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ALTERNATIVE FUELS

Pat Muzzell, Alternative Fuels Team Leader

June 19, 2009

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Topics

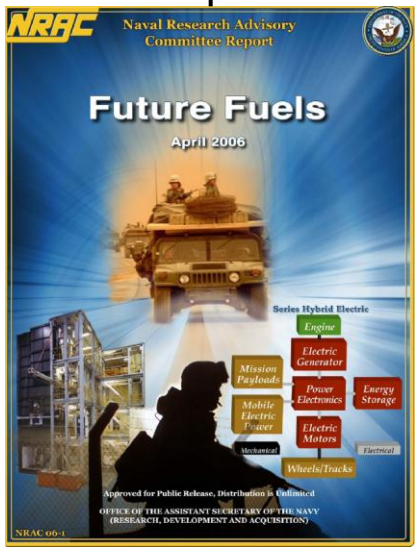
- **Introduction**
  - Transportation Market Evolution
  - Tactical Mobility Fuel
- **Single Fuel in the Battlefield**
  - What is the Single Fuel?
  - Certification / Qualification Pipeline
  - DARPA Alternative Jet Fuels Program
- **Coordinating the Overall Alternative Fuel Qualification Process**
  - Tri-Service POL Users Group
  - Notional Qualification Process
- **Army Alternative Fuels Qualification**
  - Overall
  - Army Aviation Qualification
  - Army Ground Qualification
- **Army Fuel Requirements and the JP-8 Spec**
- **Commercial Aviation Alternative Fuels Initiative (CAAFI)**
  - Roadmaps
  - Fuel Readiness Levels

Transportation Market Evolution

21st Century
Transportation market evolution continues, shaped by heightened concerns about energy security and the environment.

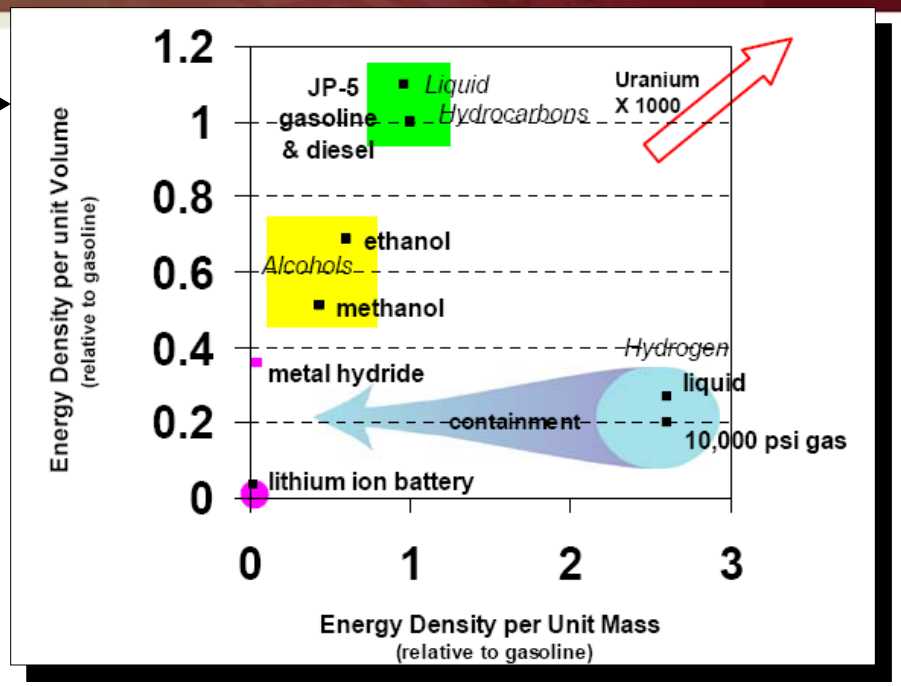
- **Alternative fuels desired in the jet/diesel fuel supply**
- **Changes in fuels supply driven by**
  - Legislation [EPAct 2005, EISA 2007], Exec Orders [EO 13423]
  - USAF Alternative Jet Fuels Program with goal to certify aircraft on alternative jet fuels by 2011
  - Commercial Aviation Alternative Fuels Initiative (CAAFI)
  - Various initiatives to manufacture alternative fuels from diverse sources
- **Army active in assessing emerging changes**
  - Tri-department coordination of alternative fuels qualification efforts

Tactical Mobility Fuel



Naval Research Advisory Committee Panel* Report (April 2006)

* Dr. Walt Bryzik panel member, Chief Scientist, TARDEC (Retired)



Liquid hydrocarbons – ideal fuel for tactical mobility

DOD SINGLE FUEL POLICY

AVIATION KEROSENE GRADE (JP-8)
MIL-DTL-83133

JP-8 (Jet A-1 plus additives) is the primary fuel used for both air and ground equipment in all theaters, overseas and Continental U.S.

- **Tactical vehicle** designs impose severe limitations on volume and weight
- **Energy density** is therefore the primary consideration for fuel
- **Hydrogen presently unsuitable** as a tactical mobility fuel
  - – made from other fuels/resources
  - – containment reduces energy density by 10-20X

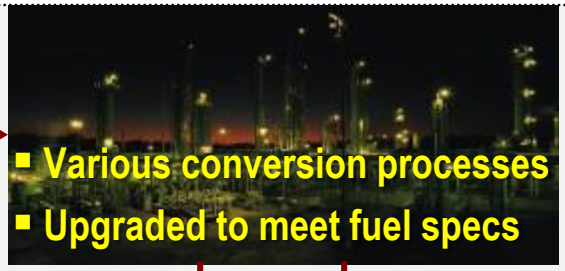
What is the Single Fuel?

