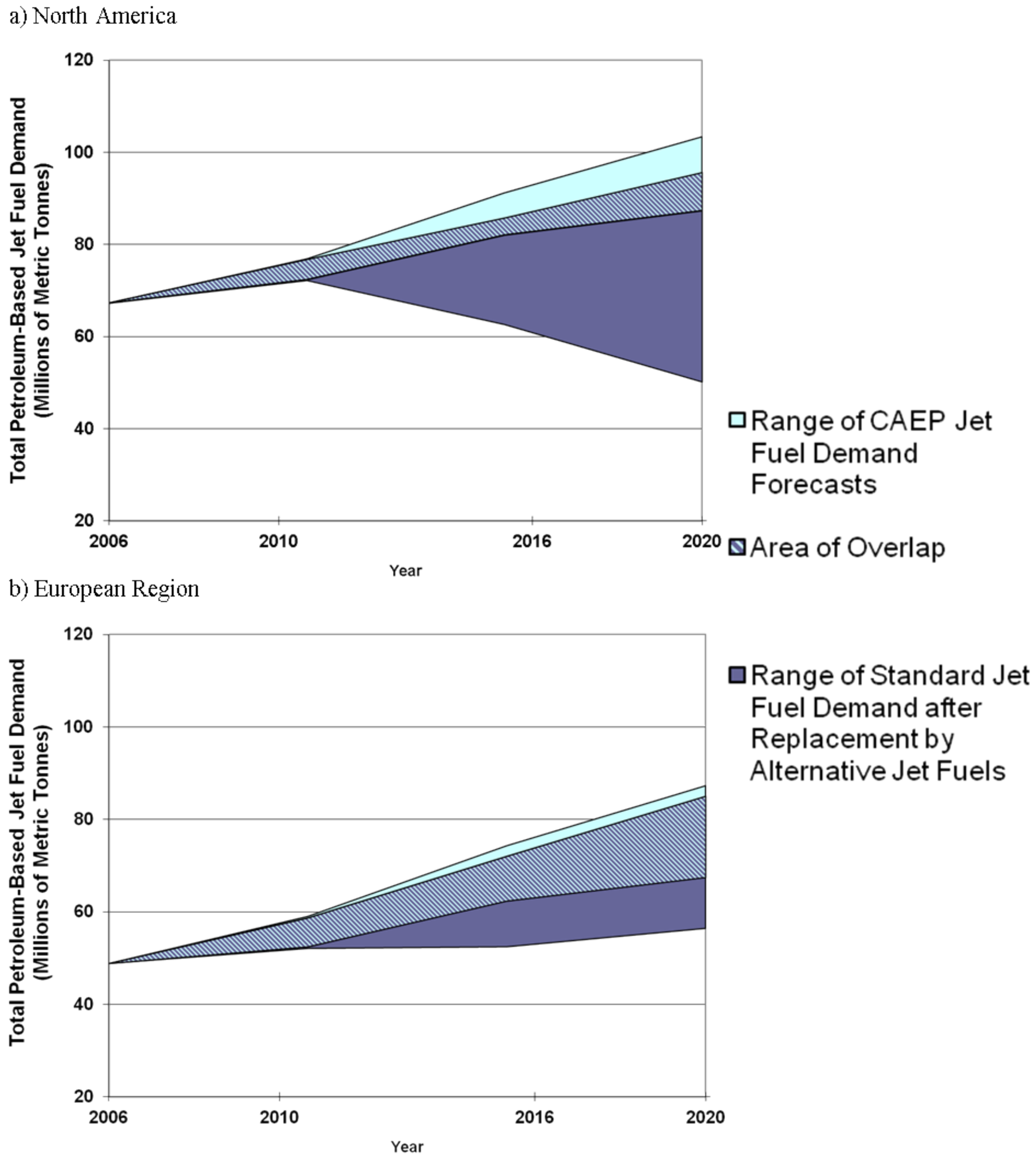
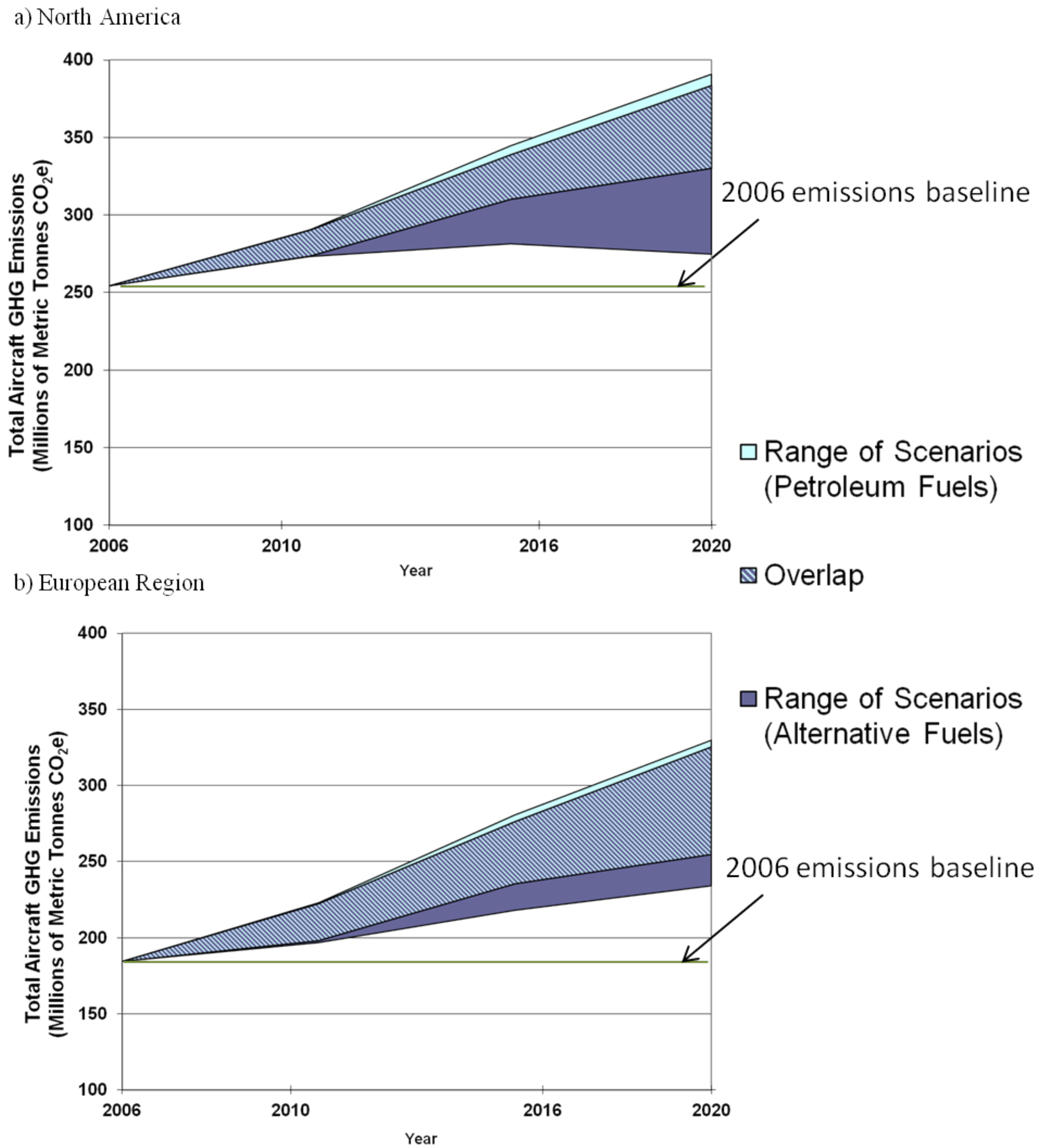


Figure 8 shows the potential reduction in GHG emissions based on the various demand and fuel production forecasts when biodiesel and ethanol are included. The range of GHG reductions possible in 2020 are from 1.9 to 2.2% in North America in the *Basic Jet* scenario to between 14.2 and 16.8% in the *Optimistic Switch+Biodiesel/Ethanol*)scenario. In Europe, the range is from 1.3 to 1.6% reduction in the most basic case and 6.3 to 8.1% in the most optimistic case (detailed tables of reductions can be found in Table 12 of Appendix D). As with the scenario analysis excluding biodiesel and ethanol, in North America total GHG emissions between 2016 and in 2020 are projected to increase in the *Basic Jet* scenario but only increase slightly in the *Expanded Jet* (298 to 301 Mt CO2e) case and *Moderate Switch+Biodiesel) (295-296)* scenarios, suggesting potential leveling off of emissions. In the *Optimistic Switch+Biodiesel/Ethanol* scenario total GHG emissions would decrease from 281 Mt CO2e in 2016 to 275 Mt in 2020. However, given the increase in jet fuel demand of approximately 6 and 10% in North America and Europe, respectively, by 2026, continued expansion of production or reduction of average LCA value for alternative fuels would be required to maintain carbon neutral growth in the aviation community. Alternatively, other approaches, such as new policies or market-based measures, may further reduce GHG emissions and facilitate achievement of carbon neutral growth goals.

Figure 8: Potential reduction in GHG emissions based on alternative jet fuel production scenarios based on expanded scenario assumptions (including 25% product switching by ethanol and biodiesel companies.



