Project 31(A) Alternative Jet Fuel Test and Evaluation

University of Dayton Research Institute

Project Lead Investigator

Steven Zabarnick, Ph.D.
Division Head
Fuels and Combustion Division
University of Dayton Research Institute
300 College Park, Dayton, OH 45469-0043
937-255-3549
Steven.Zabarnick@udri.udayton.edu

University Participants

University of Dayton Research Institute

- P.I.(s): Steven Zabarnick, Division Head
- FAA Award Number: 13-C-AJFE-UD
- Overall Period of Performance: April 8, 2015 to August 31, 2019
- Period of Performance: April 8, 2015 to March 14, 2016 – Amendment No. 006
  1. Evaluate candidate alternative fuels for their performance via the ASTM D4054 approval process
- Period of Performance: August 13, 2015 to August 31, 2016 – Amendment No. 007
  2. Evaluate candidate alternative fuels for their performance via the ASTM D4054 approval process
- Period of Performance: August 5, 2016 to August 31, 2017 – Amendment No. 012
  3. Management of Evaluation and Testing of Candidate Alternative Fuels
- Period of Performance: July 31, 2017 to August 31, 2019 – Amendment No. 016
  4. Management of Evaluation and Testing of Candidate Alternative Fuels
- Period of Performance: August 30, 2018 to August 31, 2019 – Amendment No. 021
  5. Management of Evaluation and Testing of Candidate Alternative Fuels

Project Funding Level

Amendment No. 006	$309,885
Amendment No. 007	$ 99,739
Amendment No. 012	$693,928
Amendment No. 016	$999,512
Amendment No. 021	$199,966

In-kind cost share has been obtained from:

LanzaTech	$ 55,801 (2015)
LanzaTech	$ 381,451 (2016)
Neste	$ 327,000 (2017)
Boeing	$2,365,338 (2017)

Investigation Team

Steven Zabarnick, PI, New candidate fuel qualification and certification
Richard Striebich, Researcher, Fuel chemical analysis and composition
Linda Shafer, Researcher, Fuel chemical analysis and composition
John Graham, Researcher, Fuel seal swell and materials compatibility
Zachary West, Researcher, Fuel property evaluations

Project Overview

Alternative jet fuels offer potential benefits of reducing global environmental impacts, achieving national energy security, and stabilizing fuel costs for the aviation industry. The Federal Aviation Administration is committed to the advancement of "drop in" alternative fuels and has set the aspirational goal of enabling the use of 1 billion gallons annually by 2018. Successful adoption of alternative fuels requires approval for use of the fuel by the aviation community followed by large scale production of a fuel that is cost competitive and meets safety standards of conventional jet fuel. Alternative jet fuels must undergo rigorous testing to become qualified for use and be incorporated into ASTM International Specifications.

Cost effective and coordinated performance testing capability (in accordance with ASTM D4054) to support evaluation of promising alternative jet fuels is needed. The objective of this project is to provide capability to conduct the necessary work to support alternative jet fuel evaluation of either a) to-be-determined fuel(s) that will be selected in coordination with the FAA or b) a fuel test and evaluation project with a specific fuel(s) in mind.
The proposed program should provide the following capabilities:

- Identify alternative jet fuels (which may include blends with conventional jet fuel) to be tested and that have the potential to be economically viable and support FAA's NextGen environmental goals.
- Perform engine, component, rig, or laboratory tests, or any combination thereof, to evaluate the performance of an alternative jet fuel in accordance with ASTM International standard practice D4054.
- Identify and conduct unique testing, beyond that defined in ASTM International standard practice D4054, necessary to support evaluation of alternative jet fuels for inclusion in ASTM International jet fuel specifications.
- Obtain data for baseline and alternative jet fuels to demonstrate any effects of the alternative jet fuel on aircraft performance, maintenance requirements, and reliability.
- Coordinate effort with activities sponsored by Department of Defense and/or other government parties that may be supporting relevant work.
- Report relevant performance data of the alternative fuels tested including a quantification of the effects of the alternative fuel on aircraft and/or engine performance and on air quality emissions relative to conventional jet fuel. Reported data will be shared with both the FAA (NJFCP) and the broader community (e.g., ASTM International) and with ASCENT COE Program 33 "Alternative Fuels Test Database Library."