Biomass Energy (renewable)

Fossil Energy (large U.S. resource)

Petroleum Crude Oil (declining discovery / production)

Diverse energy sources



- Various conversion processes
- Upgraded to meet fuel specs

Petroleum based | **Non-Petroleum based**

Single Fuel in the Battlefield (SFB)*: Kerosene-type (jet) fuels, whether petroleum-based or not, allowed under specs for JP-8 / JP-5 / Jet A-1

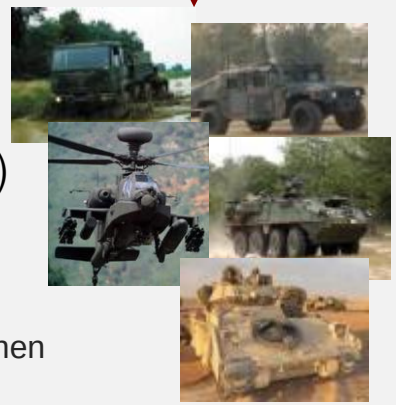
Alternative jet, diesel fuels

- Produced for dual-use (military and commercial)
- Meet specs used by military
- Often blends with petroleum-based fuels

* SFB Policy allows diesel fuel in ground equipment when supplying jet fuel not practicable or cost effective

Alternative Fuels RDT&E:

- Expand technical database on alternative fuels
- Engage in specifications development for alternative fuels
- Qualify alternative fuels for use in Army tactical / combat equipment and systems



TARDEC Alternative Fuels Focus

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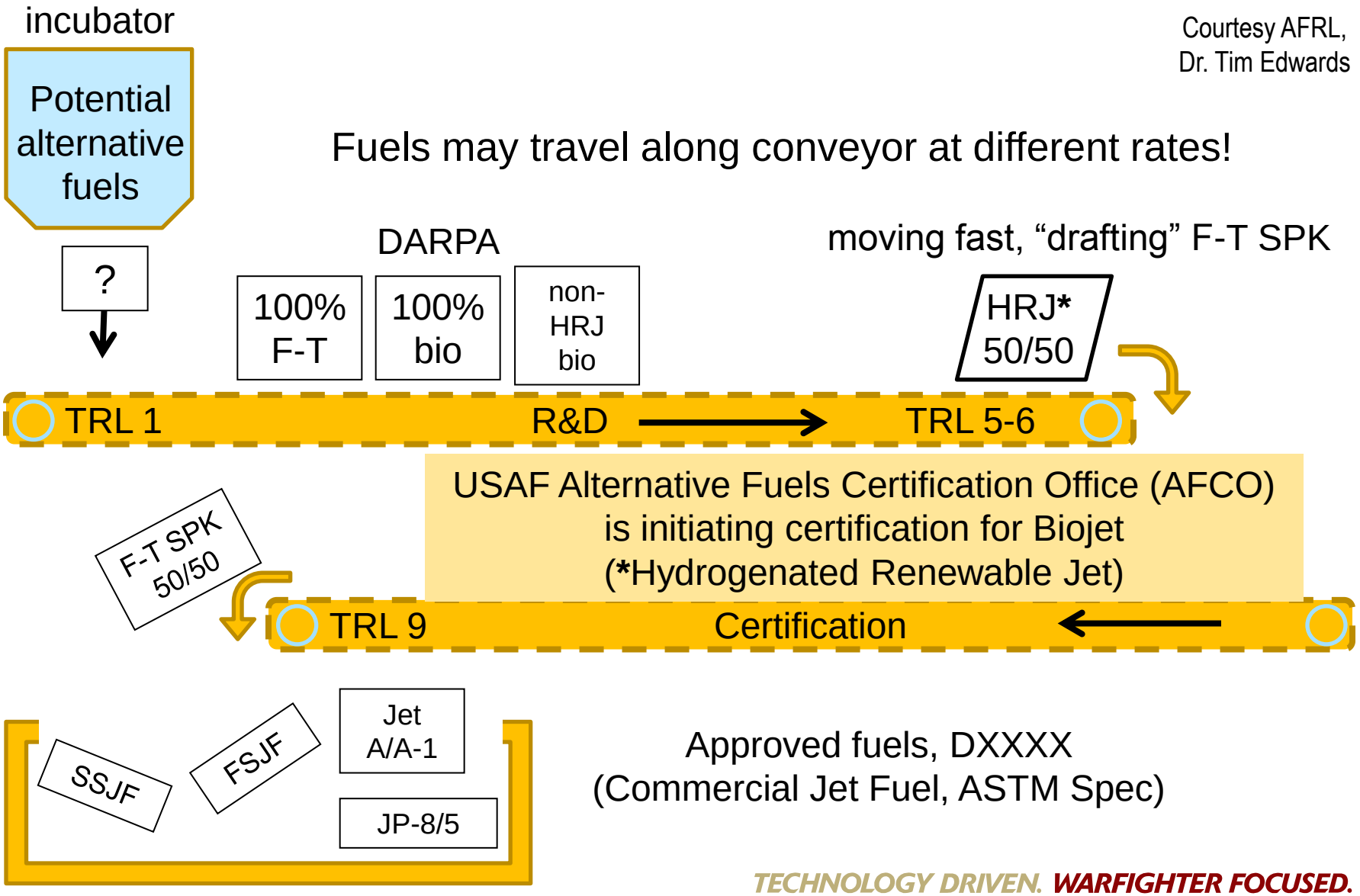
Certification / Qualification Pipeline



Hydrogenated Renewable Jet (HRJ) Properties Study - AFRL

- **HRJ properties indistinguishable from F-T SPK**
  - Spec properties (density, freeze, flash, heat of combustion, etc.)
  - Contaminants (metals, oxygenates, etc)
  - Fit-for-purpose properties (lubricity, dielectric, cetane, etc.) (in progress)
  - Combustion operability and emissions (in progress)
  - Material compatibility (in progress)
  - Blend properties (in progress)

- **Issues (same as SPK!)**
  - Density of blend
  - Aromatic content of blend
  - GHG footprint/sustainability
  - Cost (feedstock for HRJ, plant cost for F-T)

