Alternative Jet Fuel Test and Evaluation

Project 31a

Lead investigator: S. Zabarnick, University of Dayton Research Institute
Project manager: C. Shaw, FAA

October 22-23, 2019
Alexandria, VA

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 31a through FAA Award Number 13-C-AJFE-UD-023 under the supervision of Cecilia Shaw. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.

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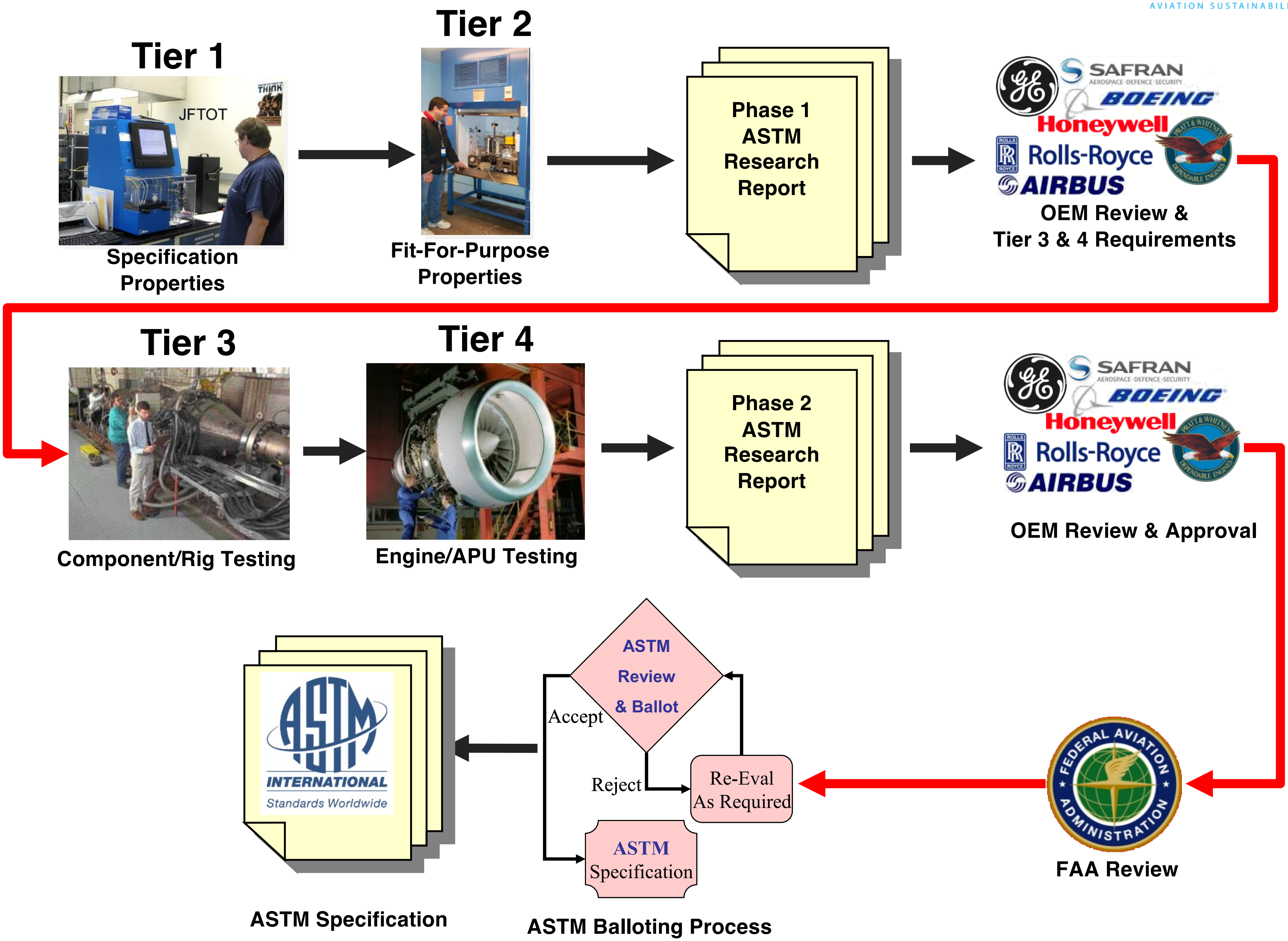
Introduction

- Motivation – Establish a centralized facility to support continued approval/certification of candidate alternative jet fuels through the ASTM process
- Objectives
  - Fuel property and composition testing
  - Support for rig/engine evaluations
  - Coordination of OEM approval process
- Outcomes and practical applications
  - ASTM research reports for OEM approval
  - Creation of D7566 annex
  - Recognized focal point for management of D4054 qualifications process
  - Increased supply of secure, safe alternative aviation fuels

