CAAFI Biennial General Meeting 2016

Key Qualification Challenges

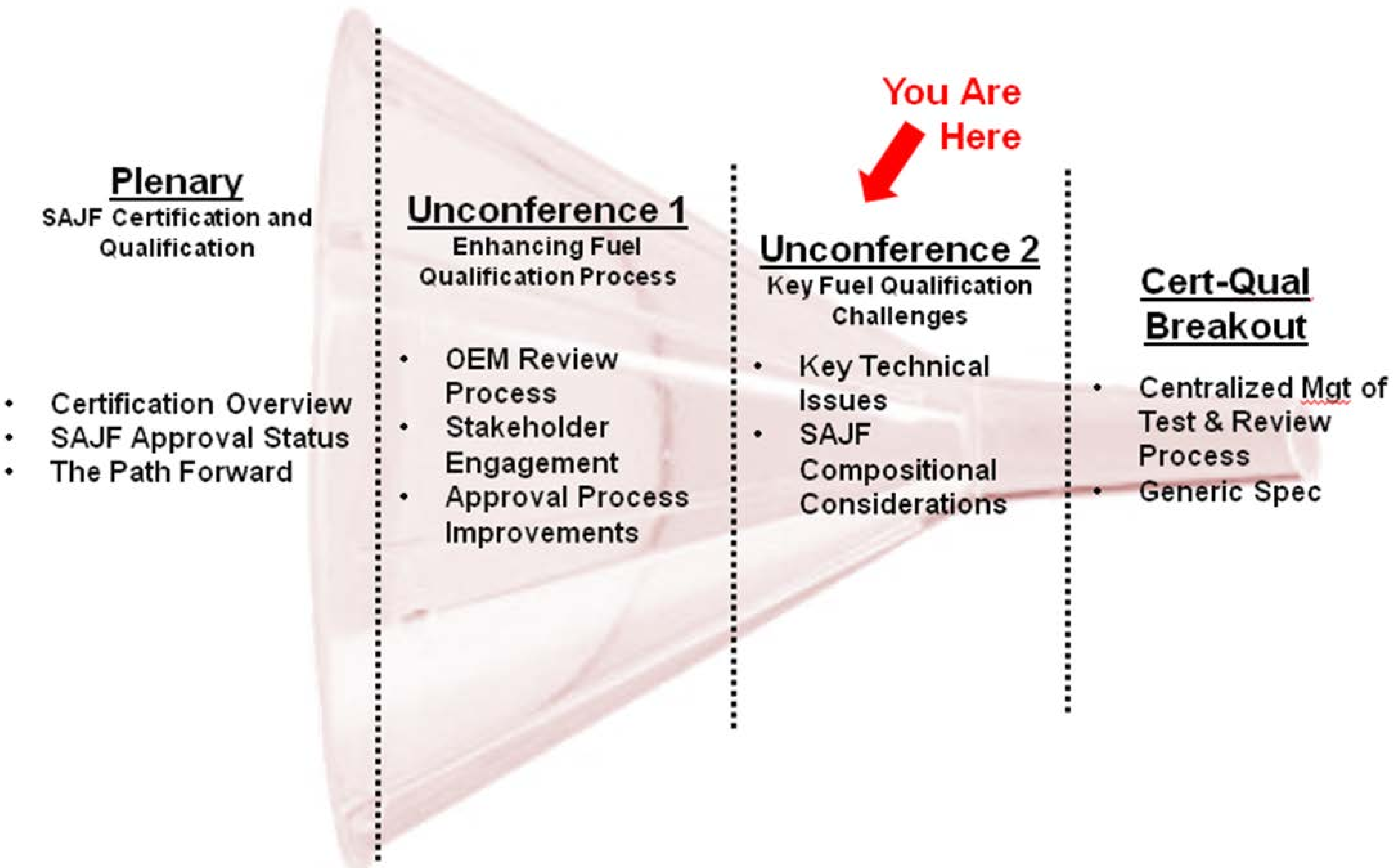
Walter E. Washington Convention Center
Washington, D.C.

Gurhan Andac
GE Aviation

COMMERCIAL AVIATION
ALTERNATIVE FUELS INITIATIVE

25 October'16

Cert-Qual agenda



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Challenges

* Resources (time and funding)
* **Predictive capabilities (modeling?)**
* **Protocols/specs based on similarity (Cliff Moses)**
* **Property test methods (Melanie Thom)**
* Slow contracting
* Centralized testing/coordination
* Management of OEM Management
* US vs Europe differences in processes/involvement
* Change of mind from producers late in the process
* Better control/tracking of samples used for data
* …

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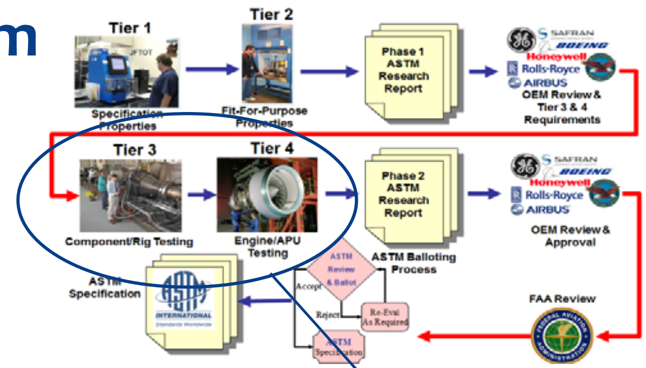
Predictive capabilities

National Jet Fuel Combustion Program

- 5 OEMs, 10+ Univ, DoD, DoT, NASA
- Develop a protocol to get to kinetic models for a new fuel

Some challenges:

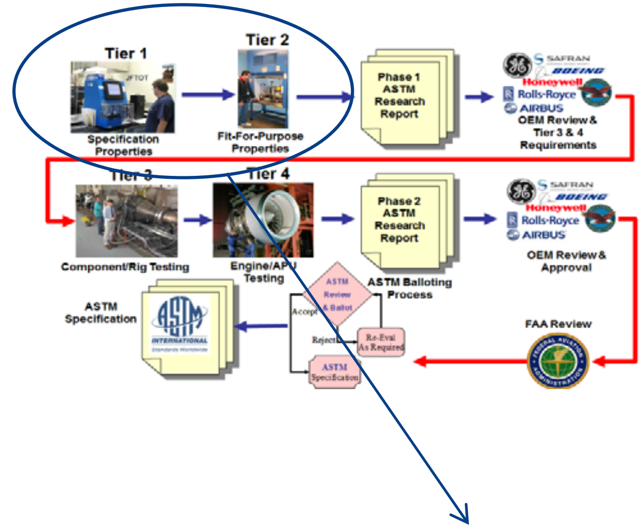
- To get to a model for a new fuel *quickly*
- Can a *reliable* model be *practical* in size?
- Develop a *common format* for all OEMs
- Are drop-in fuels similar enough that models can't differentiate?
- Do differences observed in fundamental level tests matter at system level?
- Sub-model (e.g., spray) development?



Can we predict how combustion performance will be by using modeling?

