Sustainable Alternative Jet Fuels (SAJFs)

US Perspective and Activities

By: Dr. Mohan Gupta
Office of Environment and Energy
Federal Aviation Administration

Event: 2nd ECATS Conference

Date: November 7, 2016

Aviation Environmental Challenges

- Aviation impacts community noise, air quality, water quality, energy usage, and climate change
- Environmental impacts from aviation could pose a critical constraint on capacity growth

Challenge

Want increased mobility with reduced environmental impacts and enhanced energy availability and sustainability.

FAA Environmental and Energy Strategy, Plan and SAJFs

https://www.faa.gov/about/office_org/headquarters_offices/apl/environ_policy_guidance/policy
http://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx

FAA SAJFs Activities

- Testing
  - Support Cert/Qual testing
  - Improve Cert/Qual process (NJFCP)
  - Emissions measurements
- Analysis
  - Environmental sustainability
  - Techno-economic analysis
  - Future supply
- Coordination
  - Interagency
  - Public-Private
  - State & Regional
  - International

- CLEEN Testing and Research Report Review
- A25-30, 34 National Jet Fuels Combustion Program
- A31 Alternative Jet Fuel Test & Evaluation
- A33 Alternative Jet Fuel Test Data Library
- SEMRS Jet Fuel Data Tracking

- A01 Alternative Jet Fuel Supply Chain Analysis
- A13 ACCESS 2 Micro Physical Modeling with NASA
- A24 Emissions Data Analysis for CLEEN, ACCESS, and Other Recent Tests
- A32 Worldwide Life Cycle Analysis (LCA) of Greenhouse Gas (GHG) Emissions from Petroleum Jet Fuel
- A39 Naphthalene Removal Evaluation (ASCENT - New)
- SEMRS Analysis
- Volpe Alternative Fuels Transportation Optimization Tool (AFTOT)

- CAAFI
- Farm to Fly 2.0
- Federal Alternative Jet Fuel Strategy
- International agreements

Details on ASCENT Projects are available at ascent.aero

Federal Alternative Jet Fuels R&D Strategy (FAJFS)

Research, Development, Demonstration, & Deployment (RD3)

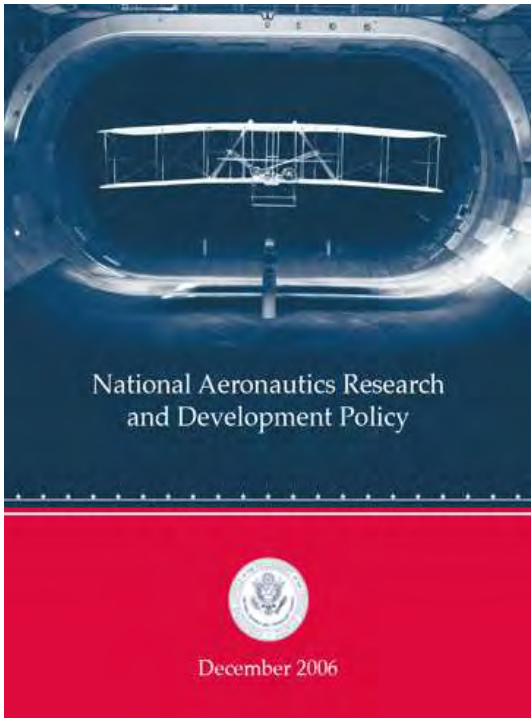
Participating 9 Federal Agencies
(USDA, DOC, DOD, DOE, DOS, FAA, EPA, NASA, NSF)

https://www.whitehouse.gov/sites/default/files/federal_alternative_jet_fuels_research_and_development_strategy.pdf
Released by OSTP on July 27, 2016

Genesis for Strategy

National AERO R&D Plan focuses on 17 aeronautics goals in four areas –

- "Mobility, Security, Safety and Environment & Energy"
- Energy Availability, Efficiency & Environmental Protection
  - Goal 1: "Enable new aviation fuels derived from diverse & domestic resources to improve fuel supply security & price stability"



Federal AJF R&D Strategy - Intended Purpose

Identify opportunities and strategically address RD3 challenges along the development path of alternative jet fuels.

Federal AJF R&D Strategy

Intended to:

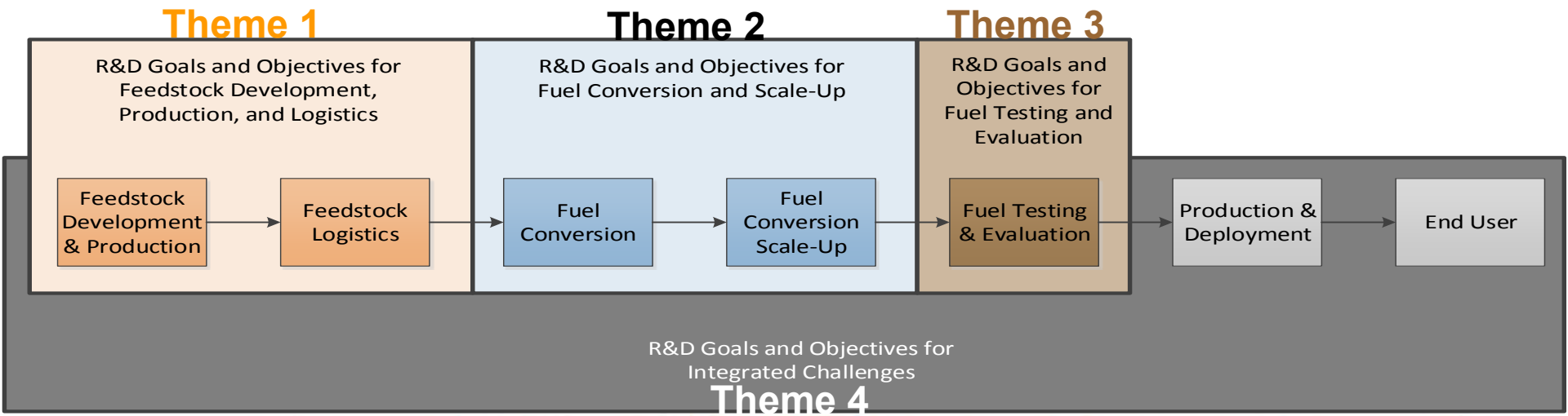
- Articulate *Aspirational yet Achievable* Objectives, *Measurable* Performance Metrics and Timeline to achieve the goal
- Mobilize the federal and non-federal stakeholders community towards achieving the common goal and objectives
- Understand industry needs and align federal strategic R&D efforts
- Integrate, align and coordinate interagency activities
- Promote increased collaboration
- Enhance technology transfer
- Help federal agencies to make their business cases to secure funding for AJF R&D activities