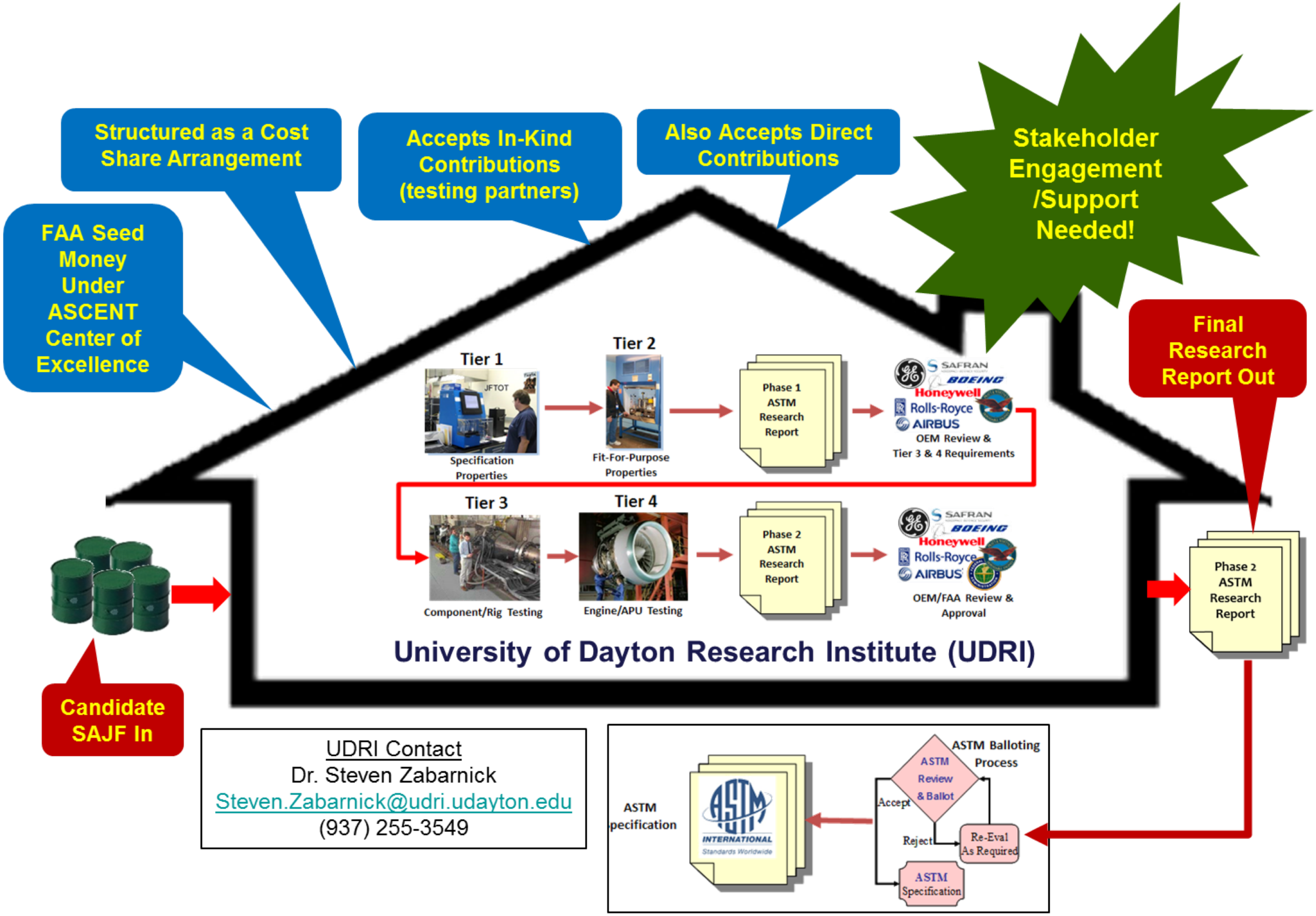
Primary Tasks

- Alternative Fuel Candidate Evaluation
  - Shell IH2, IHI Bb-oil, Swedish Biofuels, Fulcrum Bioenergy FT co-processing being tested
- Coordination of Research Report Review Process
  - ARA CHJ, Virent SAK, IHI Bb-oil (Fast Track)
- GCxGC Method Development – hydrocarbon type and trace polars methods
  - Replace D2425 mass spec method
  - Method documentation, precision determination, comparison with other labs/columns/modulators