Tests methods

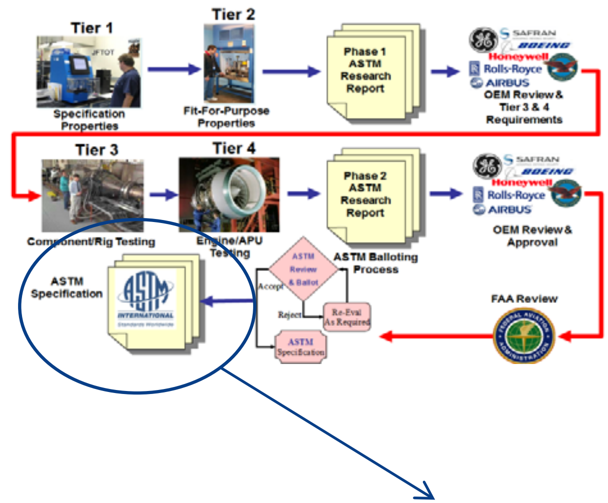
* Inadequate (e.g., large variation, valid for diesel but not for kerosene, etc.), non-existent, existent and accurate but with no clearly defined pass/fail criteria or limits, obsolete, or adequate but not readily available
* Survey first; fix later if needed
* CRC Aviation AV-23-15 Project



How adequate is the set of test methods currently in spec & D4054 requirements?

Generic spec

- ASTM D7566 Annexes set-up per “process”
- Different process produce similar products
- Low blend ratio (10%?) to lower the risk due to different process
- Focus on composition & Table 1 properties being favorable



Can we have a more generic spec to facilitate easier entry?

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FUELING SOLUTIONS FOR
SECURE & SUSTAINABLE AVIATION

CAAFI Biennial General Meeting 2016

Key Qualification Challenges
- ASTM Test Methods Survey

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Baere Aerospace Consulting, Inc.

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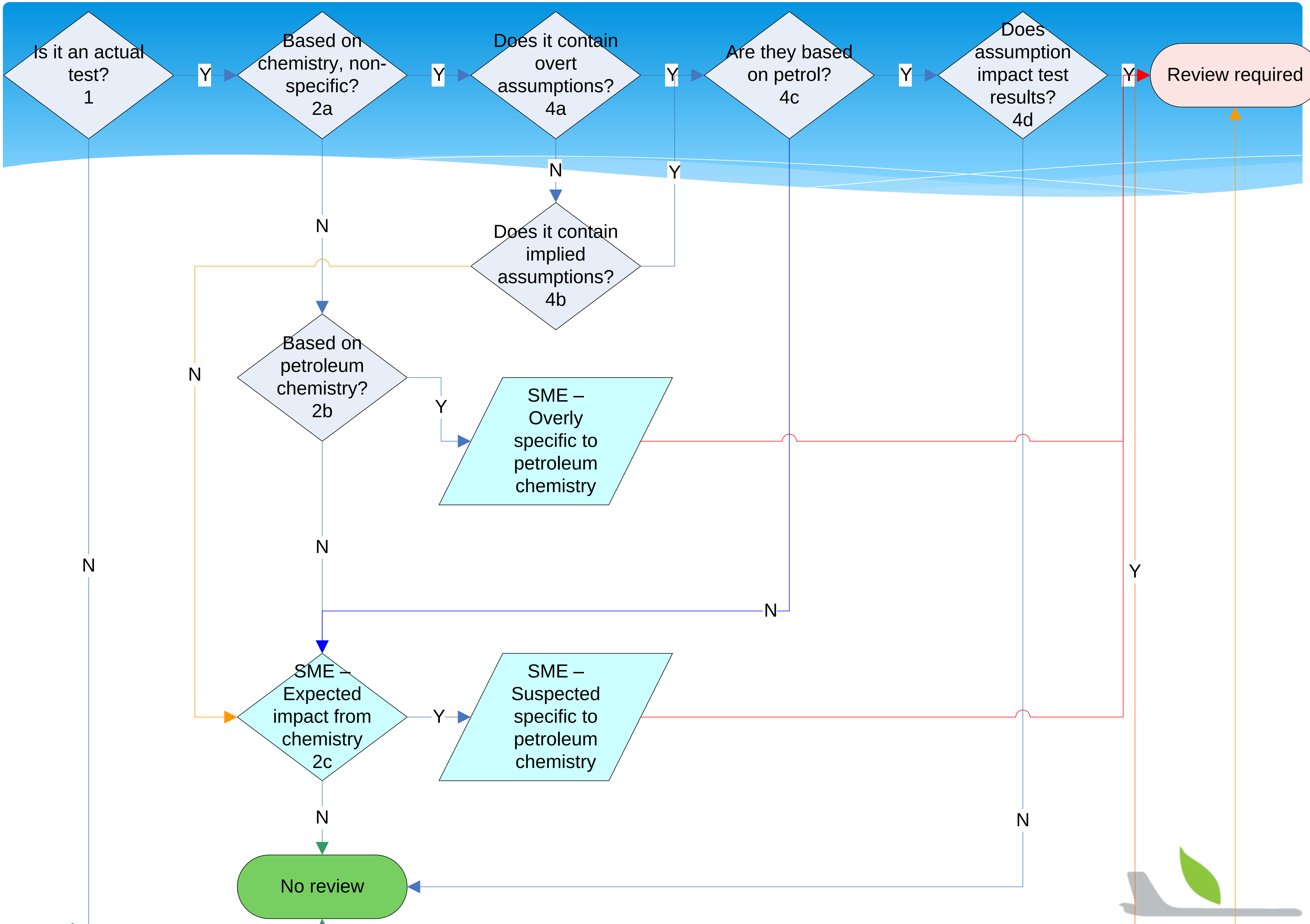
CRC Project AV-23-15

* **Adequacy of Existing Test Methods for Aviation Jet Fuel and Additive Property Evaluation**
  * Contracted by the Coordinating Research Council 9/15/16
  * Contract duration is 6 months
* **Review the specifications referenced in ASTM D1655, D7566, and D4054**
  * Why is it in the list, what is the goal, i.e. to control production, address a hardware issue, exclude something?
  * Is it based on an older test method?
  * Are there assumptions stated or implied in the use or the interpretation of results for jet fuel?
  * Is the test likely, based on stated limitations or scientific principles, to be fuel chemistry dependent?
* **General Review of Testing Accessibility**
* **Not addressing any identified issues, just finding them**


Is it an actual test? 1
Y
Based on chemistry, non-specific? 2a
Y
Does it contain overt assumptions? 4a
Y
Are they based on petrol? 4c
Y
Does assumption impact test results? 4d
Y
Review required
N
Y
Does it contain implied assumptions? 4b
N
N
Based on petroleum chemistry? 2b
Y
SME – Overly specific to petroleum chemistry
N
N
Y
N
SME – Expected impact from chemistry 2c
Y
SME – Suspected specific to petroleum chemistry
N
N
No review