Tasks 1 and 2- Evaluate Candidate Alternative Fuels for their Performance via the ASTM D4054 Approval Process and Management of Evaluation and Testing of Candidate Alternative Fuels

University of Dayton Research Institute

Objective(s)

Cost effective and coordinated performance testing capability (in accordance with ASTM D4054) to support evaluation of promising alternative jet fuels is needed. The objective of this project is to provide capability to conduct the necessary work to support alternative jet fuel evaluation of either a) to-be-determined fuel(s) that will be selected in coordination with the FAA or b) a fuel test and evaluation project with a specific fuel(s) in mind.

Research Approach

The intent of this program is to provide the capability of performing specification and fit-for-purpose (FFP) evaluations of candidate alternative fuels toward providing a pathway forward through the ASTM D4054 approval process. The UDRI team possesses the capability of performing a large of number of these evaluations and we are prepared to work with other organizations such as SwRI and engine OEM's, as needed, for their unique test capabilities. These include additional engine, APU, component, and rig evaluations. The UDRI testing capabilities cover our efforts at the laboratories of the Fuels Branch of AFRL and at our campus laboratory facilities.

The following are examples of the evaluations that UDRI is able to provide:
Tier I
1. Thermal Stability (Quartz Crystal Microbalance)
2. Freeze Point (ASTM D5972)
3. Distillation (ASTM D86)
4. Hydrocarbon Range (ASTM D6379 & D2425)

5. Heat of Combustion (ASTM D4809)
6. Density, API Gravity (ASTM D4052)
7. Flash Point (ASTM D93)
8. Aromatics (ASTM D1319)

Tier II

1. Color, Saybolt (ASTM D156 or D6045)
2. Total acid number (ASTM D3242)
3. Aromatics, (ASTM D1319 & ASTM D6379)
4. Sulfur (ASTM D 2622)
5. Sulfur mercaptan (ASTM D3227)
6. Distillation temperature (ASTM D86)
7. Flash point (ASTM D56, D93, or D3828)
8. Density (ASTM D1298 or D4052)
9. Freezing point (ASTM D2386, D5972, D7153, or D7154)
10. Viscosity, at -20˚C, (ASTM D445)
11. Net heat of combustion (ASTM D4809)
12. Hydrogen content (ASTM D3343 or D3701)
13. Smoke point (ASTM D1322)
14. Naphthalenes (ASTM D1840)
15. Calculated cetane index (ASTM D976 or D4737)
16. Copper strip corrosion (ASTM D130)
17. Existent gum (ASTM D381)
18. Particulate matter (ASTM D2276 or D5452)
19. Filtration time (MIL-DTL-83133F Appendix B)
20. Water reaction interface rating (ASTM D1094)
21. Electrical conductivity (ASTM D624)
22. Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (ASTMD3241)

Extended Physical and Chemical Characterization

1. Lubricity Evaluation- BOCLE test (ASTM D5001)
2. Low Temperature Properties – Scanning Brookfield Viscosity
3. Detect, quantify, and/or identify polar species - Analyze as necessary
4. Detect, quantify and/or identify dissolved metals - Analyze as necessary
5. Initial Material Compatibility Evaluation – Perform optical dilatometry and Partition Coefficient Measurements to determine the fuel-effected swell and the fuel solvency in 3 O-ring materials (nitrile, fluorosilicone and fluorocarbon) and up to 2 additional fuel system materials
6. Experimental Thermal Stability Evaluation – Quartz Crystal Microbalance – Measure thermal deposit tendencies and oxidation profile at elevated temperatures
7. Viscosity versus Temperature – (ASTM D445) determination of the fuels viscosity at 40˚C and -40˚C to assess the fuel's viscosity's variation with temperature

In addition to the above physical and chemical fuel evaluation capabilities, UDRI has extensive experience in evaluation of microbial growth in petroleum-derived and alternative fuels. These evaluations include standard lab culturing and colony counting methods, and advanced techniques such as quantitative polymerase chain reaction (QPCR) and metagenomic sequencing. These methods allow the quantitative measurement of microbial growth rates in candidate alternative fuels in comparison with petroleum fuels.

UDRI also has extensive experience in evaluation of elastomer degradation upon exposure to candidate alternative fuels. Various methods are used to evaluate seal swell and o-ring fixture leakage, including: optical dilatometry, measurement of sealing pressure, fuel partitioning into elastomer, and a pressurized temperature controlled o-ring test device.

UDRI is also able to perform fuel-material compatibility testing using the D4054 procedures for fuel soak testing, post-exposure non-metallic and metal materials tests, and surface and microstructural evaluation. Testing of both 68 "short-list" materials and the complete 255 materials list can be performed.

