



Air Force's Perspective on Future Aviation Fuel Research

**Air Force Research Laboratory
Aerospace Systems Directorate**



The Past - Alternative Fuels



- 2006 – MACCCR combustion efforts minimally funded
- Small alt fuels program at AFRL with DOE, Army expanded by SECAF Wynne into national-leading program
- Three parts of program (\$30-40M/yr at max)
 - AFOSR (6.1) – Future Fuel Utilization
 - AFRL/RZ (Propulsion)(6.2-6.3) – Alternative Fuels
 - Alternative Fuel Certification Office (6.4)
- Goal – support alternative fuel development and implementation by developing fuel approval process and aiding in certification
- Notable achievements:
 - Fischer-Tropsch Synthetic Paraffinic Kerosene – 2009
 - Hydroprocessed Esters and Fatty Acids - 2011

2013
end

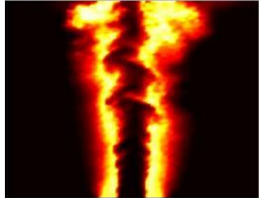


Future Fuel Utilization

Basic Research

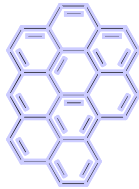


Modeling & Simulation

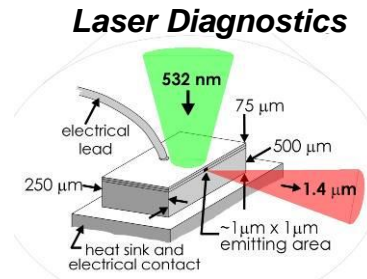


*Hydrocarbon Combustion
Chemistry/Transport*

*Supercritical Fuel
Behavior*



Providing fuel-flexible energy conversion technology



Proposed Funding

Funding: \$2M/year

Duration: 5 years (FY08-FY12)

Background

- In the near term, alternative fuels must be refined to support legacy systems (F119, F135, etc.) that are fuel inflexible
- In the long term, it will be possible to design energy conversion systems to be fuel-flexible, exploiting fuel property variations
- The Air Force will need to be proactive with energy suppliers for timely deployment of new technology

Objectives

- Develop modeling and simulation tools to assess the effects of fuel properties (chemistry and transport) on propulsion system performance
- Transition tools for optimization of fuel utilization

Benefits

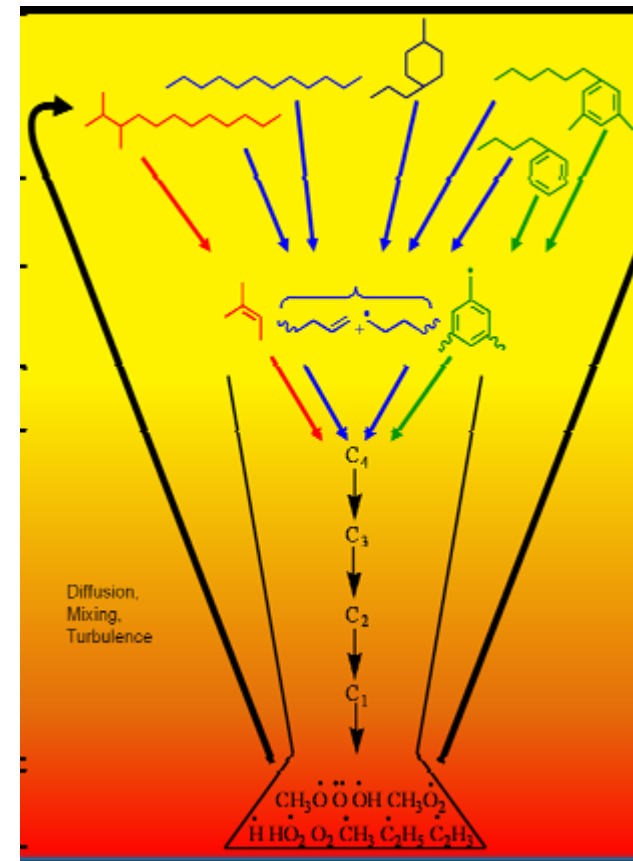
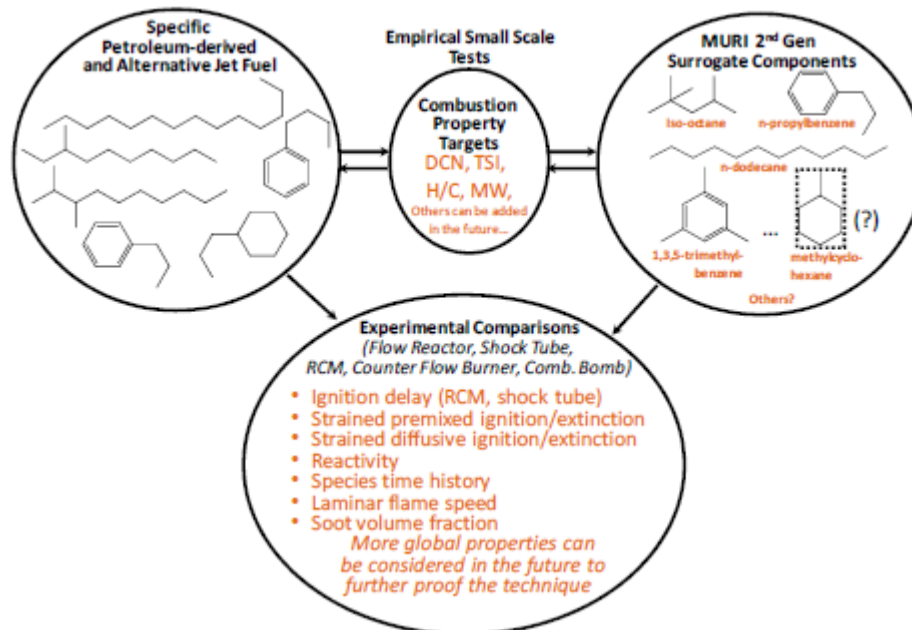
- Wider use of science-based technology design
- Reduced development time/cost for technology
- Emergence of fuel-flexible energy conversion technology
- Streamlined deployment of new fuels



Highlights of Future Fuels Utilization Program



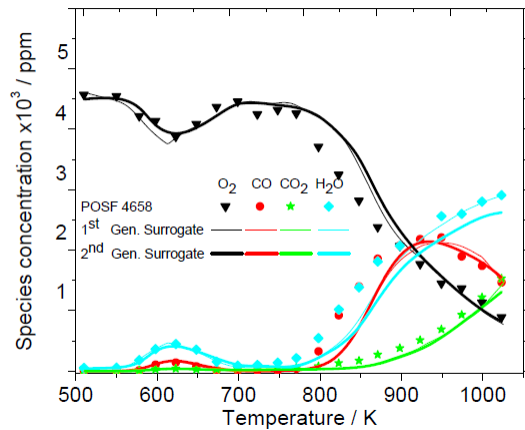
- Include complexity of “real fuels”
- Surrogate Fuel Working Groups for jet, diesel, gasoline
- MURI/IPT programs; core programs
- Better models/approaches, better (more-constrained) data sets