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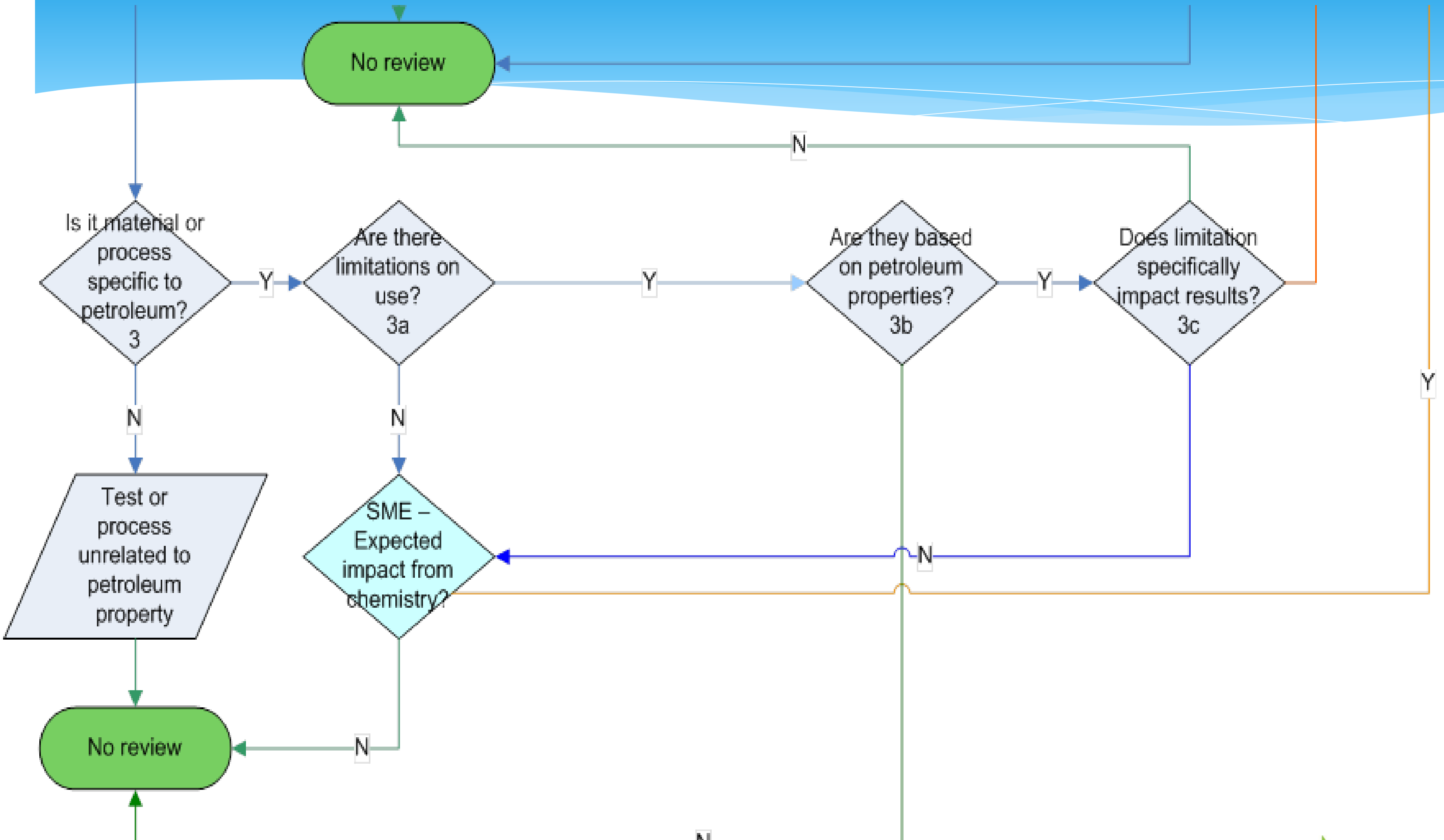
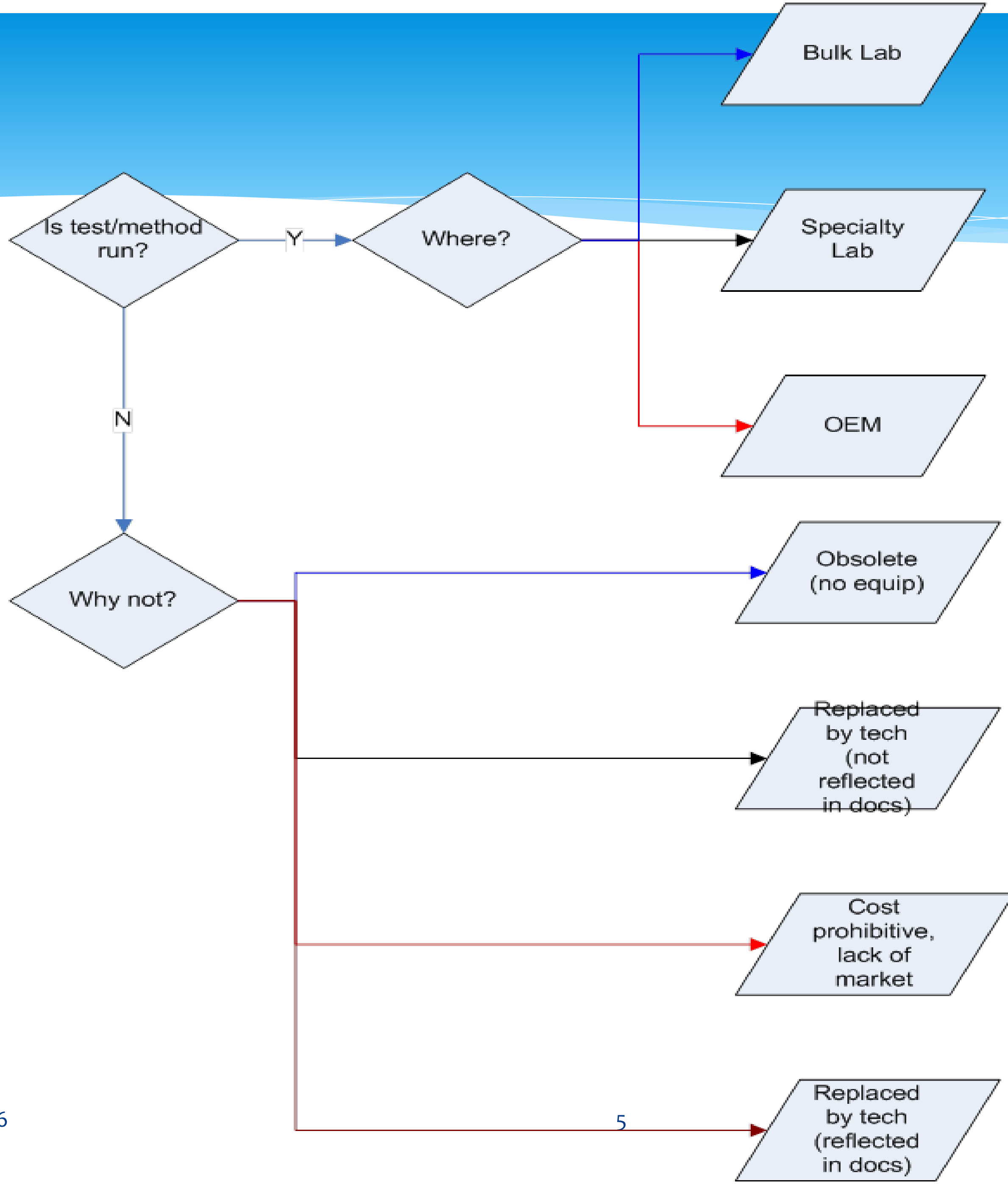


No review
N
Is it material or process specific to petroleum? 3
Y
Are there limitations on use? 3a
Y
Are they based on petroleum properties? 3b
Y
Does limitation specifically impact results? 3c
Y
N
N
Test or process unrelated to petroleum property
SME – Expected impact from chemistry?
N
No review
N
N



Is test/method run?
Y
Where?
Bulk Lab
Specialty Lab
OEM
N
Why not?
Obsolete (no equip)
Replaced by tech (not reflected in docs)
Cost prohibitive, lack of market
Replaced by tech (reflected in docs)

Definitions

* OEM – Original Equipment Manufacturer
* SME – Subject Matter Expert
* Tech – Technology

Next CRC Meeting – May 1-4, 2017, Portland OR

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Developing a Generic Annex to Safely Reduce the Effort to Approve Synthesized Fuels

Clifford Moses, PhD
Consultant

Presented to

2016 CAAFI General Meeting

Washington DC

October 25, 2016

Acknowledgement

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- Cleared for public release
- All conclusions and recommendations are those of the author and not necessarily those of UTC or the US Air Force.