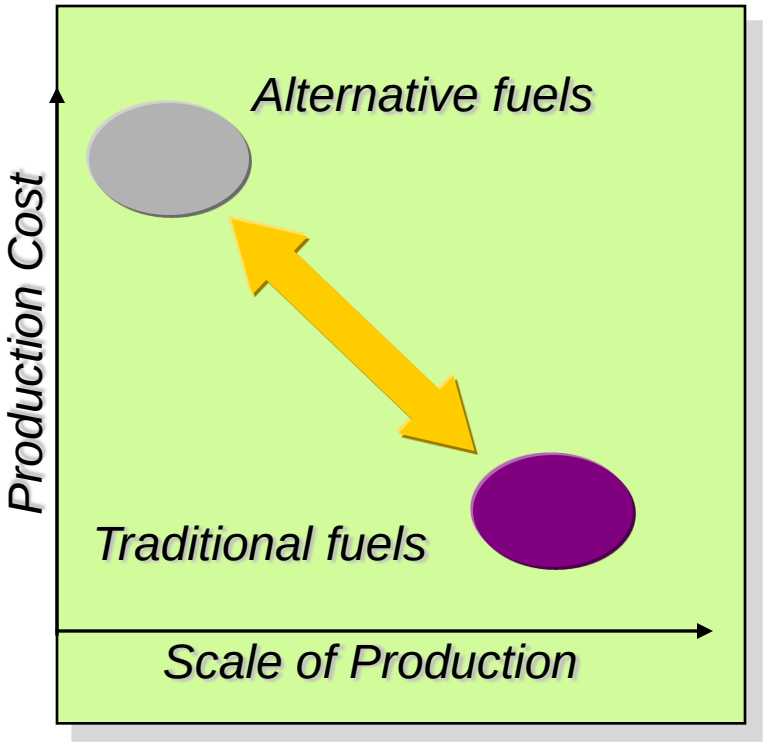
Courtesy AFRL,
Dr. Tim Edwards

DARPA Alternative Jet Fuels

- **Agricultural crop oils** (canola, jatropha, soy, palm, etc.)
  - University of North Dakota EERC
  - UOP
  - General Electric (GE)
  - Swedish Biofuels AB

HRJ (Biojet)

- **Cellulosic and algal feedstocks** that are non-competitive with food material
  - General Atomics ($19.9M)
  - SAIC ($25M)
- Acceptable **coal-derived** fuels
  - $8.4M total
  - proposals due 02 Jun 2009



Can alternative jet fuels be made on large-scale and be cost competitive?

Coordinating Overall Process for Alternative Fuel Qualification

- **Tri-Service POL Users Group**
  - Developing DoD qualification process
    - Includes all stakeholders (e.g., aircraft, ground vehicles/GSE, infrastructure . . .), OEMs
    - Process specified and mandated for alt fuel producers independent of feedstock
    - Requires process be recognized by major fuel specifications, standard agreements
  - Synthetic fuels database populated (85%)
  - JP-8 specification FT wording coordinated
  - Continued liaison with DESC SynFuels Working Group
  - Shared Lessons Learned, data and resources

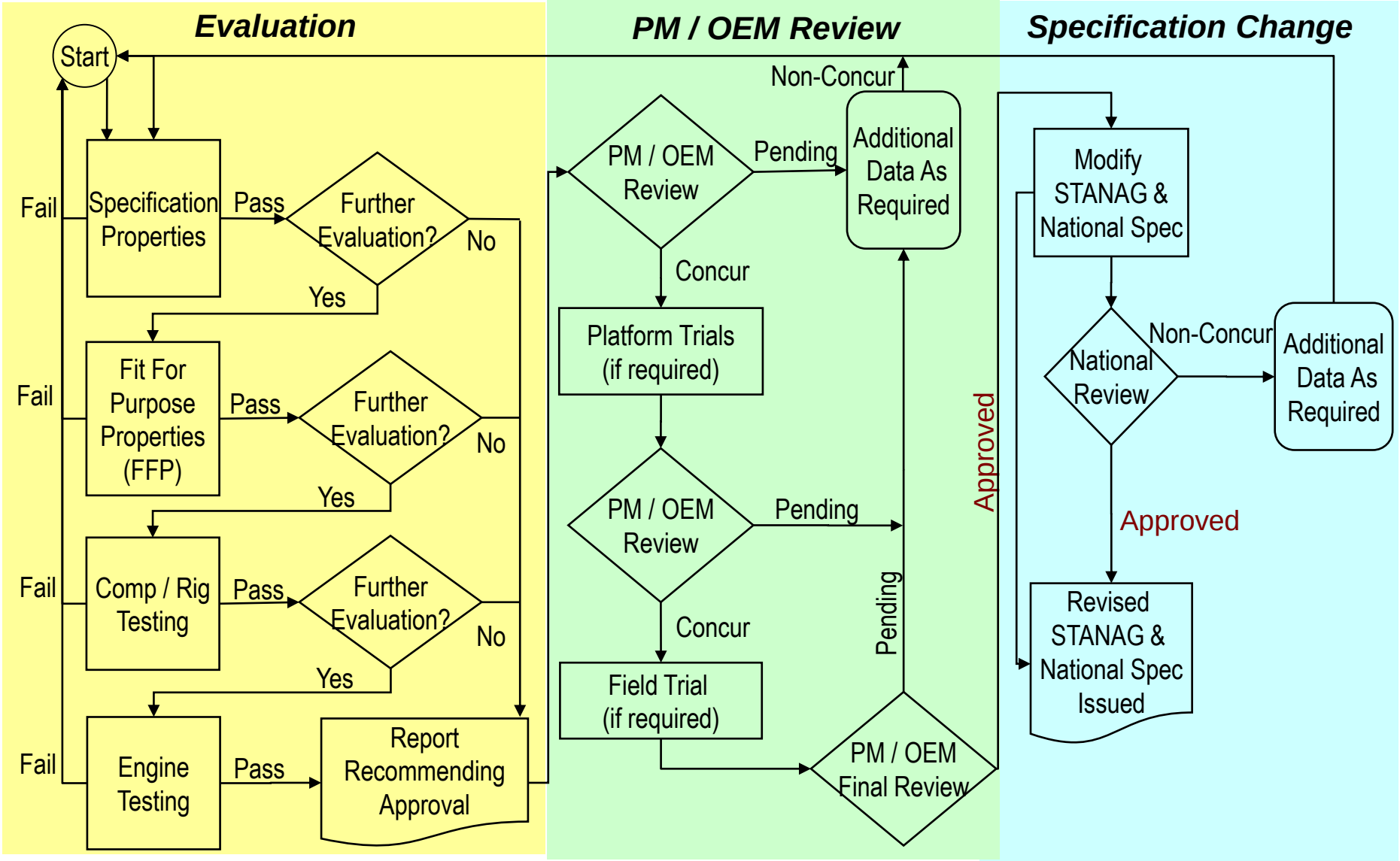
FY08 Focus

  - Conduct gap analysis – synfuel efforts, expand to biofuels, ID potential joint efforts
  - Increase visibility outside SCP world
  - More awareness needed that group exists, recognition as key OSD asset
  - Development of framework for DoD test and certification process