Planned Transition

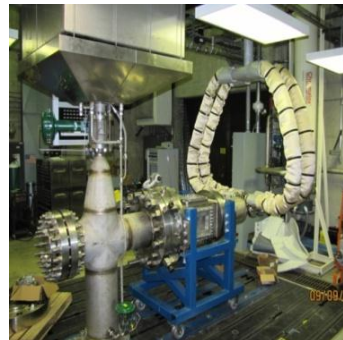
Research community



1. Real fuel samples



2. Intermediate scale

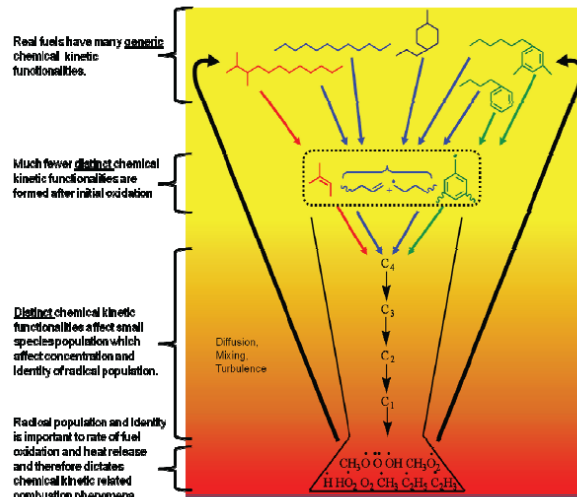
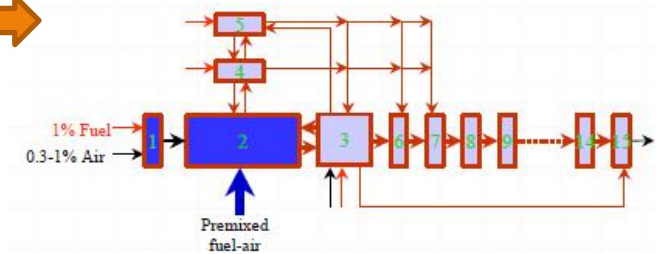
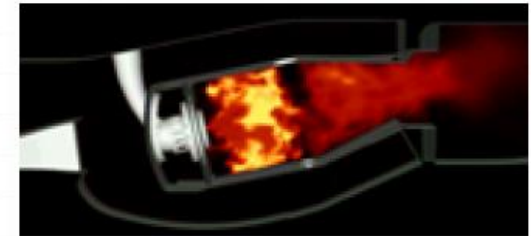


3. Joint programs!

Industry

$$\phi_{LBO} = \frac{f_{pz}}{V_{pz}} \left[\frac{\dot{m}_A}{P_3^{1.3} \exp(T_3 / 300)} \right] \left[\frac{D_0^2}{\lambda_{eff} LCV} \right]$$

Lefebvre [4]



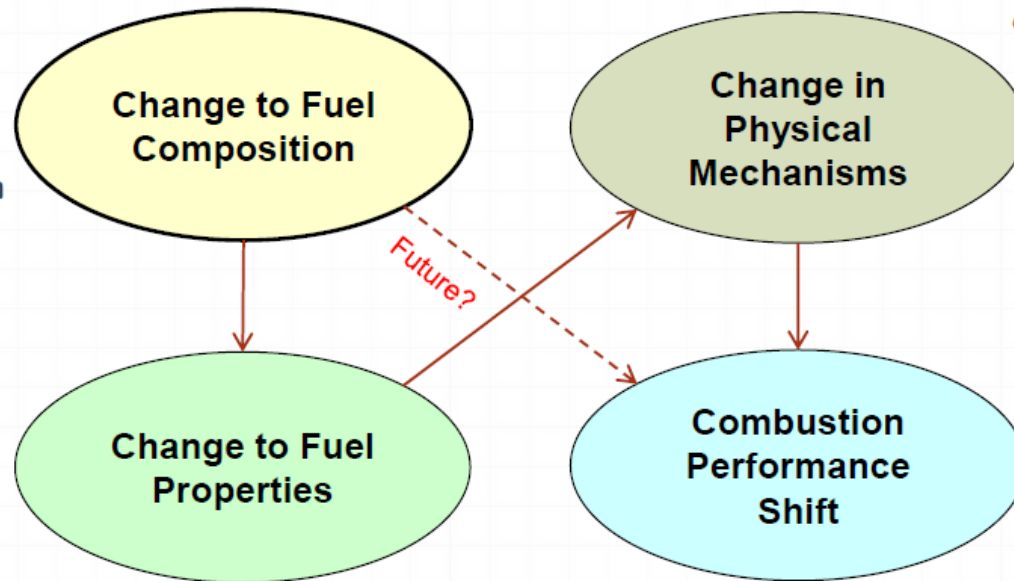


Rules and Tools Program Description



The Impact of Alt Fuels on Combustion

- Aromatics, cycloparaffins, n- and i-paraffins
- Hydrocarbon chain length
- Density vs T
- Viscosity vs T
- Flash point
- Heat of combustion
- Boiling range
- Vapor pressure
- Surface tension
- Cetane
- ...