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Pacing Factors

Key Issues identified at Certification/Qualification Panel meeting during 2014 CAAFI Annual Meeting: (from Mark Rumizen's summary presentation)

- **"ASTM D4054 Process too Lengthy and Costly"**
  - **"Extensive Fuel Property and Engine/Aircraft Testing"**
  - **"Repeating Same Tests Regardless of Compositional Similarities With Previous Fuel Approvals"**

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Background

- **~40 synthesized kerosenes and blends with conventional fuel have been evaluated**
  - Conventional jet fuel
  - F-T & HEFA SPSKs
  - 2^{nd}-generation renewable, w/wo aromatics
  - Synthesized kerosenes with aromatics
- **Independent of resource or processing:**
  - All have met Table 1 property requirements
  - All have bulk physical properties typical of conventional jet fuels
  - There have been no issues with materials compatibility
  - There have been no issues with combustor/engine/airframe performance or ground handling safety and storage

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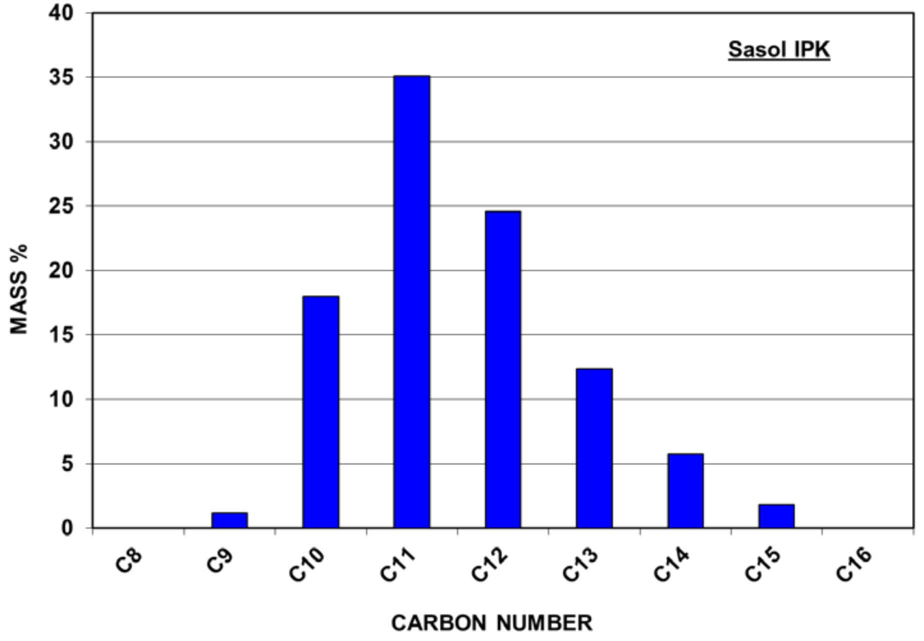
What is necessary to prove a synthesized fuel or semi-synthetic blend is fit-for-purpose?

- **Demonstrate the candidate fuel has properties and characteristics that are typical of conventional jet fuel**
  - Boiling point distribution
  - Chemistry
  - Bulk physical properties
  - Materials compatibility
  - Control of trace contaminants
  - Table 1

Boiling Point Distribution

- **Objective: BPD like jet fuel, vis-s-vis single molecules/carbon numbers**
- **Control developed in D7566 Annex 1 and continued in others**
  - T90 – T10 > 22C interim control
  - 4 contiguous carbon numbers each with more than 5% of the fuel
- **Recommend maximum flash point**

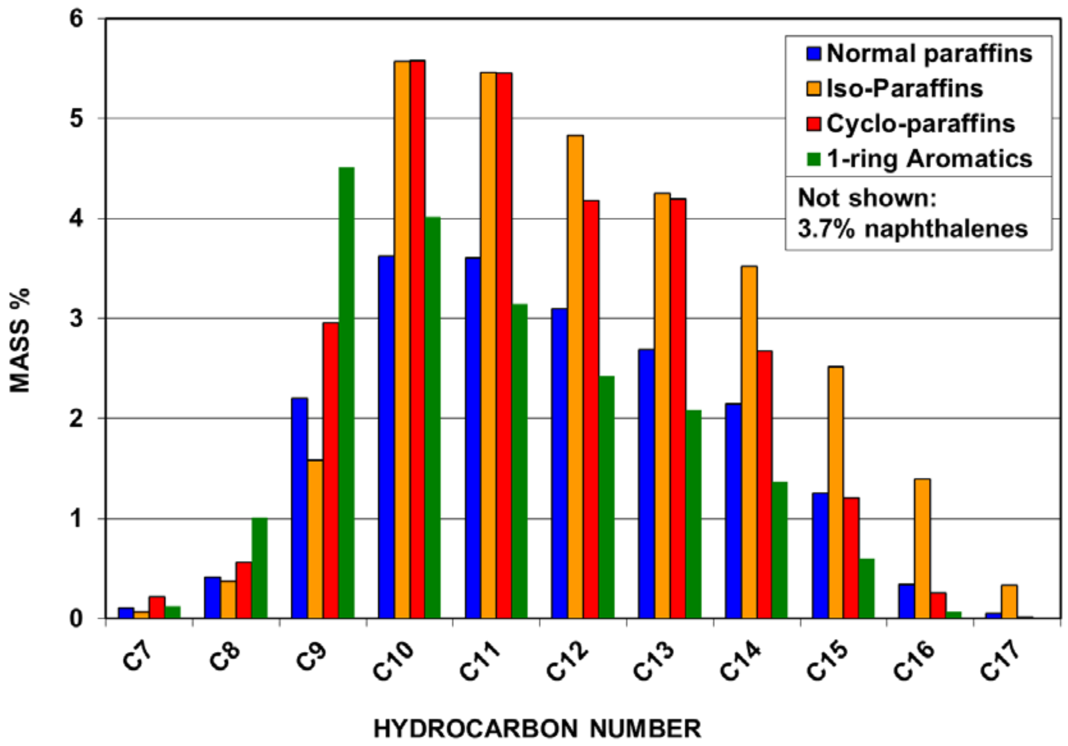


Chemistry: Distribution of Hydrocarbons (GCxGC)