D4054 Certification Process



D4054 Clearinghouse Concept



UDRI Contact
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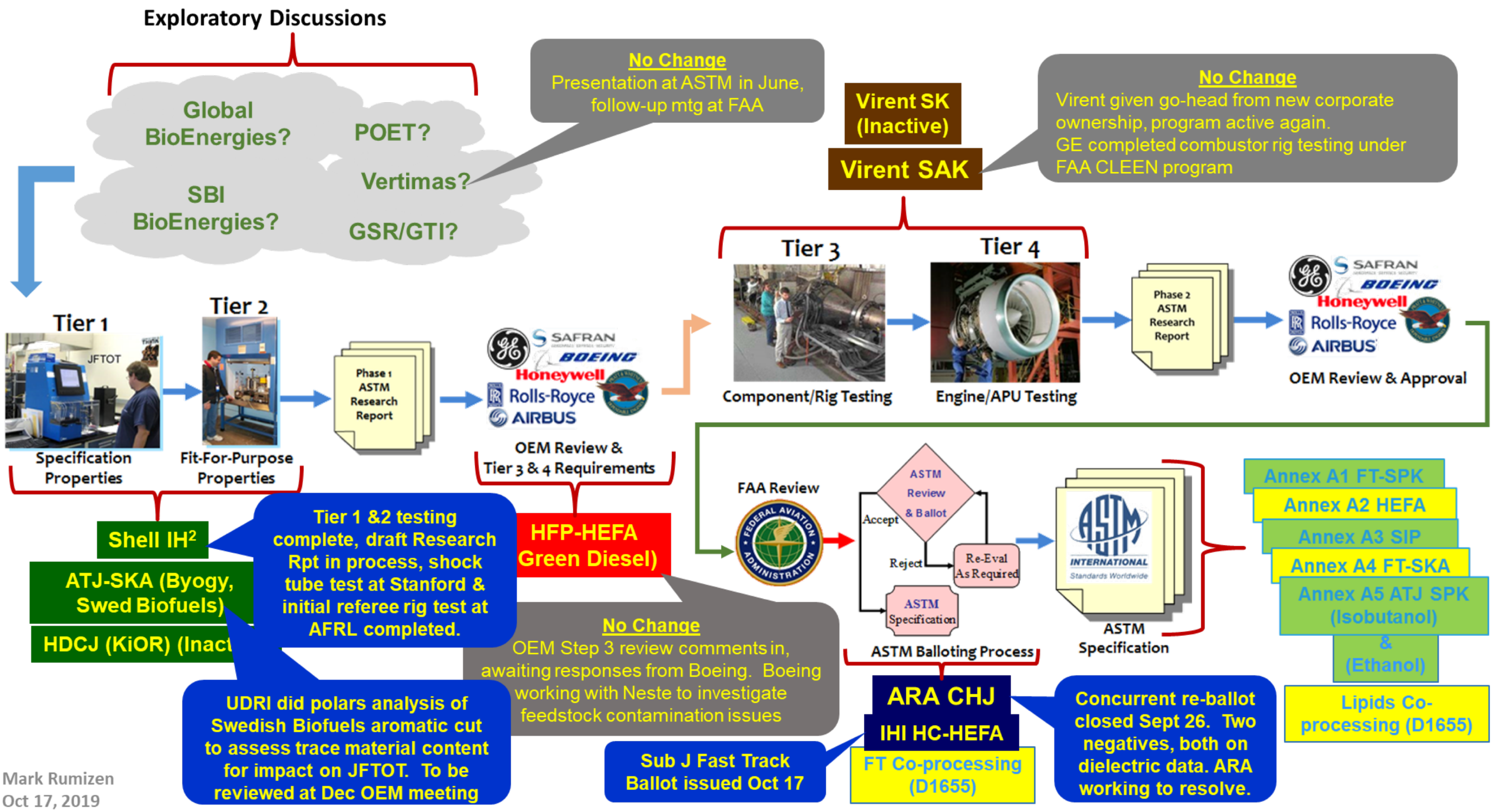
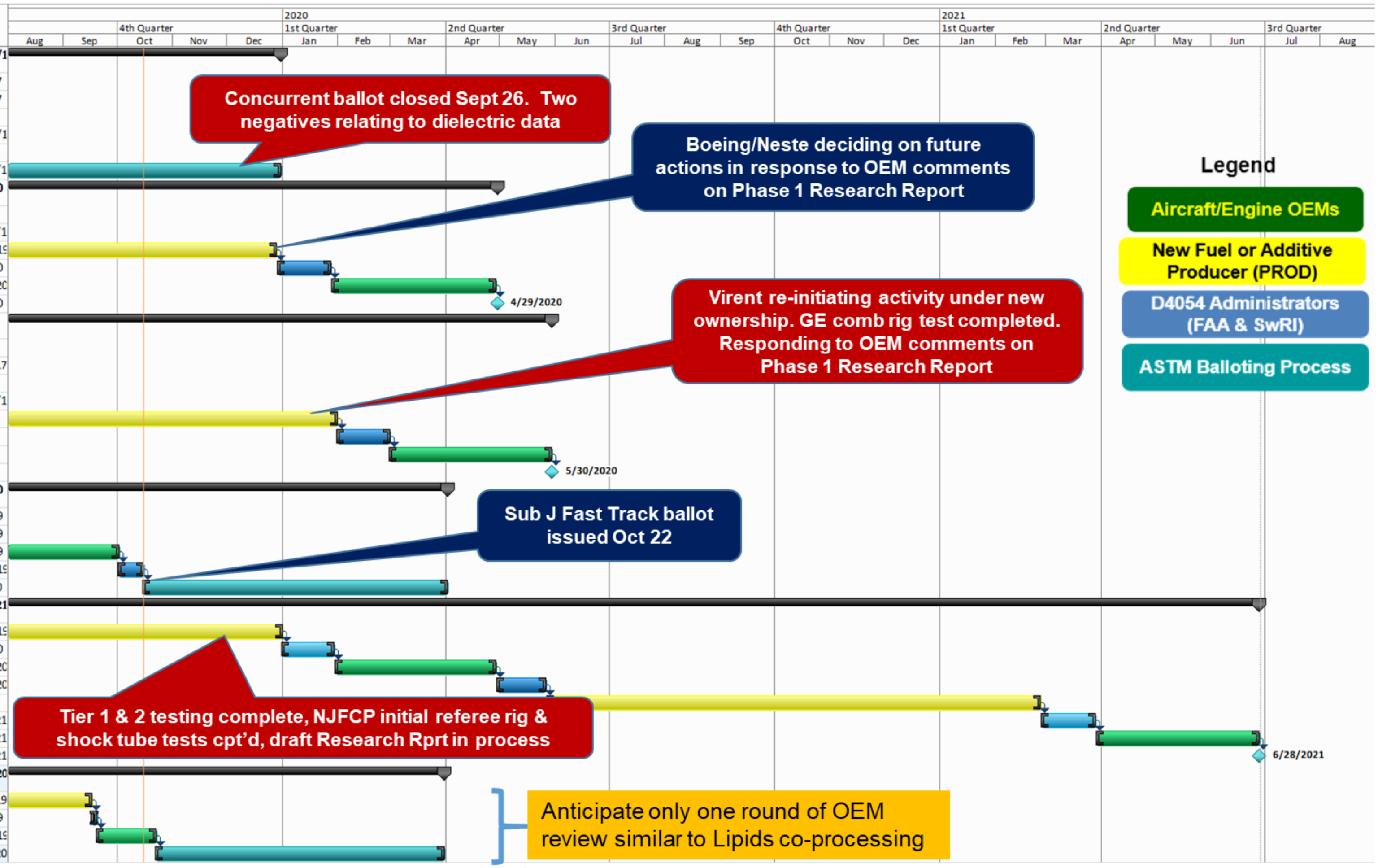
Candidate Fuels in Queue



Mark Rumizen
Oct 17, 2019

Gantt Schedule for Current Fuels

ID	Task Name	Start	Finish
1	**ARA CHJ**	**Mon 8/8/16**	**Mon 12/30/1**
2	Step 3 - Phase 1 OEM Review	Mon 8/8/16	Wed 3/1/17
3	Step 4 - Phase 1 OEM Feedback	Wed 3/1/17	Wed 3/1/17
4	Step 5 - Phase 2 Testing & Report	Wed 3/1/17	Thu 2/1/18
5	Step 6 - Entry Screening	Thu 2/1/18	Wed 10/31/1
6	Step 7 - OEM Engineering Review	Wed 10/31/1	Fri 3/1/19
7	Ballot	Fri 3/1/19	Mon 12/30/1
8	**HFP-HEFA**	**Mon 6/12/17**	**Thu 4/30/20**
9	Step 3 - Phase 1 OEM Review	Mon 6/12/17	Sat 9/30/17
10	Step 4 - D4054 Admin	Sat 9/30/17	Mon 12/31/1
11	Step 5 - Phase 2 Testing & Report	Mon 12/31/1	Sun 12/29/19
12	Step 6 - Entry Screening	Sun 12/29/19	Tue 1/28/20
13	Step 7 - OEM Engineering Review	Tue 1/28/20	Wed 4/29/20
14	Ballot	Thu 4/30/20	Thu 4/30/20
15	**Virent SAK**	**Wed 6/28/17**	**Sat 5/30/20**
16	Step 1 - Phase 1 Testing & Report	Wed 6/28/17	Fri 9/1/17
17	Step 2 - Entry Screening	Fri 9/1/17	Mon 10/2/17
18	Step 3 - Phase 1 OEM Review	Mon 1/22/18	Fri 3/16/18
19	Step 4 - Phase 1 OEM Feedback	Fri 3/16/18	Mon 12/31/1
20	Step 5 - Phase 2 Testing & Report	Mon 12/31/1	Fri 1/31/20
21	Step 6 - Entry Screening	Fri 1/31/20	Sat 2/29/20
22	Step 7 - OEM Engineering Review	Sat 2/29/20	Sat 5/30/20
23	Ballot	Sat 5/30/20	Sat 5/30/20
24	**IHI Bb-oil**	**Thu 2/28/19**	**Wed 4/1/20**
25	Step 1 - FsTrk Testing	Thu 2/28/19	Tue 5/14/19
26	Step 2 - Entry Screening	Tue 5/14/19	Thu 5/30/19
27	Step 3 - OEM FsTrk Review	Thu 5/30/19	Tue 10/1/19
28	Step 4 - Ballot Prep	Tue 10/1/19	Tue 10/15/19
29	Step 5 - Ballot Phase	Tue 10/15/19	Wed 4/1/20
30	**Shell IH2**	**Thu 2/1/18**	**Mon 6/28/21**
31	Step 1 - Phase 1 Testing & Report	Thu 2/1/18	Tue 12/31/19
32	Step 2 - Entry Screening	Tue 12/31/19	Thu 1/30/20
33	Step 3 - Phase 1 OEM Review	Thu 1/30/20	Wed 4/29/20
34	Step 4 - Phase 1 OEM Feedback	Wed 4/29/20	Wed 5/27/20
35	Step 5 - Phase 2 Testing & Report	Wed 5/27/20	Fri 2/26/21
36	Step 6 - Entry Screening	Fri 2/26/21	Mon 3/29/21
37	Step 7 - OEM Engineering Review	Mon 3/29/21	Mon 6/28/21
38	Ballot	Mon 6/28/21	Mon 6/28/21
39	**FT Co-Processing**	**Tue 1/1/19**	**Mon 3/30/20**
40	Testing and Report	Tue 1/1/19	Mon 9/16/19
41	Admin Review	Mon 9/16/19	Thu 9/19/19
42	OEM Review	Thu 9/19/19	Tue 10/22/19
43	Ballot	Tue 10/22/19	Mon 3/30/20