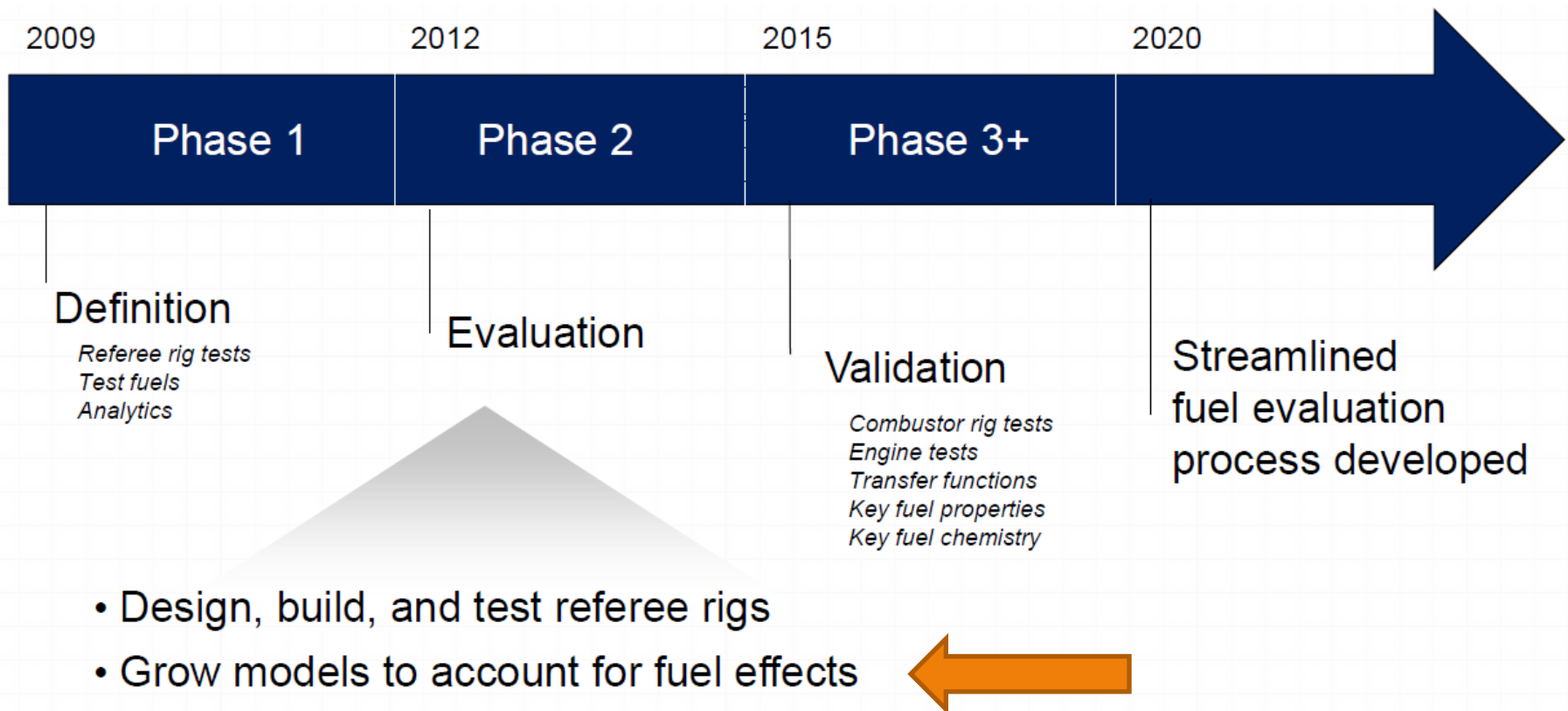


- Physical mechanisms by which fuels affect combustion:
 - Atomization and Spray Distribution
 - Evaporation
 - Chemical Kinetics
 - ...

- Combustion Performance Affected:
 - Lean Blow Out
 - Altitude re-light
 - Combustor Coking
 - Combustor dynamics
 - Emissions / Smoke / PM
 - Pattern Factor
 - Combustor Durability



Rules and Tools Info Needs



Phase II effort terminated (early) in 2013



Picking Up the Pieces



- **AFOSR modeling assets leveraged for Augmentor Design System**
- **AFCO-funded Fuel Effects in Augmentors program - ending 10/13**
- **AFRL/RQ-funded in-house program to test AFOSR IPT concept (FY13/14)**
- **DLA to fund combustor operability study at Honeywell**
- **FAA COE for Alternative Fuels**
- **SERDP/ESTCP for environmental issues**
- **?**



Assets Remaining for Collaboration



- **CRATCAF* reference fuels**

Fuel	Characteristic	Viscosity, cSt (-20 C)	Flash Point, C	Aromatics, vol %
A-1 goal	"best case"	≤ 3.4	≤ 40	≤ 14
A-1 actual (POSF 10264)		3.5	42	11.2
A-2 goal	"nominal"	4.5 ± 0.5	50 ± 3	17 ± 1
A-2 actual (POSF 10325)		4.5	48	17
A-3 goal	"worst case"	≥ 6.5 cSt	≥ 66	≥ 21
A-3 actual (POSF 10289)		6.5	60	18.3

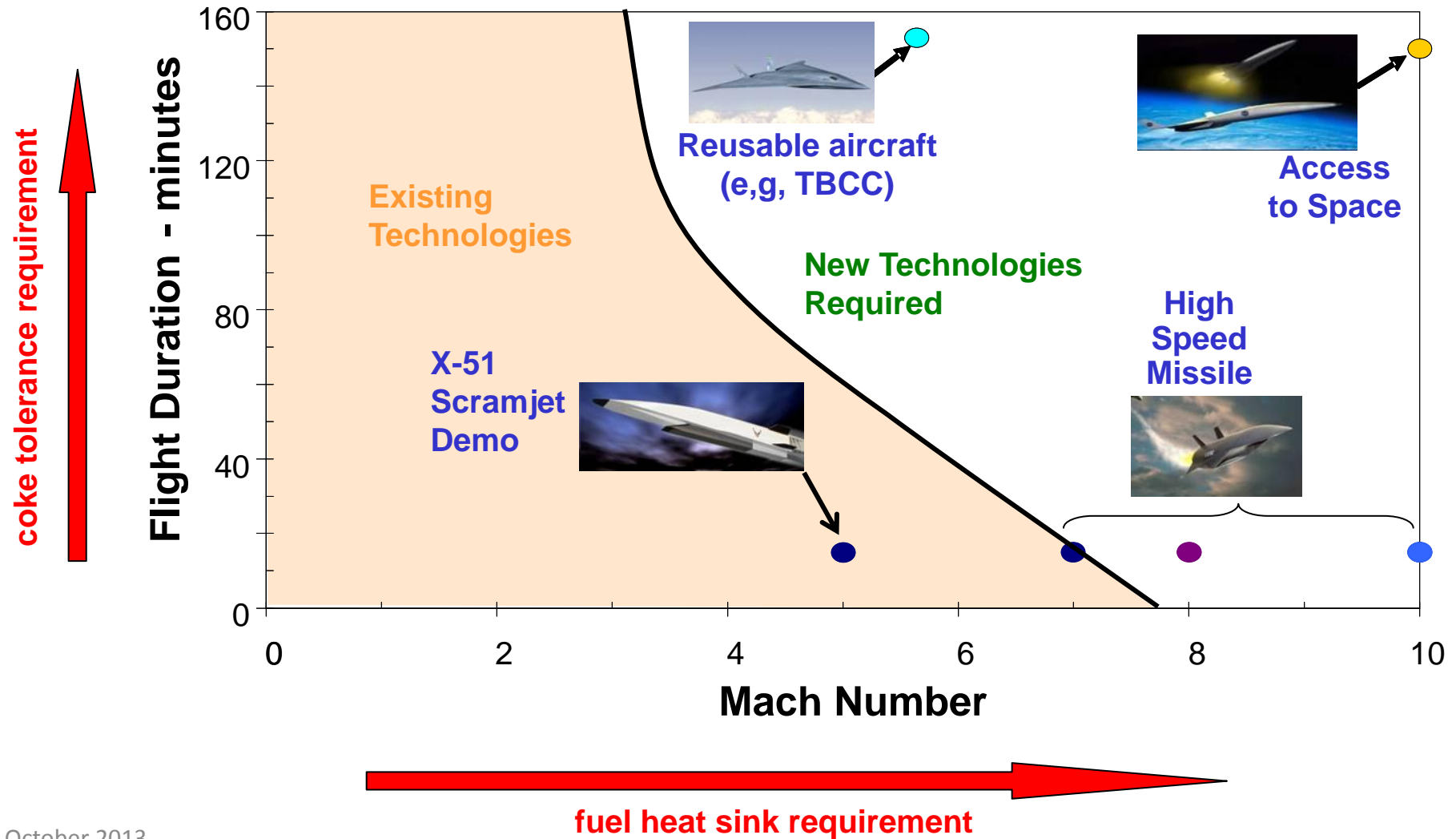
- **AFRL/RQ combustion rigs**
- **Other testing facilities (materials, composition, ...)**
- **Alternative fuels – significant quantities of F-T SPK and HEFA available, some ATJ, others evolving**