- Iso- and normal paraffins
- Cyclo-paraffins
- Aromatics

Distributed across the Boiling point range

GCxGC analyses Conventional Fuel



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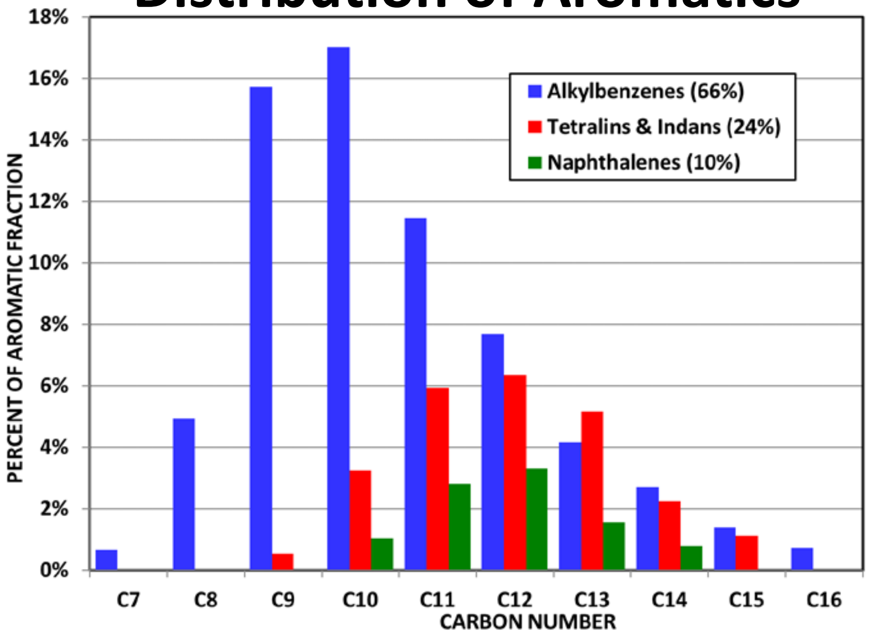
Chemistry: Aromatics in CRC World Survey (GCxGC)

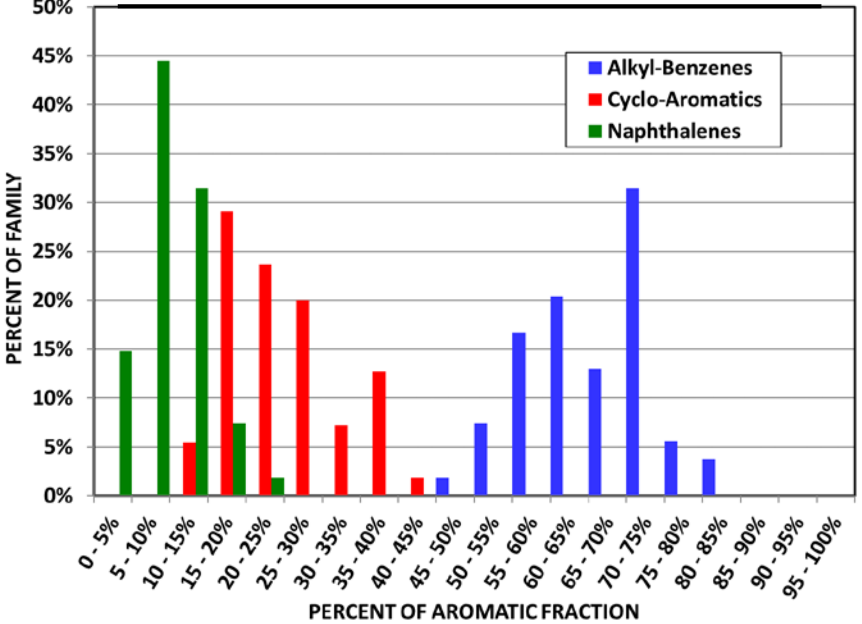
- **Aromatics are distributed across the boiling range**
  - Alkyl benzenes (single ring) 50 to 80% of aromatic fraction
  - Tetralins and indans: 10 to 40% of aromatic fraction
  - Naphthalenes (double ring) 0 to 20% of aromatic fraction

Each are distributed

Distribution of Aromatics



Concentration of Aromatic



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Chemistry "Box" of Conventional Jet Fuel

- CRC World Fuel Survey using GCxGC analysis
- Make synthesized HC kerosenes fit within the box for generic Annex independent of resource and processing

Hydrocarbon Family	Typical Conventional Jet Fuel*
n- plus iso-paraffins	50 to 90%
cyclo-paraffins	0 to 40%
aromatics (total fuel)	10 to 25%
single-ring (AF)**	50 to 90%
tetralins + indans (AF)**	10 to 45%
naphthalenes (AF)**	0 to 20%
* CRC World Fuel Survey	
**AF: aromatic fraction only	

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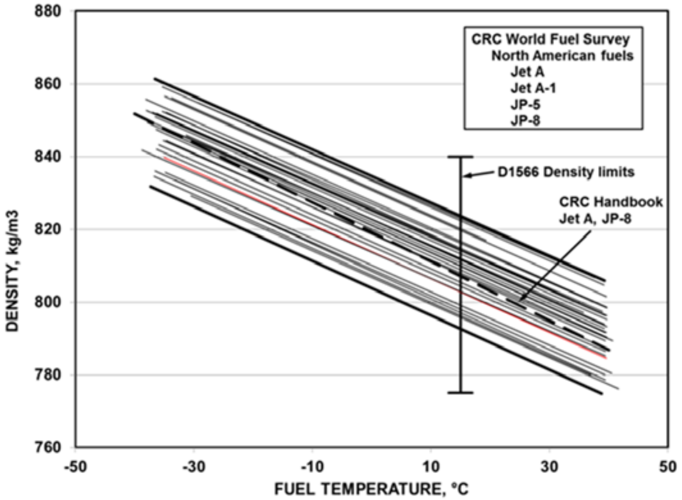
D4054 Bulk Physical Properties

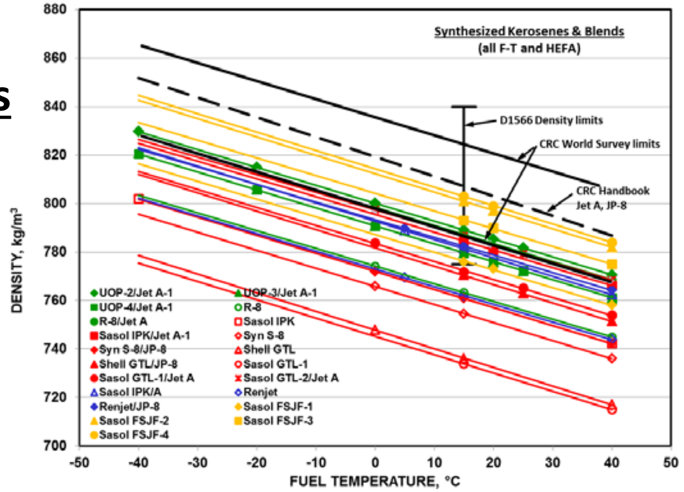
- **Bulk physical properties of kerosenes containing synthesized hydrocarbons are the same as conventional jet of similar properties**
  - Density
  - Viscosity (ASTM transformed)
  - Specific heat
  - Surface tension
  - Thermal conductivity
  - Speed of sound
  - Bulk Modulus
  - Air solubility
  - Water solubility
  - Dielectric constant?