Comparing the emissions associated with the various alternative fuel scenarios with the proxy baseline case of 2006 emissions levels based on a petroleum-only fuel pool (see Figure 8) shows that even with biodiesel and ethanol companies switching a portion of their production to jet fuel and the most optimistic (lowest) jet fuel demand forecast, jet fuel emission would not quite reach the 2005 baseline for carbon neutral growth. The emissions in North America would be 27 to

51% above 2006 levels in the *Basic Jet* scenario, 18-42% above in the *Expanded Jet* scenario, 16-40% above 2006 levels in the *Moderate Switch* scenario, and 8-32% above in the *Optimistic Switch+Biodiesel/Ethanol* scenario. Within the *Optimistic Switch + Biodiesel/ Ethanol* scenario, emissions would be 8 and 10% above the 2006 baseline in 2020 based on Low Forecasts 5 and 4 respectively, suggesting that if the best case for efficiency and operational improvements were to occur in conjunction with low demand, improvements in the average LCA value of the fuel pool might conceivably achieve emission below 2006 levels in Scenarios 6 and 7. Table 13 in Appendix D shows the complete set of comparisons of emissions to 2006 levels for the biodiesel and ethanol-inclusive analyses.

6. DISCUSSION

The scenario analysis presented here provides a general understanding of the potential role of alternative jet fuels in achieving aviation community alternative fuel use and carbon neutral growth goals in 2020 based on current technology and existing, publicly-available plans for production establishment and expansion in North America and Europe. This study estimates production from specific company plans to which a series of unifying assumptions have been applied. Forecasting alternative fuel production , as well as the GHG LCA for individual fuels, is inherently inexact. The scenarios provided in this analysis are uncertain by nature, and many assumptions were made regarding production amounts, years, and proportion of product allocated to jet fuel. With these assumptions, some potentially optimistic, including full expansion of all companies that plan to produce jet fuel and switching to production of some jet fuel by other companies, as well as unlimited feedstock availability, the results of this analysis suggest that a combination of the most optimistic demand forecasts and one of the *Switch* scenarios (Scenarios 3-7) are required for North America to achieve carbon neutral growth in aviation by 2020, but even in these scenarios that carbon neutral growth would not occur at 2005 emissions levels, the FAA's target, without the implementation of additional approaches such as market-based measures and policy changes. Likewise, the analysis suggests that carbon neutral growth is unlikely to be accomplished in the European region without substantial changes in anticipated production capacity and improvement in the average GHG LCA value of the alternative fuels. The latter result is consistent with that of the European SWAFEA program, which concluded that filling the gap to reach carbon neutral growth starting in 2020 in Europe could not be achieved with alternative jet fuels alone and would also require market-based measures and that alternative jet fuels-based stabilization of emissions at 2020 levels is unlikely until beyond 2030 [9]. These results all point to the need for a balanced approach to mitigate GHGs, as opposed to a sole reliance on alternative jet fuels to meet future GHG goals.

However, this analysis is a snapshot and even in the near term it is very likely that both capacity plans and GHG LCA results for particular fuels will change over time as the market develops. For example, if the 2008 Mexican Biofuels Promotion and Development Law [19] encourages expansion of biofuel production in Mexico, this would alter the scenarios described in this report and might improve the chances of meeting carbon neutral growth goals within North America or within the U.S. if those fuels were available north of the border. Also, as this analysis only covered planned alternative fuel production in the EU27 countries, additional production initiated in other countries in the ICAO European Region (e.g., the Russian federation and Turkey) could significantly increase the available alternative fuels and their associated GHG effects. Furthermore, the EU or North American markets could import alternative jet fuels from regions, such as South America, which were not considered in this analysis.

In addition, details of the life cycle of the fuels may alter the GHG emissions associated with individual fuels for better or worse, possibly resulting in different GHG emissions reductions than those indicated in this study. To achieve carbon neutral growth at 2005 emissions levels in North America will require expansion of proposed alternative jet fuel production, new conversion technologies, and/or reductions in average LCA value for the alternative fuels in the fuel pool to bring total emissions to 2005 levels. The present analysis indicates that the gap between scenario emissions and the 2005 target (estimated using 2006 as the baseline) is 16 to 51% greater than baseline in the scenario analysis, and 8 to 51% even when biodiesel and ethanol product switching is included.

This analysis does not project alternative fuel availability beyond 2020, as few companies had production plans beyond 2020 and as no assumptions were made about expansion beyond current planned capacity. Thus, based on the guiding rules of this analysis, in most cases the total amount of fuel projected would not increase if the scenarios were extended beyond 2020. However, as aviation continues to grow, it is anticipated that alternative jet fuels will need to play a growing part in maintaining carbon neutral growth, and the alternative fuels industry would need to both expand and reduce GHG emissions in order to achieve carbon neutral growth at 2005 levels.

Several previous studies have estimated total alternative fuel availability in the future using a bottom-up approach, or have evaluated alternative jet fuel availability in the future using modeling of feedstock availability and limitations of carbon and fuel price. Bacovsky estimated approximately 1.7 Mt of biofuels production (not necessarily jet fuel) by 2016 from 66 demonstration projects in Europe, the U.S., Brazil, and New Zealand utilizing lignocellulosic feedstocks [15]. The detailed data presented by Bacovsky were incorporated into the present study and expanded upon or updated if additional data were available. Therefore, the scenario analysis estimates presented above for Mt of jet fuel produced per annum are greater in all scenarios than the total projected biofuels production estimated in Bacovsky et al.

A recent CSIRO report claims that by 2020 Australia and New Zealand could provide enough biomass resources to replace 46% of aviation fuel with bio-based fuels [20], although this does not account for competition for feedstocks and assumes availability and use of all current biomass resources and 10% of all new biofuel resources (algae, *Pongamia*, coppiced eucalyptus [7]. Their full scenarios taking into account costs and the potential for a carbon price do not project any significant alternative bio-based jet fuel uptake in Australia before 2020 [7].

Another scenario analysis by E4Tech regarding adoption of alternative jet fuel globally utilized a top-down approach and found that several of their scenarios reached 100% jet fuel replacement over the long term [8], assuming unlimited feedstock, unlimited production capacity, and lower price for alternative jet fuels than for standard petroleum-based jet when a carbon price was included. However, even in their most optimistic uptake case (HEFA produced from existing conventional oil crops) 10% replacement was projected to be achieved in 2024. 2020 alternative fuel replacement of jet fuel is under 3% globally in all of their scenarios, which is in line with the results presented here for the European Region (3-5%) but lower than the estimates for alternative jet fuel production in North America even in the *Basic* (approximately 7-9%) and *Expanded Jet* scenarios (23-27%).

Both the CSIRO and E4Tech studies incorporate considerations of fuel costs and carbon price, which were not accounted for in the present scenario analysis study and may shift adoption of alternative jet fuels earlier or later depending on the conditions. It should be noted that these studies only considered a limited set of fuel production technologies (FT, HEFA, and, in the E4Tech study, some information on synthetic hydrocarbons).

The present scenario analysis was performed to evaluate the potential for meeting alternative fuel use and carbon neutral growth goals in North America and Europe. In both regions, there are relevant alternative fuels targets to which the results of this scenario analysis can be compared. In the U.S., these include FAA's goal for 1 billion gallons of alternative jet fuel use by military and commercial jet fuel users by 2018, the Renewable Fuels Standard (RFS) from the Environmental Protection Agency (EPA), which sets targets for total renewable fuel production in future years, and the U.S. Air Force (USAF) and U.S. Navy targets for replacement of petroleum-based jet fuel in their fleets. Similarly in the European Union, the Renewable Energy Directive provides targets for GHG emissions reductions for transportation as a whole, and the new Biofuels Flightpath Initiative has also outlined a goal for future alternative jet fuel production. The Air Transport Action Group (ATAG) has also outlined a global goal for alternative jet fuel replacement. This scenario analysis provides a glimpse of the contribution to these targets of future alternative jet fuels.

The FAA has set a goal of 1 billion gallons of alternative jet fuels by 2018 [21]. Based on the results of this scenario analysis, that goal could be achieved even in the *Basic Jet* scenario. The FAA's goal of 1 billion gallons of alternative jet fuels includes both commercial and military aviation in the U.S. by 2018; as such it includes both the USAF target of replacing 50% of their domestic U.S. jet fuel with alternative (non-petroleum-based) blended fuels by 2016 (on the order of 350 to 400 million gallons of unblended alternative fuel) [22-24] as well as the US Navy goal of 288 million gallons per year.[23]

The current year-by-year requirements of the EPA's RFS call for the production of 30 billion gallons of biofuels in 2020, of which 15 billion is required to be advanced biofuels, which are defined as having a 50% reduction in GHG Emissions over standard petroleum for non-cellulosic, 60% reduction for cellulosic [25]. Although no specific percentage or volume of jet fuel is specifically included in the RFS-2 mandate, renewable jet fuel with a sufficient GHG benefit can receive a Renewable Identification Number (RIN) and contribute to the blender's obligation under RFS-2. Using the original scenarios (no ethanol or biodiesel), the present scenario analysis suggests that the amount of renewable jet fuel to be produced in the United States that could contribute to the RFS-2 standard based on the assumptions in this analysis (assuming EPA were to find these fuels meet the standard) could potentially be 560 million (*Basic Jet*), 3.9 billion (*Expanded Jet*), 4.1 billion (*Moderate Switch*) or 5.7 billion (*Optimistic Switch*) gallons per year, ranging from 384 million to 2.1 billion gallons of cellulosic and 176 million to 3.6 billion gallons of non-cellulosic advanced renewable fuels.