Milestone(s)
The schedule for this project is dependent upon receipt of alternative fuel candidates for testing. As candidate fuels are received a schedule of testing will be coordinated with the FAA and collaborators. Our existing relationships with these organizations will help expedite this process.

Major Accomplishments
The Phase I Research Report for the LanzaTech/PNNL Ethanol-to-Jet (LT/PNNL ATJ) Synthetic Paraffinic Kerosene Fuels and Blends has been completed and submitted to the OEM's for approval. The Boeing/Neste HFP-HEFA research report has been completed and is in the process of Phase I review by the OEM's. We are awaiting arrival of the Shell IH2 and IHI Bb Oil fuels for Phase 1 evaluations.

Publications
"Evaluation of LanzaTech/PNNL Ethanol-to-Jet (LT/PNNL ATJ) Synthetic Paraffinic Kerosene Fuels and Blends Phase 1 Research Report," 2016.

"Evaluation of High Freeze Point HEFA as Blending Component for Aviation Jet Fuels," ASTM Research Report Version 1.1, 2017.

Outreach Efforts
Presentations were given at the April and Sept 2017 ASCENT meeting and meetings were held with European D4054 Clearinghouse initiators at the Rome IASH meeting in September. Meetings were held in Dayton with IHI, a Japanese company interested in entering their algae fuel in the D4054 process. We also continue to speak with Shell on their soon to be submitted IH2 fuel.

Awards
None

Student Involvement
None

Plans for Next Period
We plan to attend the ASTM December meeting in Houston and hold an OEM meeting with fuel producers in a separate session prior to the main ASTM meeting as in the past. We expect to receive the first shipment of the Shell IH2 fuel and begin the process of testing the fuel for Tier 1 and 2 evaluations. We expect to receive the first shipment of the IHI Bb oil algae fuel near the end of 2018.

Tasks 3 and 4- Management of Evaluation and Testing of Candidate Alternative Fuels
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Objective(s)
The objective of this work is to manage the evaluation and testing of candidate alternative jet fuels conducted in accordance with ASTM International standard practice D4054 (see Figure 1).

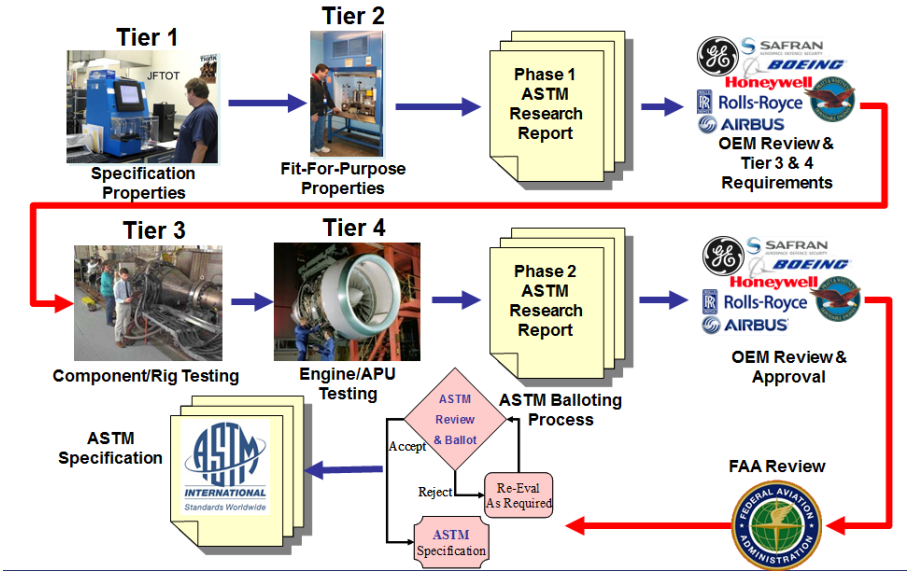

Figure 1. ASTM D4054 Qualification Process

Research Approach

UDRI will subcontract with other research organizations and/or test laboratories or OEMs to carry out the following tasks in support of evaluation and ASTM specification development for AJFs. The purpose of the project is to manage and coordinate the D4054 evaluation process shown in Figure 2 in order to facilitate transition of alternative fuels to commercial use.