Density vs. Temperature

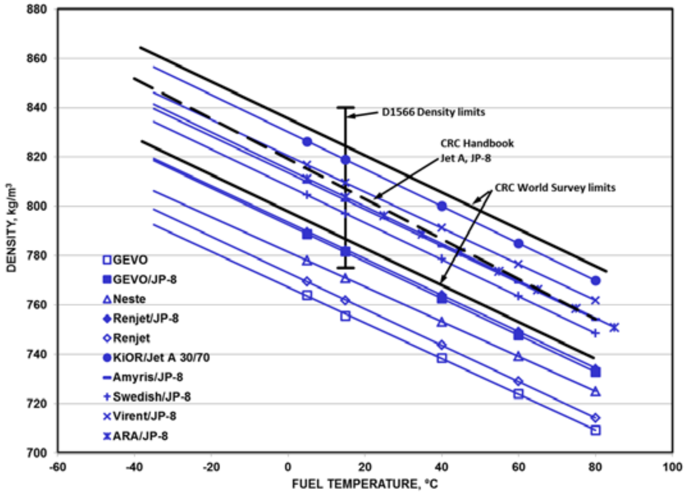
CRC WFS



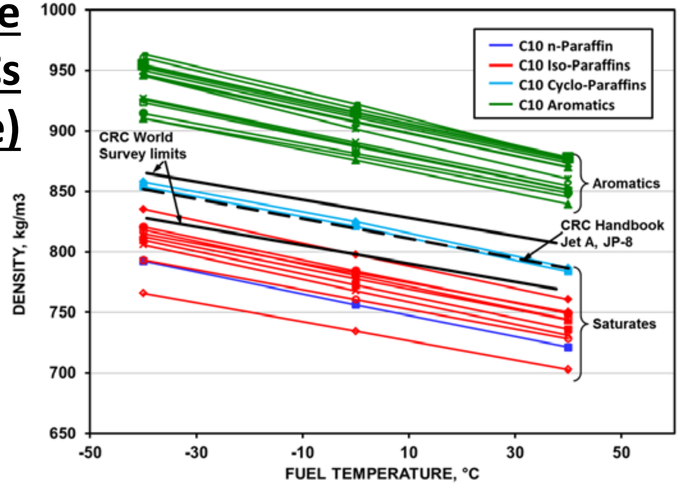
F-T and HEFA SPKs



2nd Generation Renewable Fuels



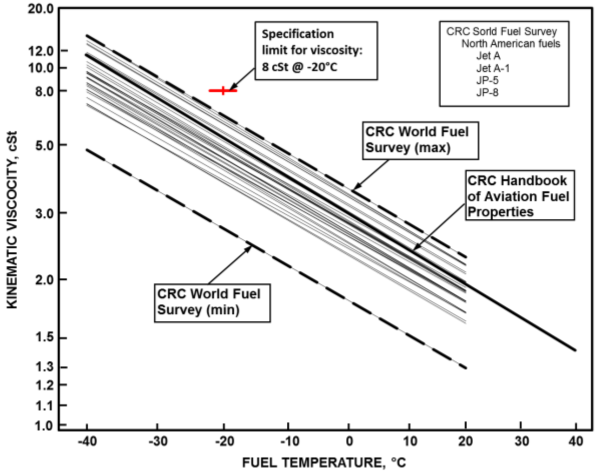
Pure HCs (different scale)



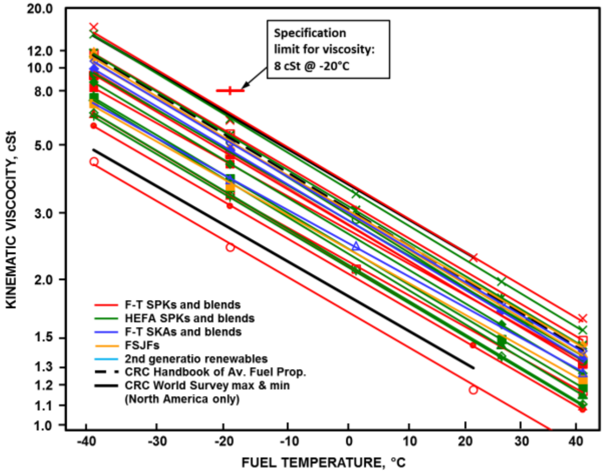
- Density is linear with temperature, and all fuels have the same slope

Viscosity vs. Temperature

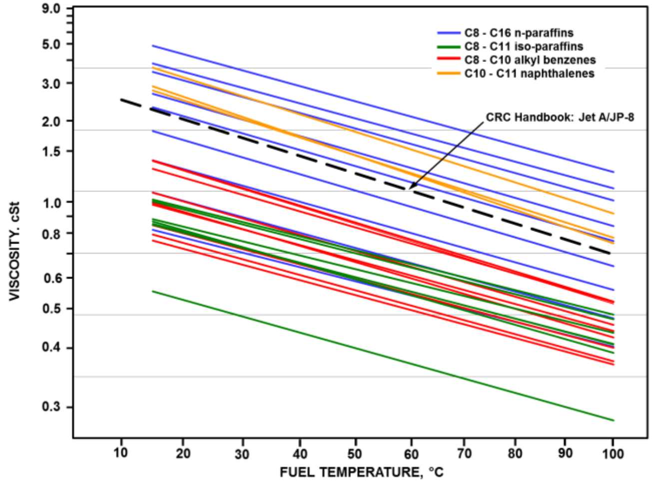
CRC WFS



All SKs



Pure HCs (different scale)



- Viscosity/temperature dependence mimic the density results

D4054 Bulk Physical Properties

- **Bulk physical properties of kerosenes containing synthesized hydrocarbons are typical of conventional jet fuels**
  - X vs Temperature of all fuels and pure HCs are linear and parallel
  - Verified with pure hydrocarbons
  - Fundamental physical chemistry
  - Final value for fuel is simply the result of combining constituents
- **All HC kerosenes with typical BPD and meeting Table 1 values for density and viscosity will have typical D4054 physical properties**

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Materials Compatibility Data Sets

- **D4054 list of materials and tests based on Air Force protocol developed for Syntroleum S-8**
- **Multiple properties on "Short-short list" of D4054 tests**
  - Typical service temperatures
  - Most syn-fuels
  - With/without synthetic aromatics
- **O-ring tests at ambient temperature on F-T, HEFA, and 2nd-generation renewable fuels (SwRI)**
- **Volume swell vs. aromatic content on 9 classes of materials for conventional and F-T fuels at ambient temperature (UDRI)**

