Project 032 Worldwide Life Cycle Analysis (LCA) of Greenhouse Gas (GHG) Emissions from Petroleum Jet Fuel

Massachusetts Institute of Technology

Project Lead Investigator

Steven Barrett
Professor
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
77 Massachusetts Avenue, 33-322, Cambridge, MA 02139
+1 (617) 452-2550
sbarrett@mit.edu

University Participants

Massachusetts Institute of Technology

- P.I.(s): Professor Steven Barrett,
- FAA Award Number: 13-C-AJFE-MIT, Amendment No. 010
- Period of Performance: December 4, 2014 to September 30, 2016 (reporting with the exception of funding levels and cost share only for period from December 4, 2014 to August 31, 2015)
- Task(s):
    1. Preliminary global baseline analysis for 2005 and 2020
    2. Analysis of changes to the baseline in 2050, assessment of opportunities for reduction in lifecycle GHG emissions
    3. Analysis of world region baseline for recent past and 2020
    4. Final report and data handover

Project Funding Level

$150,000 FAA funding and $150,000 matching funds. Sources of match are approximately $39,000 from MIT, plus 3rd party in-kind contributions of $111,000 from Byogy Renewables, Inc

Investigation Team (all MIT)

Principal Investigator: Prof. Steven Barrett
Co-Investigator: Dr. Robert Malina, Tasks 1-4
Co-Investigator: Dr. Raymond Speth, Tasks 1-4
Dr. Pooya Azadi, Postdoctoral Associate, Tasks 1-4

Project Overview

The total greenhouse gas impact of petroleum-derived fuels includes both direct combustion emissions and the well-to-pump (WTP) emissions associated with extraction, transportation, and refining of crude oil and transportation of refined products. In this project, the WTP life cycle emissions of petroleum-derived jet fuel are quantified. The analysis addresses both temporal and spatial variation in WTP emissions of jet fuel.

Tasks and Plans for Next Period

Task 1: Preliminary global baseline analysis for 2005 and 2020

1.1 Analysis of global portfolio for crude recovery emissions

- 1.2. Analysis of global transportation emissions developed
- 1.3 Analysis of global refinery emissions
- 1.4 Completion of white paper for use at ICAO steering group meeting

Task 2: Analysis of changes to the baseline in 2050, assessment of opportunities for reduction in lifecycle GHG emissions

- 2.1 Assessment of 2050 emissions baseline for jet fuel from petroleum
- 2.2 Quantification of opportunities for reduction in lifecycle GHG emissions by lifecycle stage

Plans for next period

Task 3: Analysis of world region baseline for recent past and 2020

- 3.1. Analysis of crude mix profiles by world region
- 3.2 Analysis of transportation and refinery emission profiles by world region accounting for differences in straight-run and hydroprocessed processing
- 3.3 Analysis of lifecycle GHG emissions baseline for jet fuel from petroleum by world region
- 3.4 Refinement of preliminary global baseline using world-region results

Task 4: Final report and data handover

- 4.1 Completion of white paper on project available for sponsor review
- 4.2 Data preparation for handover to Argonne National Laboratory for use in GREET model

Objectives

The main objective of this project is to calculate GHG emissions estimates for petroleum jet fuels for the recent past and for future scenarios in the coming decades. Results will be reported globally and broken out by world regions, and the impact of changes in future demand for certain petroleum products and of changes in crude properties will be quantified. Opportunities for reductions in GHG emissions along the supply chain will be estimated.

Research Approach

Background

To date, only a limited number of analyses of GHG emissions for jet fuel from petroleum sources exist, limited to the United States and generally relying on 2005 data (Skone and Gerdes 2009, Stratton et al. 2012). A recent update to the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) developed and maintained by Argonne National Laboratory includes more recent data on refining efficiency from a report by Elgowainy et al. (2014), but is still U.S.-specific, only.

To the best of our knowledge, no baseline value for jet fuel from petroleum has been established in other world regions. In Europe, for example, baseline values are calculated for diesel fuels from petroleum, but not for jet fuel (JEC 2014). Moreover, there is no baseline value on a global scale that describes average lifecycle GHG intensity of using jet fuel from petroleum, either for fuel produced now or for scenarios of projected future petroleum-derived jet fuel use. Existing values for jet and diesel that are used in the US and the EU are summarized in Figure 1.