Where to Go From Here?

Endothermic Fuels for Hypersonics

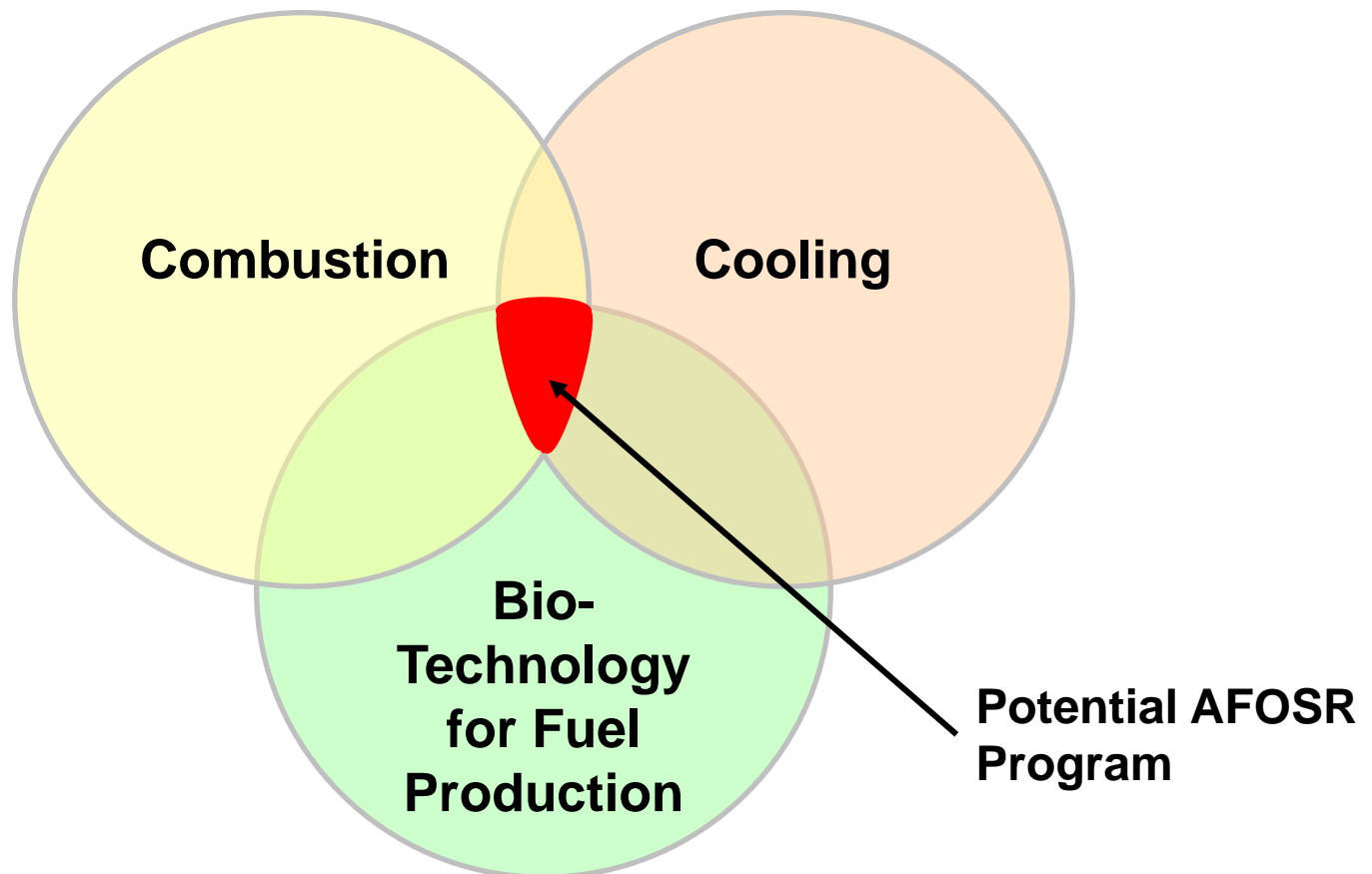
New fuel-cooling technologies will increase reliability of hypersonic demonstrators, and are required for longer duration, higher Mach number hypersonic vision vehicles.