Overarching Statement of the Strategy

Strategy sets out prioritized Federal R&D goals and objectives to address key scientific and technical challenges that inhibit the development, production, and use of economically viable alternative jet fuels that would provide environmental and social benefits relative to conventional fuels while enhancing U.S. energy security.

- **Emphasis is on technical challenges that can be addressed by Federal R&D activities.**
- **Strategy acknowledges that there are policy challenges, however, they are outside the R&D scope of this strategy.**

AJF Development Path, R&D Themes and Federal Role



DOC	X				X
DoD			X	X	
DOE	X	X	X		X
DOT				X	X
EPA					X
NASA				X	
NSF	X	X	X		
USDA	X	X	X		X

Strategy Outline

- Executive Summary
- Introduction
- Purpose and Scope
- AJF Development Path
- **R&D Goals and Objectives**
  [3 time horizons: near-(<5 years); mid-(5-10 years); and far-(>10 years) terms]
  - Feedstock Development, Production, and Logistics
  - Fuel Conversion and Scale-Up
  - Fuel Testing and Evaluation
  - Integrated Challenges
- Non-Technical Challenges
- Federal Coordination
- Public-Private Partnerships
- International Coordination
- Conclusions
- Appendix 1 Agency-Specific Contributions to Research and Development of Alternative Jet Fuels
- Appendix 2 Multi-Agency Activities that Contribute to Research and Development of Alternative Jet Fuels
- **Appendix 3 Federal AJF R&D Goals and Objectives**
  - R&D Goals and Objectives: Feedstock Development, Production, and Logistics
  - R&D Goals and Objectives for Fuel Conversion and Scale-Up
  - R&D Goals and Objectives for Fuel Testing and Evaluation
  - R&D Goals and Objectives for Integrated Challenges

https://www.whitehouse.gov/sites/default/files/federal_alternative_jet_fuels_research_and_development_strategy.pdf

Document length: 32 pages

Approved Alternative Jet Fuels

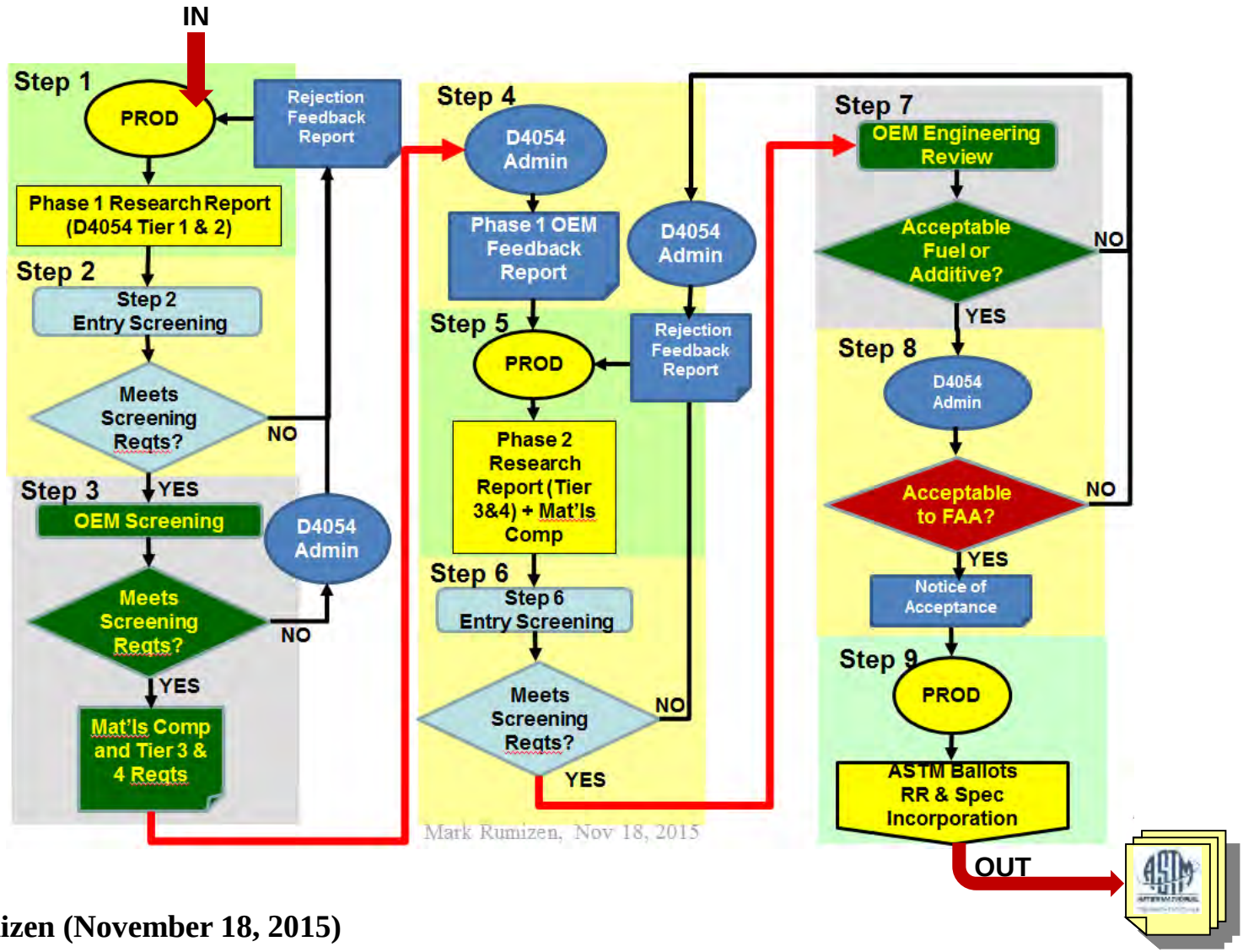
ASTM International has approved five fuel conversion pathways:

- 2009 Fischer-Tropsch (FT-SPK)
- 2011 Hydroprocessed Esters and Fatty Acids (HEFA)*
- 2014 Synthesized Iso-Paraffinic fuels (SIP)*
- 2015 Fischer-Tropsch Synthetic Kerosene with Aromatics (FT-SKA)
- 2016 Alcohol-to-Jet (ATJ-SPK)*

About a half-dozen currently undergoing ASTM approval.

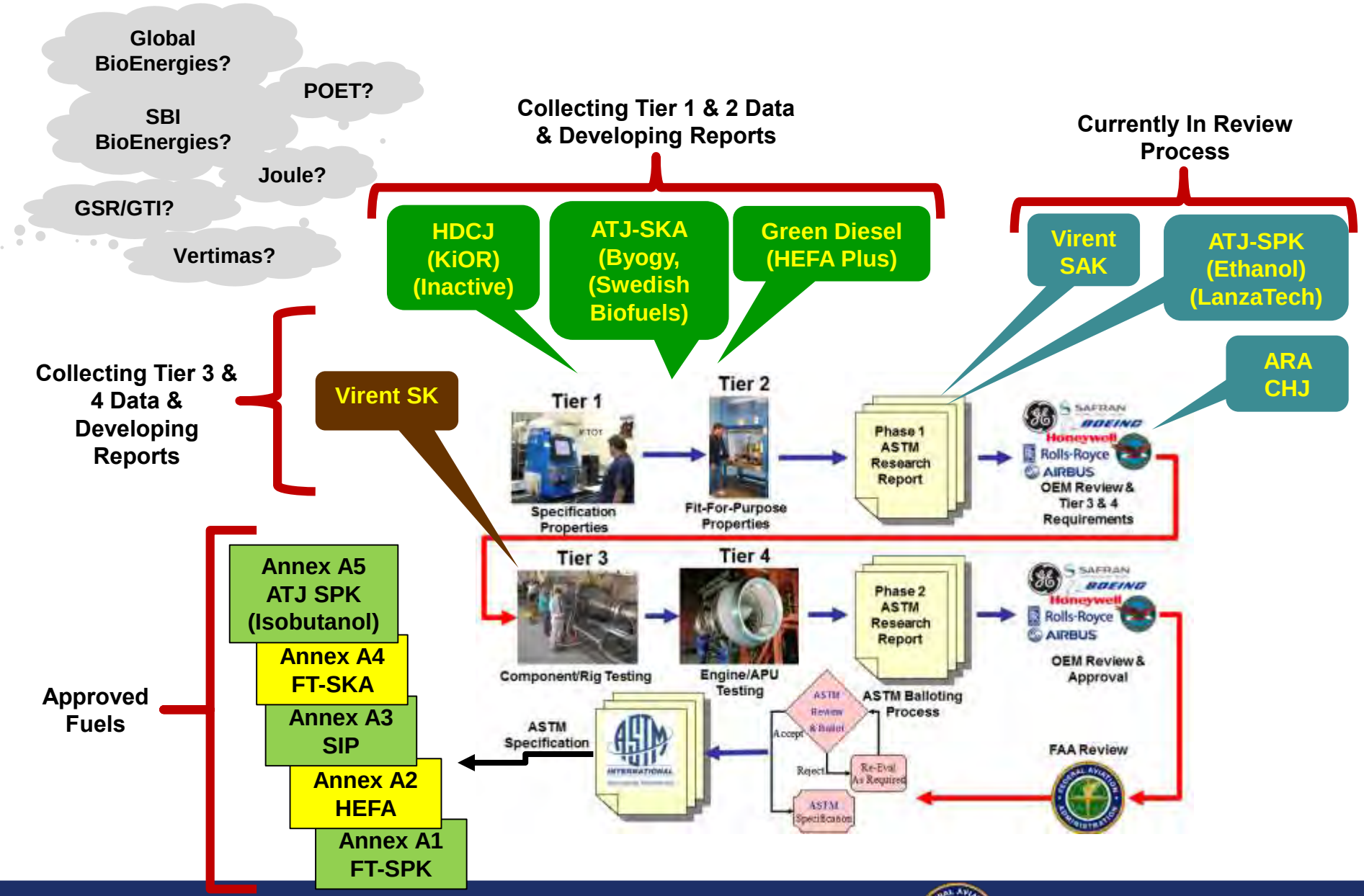
*Denotes fuel that underwent FAA sponsored testing

OEM Review Process for ASTM Approval of SAJFs



From Mark Rumizen (November 18, 2015)