Subtask 1: General Support

- Develop and make available a D4054 process guide that describes logistics procedures for handling of test fuels, documentation requirements, test report issuance and delivery, and contact information. This is intended to provide clear instructions to candidate fuel producers for entering into the ASTM D4054 process.

Subtask 2: Phase 1 Support

- Coordinate the handling of the Phase 1 candidate test fuel samples for Tier 1 and 2 testing.
- Review process description provided by the fuel producer for acceptability for incorporation into the Phase 1 research report.
- Review test data from Tier 1 and 2 testing for acceptability for incorporation into the Phase 1 research report.
- Issue and deliver a Phase 1 research report to the OEMs.
- In conjunction with the fuel producer, review and respond to comments to Phase 1 Research Report submitted by the OEMs.
- Conduct additional Tier 1 or 2 testing in response to OEM comments, as required.
- Review and consolidate OEM requirements for D4054 Tier 3 and 4 testing submitted by the OEMs.
- Deliver consolidated D4054 Tier 3 and 4 testing requirements to the fuel producer.

Subtask 3: Phase 2 Support

- Coordinate the funding and scheduling of D4054 Tier 3 and 4 testing with OEMs and other test facilities.
- Coordinate the handling of the Phase 2 candidate test fuel samples for Tier 3 and 4 testing.
- Review test data from Tier 3 and 4 testing for acceptability for incorporation into the Phase 2 research report.
- Issue and deliver the Phase 2 research report to the OEMs.
- In conjunction with the fuel producer, review and respond to comments to the Phase 2 Research Report submitted by the OEMs.
- Conduct additional Tier 3 or 4 testing in response to OEM comments as required.
- Issue and deliver Phase 2 research report addendums reporting the additional Tier 3 or 4 test results, as required.

Subtask 4: OEM Review Meetings

- Schedule periodic OEM Review Meetings to review the status of testing and research report review.
- Identify suitable meeting venues and support equipment.
- Develop agendas and coordinate with attendees for participating in the meeting.
- Record meeting minutes, including agreements, commitments, and other action items.
- Issue and distribute the meeting minutes to all attendees.

Subtask 5: Single Laboratory GCxGC Method Documentation

- Document UDRI GCxGC methodology for hydrocarbon type analysis.
- Develop reference materials for creation of GCxGC hydrocarbon type templates.
- Measure single laboratory precision of the GCxGC methods.
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Subtask 6: Multi-Laboratory GCxGC Method Documentation

- Validate precision of the methods over multiple laboratories and GCxGC methods.
- Identify alternative GCxGC methods, including column selection and order, and modulation techniques.
- Perform correlation study to determine agreement between laboratories, methods, and hardware choices.