Potential Integrated Program

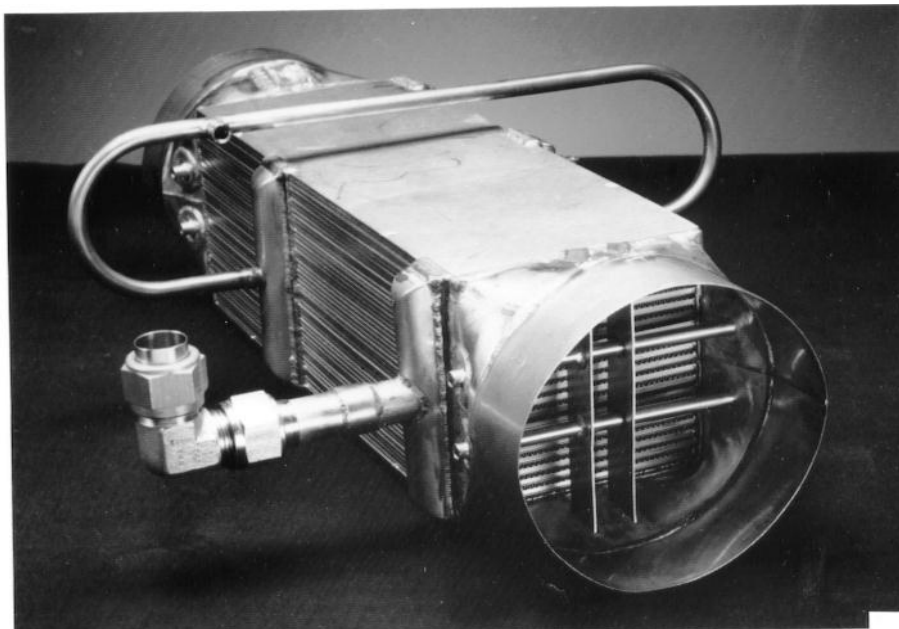
Biggest Challenge for Hypersonics – interface between fuel cooling and combustion





Endo Fuel History

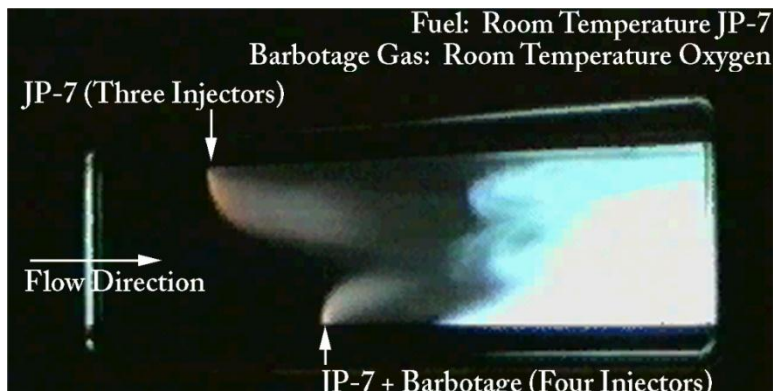
- MCH – 1960s – catalyst bed, difficult integration
- JP-7 (for SR-71) – 1990's – wall-coated catalyst, used in X-51 (2013)
- “There is no true endothermic fuel”
 - Fuel “better than JP-7” elusive





Endo Fuel Challenges

- Amount of cooling (heat sink)
 - Coking (fuel system life)
 - Transition from boost/ignition
 - Flame stabilization
 - Sustained combustion
- Current BRI
- Over Mach number range
- Fuel T, state varies
 - Fuel composition varies
 - Combustor state varies



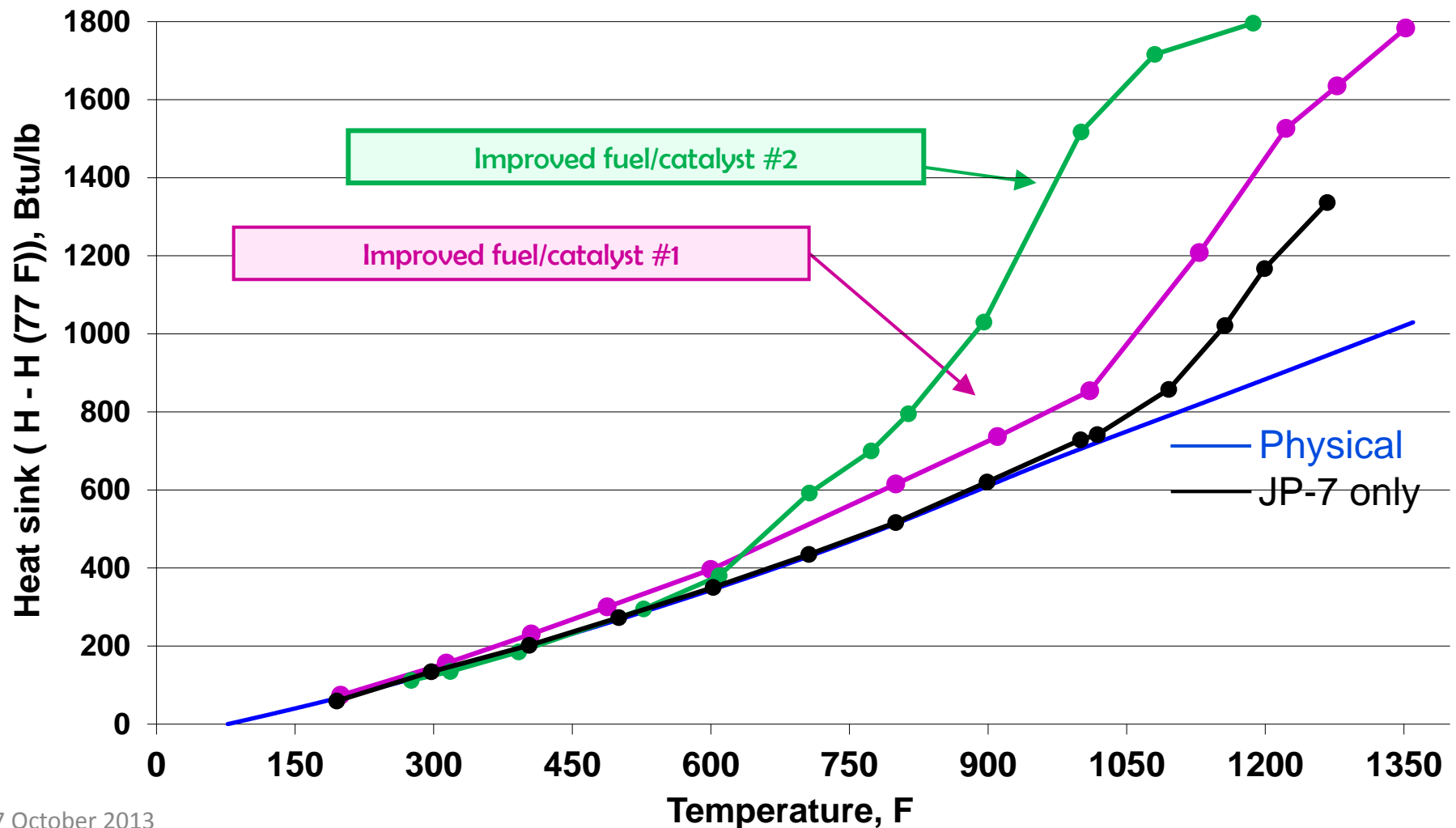
1960s – ClF_3 , alkyl boranes used for combustion enhancement for hydrocarbons