SAJF Status Under ASTM Process

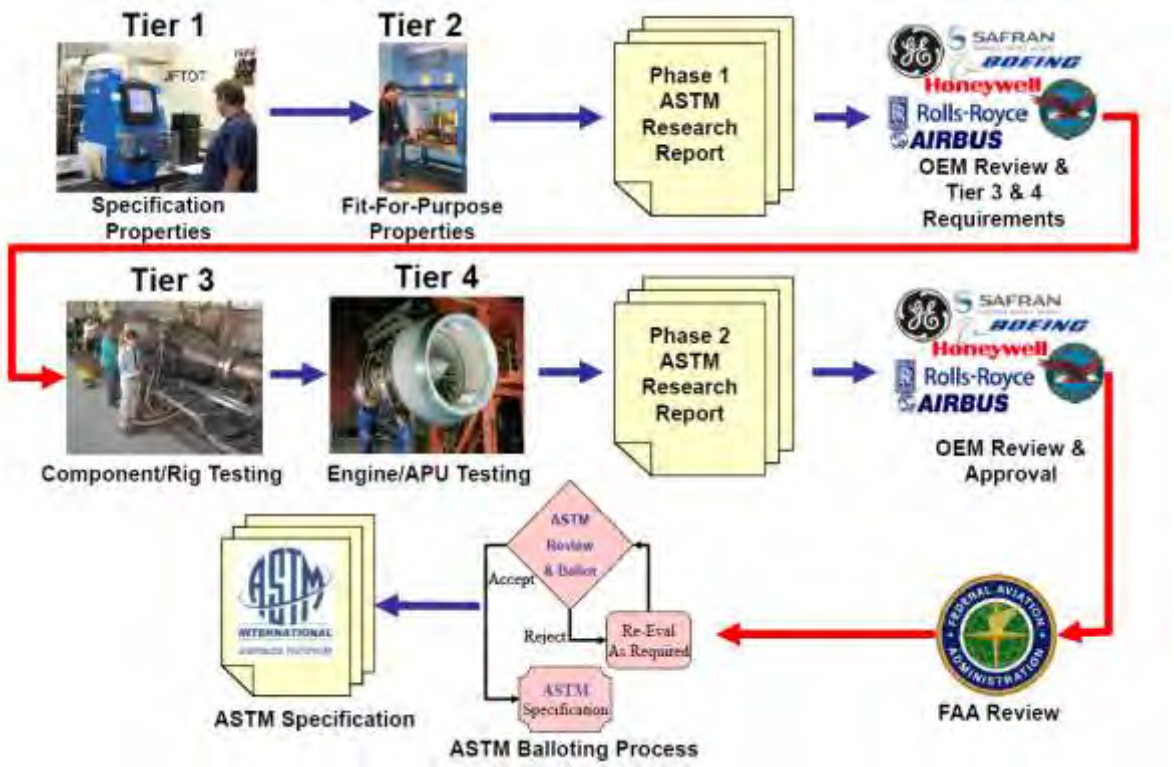


National Jet Fuels Combustion Program

Addressing One of the Goals of FAJFS

An Extract Overview

Current Two-Phase ASTM Fuel Approval Process

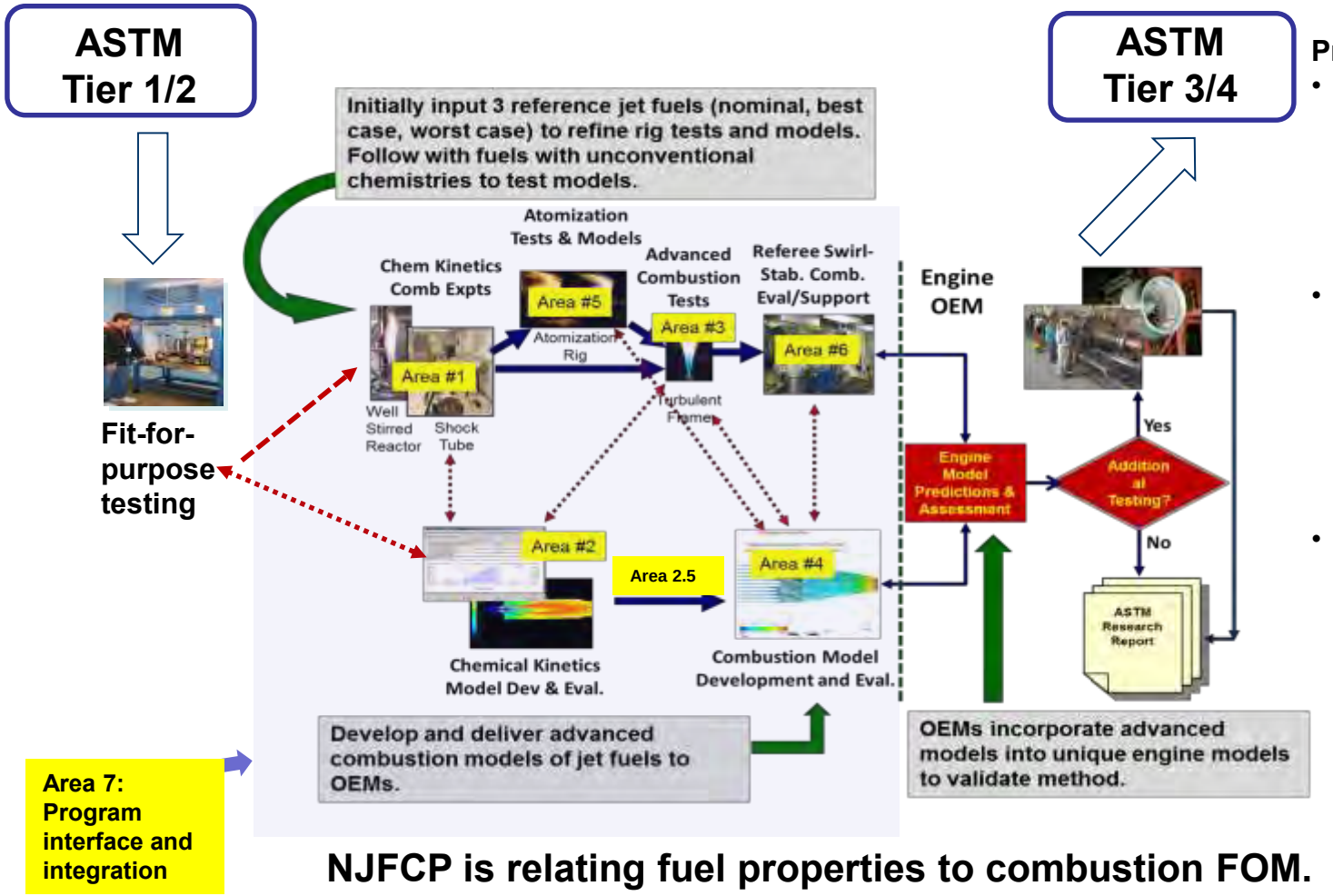


- OEMs have identified key Figures Of Merit (FOM) to determine acceptable combustion performance.
  - Altitude Relight
  - Lean Blowout
  - Cold Start
- Tier 3/4 testing is critical for evaluating FOMs. Testing costs increase significantly as fuels transition from Tier 1/2 to Tier 3/4 testing performed by the OEMs

- **Fuels approved to date have chemical compositions similar to petroleum based jet fuel**