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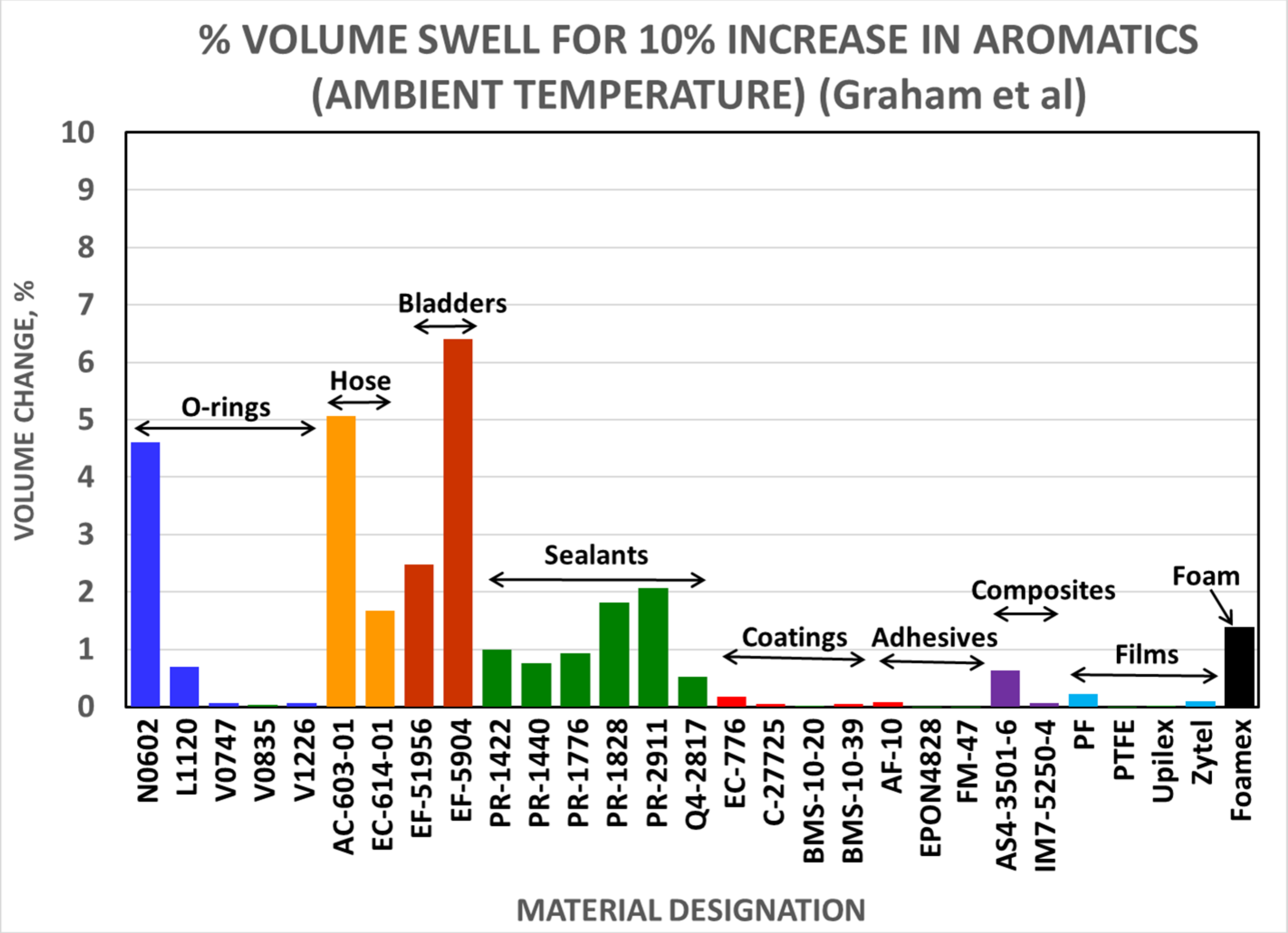
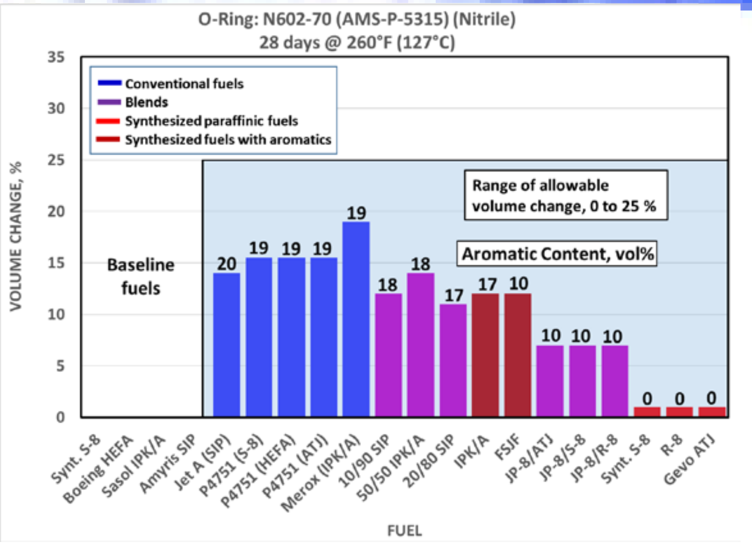
Materials Compatibility



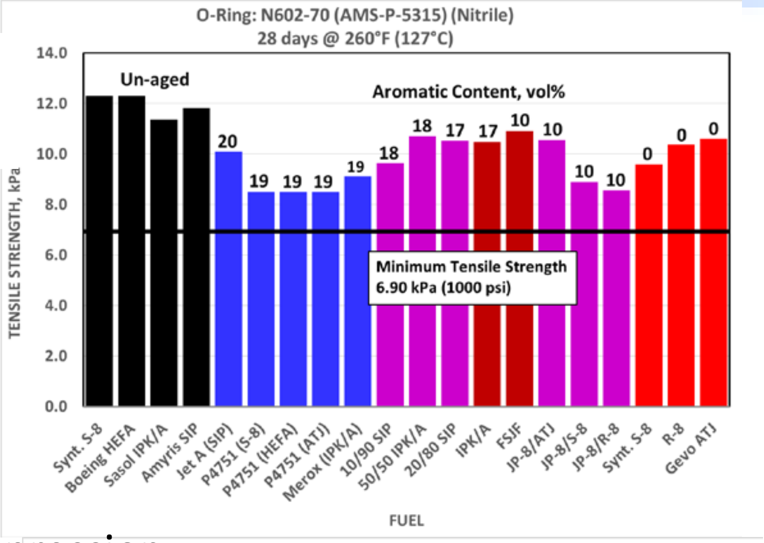
- Volume swell is considered to be the most sensitive to aromatic content (Graham et al)
- Nitrile materials are the most sensitive to aromatics