October 18, 2019

Status of Subcontracts for ASTM Research Report Review

- SwRI – ... ch report review (...
- Honeywell –
- Rolls Royce –
- GE Avi...
- Pratt ...
- Boeing –

All Subcontracts Extended to Aug 2020

Additional Funding Needed to Continue the ASTM Approval Process

Generic Annex → Fast Track Annex

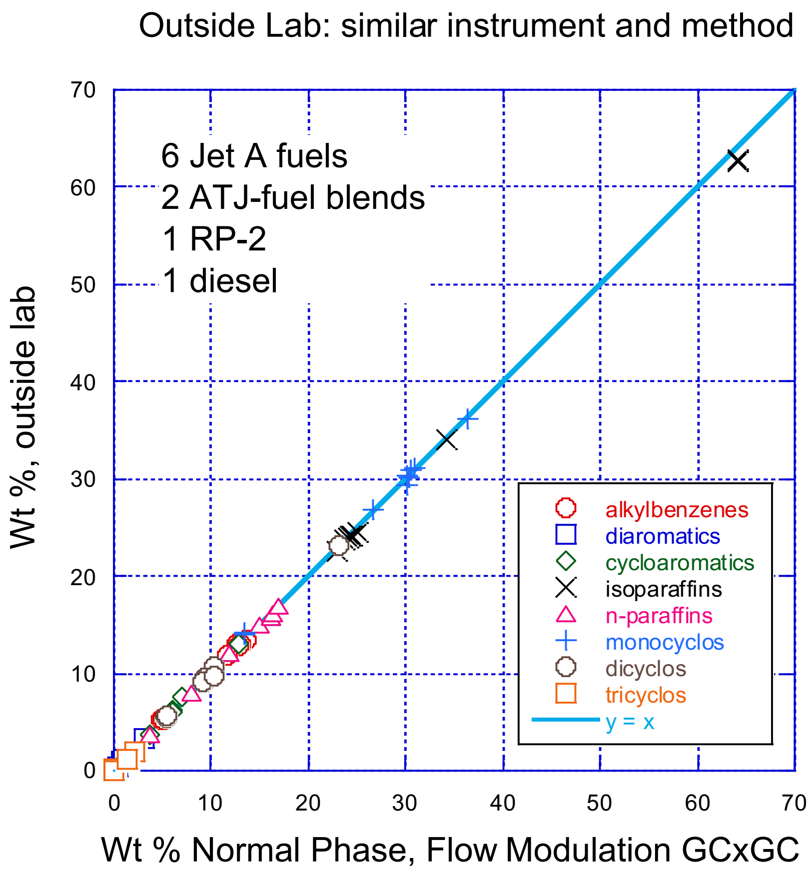
- Generic Annex D7566 – no OEM review process
  - Stringent property requirements
  - Feedstock and process not defined
  - Push back from OEMs on approval without OEM review
  - Abandoned in Spring/Summer 2018
- Fast Track Annex for D4054 – defines new streamlined approval process
  - *Stringent property requirements*
  - *More detailed Table 1 (composition, C# distribution, etc.)*
  - *Feedstock and process defined*
  - Includes OEM review requirement
  - D7566 annex produced – 10% blend limit?

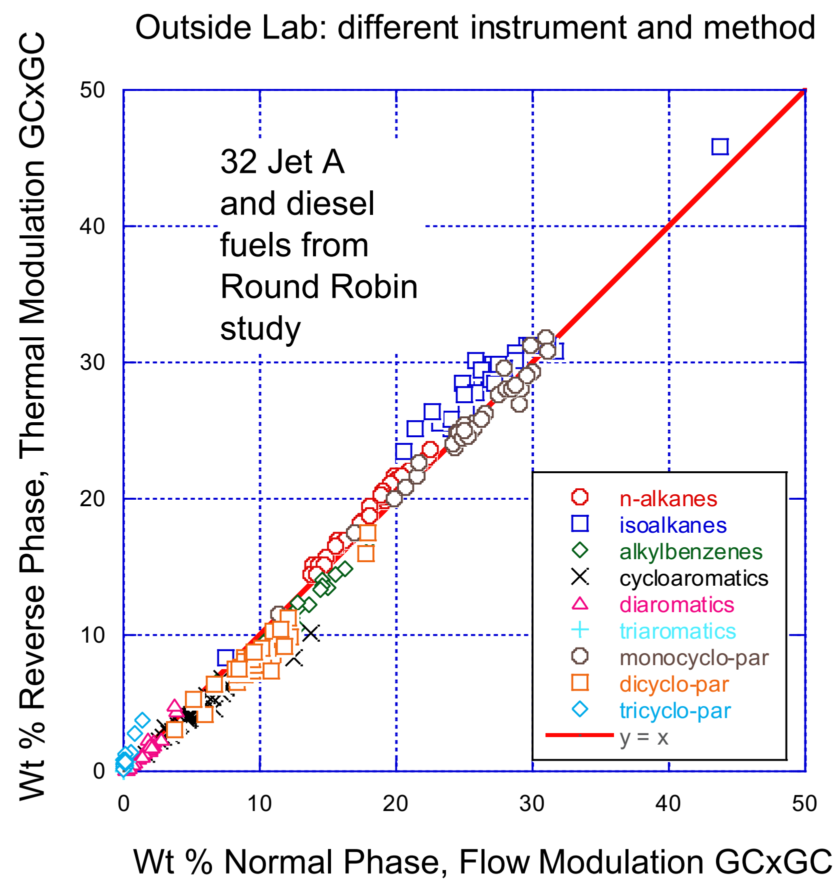
Research report

Fast Track Annex
Approved April 2019!