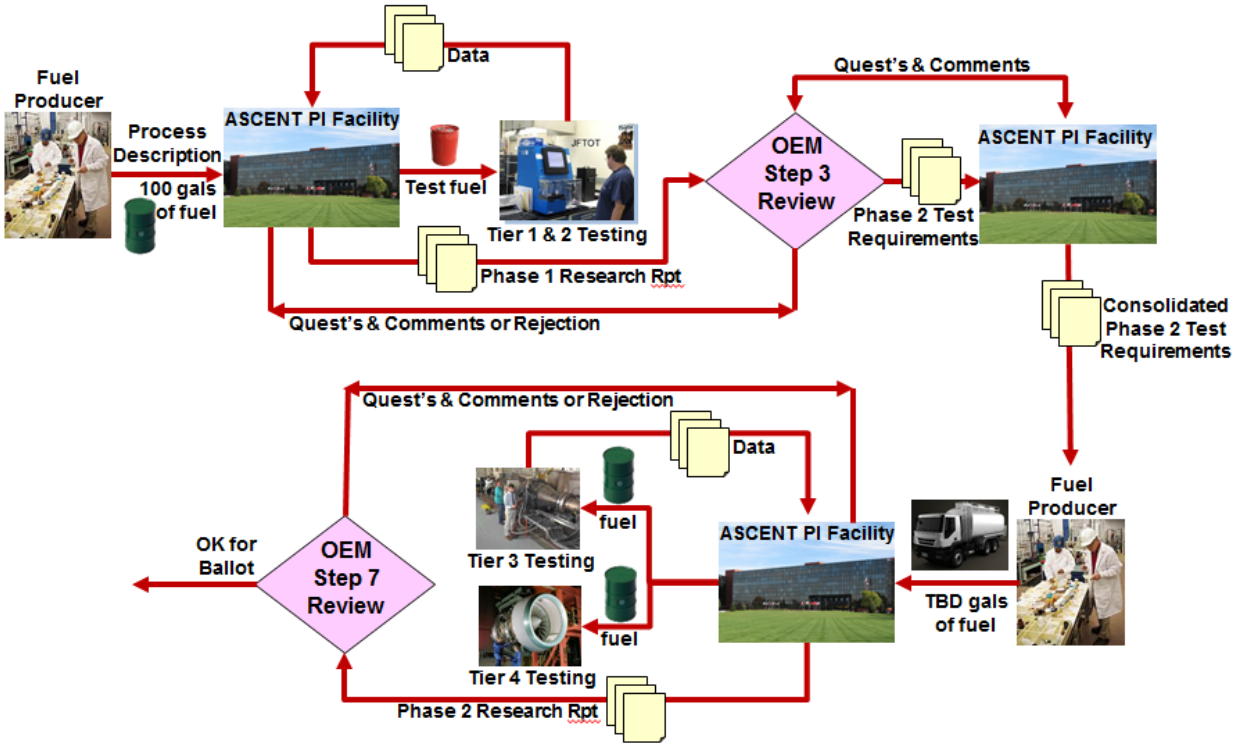

Figure 2. D4054 Evaluation Process

Milestone(s)

The schedule for this project is dependent upon receipt of alternative fuel candidates for testing. As candidate fuels are received a schedule of testing will be coordinated with the FAA and collaborators. Our existing relationships with these organizations will help expedite this process. Figure 3 shows a Gantt chart schedule for the testing and approval of candidate fuels that are in the process of being evaluated and/or about to the enter the process.