Notional Improved Fuel/Catalyst



- Desirable product for both heat sink and combustion - ethylene

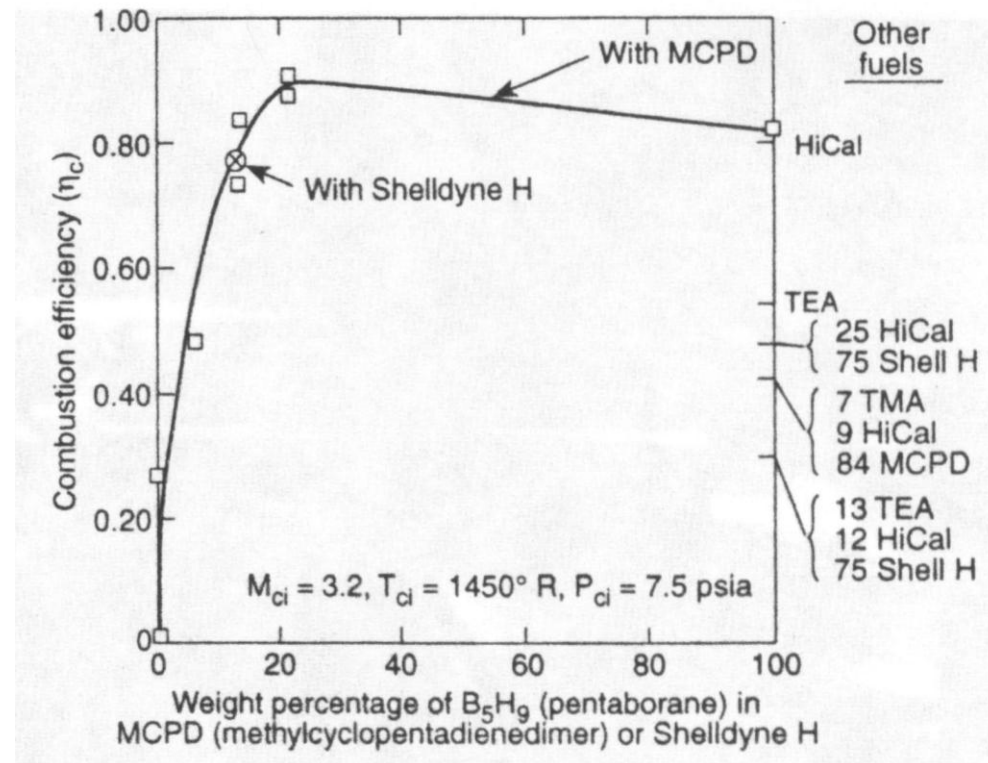




Combustion Research Needs



- Transition from boost/ignition at ~Mach 4
- Flame stabilization
- Sustained combustion
- Over Mach number range
 - Fuel T, state varies
 - Fuel composition varies
 - Combustor state varies
- Research: can fuel state be varied inside fuel system to benefit combustion?

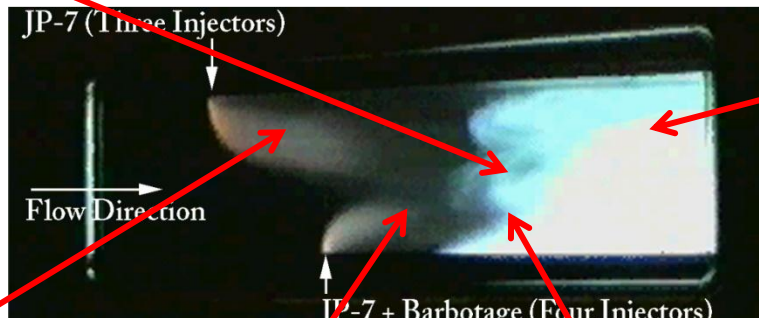


Billig, F. S., Supersonic Combustion Ramjet Missile, JPP 11(6) 1139-1146, 1995



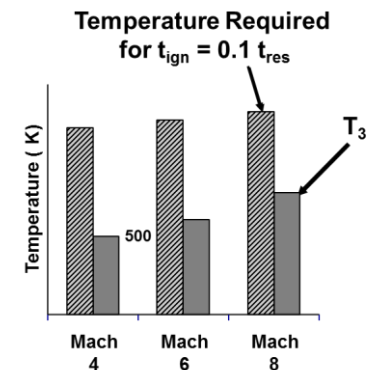
In Situ Diagnostics Needed

catalysts?



unsteadiness ~ flame
stability ~ fuel state?

effect of fuel state on
injection/mixing?



effect of radicals from
cracking inside fuel system
on ignition delay/flame
speed/flame stabilization?
Which HC radicals?

laminar flame speed \ll flow
velocity – effect of endo fuel
state on mixing/kinetics

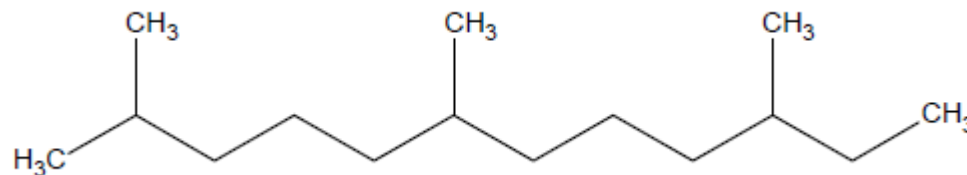
What is the role of fuel “pre-reaction” inside fuel system?
Can fuel bring in catalysts to combustor?



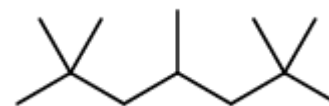
Bio-Synthesis for Affordable Single Molecules



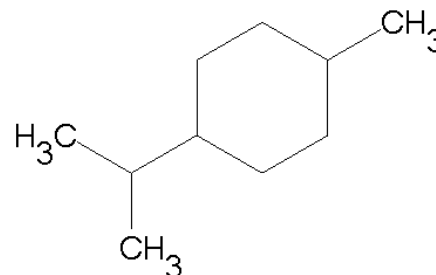
- **Farnesane**



- **Mesitylene**
(1,3,5 trimethyl benzene)