FY09 Challenges

- **Within Army**
  - Currently in evaluation phase (see process flow chart next slide)
  - Coordination with AMRDEC, need to expand to other key RDEC stakeholders

Alternative Fuel Evaluation & Approval (Notional Qualification Process)



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Army Alternative Fuels Qualification

Synfuel Blends

Develop data needed to assess fuel's suitability for use. ← → Build user knowledge of and confidence in use of fuel.

Laboratory Evaluations → **Component Evaluations** → **System Evaluations** → **Demonstrations**

- **Completed**
  - Fuel chemical composition and properties
  - Materials compatibility evaluations
  - Fuel lubricity evaluations (rotary fuel injection pump)
  - Fuel blends studies
  - Limited component/engine/system testing (ground equipment)
- **In Progress**
  - Engine performance / durability testing (NATO test cycle)
  - Test track evaluation – HMMWV
  - Tactical wheeled vehicle (5x5) pilot field demo
  - Fuel lubricity evaluations (common rail injection system)
  - Cetane - Volatility window studies
- **Planned**
  - Component/engine/system testing and demos **(Army Aviation)**

* Synfuel Blends: blends of Fischer-Tropsch Synthetic Paraffinic Kerosene and JP-8 meeting MIL-DTL-83133F

Army Aviation Qualification

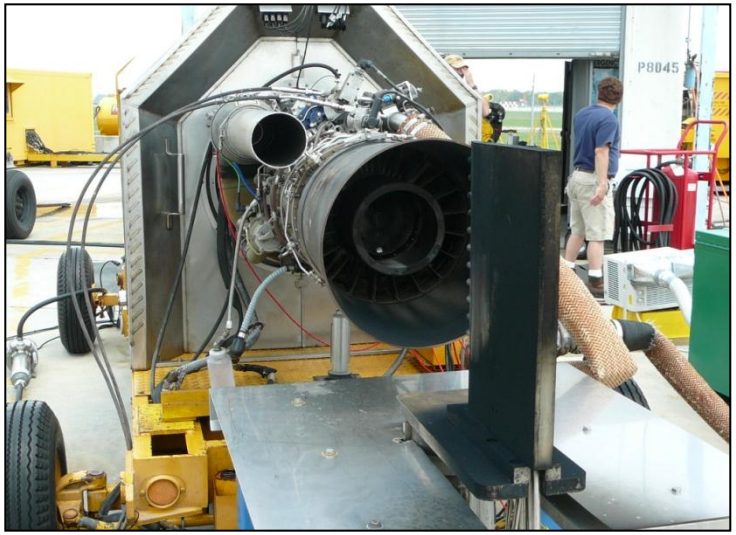
- **Alternative fuels under development for aviation: USAF is lead Service**
- **Certification complete for 50/50 F-T /JP-8 blend on several AF main engines, APUs, and ground support equipment**
- **Streamlined, knowledge-based fuels certification process codified in MIL-HDBK-510**
  - Sufficient for all future aviation fuel certification efforts
  - Maximizes data reuse – streamlines platform certification effort/reduces time & cost
- **MIL-DTL-83133F revised to allow F-T fuels to be a part of the single battlespace fuel (same process can potentially be used new alternative fuels in future)**
- **Alternative fuel blend (up to 50% F-T) to be certified for use in all AF systems by 2011 (SecAF goal)**
- **Army Aviation will leverage AF work to enable reduced certification time and costs for Army Aviation platforms.**
- **Limited alternative fuels testing performed on Army relevant aircraft engines to date: T700-GE-701C**

* Synfuel Blends: blends of Fischer-Tropsch Synthetic Paraffinic Kerosene and JP-8 meeting MIL-DTL-83133F(JP-8 spec)