GCxGC Precision Evaluation

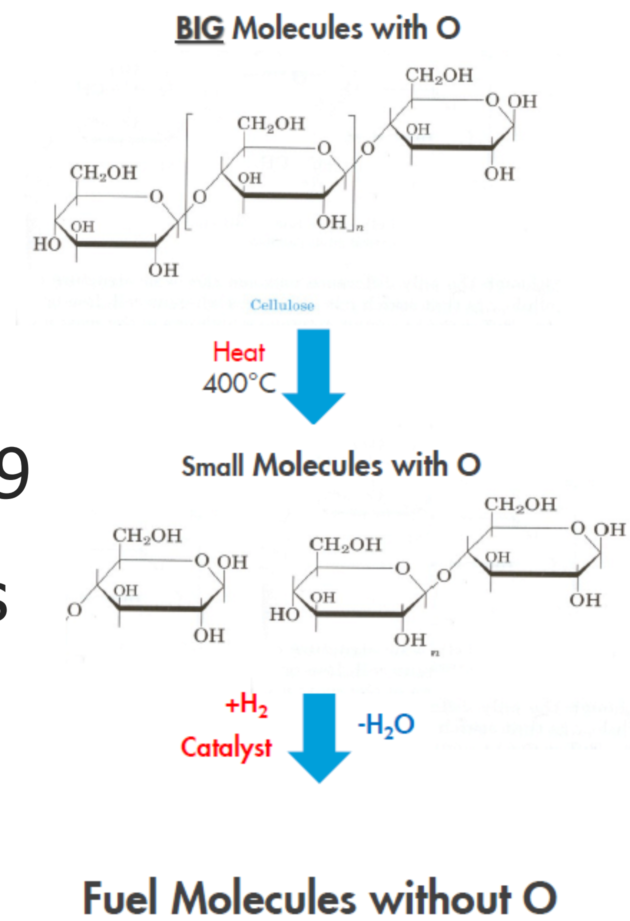
- Completed method documentation – UDRI reports
- Completed intralab precision ("little r") – repeatability
- Finalizing interlab precision ("big R") – Reproducibility
  - Modulation methods, reverse vs normal phase, etc.





Shell IH² Technology

- Hydropyrolysis & hydrotreating of biomass
- Woody biomass, MSW, Ag residue, etc.
- ~95% cycloparaffins (5% other paraffins)
- Original sample showed storage degradation
- New sample evaluated – received Jan 2019
- High cycloparaffin content – likely requires Tier 3/4 evaluations – combustor rig/APU
- NJFCP evaluation just completed
  - Referee rig cold LBO @ UDRI/AFRL
  - Shock tube ignition delay @ Stanford
  - Additional referee rig work proposed – hot LBO and ignition

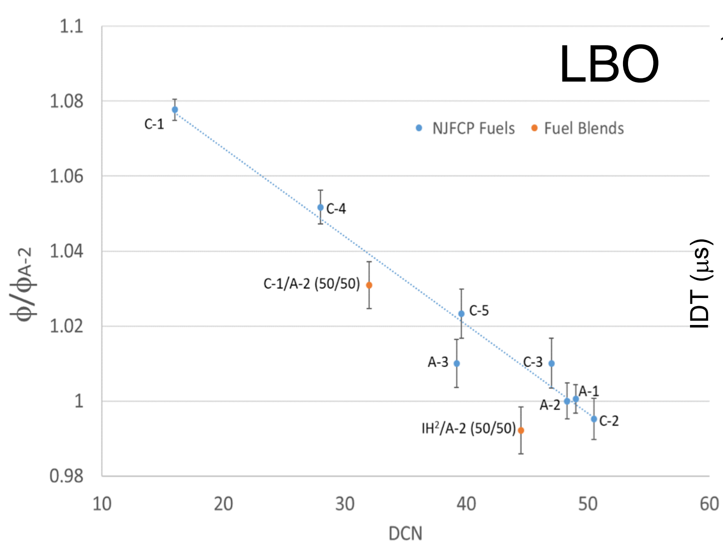


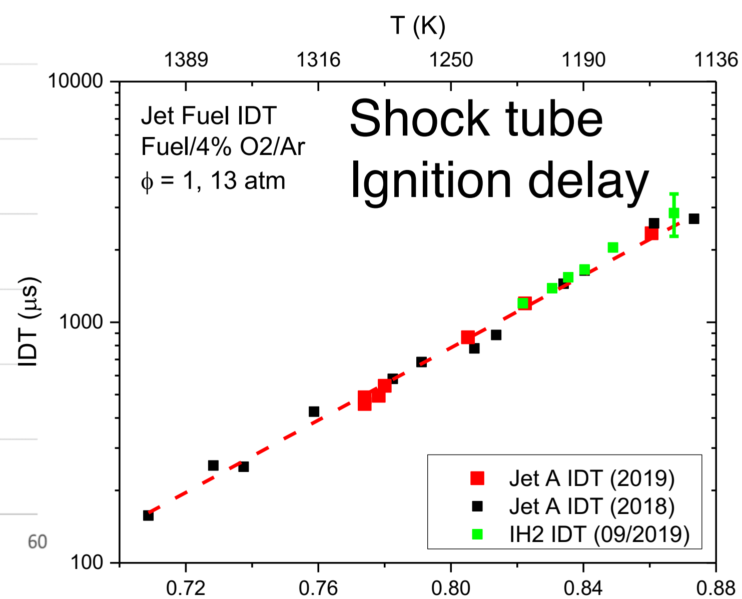
Shell IH² Results

- Unusual composition
  - Very high cycloparaffin content (95.7%)
  - Very high density (0.832 kg/m³)
- All other properties look good to date
  - Seal swell much improved over iso/normal paraffinic fuel
- 50/50 blend meets all D1655 properties
- OEMs require Tier 3 combustion and extended material compat evaluations
- Referee rig LBO similar to A-2 fuel & shock tube ignition delay is normal