The European Biofuels Flightpath initiative has articulated a goal of 600 million gallons of alternative jet fuels by 2020 [26]. This scenario analysis indicates that the Biofuels Flightpath goal is achievable even in the *Basic Jet* scenario, which shows achievement of 870 million gallons per year by 2020. The RED (Renewable Energy Directive) in the EU requires 20% reduction in GHGs compared to 1990 and 10% minimum renewable energy in transport (total target is 20% renewable energy) by 2020. [27] Based on this scenario analysis, aviation could contribute a small amount to the general reduction of GHG emission to meet these targets, as GHG emissions would be improved over the do-nothing petroleum-only baseline case by 3 to 5% without ethanol/biodiesel switching and by up to 8% with ethanol and biodiesel companies switching to jet fuel.

The Air Transport Action Group has stated a goal that biofuels will replace 6% of total global aviation fuels by 2020 [28]. Based on the present scenario analysis, this goal is achievable in North America but may be more difficult in the European region unless additional production is established, significant shifts to jet fuel occur from the biodiesel and ethanol industry, fuels are imported from other world regions, or new technologies come to fruition.

Conclusions

The goal of this analysis was to identify whether, utilizing available data of the production plans of alternative fuel producers as the basis for estimating fuel production scenarios, the alternative fuels use and carbon neutral growth goals articulated by the aviation industry could be achieved. This analysis suggests that the goal of the FAA to achieve 1 billion gallons of alternative jet fuel production by 2018 may be achievable. It also suggests that the USAF goal for replacement of 50% of its domestic jet fuel consumption, the U.S. Navy goal of 288 million gallons per year by 2020, the European Biofuels Flightpath target of 600 million gallons per year by 2020, and the Air Transport Action Group (ATAG) goal of 6% replacement of jet fuel by 2020 may also be possible. However, the analysis shows carbon neutral growth occurring in North America only with a combination of the most optimistic demand forecasts (CAEP Low Forecast 5) and either of the two *Switch* scenarios, in which all alternative jet fuel producers succeed and other companies choose to switch to some jet fuel production. Carbon neutral growth shown in these scenarios is at 2016-2020 emissions levels; none of the scenarios shows a return to 2005 emissions levels in 2020 as targeted by the FAA's carbon neutral growth goal. None of the scenarios show carbon neutral growth as likely in Europe starting in 2020. The results presented here are intended to provide a general estimate of how difficult it may be to reach carbon neutral growth goals. However, new technologies, new market conditions that lead to new alternative jet fuel companies or shifts in production focus for existing companies, imports of alternative fuels from other world regions, and improved processes to reduce GHG emissions may change the actual future alternative fuel production and GHG benefits compared to what is predicted in this report. Furthermore, the implementation of other approaches to reducing fuel demand and GHG emissions, including policy approaches and market-based measures, may facilitate achievement of carbon neutral growth goals. These results emphasize the need for a multi-pronged approach to achieving emissions reduction targets.

7. ACKNOWLEDGEMENTS

The authors would like to thank companies that provided information for this study. The authors also acknowledge extensive input and discussion with Jim Hileman, FAA (formerly of the Massachusetts Institute of Technology), for LCA background and proxy value selection, and review by Jim Hileman, Nathan Brown, and Rhett Jeffries of FAA's Office of Environment and Energy.

8. REFERENCES

1. Kim BY, Fleming GG, Lee JJ, Waitz IA, Clarke J-P, et al. (2007) System for assessing Aviation's Global Emissions (SAGE), Part 1: Model description and inventory results. Transportation Research Part D: Transport and Environment 12: 325-346.
2. IPCC (1999) Aviation and the Global Atmosphere. Available at: http://www.ipcc.ch/ipccreports/sres/aviation/index.htm. In: Penner JE, Lister DH, Griggs DJ, Dokken DJ, McFarland M, editors. Prepared in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer. Cambridge, UK: Cambridge University Press.
3. FAA (2012) National Aviation Research Plan (NARP). Provided to Congress pursuant to 49 USC 44501(c).
4. ICAO (2010) Assembly Resolution A37-19: Consolidated Statement of continuing policies and practices related to environmental protection. ICAO CAEP.
5. Perlack RD, Wright LL, Turhollow AF, Graham RL, Stokes BJ, et al. (2005) Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. DOE/GO-102995-2135 ORNL/TM-2005/66: 78.
6. Milbrandt A (2005) A geographic perspective on the current biomass resource availability in the United States. In: Laboratory NRE, editor: NREL.
7. Graham P, Reedman L, Rodriguez L, Raison J, Braid A, et al. (2011) Sustainable Aviation Fuels Road Map: Data assumptions and modelling. In: CSIRO, editor. Newcastle, NSW, Australia: CSIRO.
8. Bauen A, Howes J, Bertuccioli L, Chudziak C (2009) Review of the potential for biofuels in aviation. London, UK: E4Tech.
9. Novelli P (2011) Sustainable Way for Alternative Fuels and Energy in Aviation (SWAFEA) Final Report. Available at: www.swafea.eu/.
10. Stratton RW, Wong HM, Hileman JI (2010) Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuel, Version 1.1. Cambridge, Massachusetts: PARTNER/MIT.
11. Maurice L, Gupta M (2010) FY 10 - FY 11 NextGen Portfolio Briefings: NextGen System Development - Environment & Energy; Environmental Management System and Advanced Noise and Emissions Reduction. In: Energy FOoEa, editor. Washington, DC.
12. ACI, CANSO, IATA, ICCAIA (2009) Agenda Item 1: Aspirational goals and implementation options - A global sectoral approach for aviation. High Level Meeting on International Aviation and Climate Change. Montreal, Canada: ICAO.
13. ICAO (2007) ICAO Environmental Report 2007. Montreal, Canada: ICAO.

14. MODTF Rapporteurs (2007) Comparison of ICAO regional definitions; ICAO's Economic Analyses and Database (EAD) Division and ICAO/CAEP's MODTF. In: ICAO/CAEP, editor. CAEP/8 Modelling and Database Task Force (MODTF) Bern, Switzerland.
15. Bacovsky D, Dallos M, Worgetter M (2010) Status of Second Generation BIofuels Demonstration Facilities in June 2010. International Energy Agency.
16. Eeckels C, Otting S, Choudry A, Lewis K, Roof C (2010) Aviation Biofuel Potential to Meet Carbon Emissions Goals. In: Research and Innovative Technology Administration USDoT, editor. Cambridge, MA.
17. Ethanol Renewable Fuels Association (2011) Ethanol Industry Overview
18. Organization for Economic Cooperation and Development (OECD) (2011) OECD-FAO Agricultural Outlook 2010-2019, by commodity. OECD FAO.
19. Chavez L (2009) Mexico Bio-fuels Report. In: Service UFA, editor: USDA Foreign Agricultural Service.
20. CSIRO (2011) Flight path to sustainable aviation: towards establishing a sustainable aviation fuels industry in Australia and New Zealand. Newcastle, Australia: CSIRO.
21. Federal Aviation Administration (2011) FAA Destination 2025. Washington, DC.
22. USAF (2010) Air Force Acquisition & Technology Energy Plan. In: SAF/AQ, editor.
23. Carter NA, Stratton RW, Bredehoeft MK, Hileman JI (2011) Energy and environmental viability of select alternative jet fuel pathways. 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit. San Diego, CA.
24. Edwards JT (2011) Personal correspondence via e-mail to K. Lewis providing an estimate translating USAF alternative fuel goals to actual fuel volumes.
25. USEPA (2010) Regulatory Announcement: EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond. In: Quality OoTaA, editor. Washington, DC.
26. Airbus (2011) European Commission, Airbus, airlines & biofuel producers in aviation biofuel accord. In: Airbus, editor. Airbus Press Release, June 22, 2011. Blagnac, France: Airbus Press Office.
27. European Parliament and Council of the European Union (2009) Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. In: Commission E, editor. Directive 2009/28/EC. Official JournaloftheEuropeanUnion.
28. Steele P (2011) Welcome to the biofuel age of flight. In: ATAG, editor. Powering the future of flight: the six easy steps to growing a viable aviation biofuels industry. Geneva, Switzerland: ATAG.
29. Hileman JI (2011) Discussion with K. Lewis regarding likely size of alternative fuels facilities for the purpose of scenario analysis estimation. Cambridge, MA: Massachusetts Institute of Technology, PARTNER program.

Appendix A – Data Sources for Lists of Companies and / or Production Information

Source	Link	Database
Altenergy Mag	http://www.altenergymag.com/	North America, Europe
BBI International	http://www.bbiinternational.com/ema/DisplayPage.aspx?pageId=Home	North America, Europe
Biodiesel Magazine	http://www.biodieselmagazine.com/	North America, Europe
Biodiesel Spain	http://www.biodieselspain.com/plantas_listado.php	Europe
Biofuels Digest	http://www.biofuelsdigest.com/	North America, Europe
Biofuels Journal	http://www.biofuelsjournal.com/ads.html	North America, Europe
Biomass Digest	http://www.biomassdigest.net/	North America, Europe
Environmental News Network	http://www.enn.com/	North America, Europe
ePURE	http://www.epure.org/	Europe
Ethanol Producer Magazine	http://www.ethanolproducer.com/	North America, Europe
Ethanol Renewable Fuels Association	http://www.ethanolrfa.org	North America
Ethanol Today	http://www.ethanoltoday.com/	North America, Europe
FACTBOX Biodiesel	http://www.reuters.com/article/2010/02/08/us-biofuels-europe-biodiesel-idUSTRE6172JY20100208	Europe
FACTBOX Ethanol	http://uk.reuters.com/article/2007/05/31/biofuels-europe-ethanol-idUKL2973183520070531	Europe
Oilgae	http://www.oilgae.com/	North America
Pro-Biodiesel	http://www.platypusmedia.eu/biodiesel/	North America, Europe
Renewable Energy Focus	http://www.renewableenergyfocus.com/category/62/bioenergy/	North America, Europe
Use Corn	http://usecorn.com/plants.php	North America
IEA Demo Plants	http://biofuels.abc-energy.at/demoplants/	North America, Europe

Appendix B – Scenario Definitions and Assumptions

The four scenarios share some common assumptions identified in Table 5. Table 6 presents the assumptions that differentiate the scenarios from each other.