Army Aviation Relevant Engine Testing

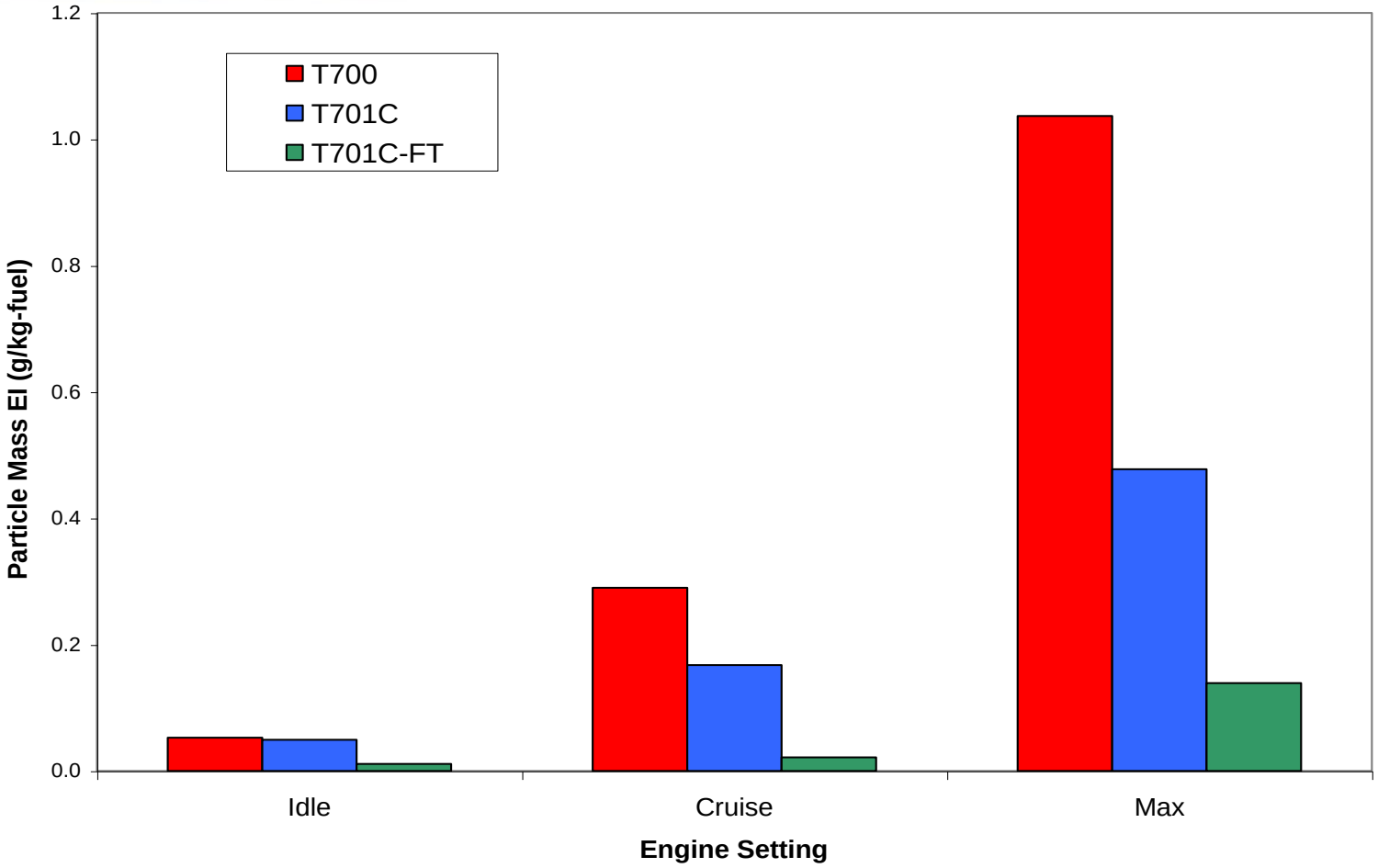
AH-64 Apache

UH-60 Blackhawk



- Tests on one T700 and two T701C engines
- Emissions tests on T701C with JP-8 and neat F-T fuel
- Test under SERDP Project

Army Aviation Relevant Engine Testing



T700-GE-T701C operated with JP-8 and neat FT fuel

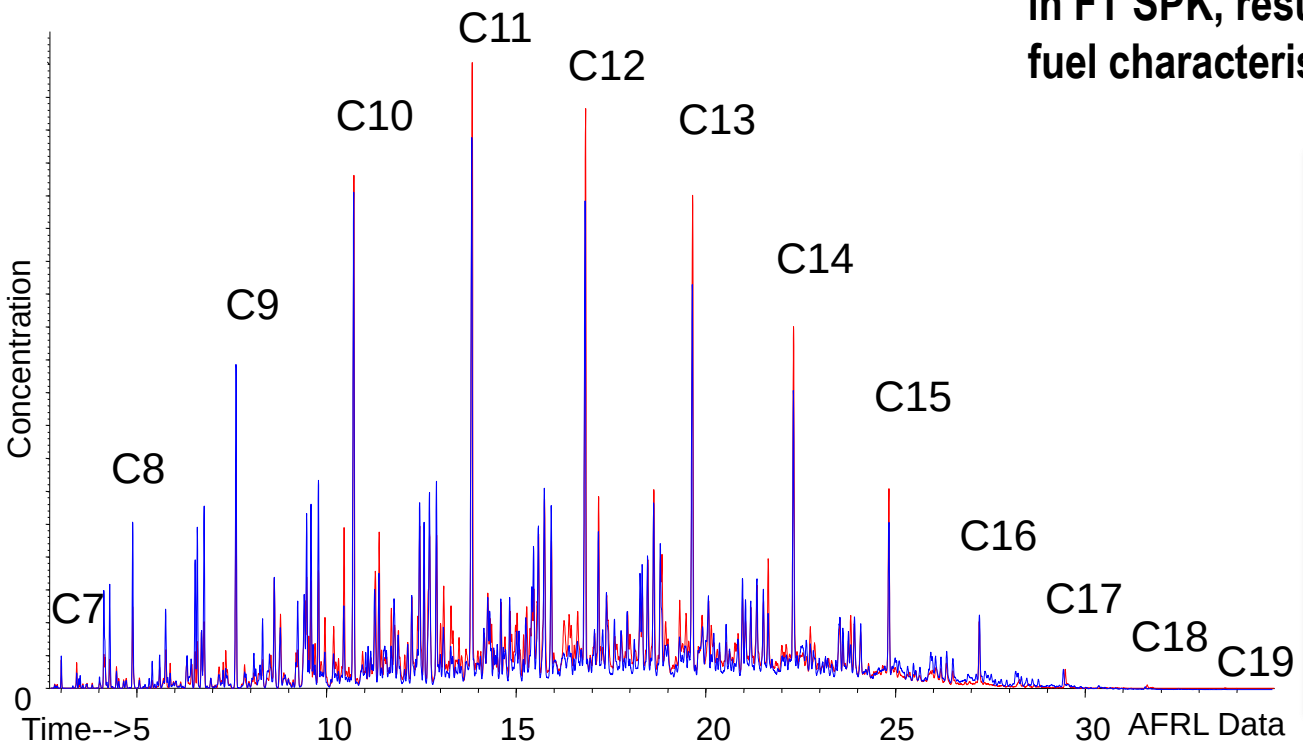
Approximately 50% lower particle mass emissions with T701C compared to T700

Reductions of ~75% in particle mass emissions for T701C with neat FT fuel

Properties of Synthetic Paraffinic Kerosene (SPK)