  - HEFA, FT and DSHC (Direct Sugar to Hydrocarbon at 10% blend) fuels performed as expected.
    - But DSHC at 20% pushed composition beyond typical range and exhibited unacceptable performance and was not approved.
- **Unlike previous fuels, new generation of candidate fuels include cycloparaffins and aromatic compounds and will demand additional testing and resources**

Overview of NJFCP Program

Vision: Develop an experimental and analytical capability to facilitate OEM's evaluation of fuel physical and chemical properties on engine operability and to streamline ASTM fuels approval process.

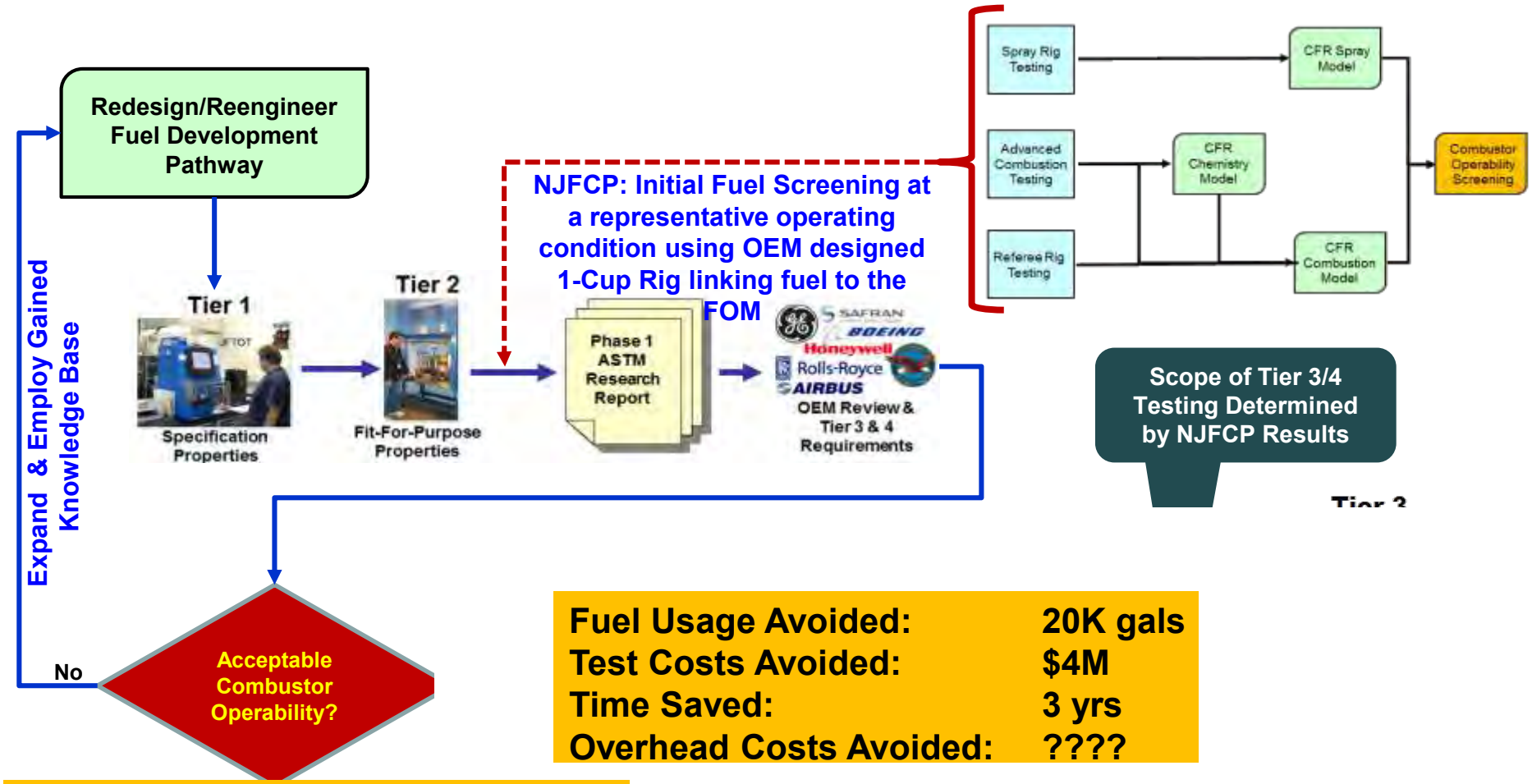


Program uniqueness:

- Integrated systemwide approach involving all stages of testing and modeling areas for identical conditions
- Real-time communication and share of info among all 6 areas (experimentalists and modelers) and OEMs
- Brings state of the art knowledge, computer capabilities, and engineering experience together

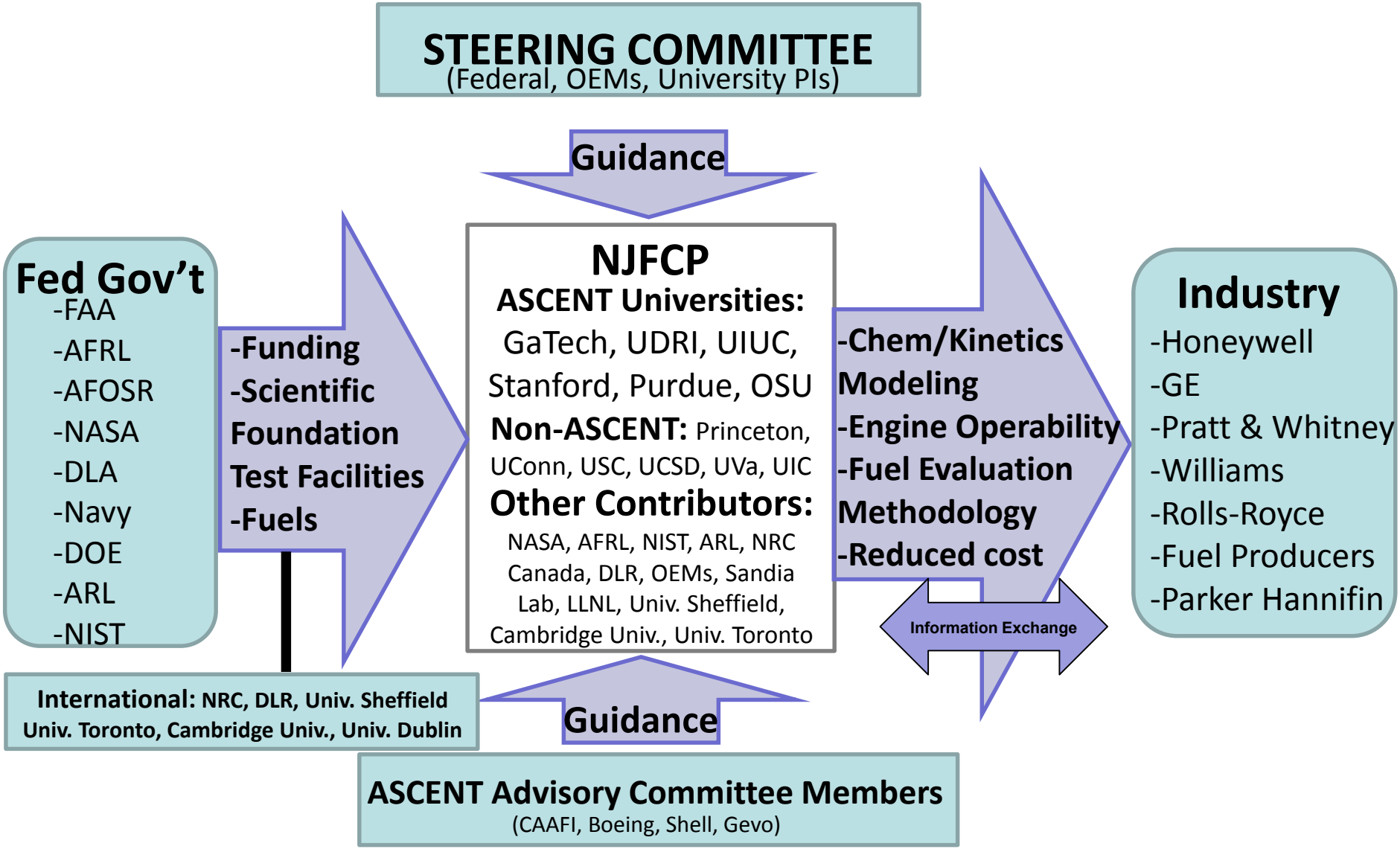
NJFCP is relating fuel properties to combustion FOM.