GCxGC Hydrocarbons

	POSF-10325 Jet A	POSF-13511 IH2-CPK-0	POSF-13512 50/50 Blend
Hydrogen Content (weight %)	14.0	13.8	13.9
Average Molecular Weight (g/mole)	159	148	153
Column1	Weight %	Weight %3	Weight %6
Total Alkylbenzenes	12.89	0.05	6.04
Total Alkylnaphthalenes	2.28	<0.01	1.06
Total Cycloaromatics	3.24	0.04	1.51
Total Aromatics	18.41	0.08	8.60
Total iso-Paraffins	28.75	1.70	14.65
Total n-Paraffins	18.96	2.56	10.56
Total Monocycloparaffins	25.11	47.12	35.53
Total Dicycloparaffins	8.53	40.33	25.83
Total Tricycloparaffins	0.23	8.21	4.80
Total Cycloparaffins	33.88	95.66	66.15



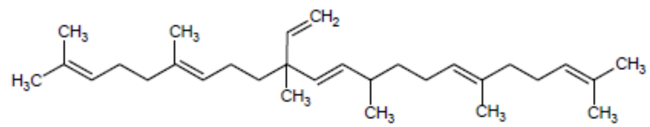


GCxGC-SPE Polars

Speciated Polars (mg/L)	Jet A POSF-10325	IH2-CPK-0 POSF-13511	50/50 Blend POSF-13512
Phenols	120	<1	64
Anilines	3	<1	1
Indoles	1	<1	<1
Quinolines	8	<1	4
Tetrahydro-quinolines	1	<1	<1
Pyridines	2	<1	1
Carbazoles	2	<1	1
Ketones	54	<1	28
Cycloketones	19	<1	10
Alcohols	20	1	11
Aldehydes	6	<1	3
Ethers	1	1	1
Esters	1	1	1
Phthalates	<1	<1	<1
Other	99	1	52
Total	**336**	**4**	**176**

IHI Bb-oil Technology

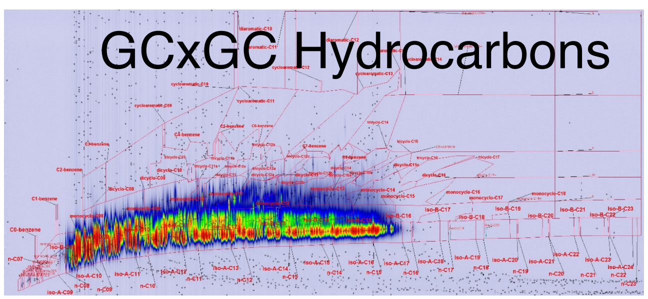
- Open pond algae cultivation – algae strain selected and bred to maximize hydrocarbon production
- Typical algal processing:
  – Cultivation, dewatering, drying, extraction, conversion
- 80-90% hydrocarbon, 10-20% free fatty acids



- Deoxygenation, hydroisomerization/ hydrocracking similar to HEFA processes
- Composition similar to HEFA except for high cycloparaffins – ~30-50%
  – high density 0.778, above HEFA SPK limit
- Submitted for Fast Track evaluation – Jan 2019

IHI Bb-SPK Results

- Cycloparaffin content (40.0%) is higher than other D7566 approved SPK's (15%) and Fast Track limit (30%)
  - Cycloparaffins are now understood to be highly desirable fuel components
- Density is high for SPK due to high cycloparaffin content
  - Annex would have higher lower limit
  - Higher density is desirable – more "fuel-like"
- All other properties look good to date
- 50/50 blend meets all D1655 properties



- Phase 1 Research Report submitted June 2019; OEM review completed Aug 2019
- Additional testing performed; new sample just received: Bb-SPK3

GCxGC Hydrocarbons

Column1	POSF-10325 Jet A	POSF-13516 IHI-Bio-SPK	POSF-13517 50/50 Blend
	Weight %	Weight %	Weight %
Total Alkylbenzenes	12.89	<0.03	6.59
Total Alkylnaphthalenes	2.28	<0.01	1.10
Total Cycloaromatics	3.24	<0.01	1.64
Total Aromatics	18.41	<0.03	9.33
Total iso-Paraffins	28.75	56.00	41.99
Total n-Paraffins	18.96	4.01	12.14
Total Monocycloparaffins	25.11	33.66	29.51
Total Dicycloparaffins	8.53	6.02	6.77
Total Tricycloparaffins	0.23	0.27	0.25
Total Cycloparaffins	33.88	39.95	36.53

GCxGC-SPE Polars

Speciated Polars (mg/L)	Jet A POSF-10325	IHI-Bio-SPK POSF-13516	50/50 Blend POSF-13517
Phenols	120	<1	57
Anilines	3	<1	1
Indoles	1	<1	<1
Quinolines	8	<1	4
Tetrahydro-quinolines	1	<1	1
Pyridines	2	<1	<1
Carbazoles	2	<1	1
Ketones	54	<1	26
Cycloketones	19	<1	9
Alcohols	20	<1	11
Aldehydes	6	<1	3
Ethers	1	<1	1
Esters	1	1	<2
Phthalates	<1	1	<2
Other	99	1	50
Total	**336**	**<5**	**165**

2019 FY New Tasks

- Fulcrum Bioenergy FT co-processing (syngas from MSW gasification) – testing VGO feed and FT/VGO product
  - To be balloted October 2019
- Referee rig cold LBO of Shell IH^2 - completed
- Combustion rig & APU evaluations of Shell IH^2 – not yet funded
- Database (Project 33) support – not yet funded
- Continued OEM research report review support – need additional funds to continue after fall/winter 2019
- GCxGC method development/documentation – continuing

Acknowledgements

- We our cost share partners:

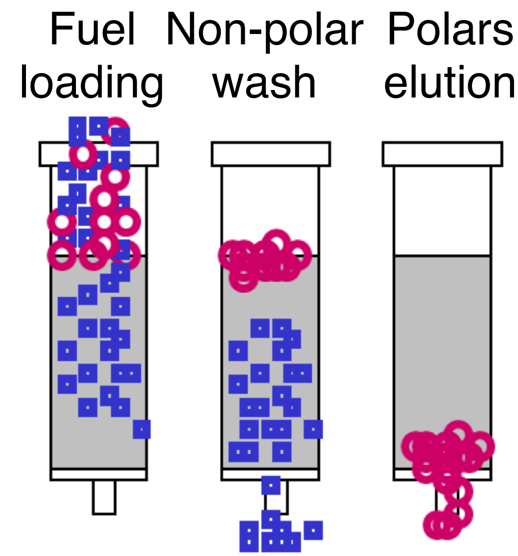
IHI Realize your dreams, BOEING, Shell, NESTE, GE Aviation, Canada NRC·CNRC, LanzaTech

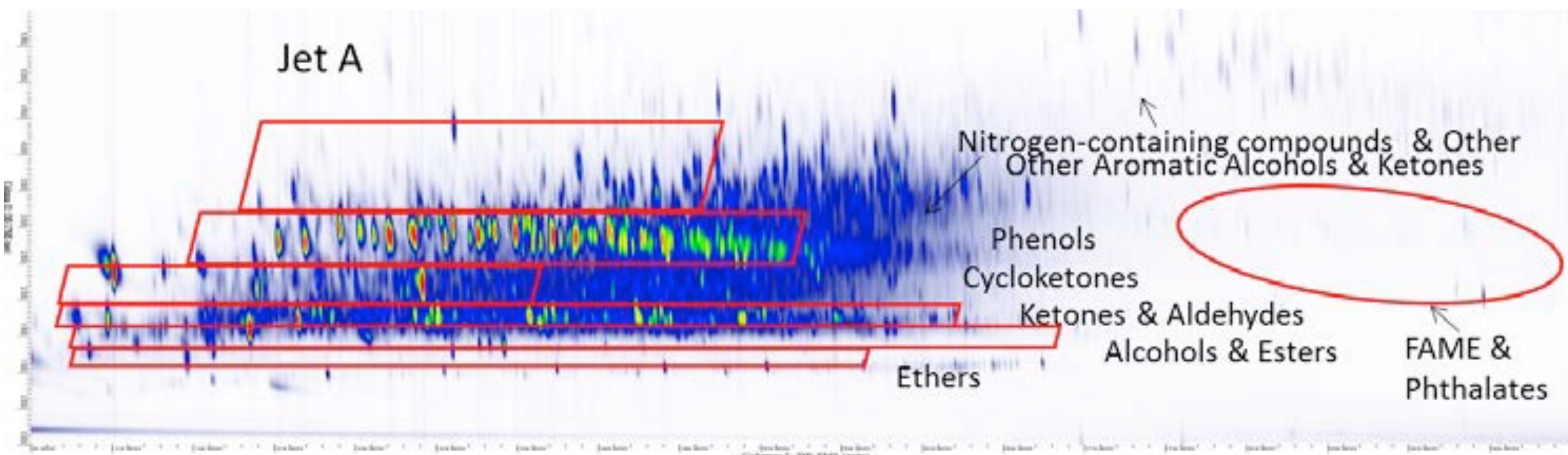
- Thanks to FAA AEE Team: Cecilia Shaw, Levent Ileri, Jim Hileman, and Mark Rumizen
- Thanks to the AFRL Fuels Branch (Tim Edwards, Paul Wrzesinski, Milissa Griesenbrock) for use of their facilities
- UDRI Team – Linda Shafer, Rich Striebich, Zach West, John Graham, Chris Klingshirn (AFRL), Rhonda Cook, Sam Tanner, Carlie Anderson, Tak Yamada, Carol Treon

Backup Slides

Chemical Composition for the Fast Track Annex

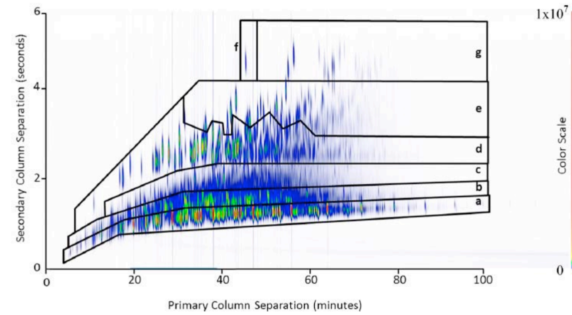
- Need to limit non-hydrocarbon species & select limits
- Sulfur, nitrogen, oxygen, and metals
- ASTM methods exist for S, N, and metals
- GCxGC with SPE for polar oxygenates/N



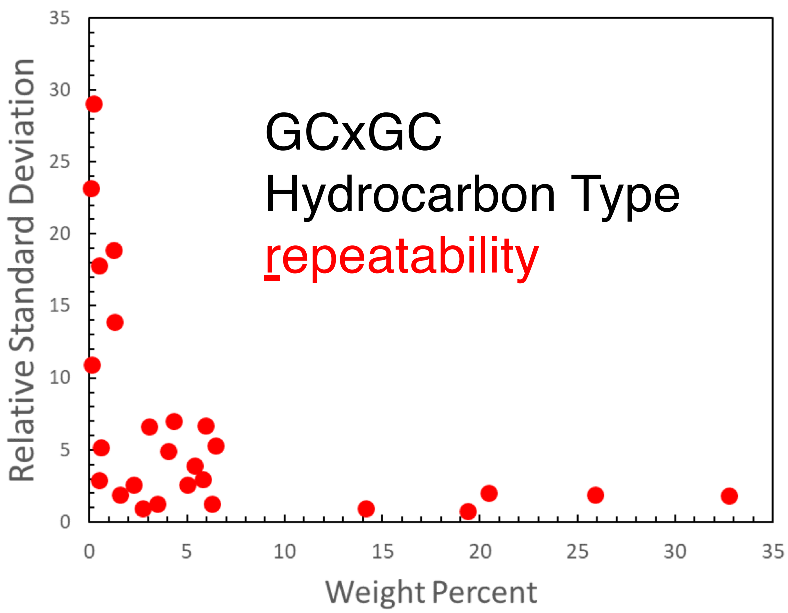


GCxGC Method Documentation & Analysis

- Two phase project – Funding received Sept 2018
  - Phase I progress
    - Document hydrocarbon type and polars methods (Completed)
    - Precision of GCxGC method (repeatability – "little r"
      - One fuel measured 5 times over 8 years (2011 - 2018)