Table 5: Common assumptions among all scenarios

Assumption	**Value(s)**	
Production level for companies specifying a single production amount or plant size	As specified by the company and/or other data sources	
Production timing	• Production begins as specified by the company or, if not specified, in 2020 • Switching of product slate to include jet fuel in companies without existing plans is assumed to start in 2015 *(a)* • Production continues through the end of the study period (2020) • Production expansion beyond initial facility is permitted in all but the basic jet case. • Production expansion is assumed to be completed in 2020 if no date provided.	
Assumed production capacity (MGY) for companies without a stated plant size	1) Fischer-Tropsch	306.6 *(a)*
	2) All processes other than Fischer-Tropsch	76.65 *(b)*
	3) Demo plant (any process)	0.1 *(c)*
	4) Pilot plant (any process)	0.01 *(d)*

Notes

(a) a start date of 2015 assumes a near-term increase in interest in producing jet fuel and a relatively short period of facility/technology adjustment to produce jet fuel. This start year is consistent with a similar assumption about product switching for BTL facilities in a previous study on UK alternative jet fuel production by E4Tech in the UK. [8]

(b) Same size as Rentech Natchez facility

(c) Size based on feedstock availability and efficiency [29]

(d) Order of magnitude scale up from pilot

(e) Based on Biofuels Digest designation for pilots

Table 6: Scenario definitions and differentiating assumptions

	Included producers of alternative jet fuels		Companies stating (1) a range of possible production levels or (2) plans to expand capacity			Companies with stated intent to produce but no stated production levels		Companies without stated intent to produce[(a)]	
Scenario Short Name	**Companies with stated intent to produce**	**Companies without stated intent to produce** [(a)]	**Lower bound of range**	**Upper bound of range**	**Reflects expansion plans** [(b)]	**Fraction of capacity assumed to be converted** [(c)]		**Fraction of capacity assumed to be converted** [(c)]	
						Pyrolysis and liquefaction	*All other processes*	*Pyrolysis and liquefaction*	*All other processe*[(d)]
Basic Jet	✓		✓			5%	10%	n/a	n/a
Expanded Jet	✓			✓	✓	5%	10%	n/a	n/a
Expanded Plus Moderate Switch	✓	✓		✓	✓	5%	10%	5%	10%
Expanded Plus Optimistic Switch	✓	✓		✓	✓	10%	25%	10%	25%
Optimistic Switch + OECD	✓	✓		✓	✓	10%	25%	10%	25%
Moderate Switch + Biodiesel	✓	✓		✓	✓	5%	10%	5%	10%
Optimistic Switch + Biodiesel/ Ethanol	✓	✓		✓	✓	10%	25%	10%	25%

Notes:

(a) Such companies were identified as producers of alternative fuels but did not have stated intent to produce alternative jet fuels; given the range of products generally made by alternative fuel producers, it was assumed that the product slate could be changed to include jet fuel if economically viable.

(b) Companies with expansion plans assumed to begin expansion two years after opening their initial facility; expansion assumed to occur at a constant rate (i.e., linearly) until maximum projected capacity is reached

(c) The conversion of biobutanol and other alcohol-producing processes to jet fuel production is calculated on the basis of energy equivalence, with net 10% of the energy in the total production being converted to jet fuel; all other processes are assumed to convert to jet fuel production on a constant-volume basis. For companies producing mixed alcohols, conversion values for ethanol were used.

(d) Biodiesel companies are only included in the last three scenarios. Companies that plan to make ethanol from standard fermentation processes (sugar/starch) or from basic cellulosic ethanol processes (acid hydrolysis or thermal breakdown of cellulosic material followed by standard fermentation processes are included only in the OECD scenario and the Optimistic Switch + Biodiesel/Ethanol scenario.

Appendix C – Number of Companies And Processes in Each Scenario

North American Analysis

Conversion Method	**Category Definition**	**Basic Jet**	**Expanded Jet**	**Expanded Jet + Mod Switch**	**Expanded Jet + Opt. switch**	**Production Data Assumed**
BB	Biobutanol	1	1	4	4	2
BD	Biodiesel	3	3	54	54	21
CBP	Consolidated Bioprocessing	2	2	4	6	3
CE	Cellulosic Ethanol	0	0	0	27	3
CRJ	Catalytic Renewable Jet Fuel	1	1	1	1	
DAO	Dark Algae Oil	1	1	1	1	1
FRJ	Fermented Renewable Jet (Advanced Fermentation)	1	1	1	1	
FT-BTL/MSW	Fischer-Tropsch from Biomass or Municipal Solid Waste	2	2	5	6	2
FT-CBTL	Fischer Tropsch-Coal Biomass to Liquid	4	4	4	4	
FT-CTL	Fischer Tropsch-Coal to Liquids	5	5	5	5	
FT-MSW	FT with MSW as feedstock			1	1	
GMA	Gasification/Catalysis to Alcohols				1	1
HEFA-D	Hydroprocessed Esters and Fatty Acids - Diesel			1	1	
HEFA-J	Hydroprocessed Esters and Fatty Acids - Jet Fuel	8	8	10	10	2
Liq	Liquefaction			1	1	
MT	Metathesis			1	1	1
OHO	Alcohol Oligomerization	4	4	5	5	1
PSH	Photosynthetic Hydrocarbons	1	1	3	3	2
Pyrol	Pyrolysis	4	4	10	10	6
SE	Standard Ethanol--includes acid and enzymatic hydrolysis				21	3
Total without ethanol/biodiesel		34	34	57	61	21
Total		37	37	111	163	48

European analysis

Conversion Method	Category Definition	Basic Jet	Expanded Jet	Expanded Jet + Mod Switch	Expanded Jet + Opt. switch	Production Data Assumed
SE	Standard Ethanol--includes acid and enzymatic hydrolysis				58	
CE	Cellulosic Ethanol				16	1
BD	Biodiesel			109	109	1
FT-BTL	Fischer-Tropsch from Biomass	3	3	6	6	
Pyrol	Pyrolysis			3	3	1
FT-CBTL	Fischer Tropsch-Coal Biomass to Liquid			1	1	
Liq	Liquefaction			1	1	
BB	Biobutanol			3	3	
HEFA-J	Hydroprocessed Esters and Fatty Acids - Jet Fuel	1	1	1	1	
OHO	Alcohol Oligomerization	1	1	1	1	
CRF	Catalytic Renewable Fuel			1	1	
GMA	Gasification/Catalysis to Alcohols				1	
Total without ethanol/biodiesel		5	5	17	18	
Total		5	5	126	201	

Appendix D – Data Tables

Table 7: Projected alternative jet fuel volume by process for each scenario and year based on scenario assumptions.

a) North America

Basic Jet Only

MGY	2012	2013	2014	2015	2016	2017	2018	2019	2020
BB	0.1	1.2	3.5	8.1	19.2	30.8	46.2	61.6	76.9
CBP	76.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0
CRJ	0.003	0.003	0.003	1.5	1.5	1.5	1.5	1.5	1.5
DAO				7.7	7.7	7.7	7.7	7.7	7.7
FRJ	0.1	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
FT-BTL	0.0	0.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
FT-BTL/MSW	0.0	0.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
FT-CBTL		124.2	124.2	497.8	497.8	497.8	497.8	497.8	727.8
FT-CTL		210.8	210.8	474.5	551.1	551.1	551.1	608.6	972.7
FT-MSW									
GMA									
HEFA-D									
HEFA-J	153.1	153.1	153.1	320.8	320.8	320.8	330.8	330.8	330.8
Liq									
MT									
OHO	10.1	163.4	163.4	183.3	183.3	183.3	183.3	183.3	183.3
PSH	0.0025	0.025	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Pyrol	14.5	24.5	41.9	59.2	76.6	93.9	129.2	146.6	171.2

Expanded Jet Only

MGY	2012	2013	2014	2015	2016	2017	2018	2019	2020
BB	0.1	1.2	3.5	8.1	19.2	30.8	46.2	61.6	76.9
CBP	76.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0
CRJ	0.029	0.029	0.029	1.5	1.5	1.5	1.5	1.5	2.2

DAO				7.7	7.7	7.7	7.7	7.7	7.7
FRJ	0.1	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
FT-BTL	0.0	0.0	15.0	15.0	15.0	30.0	45.0	60.0	75.0
FT-BTL/MSW	0.0	0.0	16.0	64.0	64.0	64.0	74.7	85.3	96.0
FT-CBTL		124.2	124.2	497.8	534.3	570.8	652.6	734.5	1046.3
FT-CTL		210.8	210.8	474.5	551.1	551.1	737.9	982.1	1533.0
FT-MSW									
GMA									
HRD									
HRJ	153.2	153.2	155.1	681.9	1041.0	1400.2	1826.0	2249.9	2673.7
Liq									
MT									
OHO	10.1	203.4	253.4	629.9	679.9	679.9	839.9	1099.8	1259.8
PSH	0.003	0.025	2.0	10.0	20.0	100.0	200.0	500.0	1000.0
Pyrol	14.5	24.5	41.9	59.2	76.6	93.9	129.2	146.6	183.2