Improved OEM Screening of Fuels with NJFCP Integration



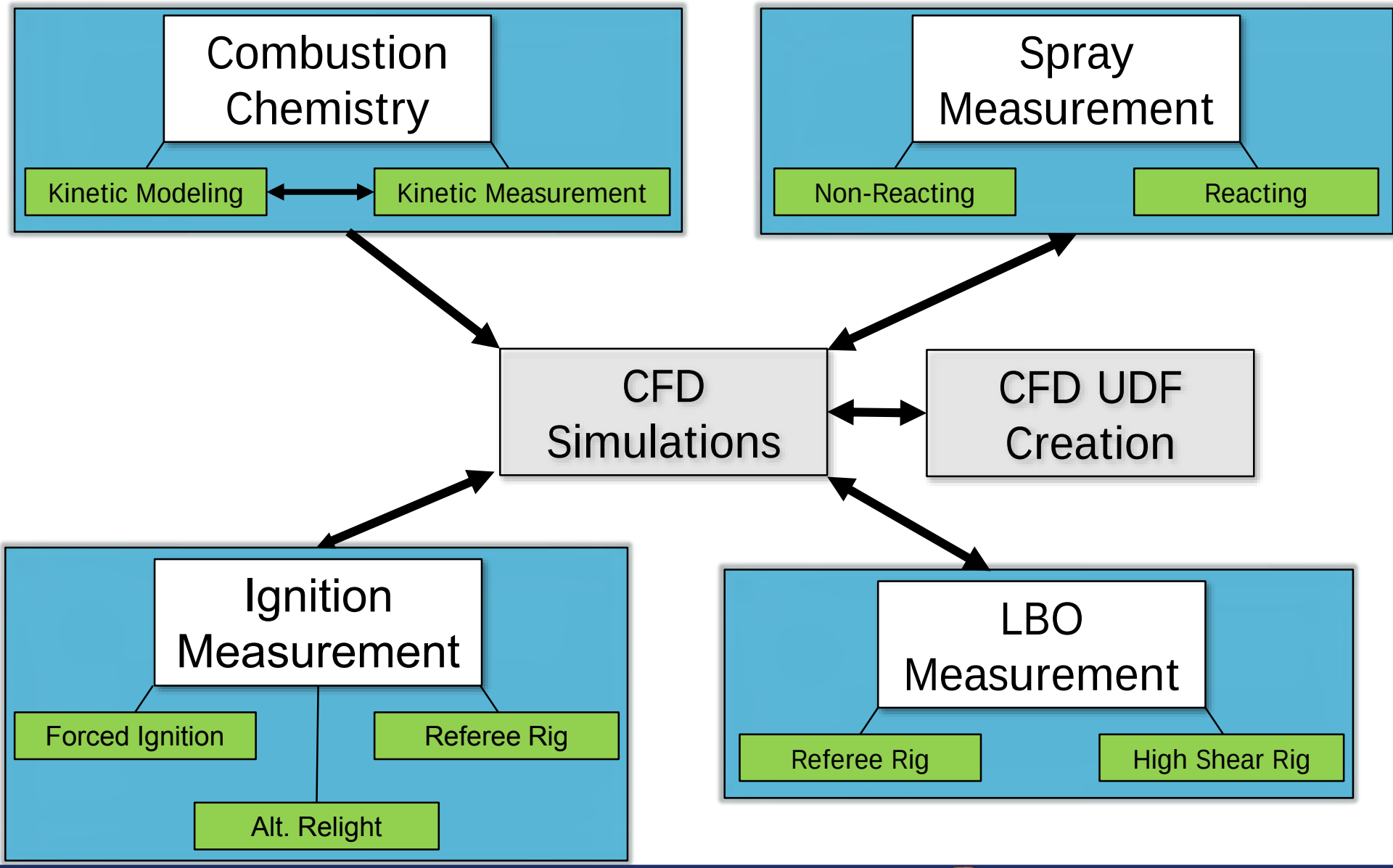
Benefits: Early fuel screening, targeted Tier 3 and 4 tests, and increased OEM confidence

Program Sponsors, Contributors, Performers & Industry Members



A strong community of hundreds of international participants from 40 entities

Mapping NJFCP Areas to Topics



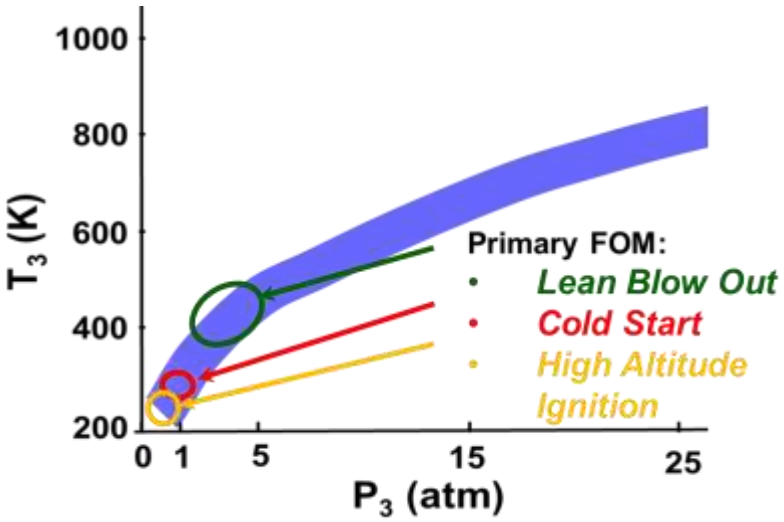
ASCENT* Project PIs and Key Contributors

- Area 1: Ron Hanson (Stanford), Tom Bowman (Stanford), Dave Davidson (Stanford), Shock Tube and Flow Reactor Studies.
- Area 2: Hai Wang (Stanford), Chemical Kinetics Model Development and Evaluation.
- Area 2.5: Tianfeng Lu (U. Conn), Wenting Sun (Georgia Tech), Stephen Zeppieri (UTRC), Computational Acceleration.
- Area 3: Tim Lieuwen (Georgia Tech), Jerry Sietzman (Georgia Tech), David Blunck (Oregon State), Fred Dryer (Princeton), Tonghun Lee (Illinois Urbana-Champaign), Advanced Combustion.
- Area 4: Suresh Menon (Georgia Tech), Matthias Ihme (Stanford), Venkat Raman (U. Michigan), Combustion Model Development and Evaluation.
- Area 5: Robert Lucht (Purdue), Paul E. Sojka (Purdue), Scott Meyer (Purdue), Carson Slabaugh (Purdue), Jay Gore (Purdue), Atomization Tests and Models.
- Area 6: Scott Stouffer (Dayton), Steven Zabarnick (Dayton), Tonghun Lee (Illinois Urbana-Champaign), Referee Combustor.
- Area 7: Josh Heyne (Dayton), Med Colket (contractor), Alex Briones (Dayton), Coordination.