JP-8

Fischer-Tropsch (FT) SPK*



- **Nothing in FT SPK that is not in JP-8**
- **Not all compounds in JP-8 are necessarily in FT SPK, results in some differences in fuel characteristics**

Aromatics:
Lower fuel density and volumetric energy density, higher Cetane No., less solvency

Sulfur:
No exhaust SOx

Trace compounds:
Less inherent fuel lubricity

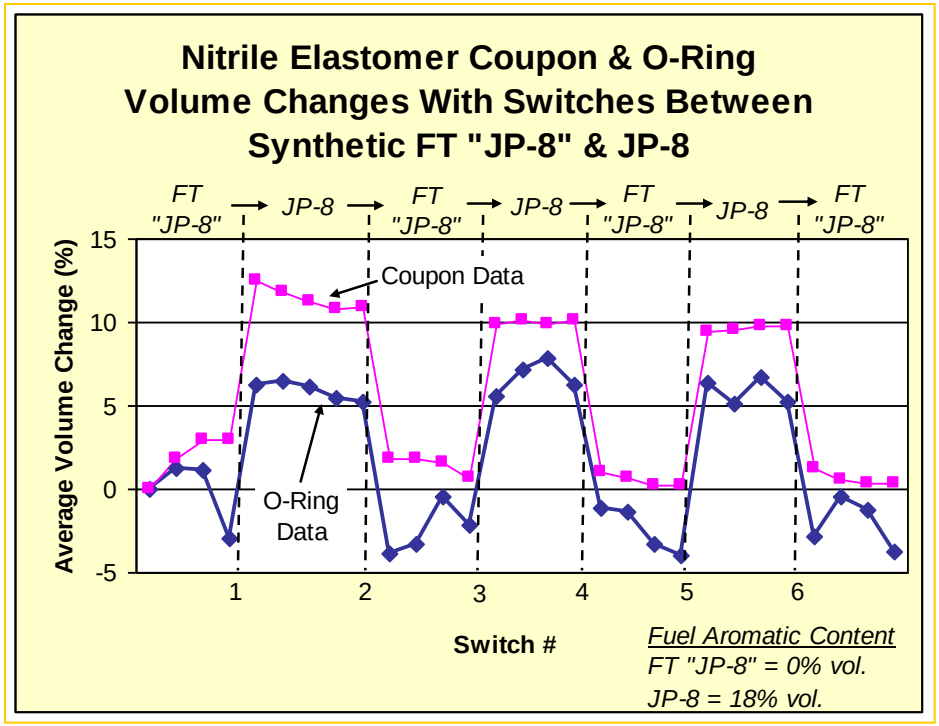
- **Can impact component or engine performance and durability**

***Synthetic-Paraffinic Kerosene:**
Hydrocarbons distributed across the full jet fuel boiling range and having on whole properties suitable for use as an aviation fuel.

Fuel Blends Are Implementation Path

- **TARDEC elastomer compatibility evaluations* supported a "blends implementation path"**
- **Blends of up to 50% by volume FT SPK with JP-8**
  - Blends minimize/eliminate risk of fuel leaks due to change in fuel aromatic content
- **Other aspects supporting a blends implementation path**
  - Production capacity will build slowly
  - Lower energy density of FT SPK

***SAE Paper 2007-01-1453**



- Nitrile components swell in JP-8, then shrink when switched into FT SPK (FT "JP-8")
- O-ring shrinkage increases risk of sealing failures
- Using unaffected o-ring elastomers or FT SPK in blends with JP-8 are ways to reduce this risk

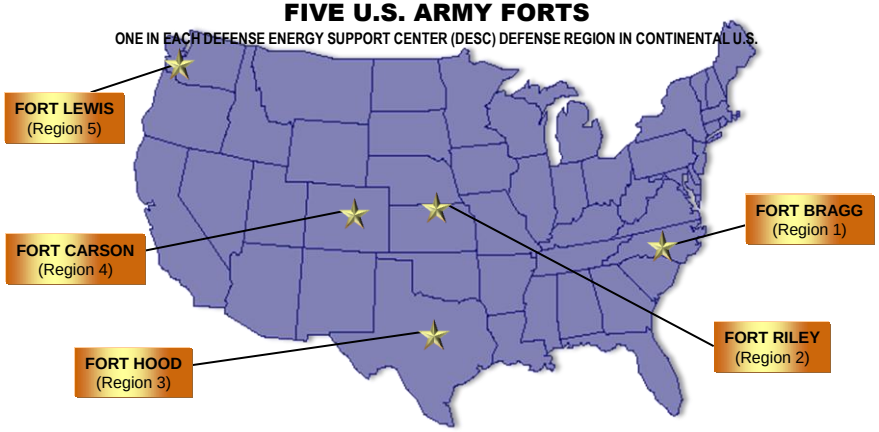
Blends Study

- **FT SPK/JP-8 Blend Properties**
  - Compared properties of blends with typical properties of JP-8 (CONUS, 2004)
  - Determined properties of blends (up to 50% FT SPK) generally fell within typical “property box” of JP-8
  - Study documented in **SAE Paper 2006-01-0702**
- **Follow-on study looked at typical JP-8 in use at five Army installations in CONUS**
  - Determined that at four of the five installations blends with the maximum reduction of 50% by volume petroleum content (JP-8) are possible
  - Study results documented in **2007 IASH Conference Poster** (see next slide)
    - International Association of the Stability, Handling and Use of Liquid Fuels (IASH)