Expanded Jet Plus Moderate Switch									
MGY	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
BB	**0.1**	**1.2**	**3.5**	**28.1**	**39.3**	**50.8**	**66.2**	**81.6**	**97.0**
CBP	76.0	76.0	76.0	91.3	91.3	91.3	91.3	91.3	91.3
CRJ	0.029	0.029	0.029	1.5	1.5	1.5	1.5	1.5	2.2
DAO				7.7	7.7	7.7	7.7	7.7	7.7
FRJ	0.1	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
FT-BTL	0.0	0.0	15.0	26.8	26.8	41.8	91.8	141.8	191.8
FT-BTL/MSW	0.0	0.0	16.0	125.2	125.2	125.2	135.9	146.5	157.2
FT-CBTL		124.2	124.2	497.8	534.3	570.8	652.6	734.5	1046.3
FT-CTL		210.8	210.8	474.5	551.1	551.1	737.9	982.1	1533.0
FT-MSW				2.1	2.1	2.1	2.1	2.1	2.1
GMA									

HRD				10.0	10.0	10.0	10.0	10.0	10.0
HRJ	153.2	153.2	155.1	702.6	1061.7	1420.8	1846.7	2270.5	2694.3
Liq				0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
MT				7.7	7.7	7.7	7.7	7.7	7.7
OHO	10.1	203.4	253.4	637.6	687.6	687.6	847.5	1107.5	1267.5
PSH	0.003	0.025	2.0	23.1	33.1	113.1	213.1	513.1	1013.1
Pyrol	14.5	24.5	41.9	79.9	97.2	114.6	149.9	167.2	203.9

Expanded Jet Plus Optimistic Switch									
MGY	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
BB	**0.3**	**2.9**	**8.7**	**70.3**	**98.2**	**127.0**	**165.5**	**204.0**	**242.4**
CBP	77.5	77.5	77.5	130.6	130.6	130.6	130.6	130.6	130.6
CRJ	0.1	0.1	0.1	3.7	3.7	3.7	3.7	3.7	5.5
DAO				19.2	19.2	19.2	19.2	19.2	19.2
FRJ	0.3	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
FT-BTL	0.0	0.0	15.0	44.5	44.5	59.5	162.0	264.5	367.0
FT-BTL/MSW	0.0	0.0	16.0	217.0	217.0	217.0	227.7	238.3	249.0
FT-CBTL		124.2	124.2	497.8	534.3	570.8	652.6	734.5	1046.3
FT-CTL		210.8	210.8	474.5	666.1	666.1	852.9	1183.3	1820.4
FT-MSW				5.3	5.3	5.3	5.3	5.3	5.3
GMA				11.7	11.7	11.7	11.7	11.7	11.7
HRD				25.0	25.0	25.0	25.0	25.0	25.0
HRJ	153.2	153.2	155.1	745.0	1104.2	1463.3	1889.2	2313.0	2736.8
Liq				0.001	0.001	0.001	0.001	0.001	0.001
MT				19.2	19.2	19.2	19.2	19.2	19.2
OHO	10.1	203.4	253.4	649.1	699.1	699.1	859.0	1119.0	1279.0
PSH	0.00	0.03	2.0	42.8	52.8	132.8	232.8	532.8	1032.8
Pyrol	14.5	24.5	41.9	100.5	117.9	135.2	170.6	187.9	224.5

b) Europe

Basic Jet Only									
MGY	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
BB									
CRJ									
FT-BTL	0.005	0.005	0.005	83.3	94.9	94.9	94.9	94.9	94.9
FT-CBTL									
GMA									
HEFA-J	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9
Liq									
OHO	0.0	0.0	0.0	7.7	7.7	7.7	7.7	7.7	7.7
Pyrol									

Expanded Jet Only									
MGY	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
BB									
CRJ									
FT-BTL	0.005	0.005	0.005	83.3	94.9	94.9	134.9	174.9	214.9
FT-CBTL									
GMA									
HEFA-J	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9
Liq									
OHO				7.7	7.7	7.7	7.7	7.7	7.7
Pyrol									

Expanded Jet Plus Moderate Switch									
MGY	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
BB				12.8	12.8	12.8	12.8	12.8	12.8

CRJ				0.001	0.001	0.001	0.001	0.001	0.001
FT-BTL	0.005	0.005	0.005	117.6	129.2	129.2	169.2	209.2	249.2
FT-CBTL				5.1	7.5	7.5	7.5	7.5	7.5
GMA									
HEFA-J	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9
Liq				0.006	0.006	0.006	0.006	0.006	0.006
OHO				7.7	7.7	7.7	7.7	7.7	7.7
Pyrol				3.8	4.7	5.5	17.7	29.9	42.1

Expanded Jet Plus Optimistic Switch

MGY	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
BB				32.1	32.1	32.1	32.1	32.1	32.1
CRJ				0.003	0.003	0.003	0.003	0.003	0.003
FT-BTL	0.005	0.005	0.005	169.0	180.5	180.5	220.5	260.5	300.5
FT-CBTL				12.9	18.7	18.7	18.7	18.7	18.7
GMA				4.4	4.4	4.4	4.4	4.4	4.4
HEFA-J	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9	697.9
Liq				0.015	0.015	0.015	0.015	0.015	0.015
OHO				19.2	19.2	19.2	19.2	19.2	19.2
Pyrol				7.6	9.3	11.1	35.4	59.8	84.2

Table 8: Percent replacement of each CAEP demand forecast ("consensus" and "low" versions) by alternative fuels based on scenario assumptions

a) North America

	Jet Only % Replacement				Expanded Jet Only % Replacement				Expanded Jet/Mod. Switch % Replacement				Expanded Jet/Opt. Switch % Replacement			
Forecast	2006	2010	2016	2020	2006	2010	2016	2020	2006	2010	2016	2020	2006	2010	2016	2020
Consensus 1	0.0%	0.0%	5.6%	7.2%	0.0%	0.0%	9.7%	22.3%	0.0%	0.0%	10.3%	23.1%	0.0%	0.0%	11.8%	25.5%
Consensus 2	0.0%	0.0%	5.7%	7.5%	0.0%	0.0%	9.9%	23.3%	0.0%	0.0%	10.5%	24.1%	0.0%	0.0%	12.1%	26.7%
Consensus 3	0.0%	0.0%	5.7%	7.5%	0.0%	0.0%	10.0%	23.4%	0.0%	0.0%	10.6%	24.3%	0.0%	0.0%	12.1%	26.9%
Consensus 4	0.0%	0.0%	5.8%	7.8%	0.0%	0.0%	10.2%	24.3%	0.0%	0.0%	10.8%	25.2%	0.0%	0.0%	12.4%	27.9%
Consensus 5	0.0%	0.0%	5.9%	8.0%	0.0%	0.0%	10.3%	24.7%	0.0%	0.0%	10.9%	25.6%	0.0%	0.0%	12.5%	28.4%
Low Scenario 1	0.0%	0.0%	5.8%	7.7%	0.0%	0.0%	10.2%	23.8%	0.0%	0.0%	10.8%	24.7%	0.0%	0.0%	12.4%	27.3%
Low Scenario 2	0.0%	0.0%	6.0%	8.0%	0.0%	0.0%	10.4%	24.8%	0.0%	0.0%	11.1%	25.7%	0.0%	0.0%	12.7%	28.5%
Low Scenario 3	0.0%	0.0%	6.0%	8.0%	0.0%	0.0%	10.4%	25.0%	0.0%	0.0%	11.1%	25.9%	0.0%	0.0%	12.7%	28.7%
Low Scenario 4	0.0%	0.0%	6.1%	8.3%	0.0%	0.0%	10.7%	25.9%	0.0%	0.0%	11.4%	26.9%	0.0%	0.0%	13.0%	29.8%
Low Scenario 5	0.0%	0.0%	6.2%	8.5%	0.0%	0.0%	10.8%	26.4%	0.0%	0.0%	11.5%	27.3%	0.0%	0.0%	13.1%	30.3%

b) European Region

	Jet Only % Replacement				Expanded Jet Only % Replacement				Expanded Jet/Mod. Switch % Replacement				Expanded Jet/Opt. Switch % Replacement			
Forecast	2006	2010	2016	2020	2006	2010	2016	2020	2006	2010	2016	2020	2006	2010	2016	2020
Consensus 1	0.0%	0.0%	3.4%	2.9%	0.0%	0.0%	3.4%	3.2%	0.0%	0.0%	3.3%	3.3%	0.0%	0.0%	3.7%	3.8%
Consensus 2	0.0%	0.0%	3.5%	3.1%	0.0%	0.0%	3.5%	3.5%	0.0%	0.0%	3.5%	3.6%	0.0%	0.0%	3.9%	4.1%
Consensus 3	0.0%	0.0%	3.5%	3.1%	0.0%	0.0%	3.5%	3.5%	0.0%	0.0%	3.5%	3.6%	0.0%	0.0%	3.9%	4.1%
Consensus 4	0.0%	0.0%	3.7%	3.3%	0.0%	0.0%	3.7%	3.7%	0.0%	0.0%	3.6%	3.8%	0.0%	0.0%	4.1%	4.3%
Consensus 5	0.0%	0.0%	3.7%	3.3%	0.0%	0.0%	3.7%	3.8%	0.0%	0.0%	3.7%	3.9%	0.0%	0.0%	4.1%	4.4%
Low Scenario 1	0.0%	0.0%	3.6%	3.2%	0.0%	0.0%	3.6%	3.6%	0.0%	0.0%	3.6%	3.7%	0.0%	0.0%	4.0%	4.3%
Low Scenario 2	0.0%	0.0%	3.8%	3.4%	0.0%	0.0%	3.8%	3.9%	0.0%	0.0%	3.7%	4.0%	0.0%	0.0%	4.2%	4.6%
Low Scenario 3	0.0%	0.0%	3.8%	3.5%	0.0%	0.0%	3.8%	3.9%	0.0%	0.0%	3.7%	4.0%	0.0%	0.0%	4.2%	4.6%
Low Scenario 4	0.0%	0.0%	4.0%	3.6%	0.0%	0.0%	4.0%	4.1%	0.0%	0.0%	3.9%	4.2%	0.0%	0.0%	4.4%	4.8%
Low Scenario 5	0.0%	0.0%	4.0%	3.7%	0.0%	0.0%	4.0%	4.2%	0.0%	0.0%	4.0%	4.3%	0.0%	0.0%	4.4%	4.9%