FAA, NASA, and AFRL Funded Activities

Figures of Merit (FOM) to Topics and Players

T_3-P_3 Regimes of Interest



Aim to map NJFCP fuels to stability curve via:

- Experimental interpolation and
- Detailed modeling

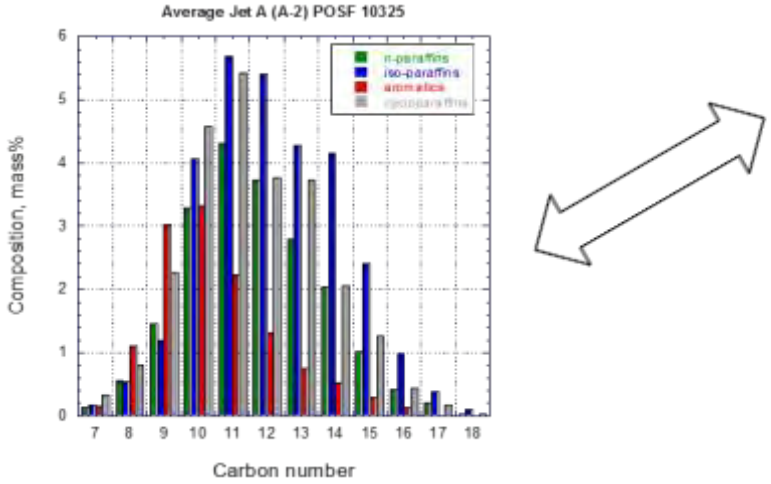
NJFCP Topic Areas for FOM Mapping:

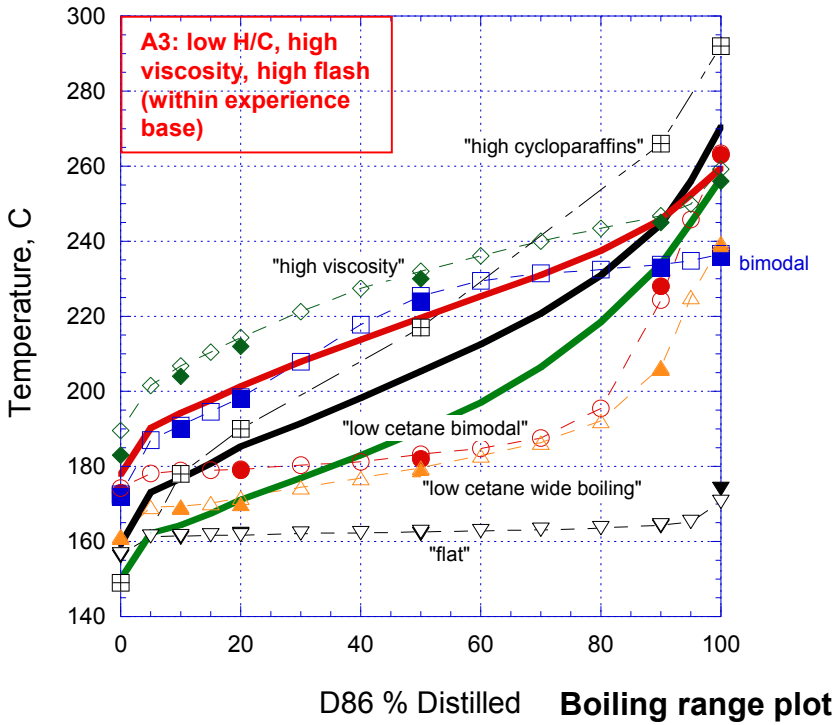
- Combustion Chemistry
  - Areas 1, 2, and 2.5, USC, UIC, UVa, UCSD, and Univ. of Dublin
- Lean Blow Out
  - Areas 3 and 6, Univ. of Cambridge and Sheffield, DLR Germany, NASA, and OEMs
- Ignition
  - Areas 3 and 6, ARL, and NRC Canada
- Spray
  - Areas 5 and 6, NRC Canada, and ARL
- CFD Modeling
  - Areas 4 and 4/5, UTRC, and OEMs
- UDF Development
  - Area 4, 4/5, and 7 and OEMs

FAA, NASA, AFRL (DLA and NavAir), and Allied Partner Funded Activities

Fuel Candidates and Screening

- Reference Fuels Required to Characterize Rig and Engine Fuel Response
- Category A: Three Conventional (Petroleum) Fuels
  --“Best” case (A-1) --“Average” (A-2) --“Worst” case (A-3)
- Category C: Six “Test Fluids” With Unusual Properties
  - **C-1: low cetane, narrow boiling (downselected)**
  - C-2: bimodal boiling, aromatic front end
  - C-3: high viscosity
  - C-4: low cetane, wide boiling
  - **C-5: narrow boiling, full fuel (downselected)**
  - **C-6 and C-6a: high cycloparaffins**





Boiling range plot

C-1 and C-5 were selected for detailed study in Year 1.
C-6 and C-6a are still being sought in sufficient quantities.

Summary of Integrated NJFCP Program

1. Year 1 Accomplishments
   - Demonstrated fuel effects in aeroengine rigs on LBO ✓
   - Created kinetic models for different fuels ✓
   - Demonstrated fuel effects in burner rig simulations ✓

2. Year 2 Objectives
   - Develop and demonstrate capabilities for altitude ignition experiments (i.e. cold fuel-air and/or low pressure capabilities)– *in progress*
   - Demonstrate fuel-dependent CFD and chemistry models towards FOM sensitivity - *in progress*
   - Develop and demonstrate physics-based fuel-dependent spray models for CFD- *in progress*

3. Overall Program Goals
   - Develop an experimental and analytical capability to enable OEMs to evaluate fuel physical and chemical properties on engine operability primary Figures of Merit towards the streamlining of fuels through the ASTM approval process