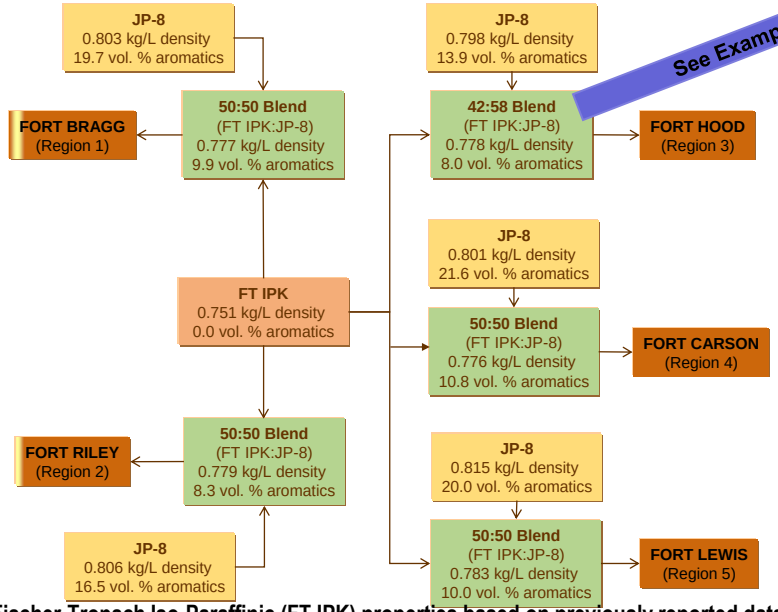
Synfuel Blends Study

FUEL BLENDS STUDY BASED ON JP-8 USED AT FIVE U.S. ARMY FORTS

ONE IN EACH DEFENSE ENERGY SUPPORT CENTER (DESC) DEFENSE REGION IN CONTINENTAL U.S.



50% REDUCTION IN PETROLEUM FUEL (JP-8) POSSIBLE AT FOUR OF THE FIVE FORTS IN STUDY



– Fischer-Tropsch Iso-Paraffinic (FT IPK) properties based on previously reported data

– JP-8 typical properties based on DESC data for several fuel deliveries during April 2006 – March 2007

DETERMINING MAXIMUM PERCENTAGE OF FT IPK POSSIBLE IN BLEND WITH GIVEN BATCH OF JP-8

How to Use Chart:

1) Start at left Y-axis with density for given JP-8, read across to density curve (blue) and down to X-axis, note percentage.

2) Then, at right Y-axis with aromatics for given JP-8, read across to aromatics curve (green) and down to X-axis, note percentage.

3) The lower value noted is the maximum FT IPK possible to result in a blend with density ≥ 0.775 kg/L and aromatics ≥ 8.0 vol. %.

>> Blends to be no more than half synthetics by volume.

>> If both percentages > 50 vol. %, then maximum possible FT IPK is 50 vol. %.

Example:

Given batch of JP-8 with density of 0.798 kg/L and aromatics of 13.9 vol. %.

1) Based on JP-8 density, percentage is 49 vol. %.

2) Based on JP-8 aromatics, percentage is 42 vol. %.

3) For this given batch of JP-8, the maximum FT IPK possible in blend is 42 vol. % (lower value).

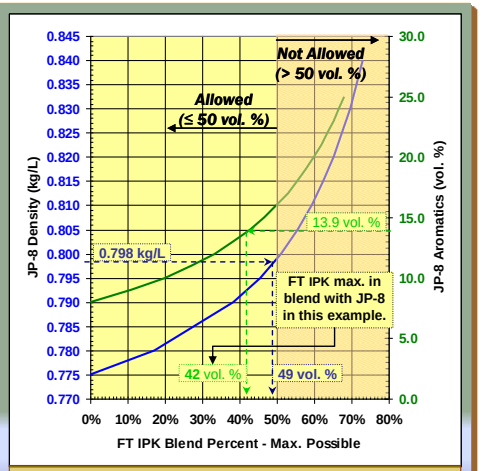
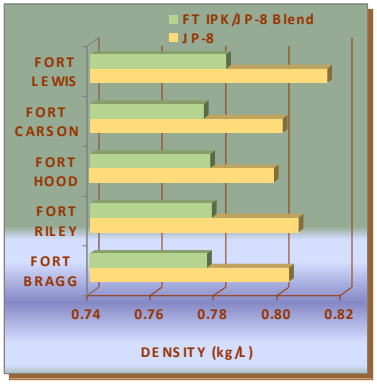


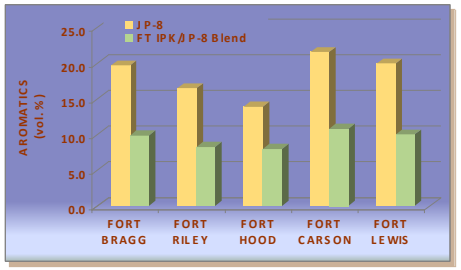
Chart Basis

FT IPK: density = 0.751 kg/L, aromatics = 0.0 vol. %

Curves can be re-plotted to accommodate FT IPK property values differing from those on which this chart is based.