Table 9: GHG emissions reductions for each CAEP demand forecast by based on scenario assumptions.

c) North America

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0.0%	0.0%	1.5%	1.7%	0.0%	0.0%	3.1%	7.3%	0.0%	0.0%	3.5%	7.9%	0.0%	0.0%	4.2%	9.0%
Consensus 2	0.0%	0.0%	1.5%	1.8%	0.0%	0.0%	3.2%	7.7%	0.0%	0.0%	3.6%	8.3%	0.0%	0.0%	4.3%	9.4%
Consensus 3	0.0%	0.0%	1.5%	1.8%	0.0%	0.0%	3.2%	7.7%	0.0%	0.0%	3.6%	8.3%	0.0%	0.0%	4.3%	9.5%
Consensus 4	0.0%	0.0%	1.5%	1.8%	0.0%	0.0%	3.3%	8.0%	0.0%	0.0%	3.7%	8.6%	0.0%	0.0%	4.4%	9.8%
Consensus 5	0.0%	0.0%	1.6%	1.9%	0.0%	0.0%	3.3%	8.1%	0.0%	0.0%	3.7%	8.8%	0.0%	0.0%	4.4%	10.0%
Low Scenario 1	0.0%	0.0%	1.5%	1.8%	0.0%	0.0%	3.3%	7.8%	0.0%	0.0%	3.7%	8.4%	0.0%	0.0%	4.4%	9.6%
Low Scenario 2	0.0%	0.0%	1.6%	1.9%	0.0%	0.0%	3.4%	8.2%	0.0%	0.0%	3.8%	8.8%	0.0%	0.0%	4.5%	10.0%
Low Scenario 3	0.0%	0.0%	1.6%	1.9%	0.0%	0.0%	3.4%	8.2%	0.0%	0.0%	3.8%	8.9%	0.0%	0.0%	4.5%	10.1%
Low Scenario 4	0.0%	0.0%	1.6%	2.0%	0.0%	0.0%	3.4%	8.5%	0.0%	0.0%	3.9%	9.2%	0.0%	0.0%	4.6%	10.5%
Low Scenario 5	0.0%	0.0%	1.6%	2.0%	0.0%	0.0%	3.5%	8.7%	0.0%	0.0%	3.9%	9.4%	0.0%	0.0%	4.7%	10.7%

d) European Region

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0.0%	0.0%	1.8%	1.5%	0.0%	0.0%	1.8%	1.8%	0.0%	0.0%	1.7%	1.9%	0.0%	0.0%	2.0%	2.2%
Consensus 2	0.0%	0.0%	1.9%	1.7%	0.0%	0.0%	1.9%	2.0%	0.0%	0.0%	1.8%	2.0%	0.0%	0.0%	2.1%	2.4%
Consensus 3	0.0%	0.0%	1.9%	1.7%	0.0%	0.0%	1.9%	2.0%	0.0%	0.0%	1.8%	2.0%	0.0%	0.0%	2.1%	2.4%
Consensus 4	0.0%	0.0%	2.0%	1.8%	0.0%	0.0%	2.0%	2.1%	0.0%	0.0%	1.9%	2.1%	0.0%	0.0%	2.2%	2.5%
Consensus 5	0.0%	0.0%	2.0%	1.8%	0.0%	0.0%	2.0%	2.1%	0.0%	0.0%	1.9%	2.2%	0.0%	0.0%	2.2%	2.6%
Low Scenario 1	0.0%	0.0%	2.0%	1.7%	0.0%	0.0%	2.0%	2.1%	0.0%	0.0%	1.9%	2.1%	0.0%	0.0%	2.2%	2.5%
Low Scenario 2	0.0%	0.0%	2.0%	1.8%	0.0%	0.0%	2.0%	2.2%	0.0%	0.0%	2.0%	2.3%	0.0%	0.0%	2.3%	2.7%
Low Scenario 3	0.0%	0.0%	2.0%	1.9%	0.0%	0.0%	2.0%	2.2%	0.0%	0.0%	2.0%	2.3%	0.0%	0.0%	2.3%	2.7%
Low Scenario 4	0.0%	0.0%	2.1%	2.0%	0.0%	0.0%	2.1%	2.4%	0.0%	0.0%	2.1%	2.4%	0.0%	0.0%	2.4%	2.8%
Low Scenario 5	0.0%	0.0%	2.2%	2.0%	0.0%	0.0%	2.2%	2.4%	0.0%	0.0%	2.1%	2.4%	0.0%	0.0%	2.4%	2.9%

Table 10: Percent reduction (or increase) in GHG emissions for each CAEP demand forecast compared with 2006 emissions (a proxy for 2005, the baseline for carbon neutral growth targets) based on scenario assumptions.

a) North America

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0%	-14%	-34%	-51%	0%	-14%	-31%	-42%	0%	-14%	-31%	-42%	0%	-14%	-30%	-40%
Consensus 2	0%	-13%	-30%	-45%	0%	-13%	-28%	-36%	0%	-13%	-28%	-35%	0%	-13%	-27%	-33%
Consensus 3	0%	-13%	-30%	-43%	0%	-13%	-28%	-35%	0%	-13%	-27%	-34%	0%	-13%	-26%	-32%
Consensus 4	0%	-10%	-27%	-38%	0%	-10%	-25%	-29%	0%	-10%	-24%	-29%	0%	-10%	-23%	-27%
Consensus 5	0%	-10%	-26%	-36%	0%	-10%	-24%	-27%	0%	-10%	-23%	-26%	0%	-10%	-22%	-25%
Low Scenario 1	0%	-12%	-27%	-41%	0%	-12%	-25%	-32%	0%	-12%	-24%	-32%	0%	-12%	-23%	-30%
Low Scenario 2	0%	-10%	-24%	-35%	0%	-10%	-22%	-27%	0%	-10%	-21%	-26%	0%	-10%	-20%	-24%
Low Scenario 3	0%	-10%	-24%	-34%	0%	-10%	-22%	-25%	0%	-10%	-21%	-25%	0%	-10%	-20%	-23%
Low Scenario 4	0%	-8%	-21%	-29%	0%	-8%	-19%	-21%	0%	-8%	-18%	-20%	0%	-8%	-17%	-18%
Low Scenario 5	0%	-8%	-20%	-27%	0%	-8%	-18%	-19%	0%	-8%	-17%	-18%	0%	-8%	-16%	-16%

b) European Region

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0%	-21%	-50%	-76%	0%	-21%	-50%	-76%	0%	-21%	-50%	-76%	0%	-21%	-49%	-75%
Consensus 2	0%	-17%	-43%	-64%	0%	-17%	-43%	-63%	0%	-17%	-43%	-63%	0%	-17%	-42%	-62%
Consensus 3	0%	-17%	-43%	-63%	0%	-17%	-43%	-62%	0%	-17%	-43%	-62%	0%	-17%	-42%	-61%
Consensus 4	0%	-12%	-36%	-54%	0%	-12%	-36%	-53%	0%	-12%	-36%	-53%	0%	-12%	-36%	-53%
Consensus 5	0%	-11%	-35%	-51%	0%	-11%	-35%	-51%	0%	-11%	-35%	-51%	0%	-11%	-34%	-50%
Low Scenario 1	0%	-16%	-38%	-57%	0%	-16%	-38%	-56%	0%	-16%	-38%	-56%	0%	-16%	-38%	-56%
Low Scenario 2	0%	-13%	-32%	-46%	0%	-13%	-32%	-46%	0%	-13%	-32%	-46%	0%	-13%	-32%	-45%
Low Scenario 3	0%	-13%	-32%	-45%	0%	-13%	-32%	-45%	0%	-13%	-32%	-45%	0%	-13%	-32%	-44%
Low Scenario 4	0%	-8%	-26%	-38%	0%	-8%	-26%	-37%	0%	-8%	-26%	-37%	0%	-8%	-26%	-37%
Low Scenario 5	0%	-7%	-25%	-35%	0%	-7%	-25%	-35%	0%	-7%	-25%	-35%	0%	-7%	-25%	-34%

Table 11: Percent replacement of each CAEP demand forecast by alternative fuels based on expanded scenario assumptions (including 25% product switch by biodiesel and ethanol companies).