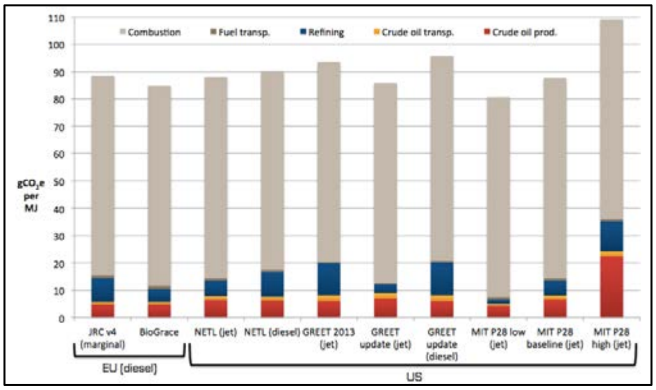

Figure 1: Lifecycle GHG emission values used as baselines in the EU and U.S. (Malina et al. 2014).

This is a particularly important research gap given the ongoing efforts under the Committee on Aviation Environmental Protection (CAEP) of the International Civil Aviation Organization (ICAO) to include alternative fuels into a global system of market-based measures, which requires the existence of a petroleum-centric benchmark to compare an alternative fuel to, so that airlines can receive appropriate monetary credits for using these fuels. Moreover, a baseline is required for current work under the Alternative Fuels Task Force (AFTF) of ICAO CAEP to estimate the potential contribution of large-scale alternative jet fuel introduction to mitigating aviation's climate impact by the year 2050.

Moreover, from a temporal perspective, the crude mix used in refineries changes over time, as do refining and recovery practices and product slates produced, which might impact on associated lifecycle emissions for jet fuel from petroleum both globally and within specific world regions. For example, using the most recent update to GREET, average lifecycle GHG emissions attributable to jet from petroleum in the U.S. are estimated at 85.8 gCO2e per MJ of jet fuel, whereas Skone and Gerdes (2009) reported 88.0 gCO2e per MJ (Malina et al., 2014).

Methodology

For both conventional and unconventional (e.g., oil sands, shale) petroleum-derived jet fuels, we investigate and quantify greenhouse gas emissions in all stages of the petroleum-derived jet fuel lifecycle (crude recovery, feedstock transportation, feedstock-to-fuel conversion, jet fuel transportation, and jet fuel combustion). For the recovery stage, we will build upon existing analyses on emission profiles for different representative crude types and recovery practices such as the analyses by Rahman et al. (2014), Bouvart et al. (2013), Garg et al. (2013), Charpentier (2009) and Skone and Gerdes (2009). In case of missing data for emissions associated with recovery of certain crude types, we approximate them with emissions from crude types with similar recovery practices.

Data on crude mixes used in the different world regions have been obtained from existing analysis mentioned above and by data from the International Energy Agency (IEA) and the Energy Information Administration (EIA). This data is necessary both for assigning recovery emissions to jet fuel produced in a particular word region, and for estimating refinery emissions. Scenarios for future crude mixes will be developed by using data about crude reserves by country or world-region such as those maintained by OECD and EIA.

Refinery GHG emissions are based on refinery usage statistics in world regions where this data is available (i.e. U.S. and Europe), and estimated based on refinery configurations and capacities in other regions. Characteristics of the input crude slate such as sulfur content and API gravity have been used to determine process energy requirements and resulting emissions. We use available information to estimate the relative amounts of straight-run and hydroprocessed jet fuel that are produced by refineries worldwide. We use insights from process-level refinery linear programming (LP) models to both estimate the emissions from both the production of straight-run and hydroprocessed jet fuels as well as understand how changes in relative transportation fuel demand affects refinery energy usage and GHG production, and how those changes affect the GHG emissions attributed jet fuel. For future scenarios where demand for jet fuel may exceed straight-run production capabilities, emissions will be estimated for the upgrading processes needed to convert other fractions of the input crude to jet fuel. Changes in refinery emissions associated with more stringent fuel standards (e.g. ultra-low-sulfur jet) may also be calculated.

Feedstock and product transportation emissions for each world region are calculated by combining representative transportation distances with emission profiles of representative means of transportations accessible in the GREET and/or SimaPro tools.

We will investigate and quantify opportunities for reducing lifecycle GHG emissions of jet fuel from petroleum by lifecycle step. Opportunities that will be quantified, for example, include the use of utilities and inputs produced from renewable resources, changes in refinery configurations and practices, changes in crude sourcing and associated transportation distances, and modes of transportation used.

Calculations will be made available for implementation into the GREET model, if desired by FAA.