- **Oligomerized iso-butanol**
- **Isopropyl methyl cyclohexane**

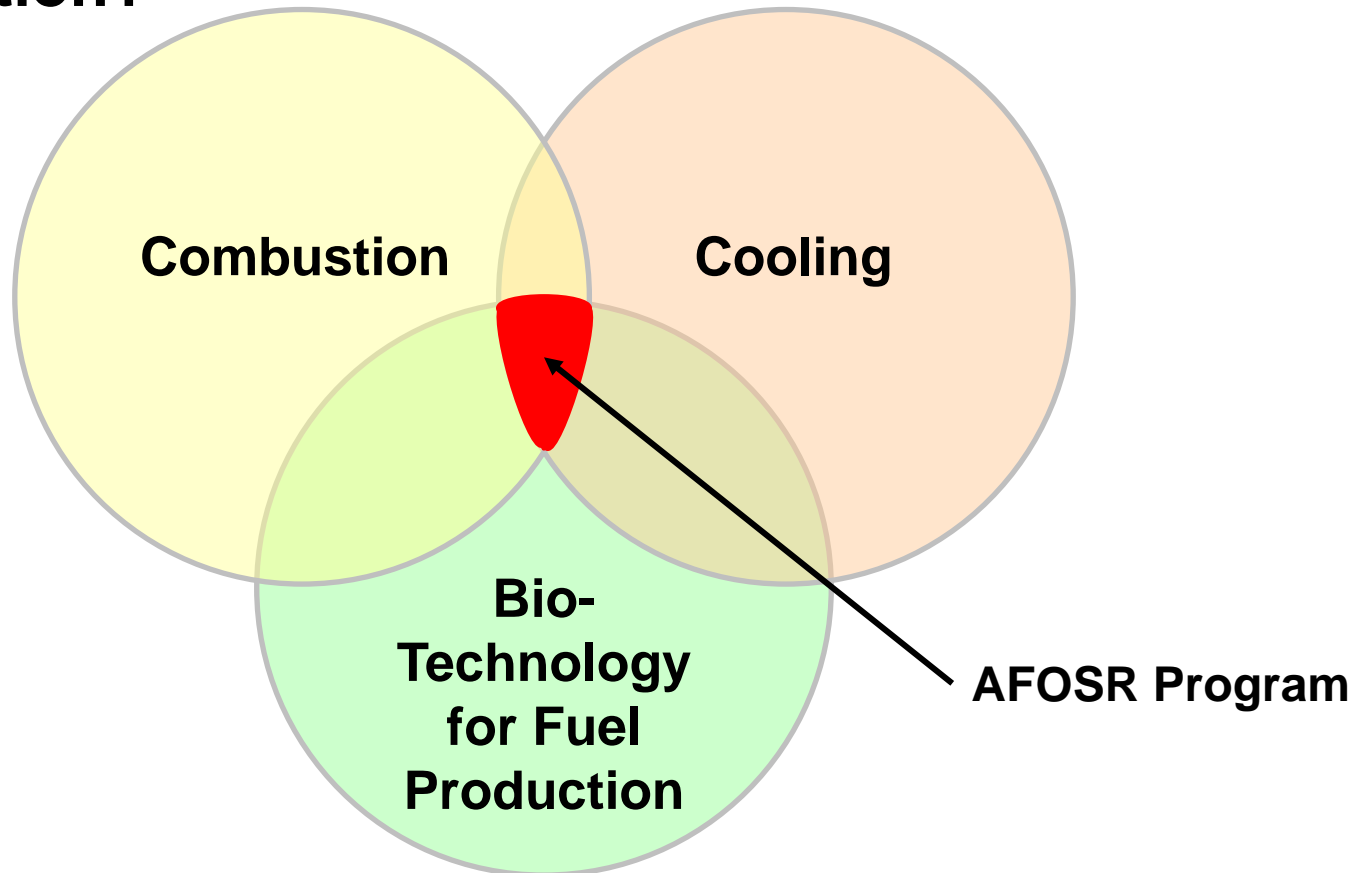


Affordable source of large quantities of single molecules for kinetic studies



Summary

- **Potential theme: Can fuel composition and endothermic reactions during cooling be controlled to improve combustion?**