a) North America

	Jet Only % Replacement				Expanded Jet Only % Replacement				Expanded Jet/Mod. Switch % Replacement				Expanded Jet/Opt. Switch % Replacement			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0.0%	0.0%	6.0%	7.6%	0.0%	0.0%	10.2%	22.7%	0.0%	0.0%	12.2%	24.8%	0.0%	0.0%	21.3%	35.9%
Consensus 2	0.0%	0.0%	6.2%	7.9%	0.0%	0.0%	10.5%	23.8%	0.0%	0.0%	12.5%	26.0%	0.0%	0.0%	21.8%	37.5%
Consensus 3	0.0%	0.0%	6.2%	8.0%	0.0%	0.0%	10.5%	23.9%	0.0%	0.0%	12.5%	26.2%	0.0%	0.0%	21.8%	37.8%
Consensus 4	0.0%	0.0%	6.3%	8.3%	0.0%	0.0%	10.8%	24.8%	0.0%	0.0%	12.8%	27.1%	0.0%	0.0%	22.3%	39.2%
Consensus 5	0.0%	0.0%	6.4%	8.4%	0.0%	0.0%	10.9%	25.3%	0.0%	0.0%	12.9%	27.6%	0.0%	0.0%	22.5%	39.9%
Low Scenario 1	0.0%	0.0%	6.3%	8.1%	0.0%	0.0%	10.8%	24.3%	0.0%	0.0%	12.8%	26.6%	0.0%	0.0%	22.3%	38.4%
Low Scenario 2	0.0%	0.0%	6.5%	8.4%	0.0%	0.0%	11.0%	25.4%	0.0%	0.0%	13.1%	27.7%	0.0%	0.0%	22.8%	40.0%
Low Scenario 3	0.0%	0.0%	6.5%	8.5%	0.0%	0.0%	11.0%	25.6%	0.0%	0.0%	13.1%	27.9%	0.0%	0.0%	22.9%	40.4%
Low Scenario 4	0.0%	0.0%	6.6%	8.8%	0.0%	0.0%	11.3%	26.5%	0.0%	0.0%	13.5%	28.9%	0.0%	0.0%	23.4%	41.8%
Low Scenario 5	0.0%	0.0%	6.7%	8.9%	0.0%	0.0%	11.4%	26.9%	0.0%	0.0%	13.6%	29.4%	0.0%	0.0%	23.6%	42.5%

b) European Region

	Jet Only % Replacement				Expanded Jet Only % Replacement				Expanded Jet/Mod. Switch % Replacement				Expanded Jet/Opt. Switch % Replacement			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0.0%	0.0%	3.1%	2.6%	0.0%	0.0%	3.1%	3.0%	0.0%	0.0%	6.1%	5.8%	0.0%	0.0%	13.3%	12.6%
Consensus 2	0.0%	0.0%	3.2%	2.8%	0.0%	0.0%	3.2%	3.2%	0.0%	0.0%	6.4%	6.2%	0.0%	0.0%	13.9%	13.5%
Consensus 3	0.0%	0.0%	3.2%	2.8%	0.0%	0.0%	3.2%	3.3%	0.0%	0.0%	6.4%	6.2%	0.0%	0.0%	13.9%	13.6%
Consensus 4	0.0%	0.0%	3.4%	3.0%	0.0%	0.0%	3.4%	3.4%	0.0%	0.0%	6.7%	6.6%	0.0%	0.0%	14.5%	14.3%
Consensus 5	0.0%	0.0%	3.4%	3.1%	0.0%	0.0%	3.4%	3.5%	0.0%	0.0%	6.7%	6.7%	0.0%	0.0%	14.7%	14.6%
Low Scenario 1	0.0%	0.0%	3.3%	2.9%	0.0%	0.0%	3.3%	3.4%	0.0%	0.0%	6.6%	6.5%	0.0%	0.0%	14.3%	14.1%
Low Scenario 2	0.0%	0.0%	3.5%	3.2%	0.0%	0.0%	3.5%	3.6%	0.0%	0.0%	6.9%	6.9%	0.0%	0.0%	15.0%	15.1%
Low Scenario 3	0.0%	0.0%	3.5%	3.2%	0.0%	0.0%	3.5%	3.7%	0.0%	0.0%	6.9%	7.0%	0.0%	0.0%	15.0%	15.2%
Low Scenario 4	0.0%	0.0%	3.7%	3.3%	0.0%	0.0%	3.7%	3.8%	0.0%	0.0%	7.2%	7.3%	0.0%	0.0%	15.7%	16.0%
Low Scenario 5	0.0%	0.0%	3.7%	3.4%	0.0%	0.0%	3.7%	3.9%	0.0%	0.0%	7.3%	7.5%	0.0%	0.0%	15.8%	16.3%

Table 12: GHG emissions reductions for each CAEP demand forecast based on expanded scenario assumptions (including 25% product switching by biodiesel and ethanol companies)..

a) North America

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0.0%	0.0%	1.7%	1.9%	0.0%	0.0%	3.4%	7.6%	0.0%	0.0%	4.4%	8.8%	0.0%	0.0%	8.3%	14.2%
Consensus 2	0.0%	0.0%	1.7%	2.0%	0.0%	0.0%	3.5%	7.9%	0.0%	0.0%	4.5%	9.2%	0.0%	0.0%	8.5%	14.8%
Consensus 3	0.0%	0.0%	1.7%	2.0%	0.0%	0.0%	3.5%	8.0%	0.0%	0.0%	4.6%	9.2%	0.0%	0.0%	8.5%	14.9%
Consensus 4	0.0%	0.0%	1.8%	2.1%	0.0%	0.0%	3.6%	8.3%	0.0%	0.0%	4.7%	9.6%	0.0%	0.0%	8.8%	15.5%
Consensus 5	0.0%	0.0%	1.8%	2.1%	0.0%	0.0%	3.6%	8.4%	0.0%	0.0%	4.7%	9.7%	0.0%	0.0%	8.8%	15.7%
Low Scenario 1	0.0%	0.0%	1.8%	2.0%	0.0%	0.0%	3.6%	8.1%	0.0%	0.0%	4.7%	9.4%	0.0%	0.0%	8.8%	15.1%
Low Scenario 2	0.0%	0.0%	1.8%	2.1%	0.0%	0.0%	3.6%	8.4%	0.0%	0.0%	4.8%	9.8%	0.0%	0.0%	9.0%	15.8%
Low Scenario 3	0.0%	0.0%	1.8%	2.1%	0.0%	0.0%	3.6%	8.5%	0.0%	0.0%	4.8%	9.9%	0.0%	0.0%	9.0%	15.9%
Low Scenario 4	0.0%	0.0%	1.9%	2.2%	0.0%	0.0%	3.7%	8.8%	0.0%	0.0%	4.9%	10.2%	0.0%	0.0%	9.2%	16.5%
Low Scenario 5	0.0%	0.0%	1.9%	2.2%	0.0%	0.0%	3.8%	9.0%	0.0%	0.0%	4.9%	10.4%	0.0%	0.0%	9.3%	16.8%

b) European Region

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0.0%	0.0%	1.6%	1.3%	0.0%	0.0%	1.6%	1.7%	0.0%	0.0%	3.0%	3.0%	0.0%	0.0%	6.2%	6.3%
Consensus 2	0.0%	0.0%	1.7%	1.4%	0.0%	0.0%	1.7%	1.8%	0.0%	0.0%	3.2%	3.2%	0.0%	0.0%	6.5%	6.7%
Consensus 3	0.0%	0.0%	1.7%	1.5%	0.0%	0.0%	1.7%	1.8%	0.0%	0.0%	3.2%	3.3%	0.0%	0.0%	6.5%	6.8%
Consensus 4	0.0%	0.0%	1.7%	1.5%	0.0%	0.0%	1.7%	1.9%	0.0%	0.0%	3.3%	3.4%	0.0%	0.0%	6.8%	7.1%
Consensus 5	0.0%	0.0%	1.7%	1.6%	0.0%	0.0%	1.7%	1.9%	0.0%	0.0%	3.3%	3.5%	0.0%	0.0%	6.9%	7.3%
Low Scenario 1	0.0%	0.0%	1.7%	1.5%	0.0%	0.0%	1.7%	1.9%	0.0%	0.0%	3.3%	3.4%	0.0%	0.0%	6.7%	7.0%
Low Scenario 2	0.0%	0.0%	1.8%	1.6%	0.0%	0.0%	1.8%	2.0%	0.0%	0.0%	3.4%	3.6%	0.0%	0.0%	7.0%	7.5%
Low Scenario 3	0.0%	0.0%	1.8%	1.6%	0.0%	0.0%	1.8%	2.0%	0.0%	0.0%	3.4%	3.6%	0.0%	0.0%	7.0%	7.6%
Low Scenario 4	0.0%	0.0%	1.9%	1.7%	0.0%	0.0%	1.9%	2.1%	0.0%	0.0%	3.6%	3.8%	0.0%	0.0%	7.4%	8.0%
Low Scenario 5	0.0%	0.0%	1.9%	1.7%	0.0%	0.0%	1.9%	2.1%	0.0%	0.0%	3.6%	3.9%	0.0%	0.0%	7.4%	8.1%

Table 13: Percent reduction (or increase) in GHG emissions for each CAEP demand forecast compared with 2006 emissions (a proxy for 2005, the baseline for carbon neutral growth targets) based on expanded scenario assumptions (including 25% product switching by biodiesel and ethanol companies). Negative values indicate a difference above 2006 emissions levels.