Milestone(s)

Due Date	**Milestone**
May 1st, 2015	MS 1 (related to Task 1): Crude extraction emission's profiles compiled
August 1st, 2015	MS 2 (related to Task 1): Preliminary global baseline results available for FAA discussions
Mid October 2015	MS 3 (related to Task 1): Presentation of preliminary global baseline emissions at CRC Workshop
November 1st, 2015	MS 4 (related to Task 1): White paper available on preliminary global baseline for use at ICAO Steering group meeting
March 1st, 2016	MS 5 (related to Task 2): Preliminary results of GHG emissions baseline for 2050 available for discussion
May 1st, 2016	MS 6 (related to Task 3): World-region specific baseline results available for discussion
June 1st, 2016	MS 7 (related to Task 2): Opportunities for lifecycle GHG reductions for jet fuel from petroleum available for discussion
September 30th, 2016	MS 8 (related to Task 4): White paper on project available for FAA review

Major Accomplishments

We have thus far fulfilled the requirements of MS1 and MS2, i.e. the emissions associated with extraction of crude and global baseline results of jet fuel WTP emissions. The analysis is based on a country-specific life cycle model encompassing data on each lifecycle stage that allows for calculating world-region-specific and global WTP emissions for each fuel type. We have gathered the required raw data from over twenty international and national agencies, as well as private companies. In total, 72 sources of emission associated with crude production in 90 countries, refining in 687 refineries across 112 countries, and global crude and product movements have been quantified.

For the year 2005 (Figure 2), we estimate the global mean WTP emissions for an average unit of gasoline, diesel, jet fuel, and bunker fuel to be 21.5, 18.6, 14.6, and 12.7.0 gCO2-e/MJ, respectively. The differences in WTP emissions of these petroleum-based fuels are primarily attributed to the differences in the extent to which catalytic cracking, hydrocracking, and hydrotreating refinery units contribute to producing each fuel.

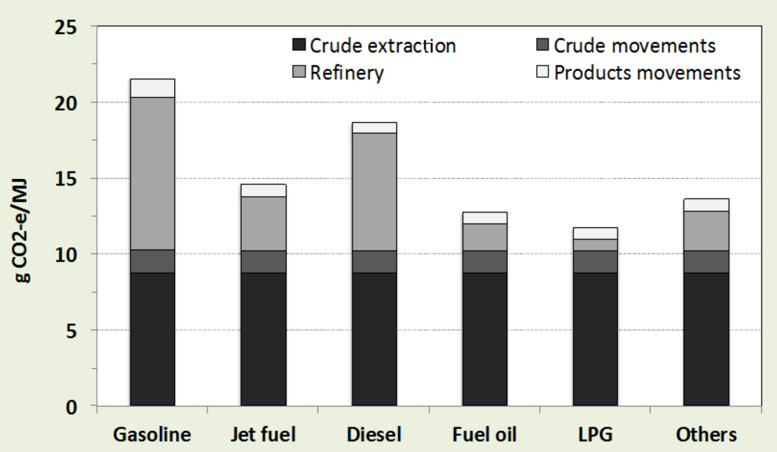

Figure 2: Global average Lifecycle GHG emission values of petroleum-derived fuels in 2005.

Between 2005 and 2012, changes in regional supply and demand for the different fuel products and increasing exploitation of unconventional petroleum resources increased WTP emissions while reductions in flaring and fugitive emissions reduced WTP emissions. The global mean WTP emissions for an average unit of gasoline, diesel, jet fuel, and bunker fuel to be 22.5, 18.7, 14.8, and 13.0 gCO2-e/MJ, respectively (Figure 3). The differences in WTP emissions of these petroleum-based fuels are primarily attributed to the differences in the extent to which catalytic cracking, hydrocracking, and hydrotreating refinery units contribute to producing each fuel. Overall, per-unit WTP emissions increased by 4% between 2005 and 2012.

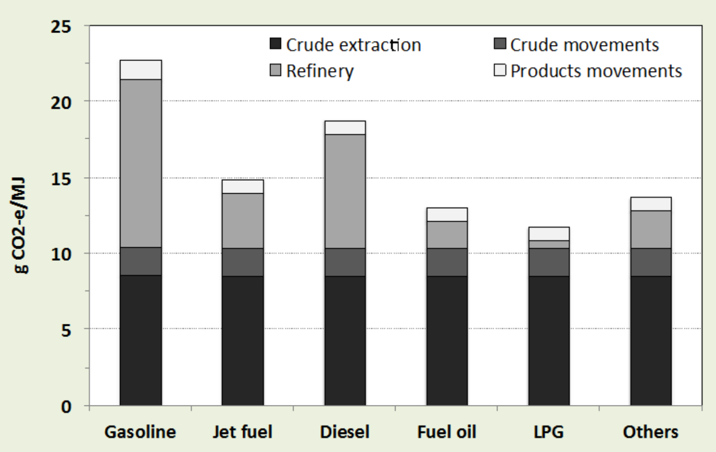

Figure 3: Global average Lifecycle GHG emission values of petroleum-derived fuels in 2012.