MATERIALS COMPATIBILITY RESULTS: N0602 O-RINGS, 28 DAYS @ 265°F

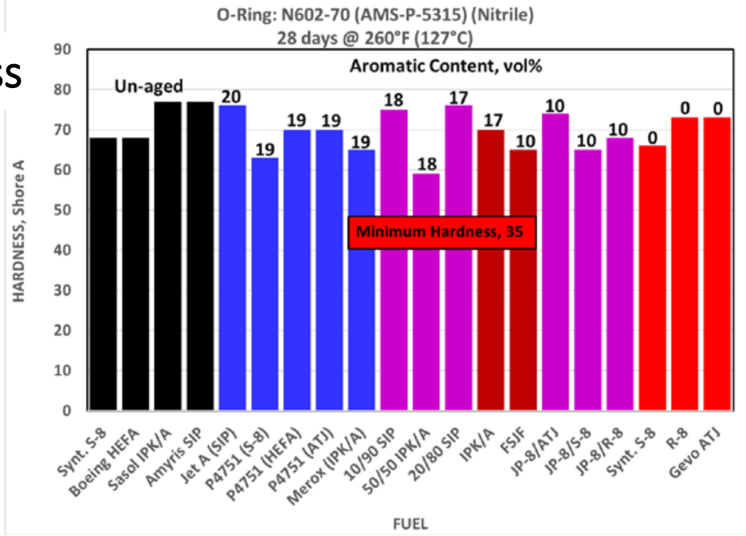
Volume Change



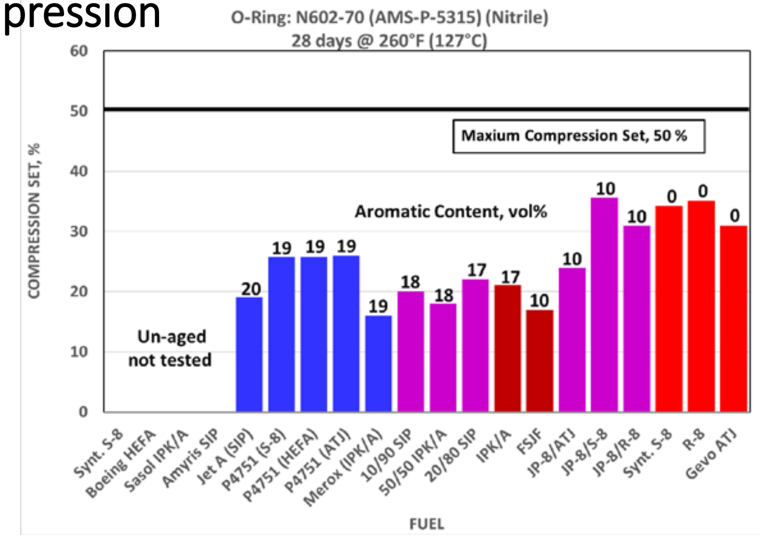
Tensile Strength



Hardness



Compression Set



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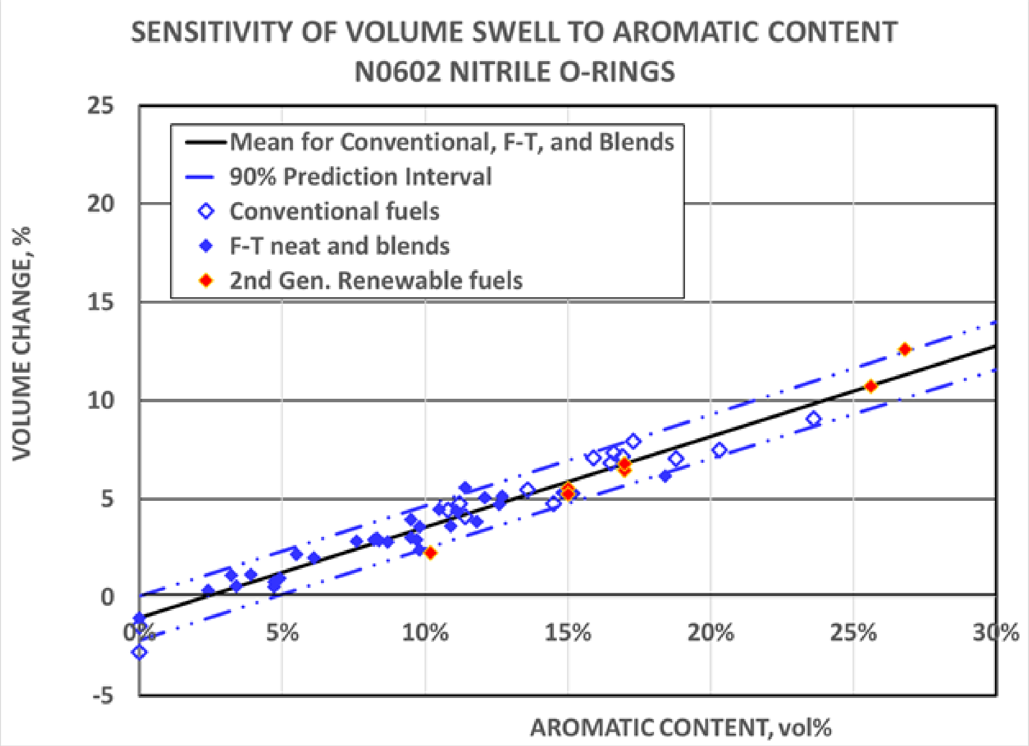
Materials Response to Aromatics

- **Materials**
  - O-rings
  - Sealants
  - Coatings
  - Adhesives
  - Hoses
  - Bladder liners
  - Films
- **Fuels**
  - Conventional jet
  - F-T paraffinic
  - Renewable w/wo aromatics
- **Responses are linear; small scatter**
- **Materials respond to synthesized aromatics the same as aromatics in petroleum-derived jet fuel**



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Materials Compatibility Conclusions

- **All synthesized jet fuels and blends with aromatics >8% have demonstrated materials compatibility typical of conventional fuels with similar aromatic content regardless of resource or processing**
  - All fuel system materials are developed and qualified to be compatible with hydrocarbon kerosenes (8 – 25% aromatics)
  - We are evaluating hydrocarbon kerosenes with 8 – 25% aromatics.

- **Minimum of 8% aromatics in final fuel is a necessary and sufficient condition for materials compatibility**

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Other issues

- **Most other properties/issues are due to non-HC contaminants and can be addressed by additives and/or Annex specification table.**
  - Thermal stability
  - Lubricity
  - Electrical conductivity
  - Storage stability
  - Effects on filter/coalescers
  - …

Personal Thoughts on Fit-for-Purpose

- **We are not making new fuels; we are making the same fuels from new resources**
- **Source and processing don't matter if there is sufficient downstream processing, i.e., hydrotreating, etc. (Dennis Hoskin)**
  - 325°C JFTOT breakpoint

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Summary

- **Defined chemistry box of conventional jet fuel**
- **Demonstrated that if a hydrocarbon kerosene meets Table 1 specification property requirements, the bulk physical properties have to be typical of conventional jet**
- **Shown that non-metallic materials respond to synthesized aromatics the same as aromatics in conventional jet fuels**
  - Linear with aromatic content
  - 8% aromatics is necessary and sufficient condition to maintain desirable swell characteristics
- **Other issues can be addressed by specification tables and/or additives**
  - Table AX.1 Detailed Batch Requirements
  - Table AX.2 Other Detailed Requirements

Conclusions

- **Don't need a separate evaluation and Annex for every new fuel resource/process.**
  - GCxGC to determine chemistry and distribution of carbon #s and isomers
    - Cyclo-paraffins: ≤ 30%
    - Aromatics: ≤ 20% of fuel and distributed
    - Tetralins and indans: < 30% of aromatics
    - Carbon numbers: ≥ 4 significant contiguous numbers
  - ≥ 325°C JFTOT breakpoint
  - Typical boiling point distribution, not distorted
  - Add maximum flash point
  - Tables AX.1 and AX.2
  - …

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Conclusions (cont.)

- **We can safely develop a new generic Annex for synthesized kerosenes independent of resource or conversion process**
  - HC kerosenes typical of conventional fuel
  - Focused controls beyond Table 1 on critical issues
  - Allow up to 10% blend
  - Forego further FFP and component testing
- **Allow earlier entrance into production**
- **Approval efforts would focus on fuels that are not typical kerosenes to determine blending constraints with conventional jet fuel**
  - High concentrations of only a few molecules
  - 1 or 2 carbon numbers
  - Abnormal boiling point distributions
  - JFTOT breakpoint < 325°C

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Way Forward

- The US Air Force is funding a team to develop a generic Annex independent of resource and conversion processing
  - Tim Edwards, USAF
  - George Wilson, SwRI
  - Chris Lewis, consultant
  - Cliff Moses, consultant

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