a) North America

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0%	-14%	-33%	-51%	0%	-14%	-31%	-42%	0%	-14%	-30%	-40%	0%	-14%	-24%	-32%
Consensus 2	0%	-13%	-30%	-44%	0%	-13%	-28%	-35%	0%	-13%	-26%	-34%	0%	-13%	-21%	-25%
Consensus 3	0%	-13%	-30%	-43%	0%	-13%	-28%	-34%	0%	-13%	-26%	-32%	0%	-13%	-21%	-24%
Consensus 4	0%	-10%	-27%	-38%	0%	-10%	-24%	-29%	0%	-10%	-23%	-27%	0%	-10%	-18%	-19%
Consensus 5	0%	-10%	-26%	-35%	0%	-10%	-23%	-27%	0%	-10%	-22%	-25%	0%	-10%	-17%	-17%
Low Scenario 1	0%	-12%	-27%	-41%	0%	-12%	-24%	-32%	0%	-12%	-23%	-30%	0%	-12%	-18%	-22%
Low Scenario 2	0%	-10%	-24%	-35%	0%	-10%	-22%	-26%	0%	-10%	-20%	-24%	0%	-10%	-15%	-16%
Low Scenario 3	0%	-10%	-24%	-34%	0%	-10%	-21%	-25%	0%	-10%	-20%	-23%	0%	-10%	-15%	-15%
Low Scenario 4	0%	-8%	-21%	-29%	0%	-8%	-18%	-20%	0%	-8%	-17%	-18%	0%	-8%	-12%	-10%
Low Scenario 5	0%	-8%	-20%	-27%	0%	-8%	-17%	-18%	0%	-8%	-16%	-16%	0%	-8%	-11%	-8%

a) European Region

	Jet Only % GHG Reduction				Expanded Jet Only % GHG Reduction				Expanded Jet/Mod. Switch % GHG Reduction				Expanded Jet/Opt. Switch % GHG Reduction			
Forecast	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**	**2006**	**2010**	**2016**	**2020**
Consensus 1	0%	-21%	-50%	-76%	0%	-21%	-50%	-76%	0%	-21%	-48%	-74%	0%	-20%	-43%	-68%
Consensus 2	0%	-17%	-43%	-64%	0%	-17%	-43%	-63%	0%	-17%	-41%	-61%	0%	-16%	-36%	-55%
Consensus 3	0%	-17%	-43%	-63%	0%	-17%	-43%	-62%	0%	-17%	-41%	-60%	0%	-16%	-36%	-54%
Consensus 4	0%	-12%	-36%	-54%	0%	-12%	-36%	-54%	0%	-12%	-34%	-51%	0%	-11%	-29%	-46%
Consensus 5	0%	-11%	-35%	-51%	0%	-11%	-35%	-51%	0%	-11%	-33%	-49%	0%	-11%	-28%	-43%
Low Scenario 1	0%	-16%	-39%	-57%	0%	-16%	-39%	-57%	0%	-16%	-36%	-54%	0%	-16%	-32%	-48%
Low Scenario 2	0%	-13%	-32%	-47%	0%	-13%	-32%	-46%	0%	-13%	-30%	-44%	0%	-13%	-25%	-38%
Low Scenario 3	0%	-13%	-32%	-46%	0%	-13%	-32%	-45%	0%	-13%	-30%	-43%	0%	-13%	-25%	-37%

Low Scenario 4	0%	-8%	-26%	-38%	0%	-8%	-26%	-38%	0%	-8%	-24%	-35%	0%	-7%	-19%	-29%
Low Scenario 5	0%	-7%	-25%	-36%	0%	-7%	-25%	-35%	0%	-7%	-23%	-33%	0%	-7%	-18%	-27%

Appendix E – LCA Assumptions and Values Utilized

1) Key assumption: LCA values cannot be precise because many of the fuel types have not yet been run in a manner comparable to that done by Stratton et al. 2010. Certain fuels are therefore used as proxies for others due to similarity of processing steps. However, to emphasize their approximate nature, the LCA values are presented as a round fraction of the baseline petroleum GHG LCA value (87.5 gCO2e/MJ)

2) For HEFA fuels, we assumed that:
    a. HEFA is moderately feedstock insensitive if algae are excluded (based on previous MIT work), and existing HEFA calculations provide upper, lower, and average value for HEFA LCA
    b. HEFA values are the closest available proxy for metathesis process
    c. HEFA values will be used for any biodiesel/plant oil company because we will assume biodiesel will be converted to jet via the HEFA process

3) For FT fuels, we assumed that:
    a. "typical" BTL and CTL values (with CCS) from the Stratton et al. report provide the mean value for those processes.
    b. BTL and CTL values also provide the min/max (respectively) for CBTL plants, with the "typical" value from the Stratton et al. report (which assumes 20% biomass) as the moderate value for CBTL.

4) For pyrolysis, we assumed that:
    a. Pyrolysis is a liquefaction technique, as is FT
    b. Pyrolysis requires more hydrogen but less energy for the liquefaction (i.e., gasification/catalysis in FT) step than FT and therefore may come relatively close to FT for process GHG emissions
    c. Therefore, for pyrolysis of biomass, the BTL LCA value is the closest available proxy

5) For sugar/cellulosic/corn based processes (alcohols, advanced fermentation, CBP, alcohol oligomerization, dark algae, etc.)
    a. Because the main steps are similar to ethanol fermentation (cellulosic, sugar, or starch ethanol can be correlated to feedstock-based processes in these categories), and because the LCA value is based on energy (per megajoule rather than per gallon), the LCA value for the appropriate feedstock-based ethanol production can be used as a proxy for these other processes.
    b. The key missing step from most of these is alcohol oligomerization, which may or may not be energy intensive, but we assume it is similar to hydroprocessing as a process step, so add 10 g CO2e/MJ to these processes (based on the breakdown of GHG emissions for hydroprocessing in the Stratton et al. report.

6) For algal fuels:
    a. Use values from Stratton et al.
    b. Apply to photosynthetic hydrocarbon processes because inputs should be similar.

Table 14: Greenhouse gas LCA values as fraction of standard petroleum, used to calculate GHG benefits of alternative fuels production.

Process	**Surrogate for:**	**Approximate LCA Value relative to Standard Petroleum Baseline**
HEFA	Metathesis, biodiesel	½
Algae HEFA	Algal oil, algal ethanol, photosynthetic HCs,	½
Sugar (cane) ethanol	Advanced fermentation, alcohol oligomerization (depending on feedstock)	2/5
Cellulosic/waste ethanol	CBP, advanced fermentation, alcohol oligomerization	1/8
Corn/starch ethanol	Advanced fermentation, OH oligomerization, etc.	¾
FT-BTL	Pyrolysis	1/5
FT-CBTL (w/CCS)		2/3
FT-CTL (w/CCS)		9/8
FT-GTL (no CCS)		9/8 (w/o ccs)

Appendix F – CAEP Forecasts of Future Aviation Fuel Demand

The CAEP Forecasts for Aviation Fuel Demand are:

Scenario 1 (*CAEP7 Baseline*): Maintains current operational efficiency levels through NextGen and SESAR, but does not include any technology improvements beyond those available in current (2006) production aircraft.

Scenario 2 (*Low Aircraft Technology and Moderate Operational Improvement*): Maintenance of operational efficiency (Scenario 1), plus fuel burn improvements of 0.96 percent per annum for all aircraft entering the fleet after 2006 and prior to 2015, and 0.57 percent per annum for all aircraft entering the fleet beginning in 2015 out to 2036.

Scenario 3 (*Moderate Aircraft Technology and Operational Improvement*): Maintenance of operational efficiency (Scenario 1), plus fuel burn improvements of 0.96 percent per annum for all aircraft entering the fleet after 2006 out to 2036.

Scenario 4 (*Advanced Aircraft Technology and Operational Improvement*): Maintenance of operational efficiency (Scenario 1), plus fuel burn improvements of 1.16 percent per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide advanced operational improvements of 2% by 2016 and 4% by 2026.

Scenario 5 (*Optimistic Aircraft Technology and Advanced Operational Improvement*): Maintenance of operational efficiency (Scenario 1), plus optimistic fuel burn improvement of 1.5 percent per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide advanced operational improvements of 2% by 2016 and 4% b 2026 This scenario goes beyond the improvements based on industry-based recommendations.

Table 15: CAEP jet fuel demand forecasts for a) North America and b) Europe, based on the Aviation Fuel Demand Query Tool version 1.0.0.0.

a) North America demand forecasts (megatonnes of jet fuel)					
Demand Forecast	2006	2010	2016	2020	2026
Consensus Scenario 1	67.29	76.86	91.23	103.44	121.76
Consensus Scenario 2	67.29	76.00	89.10	98.98	113.79
Consensus Scenario 3	67.29	75.94	88.94	98.17	112.00
Consensus Scenario 4	67.29	74.26	86.80	94.66	106.19
Consensus Scenario 5	67.29	73.98	86.08	93.09	103.36
Low Scenario 1	67.29	75.10	86.82	96.74	111.63
Low Scenario 2	67.29	74.31	84.88	92.74	104.52
Low Scenario 3	67.29	74.26	84.74	92.02	102.93

Low Scenario 4	67.29	72.62	82.70	88.75	97.62
Low Scenario 5	67.29	72.37	82.06	87.34	95.09

b) Europe demand forecasts (megatonnes of jet fuel)

Demand Forecast	2006	2010	2016	2020	2026
Consensus Scenario 1	48.8	59	74.3	87.3	106.8
Consensus Scenario 2	48.8	57.1	71	81.2	96.4
Consensus Scenario 3	48.8	57.1	71	80.7	95.0
Consensus Scenario 4	48.8	54.6	67.7	76.5	89.5
Consensus Scenario 5	48.8	54.4	67.1	75.1	86.9
Low Scenario 1	48.8	56.8	68.8	77.9	91.5
Low Scenario 2	48.8	55	65.8	72.7	82.9
Low Scenario 3	48.8	55	65.8	72.2	81.8
Low Scenario 4	48.8	52.7	62.8	68.6	77.1
Low Scenario 5	48.8	52.4	62.3	67.4	75.0