Furthermore, we estimate that by 2020, global mean emissions will be 4% higher than in 2012 baseline (Figure 4) mostly due to higher shares of unconventional crudes and hydroprocessed refined products.

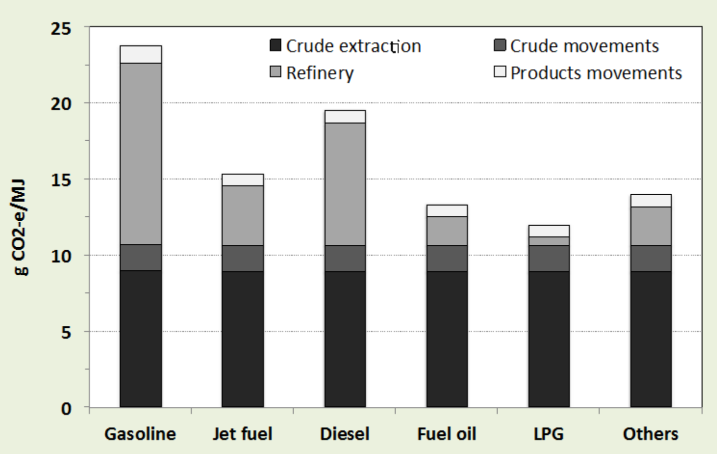

Figure 4: Estimated global average Lifecycle GHG emission values of petroleum-derived fuels in 2020.

Figure 5 demonstrates the refinery emissions associated with production of jet fuel from major production pathways. Depending on the processes involved, the jet fuel refinery emission can vary from 0.9 to 16.9 g CO_2-e/MJ with the global average of 4.2 g CO_2-e/MJ. After accounting for the share of emissions from refinery flaring and credits from refinery co-generation, the global average refinery emission attributable to jet fuel is estimated at 3.7 g CO_2-e/MJ.

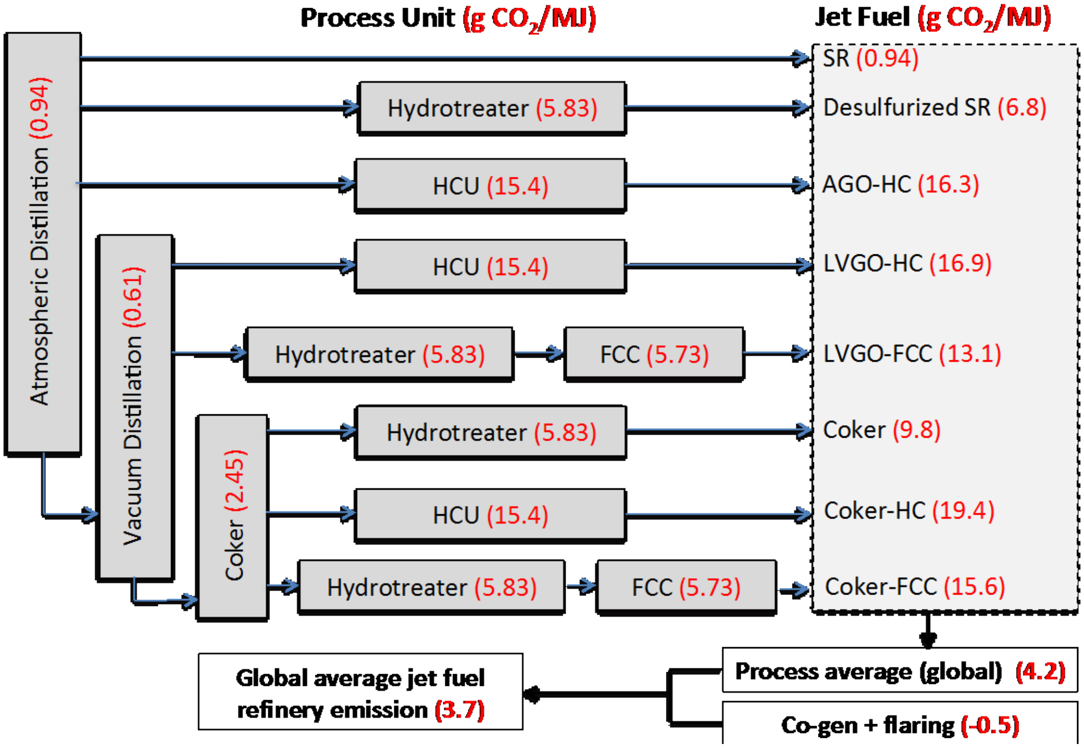

Figure 5: Jet fuel refinery GHG emissions under different production pathways.