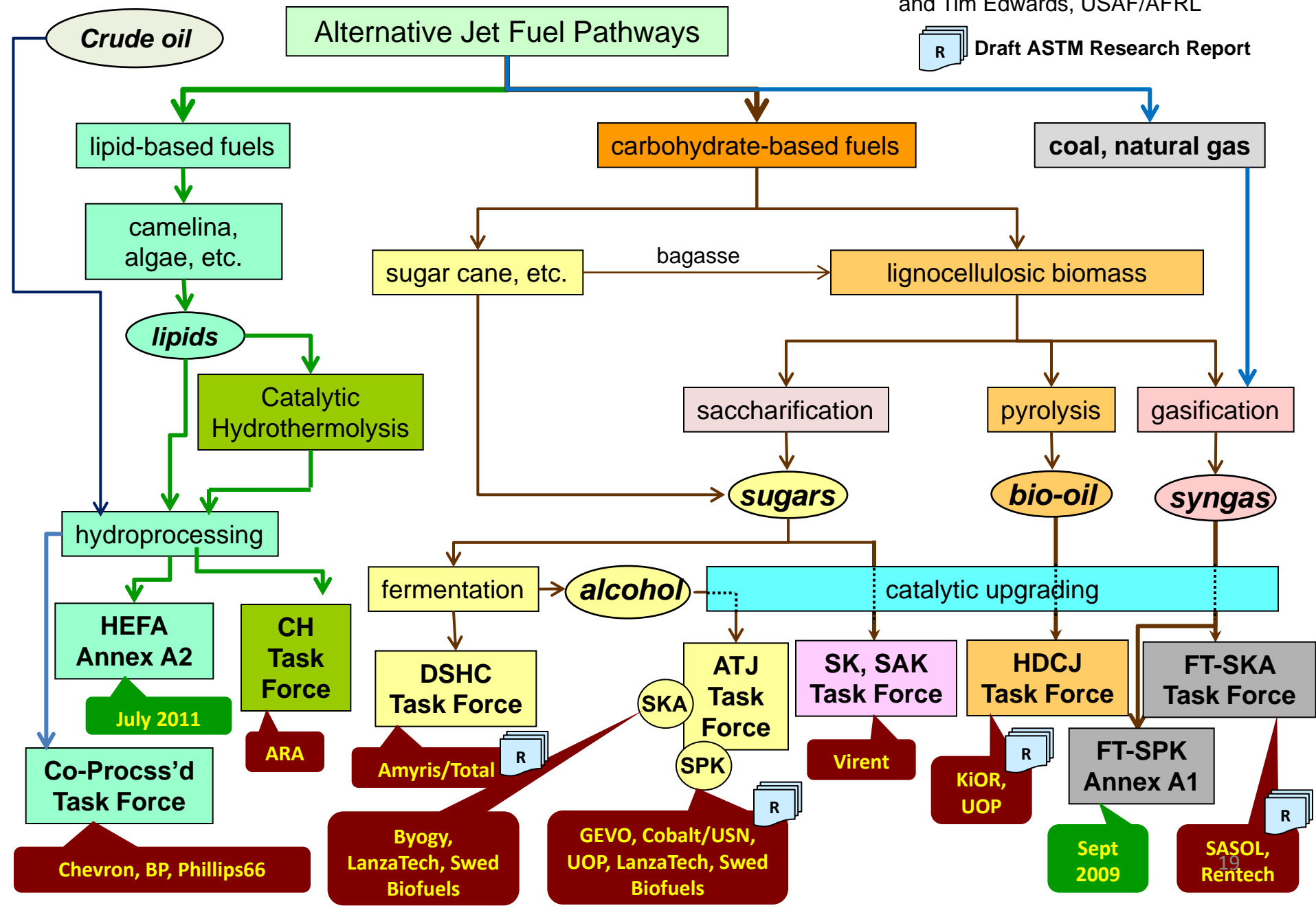


ASTM D7566 TASK FORCES

Adapted from Brown, Iowa State, 2012
and Tim Edwards, USAF/AFRL



Draft ASTM Research Report





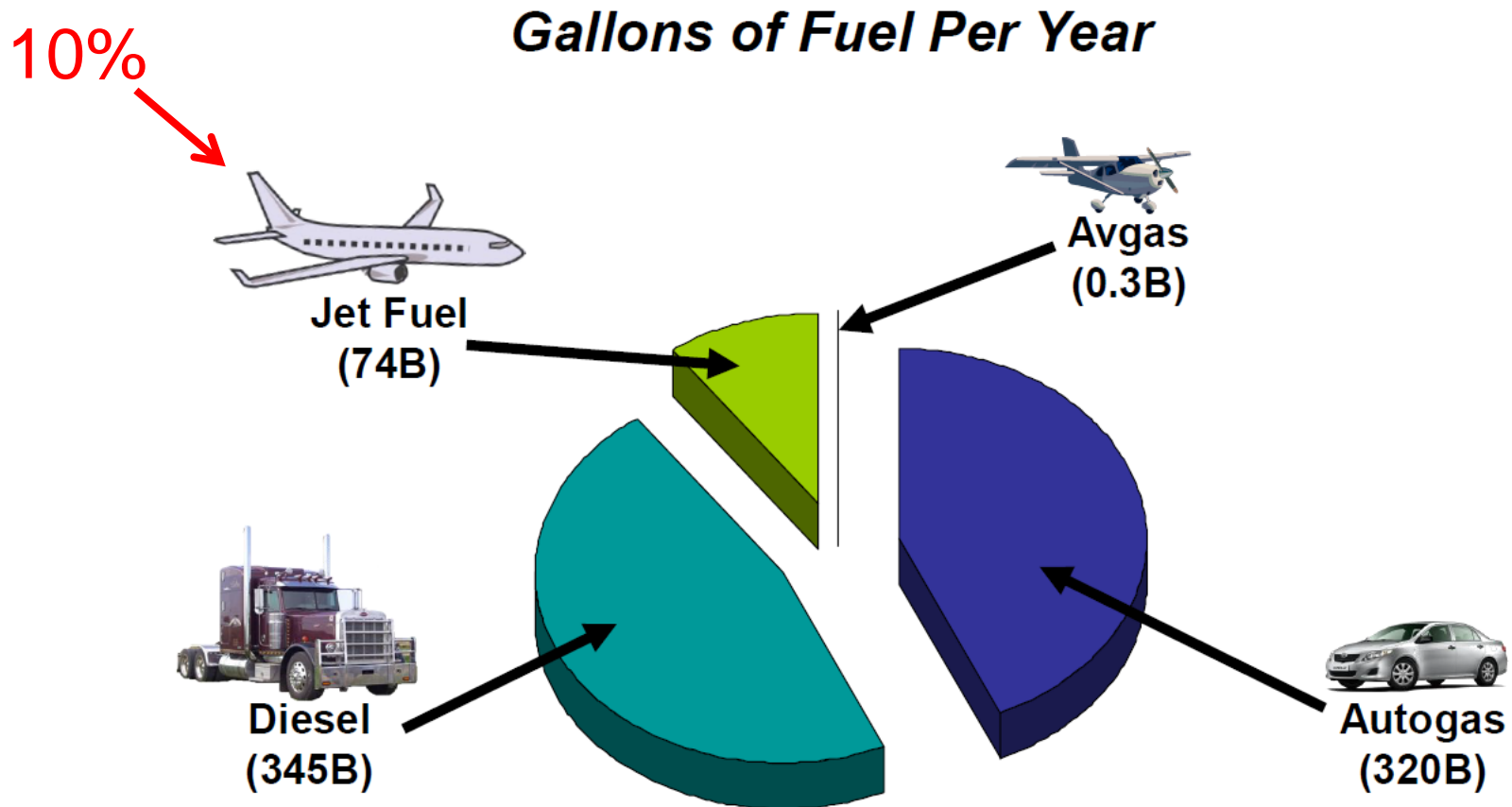
Key Alternative Fuel Issues

- **Developing efficient certification process**
 - Fuels differentiated by process
 - Issue – industry funding data review internally – for how long?
- **Interagency coordination**
 - CAAFI
 - Tri-Service
- **Certification vs fuel production (chicken vs egg)**

Key Unsolved Issue: How much engine testing (\$) required? How to do the testing?



Aviation's Share of Transportation



World-wide – U.S. has higher gasoline/diesel ratio



Air Force Jet Fuel Data



- AF annual jet fuel use: 2.5B gallons, >\$9B (2013)
- 81% of total AF energy use
- >8% of budget (2011)
- AF fuels naturally divides into:
 - Bulk fuels – fuels for aircraft and other reusable systems – fuel selection driven by cost/logistics and performance
 - Specialty fuels – fuels for rockets, missiles and other expendable vehicles – fuel selection driven by performance
- Notable Trends: Convert CONUS jet fuel use from JP-8 to Jet A by 2017 (AFSO 21)

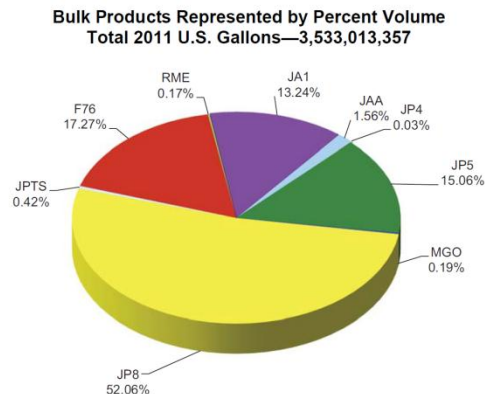


Figure 1 Energy utilization across the Armed Forces and Aviation Operations (FY2009)