	Mean (n=5), (wt%)	Standard deviation	RSD, %
benzene	<0.01	-	-
toluene	0.10	0.01	11
C2 - benzene	0.58	0.03	5.2
C3 - benzene	2.25	0.06	2.6
C4 - benzene	3.46	0.04	1.3
C5 - benzene	2.74	0.03	1.0
C6+ benzenes	5.00	0.13	2.6
Total Alkylbenzenes	14.13	0.14	1.0
Total Alkylnaphthalenes	1.55	0.03	1.9
indans and tetralins	6.28	0.08	1.3
C07 and lower-iso	0.21	0.06	29
C08-iso-	0.51	0.09	18
C09-iso-	1.28	0.18	14
C10-iso-	4.05	0.20	4.9
C11-iso-	6.46	0.34	5.3
C12-iso-	5.93	0.40	6.7
C13-iso-	5.83	0.17	3.0
C14-iso-	4.30	0.30	7.0
C15-iso-	3.08	0.20	6.6
C16-iso-	1.22	0.23	19
C17 and greater	0.48	0.01	2.9
Total iso-Paraffins	32.77	0.61	1.9
Total n-Paraffins	19.36	0.15	0.8
Monocycloparaffins	20.44	0.41	2.0
Dicycloparaffins	5.40	0.21	3.9
Tricycloparaffins	0.05	0.01	23
Total Cycloparaffins	25.9	0.49	1.9



GCxGC Method Development & Documentation

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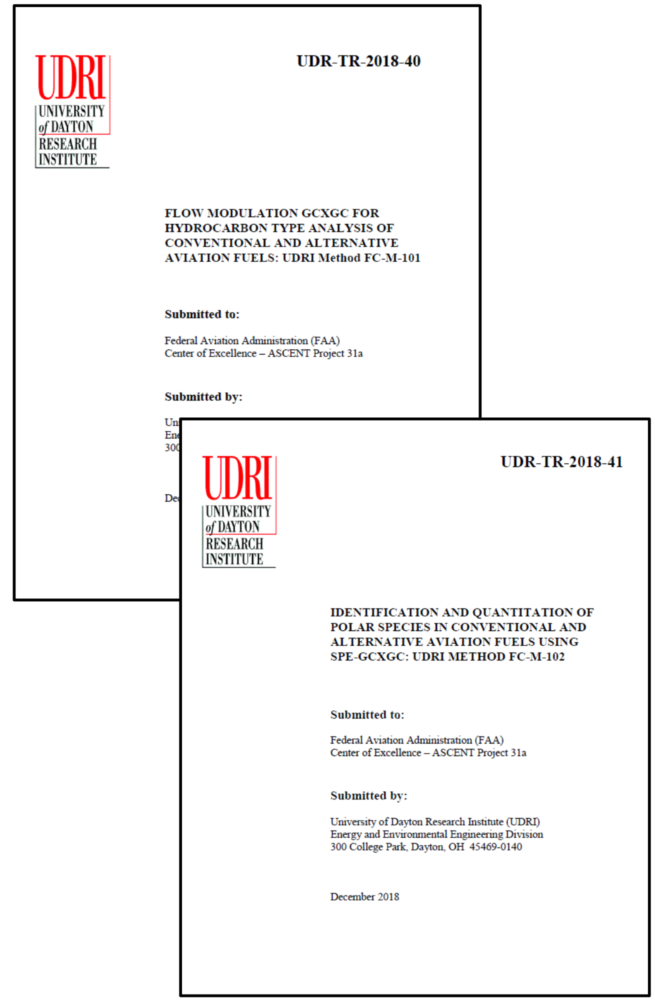
- Phase I progress (continued)
- UDRI Method FC-M-101, "Flow Modulation GCxGC for Hydrocarbon Type Analysis of Conventional and Alternative Aviation Fuels," UDR-TR-2018-40
- UDRI Method FC-M-102, "Identification and Quantification of Polar Species in Conventional and Alternative Aviation Fuel Using SPE-GCxGC," UDR-TR-2018-41
- These are included in Fast Track Annex (D4054) – replace in D7566 annexes?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UDR-TR-2018-40

FLOW MODULATION GCXGC FOR HYDROCARBON TYPE ANALYSIS OF CONVENTIONAL AND ALTERNATIVE AVIATION FUELS: UDRI Method FC-M-101

Submitted to:

Federal Aviation Administration (FAA)
Center of Excellence – ASCENT Project 31a

Submitted by:

UDRI UNIVERSITY of DAYTON RESEARCH INSTITUTE

UDR-TR-2018-41

IDENTIFICATION AND QUANTITATION OF POLAR SPECIES IN CONVENTIONAL AND ALTERNATIVE AVIATION FUELS USING SPE-GCXGC: UDRI METHOD FC-M-102

Submitted to:

Federal Aviation Administration (FAA)
Center of Excellence – ASCENT Project 31a

Submitted by:

University of Dayton Research Institute (UDRI)
Energy and Environmental Engineering Division
300 College Park, Dayton, OH 45469-0140

December 2018

GCxGC Method Documentation & Analysis (Phase II progress)

- Reproducibility – "big R"
- Comparison with external lab
  - Identical GCxGC system
    - Columns, modulator, chrom condx, template, etc.
  - RSD usually <2%, except low levels

	Weight %			Relative Difference, %		
	JP-8	HEFA	diesel	JP-8	HEFA	diesel
Alkylbenzenes	14.0	<0.01	8.50	0.91	-	10
Diaromatics	1.55	<0.01	2.92	1.9	-	5.4
Cycloaromatics	6.23	<0.01	13.6	0.60	-	15
Total Aromatics	21.8	<0.01	25.1	0.89	-	3.3
iso-Paraffins	32.3	85.5	23.5	2.0	0.68	0.12
n-Paraffins	18.8	12.2	13.7	1.2	2.0	1.4
Total Paraffins	51.1	97.6	37.2	0.81	0.33	0.58
Monocycloparaffins	21.4	2.35	24.1	1.2	12	1.9
Dicycloparaffins	5.60	0.038	11.9	7.9	58	0.05
Tricycloparaffins	0.094	<0.01	1.45	13	-	11
Total Cycloparaffins	27.1	2.38	37.5	0.82	13	0.82

- Comparison with four external labs
  - Various GCxGC systems – modulators (flow and thermal), column sets (P/NP vs NP/P), chrom condx, templates, etc.
  - Currently coordinating reporting methods, templates
  - Beginning results comparison