Publications

Life Cycle GHG Emission of Jet Fuel from Conventional Oils and Forecasted Crude mix in 2020, submitted to ICAO AFTF

Outreach Efforts

FAA monthly project updates from January to September.
AFTF LCA Task group working meeting on fossil fuel baseline

Awards

None.

Student Involvement

None.

Plans for Next Period

The research in the following year will be focused on MS3 through MS8. We will be presenting our findings on global baseline emissions at the CRC workshop in October 2015, and we will submit our written contribution to ICAO steering group by November.

We will extend our current global baseline analysis to year 2050 based on different scenarios that will be defined with regard to crude production (grade and region) as well as the forecasted demand slate. The results will be submitted by March 2016.

As for the next stage of the project, we will compile the country-specific emissions to calculate the world region-specific emissions in 2012 and 2020. As a part of this step, we will calculate the intra-region and inter-region emissions associated with movements of crude and refined products and will allocate those emission along with their respective upstream emissions separately to the region where the final fuel consumption takes place. Next, the results obtained for year 2050 along with sensitivity analysis will be used to identify and quantify the opportunities for reducing the WTP emissions of jet fuel.

Finally, all of the findings of the study will be compiled into a white paper and will be submitted as MS8 in September 2016.

References

Bouvart, F. / Saint-Antonin, V. / Gruson, J. (2013): Well-to-tank carbon impact of fossil fuels, ADEME report PAE02 002 600, Rueil-Malmaison, France.

Caiazzo, F. / Malina, R. / Staples, M. / Wolfe, P. / Yim, S. / Barrett, S. (2014): Quantifying the climate impacts of albedo changes due to biofuel production: a comparison with biogeochemical effects. in: Environmental Research Letters Vol. 9, 024015.

Charpentier, A. / Bergerson, J. / MacLean, H. (2009): Understanding the Canadian oil sands industry's greenhouse gas emissions. Environmental Research Letters, Vol. 4(1), 014005.

Elgowainy, A. / Han, J. / Cai, H. / Wang, M. / Forman, G. / Divita, V. (2014): Energy Efficiency and Greenhouse Gas Emission Intensity of Petroleum Products at US Refineries. Environmental science & technology, in press.

Garg A. / Vishwanathan S. / Avashia V (2013): Life cycle greenhouse gas emission assessment of major petroleum oil products for transport and household sectors in India. Energy Policy, Vol. 58, pp. 38-48.

ICAO CAEP (2014): Draft LCA methodology report, Information Paper CAEP-SG/20142-IP/5, Montreal, Canada.

JEC (2014): Well-to-tank report Report Version 4.a, Ispra, Italy.

Malina, R. / Staples M. / Wang, M.: “A quantitative comparison of LC GHG accounting for alternative fuels in the US and EU”, Inaugural meeting ICAO CAEP AFTF April 1, 2014, Montreal, Canada.

Rahman, M. /, Canter, C., / Kumar, A. (2014): Greenhouse gas emissions from recovery of various North American conventional crudes. *Energy*, in press.

Seber, G. / Malina, R. / Pearlson, M. / Olcay, H. / Hileman, J. / Barrett, S (2014): Environmental and economic assessment of producing hydroprocessed jet and diesel fuel from waste oils and tallow, in: Biomass and Bioenergy, Vol. 67, pp. 108-118.

Skone, T / Gerdes, K (2009): Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels, DOE/NETL-2009/1346, National Energy and Technology Laboratory, Pittsburgh, PA.

Speth, R. / Chow, E. / Malina, R. / Barrett, S. / Heywood, J. / Green, W. (2014): Economic and Environmental Benefits of Higher-Octane Gasoline, in: Environmental Science and Technology Vol. 48 (12), pp. 6561-6568.

Staples, M. / Malina, R. / Olcay, H. / Pearlson, M. / Hileman, J. / Boies, A. / Barrett, S. (2014): Lifecycle greenhouse gas footprint and minimum selling price of renewable diesel and jet fuel from fermentation and advanced fermentation production technologies, in: Energy and Environmental Science, Vol. 7, pp. 1545-1554.

Stratton, R. / Wong, H. / Hileman, J. (2011): Quantifying variability in life cycle greenhouse gas inventories of alternative middle distillate transportation fuels. Environmental science & technology, Vol. 45(10), pp. 4637-4644.