D4054 Clearinghouse
Forecasted Fuel Evaluation Schedule

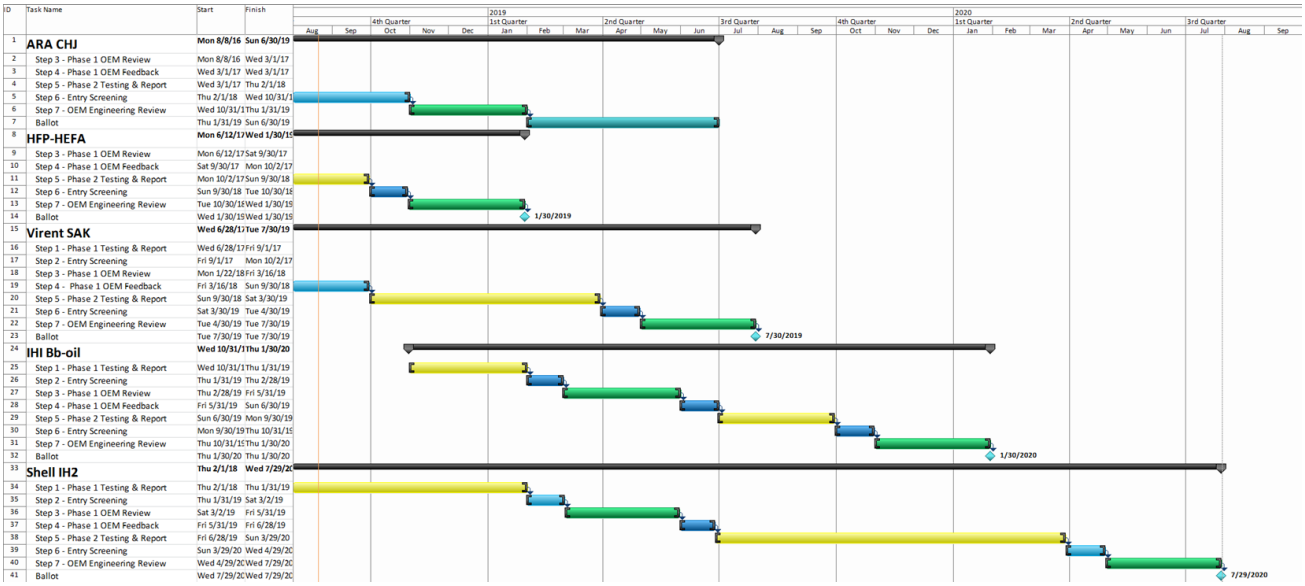

Figure 3. Schedule for Fuel Evaluations

Major Accomplishments

A major accomplishment of this project is the approval of the LanzaTech Ethanol-to-Jet Synthetic Paraffinic Kerosene Fuel and inclusion into Annex A5 of ASTM D7566 in March 2018. The Boeing/Neste HFP-HEFA research report has been completed and is in the process of Phase I review by the OEM's. The Virent SAK fuel Phase 1 research report is completed and awaiting evaluation by the OEM committee. The ARA CHJ fuel report is in the hands of the supplier after OEM feedback. UDRI performed initial testing of the Shell IH2 fuel and provided feedback and guidance to the supplier for methods which will improve the quality and stability of a future sample submission. We are awaiting the imminent arrival of this second Shell IH2 sample and an initial sample of the IHI Bb Oil fuel for Phase 1 evaluations. We held OEM meetings on the fuel approval process at the December 2017 ASTM D02 meeting in Houston and the March 2018 UK MoD Aviation Fuels Committee meeting in London.

We began support of the development of a generic annex for a more rapid approval of fuels to D7566. The generic annex concept was abandoned in the spring of 2018 as the OEMs wanted to continue to have approval authority for new production processes and feedstocks (the generic annex did not require OEM approval). A new concept was developed, called the "fast track annex," which would provide (via D4054) a rapid approval pathway for new fuels that meet a set of strict composition and performance criteria. This fast track annex is being viewed positively and was submitted for ASTM balloting in October 2018.

We evaluated an oxygen measurement instrument (the Elementar Oxycube with IR detector) for measurement of low concentrations of oxygenate contaminants in candidate fuels. The OEM committee is concerned that current chemical analysis techniques may not be able to detect all of the species. Via a catalytic partial reduction, the instrument converts all O atoms in a sample to CO followed by IR detection. We evaluated the instrument using multiple sample injection methods for its ability to measure down to 10 ppm oxygen. Unfortunately, background oxygen molecules and dissolved water interfere with the measurement. Working closely with the instrument company we determined that the instrument was unable to provide the required detection limit, repeatability, and reproducibility needed for measuring low levels of oxygenate contaminants in candidate fuel samples.

We continue to provide feedback to fuel suppliers and the OEM committee on the candidate fuel evaluation schedule via the Gantt chart shown in Figure 3. The chart is updated frequently as testing and evaluation is accomplished and schedule changes occur.

We have held biweekly meetings with the Shell IH2 team on the status of the fuel submission and the planned testing. We have also held monthly meetings with the IHI Bb Oil team on their fuel submission.

We attended the ASTM OEM meeting (December 2017 in Houston) with engine and airframe OEMs to review progress on ASTM research report reviews. We gave a presentation on the chemical analysis of heteroatomic polars for development of a generic annex for alternative fuel certification. We presented a project overview at the ASCENT April 2018 ASCENT meeting in Cambridge, MA. We also attended the March 2018 AFC meeting in London and discussed alternative fuel qualification and certification with the FAA and OEMs. Discussions with alternative fuel candidate producers also occurred at each of these meetings.

Publications

"Evaluation of High Freeze Point HEFA as Blending Component for Aviation Jet Fuels," ASTM Research Report Version 1.1, 2017.

UDRI Method FC-M-101, "Flow Modulation GCxGC for Hydrocarbon Type Analysis of Conventional and Alternative Aviation Fuels," UDR-TR-2018-40.

UDRI Method FC-M-102, "Identification and Quantification of Polar Species in Conventional and Alternative Aviation Fuel Using SPE-GCxGC," UDR-TR-2018-41

Outreach Efforts

Presentations on Project 31a were given at the April (Boston) and October (Alexandria) 2018 ASCENT meetings. Meetings were held with the OEM team, FAA, and others at the December 2017 ASTM D02 Committee Meeting in Houston TX and the March 2018 UK MoD Aviation Fuels Committee meeting in London UK. Monthly meetings were held in Dayton with IHI, a Japanese company interested in entering their algae fuel in the D4054 process. We also continue to have biweekly teleconferences with Shell on their soon to be submitted IH2 fuel.

Awards

None

Student Involvement

Amanda Arts, University of Kentucky Co-op Student

Plans for Next Period

We plan to attend the ASTM December meeting in Atlanta and hold an OEM meeting with fuel producers in a separate session prior to the main ASTM meeting as in the past. We expect to receive the first shipment of the Shell IH2 fuel and begin the process of testing the fuel for Tier 1 and 2 evaluations. We expect to receive the first shipment of the IHI Bb oil algae fuel near the end of 2018 and will begin testing at that time.