LESS VARIATION IN PROPERTIES FOR SYNTHETIC FUEL BLENDS AS COMPARED TO PETROLEUM-ONLY DERIVED FUEL





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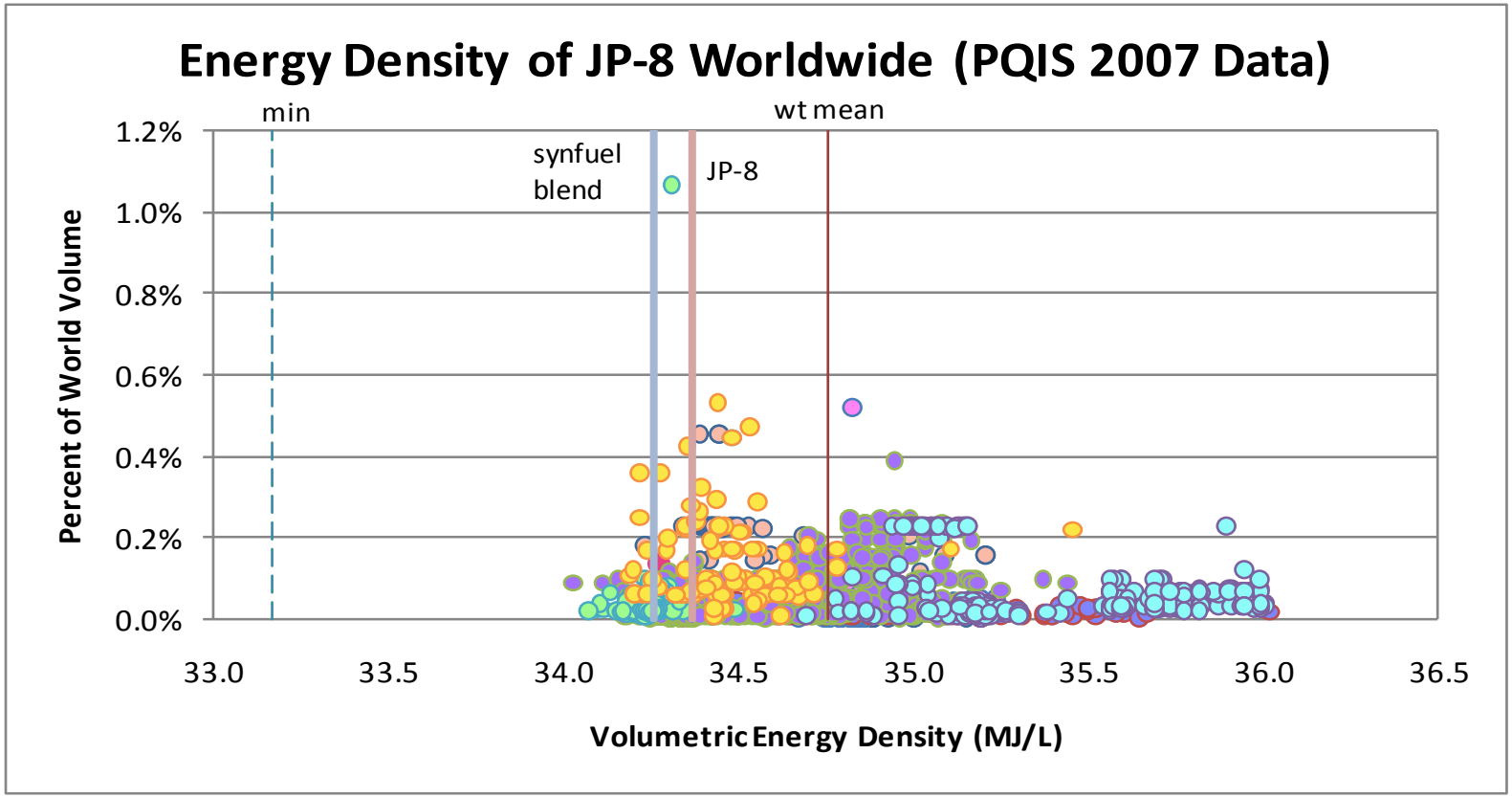
Property Values of Synfuel Blends* Fit Within Range for JP-8

EXAMPLE: Volumetric Energy Density (see chart)

(1) JP-8 batches procured in 2007 worldwide, range and distribution, wt. mean.**

(2) Test fuels, GEP engine evaluation. JP-8 and synfuel blend

(3) Minimum shown is calculated from what is allowed by JP-8 spec. for minimum density and minimum net heat of combustion.

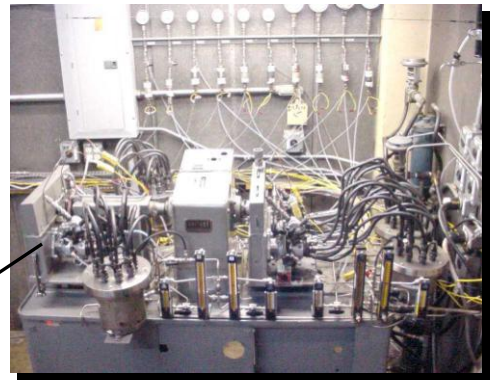


* Synfuel Blends: blends of Fischer-Tropsch Synthetic Paraffinic Kerosene and JP-8 meeting MIL-DTL-83133F(JP-8 spec)

** Calculated values; batches missing data not included

Lubricity Testing
TARDEC F&L Research Facility

- **Bench-top lubricity evaluations**
  - BOCLE, SLBOCLE, and HFRR battery
  - BOCLE indicated improved lubricity of FT fuel treated with CI/LI additive per QPL-25107



- **Rotary fuel injection pump test rig testing**
  - Showed FT SPK with lubricity improved to a level indicative of acceptable field performance
  - Both at min. and max. treat rates per QPL-25017
  - Results documented in **SAE Paper 2004-01-2961**

"Early Demo" – Tactical Generators TARDEC F&L Research Facility

- **Objective:** Operate tactical equipment using 50:50 FT synthetic fuel blend
- **Test Protocol**
  - Three 10 kW generator sets
  - Gen sets "broken-in" using Ultra-Low Sulfur Diesel (ULSD)
  - Gen sets fueling during test, operating cycles (% of total time)
    - Gen sets #1 & # 3
      - 10% – ULSD
      - 45% – JP-8
      - 45% – 50:50 blend of FT SPK:JP-8
    - Gen set # 2
      - 100% – FT SPK
  - Tests conducted for 1000 hrs at 50% load
- **Some Results** (final report in DTIC)
  - No reliability issues encountered
  - Power generation unchanged for all fuel cases
  - Exhaust emission checked; NOx lower using fuel blend than for JP-8

TWV Pilot Field Demo
TARDEC F&L Research Facility

- **Determine effects of using fuel blend in a subset Army legacy ground vehicles**
- **Field demonstration fleet (variety of wheeled vehicles) at Ft. Bliss, TX**
  - (2) M998 HMMWV
  - (9) M925 A2 5-Ton truck
  - (10) M1075 LMTV
  - (10) M1083 A1 FMTV
  - (2) M1089 A1 FMTV
  - (1) M984 A1 HEMTT
  - (1) M978 HEMTT
  - (10) M915 A4 TRAC
  - Control vehicles of the same type, operated on JP-8 will be included
- **Data generation**
  - Monthly fleet performance monitoring and fuel analyses
  - Vehicle fuel injection systems pre-test inspections for operation / fuel leaks
  - Up to 10 fuel injection system (blend fueled vehicles) post-test inspections (or earlier if needed) to check operation / fuel leaks
- **No recordable issues to-date**
- **Field demo expected to finish in July 2009**

Army Fuel Requirements and the JP-8 Specification

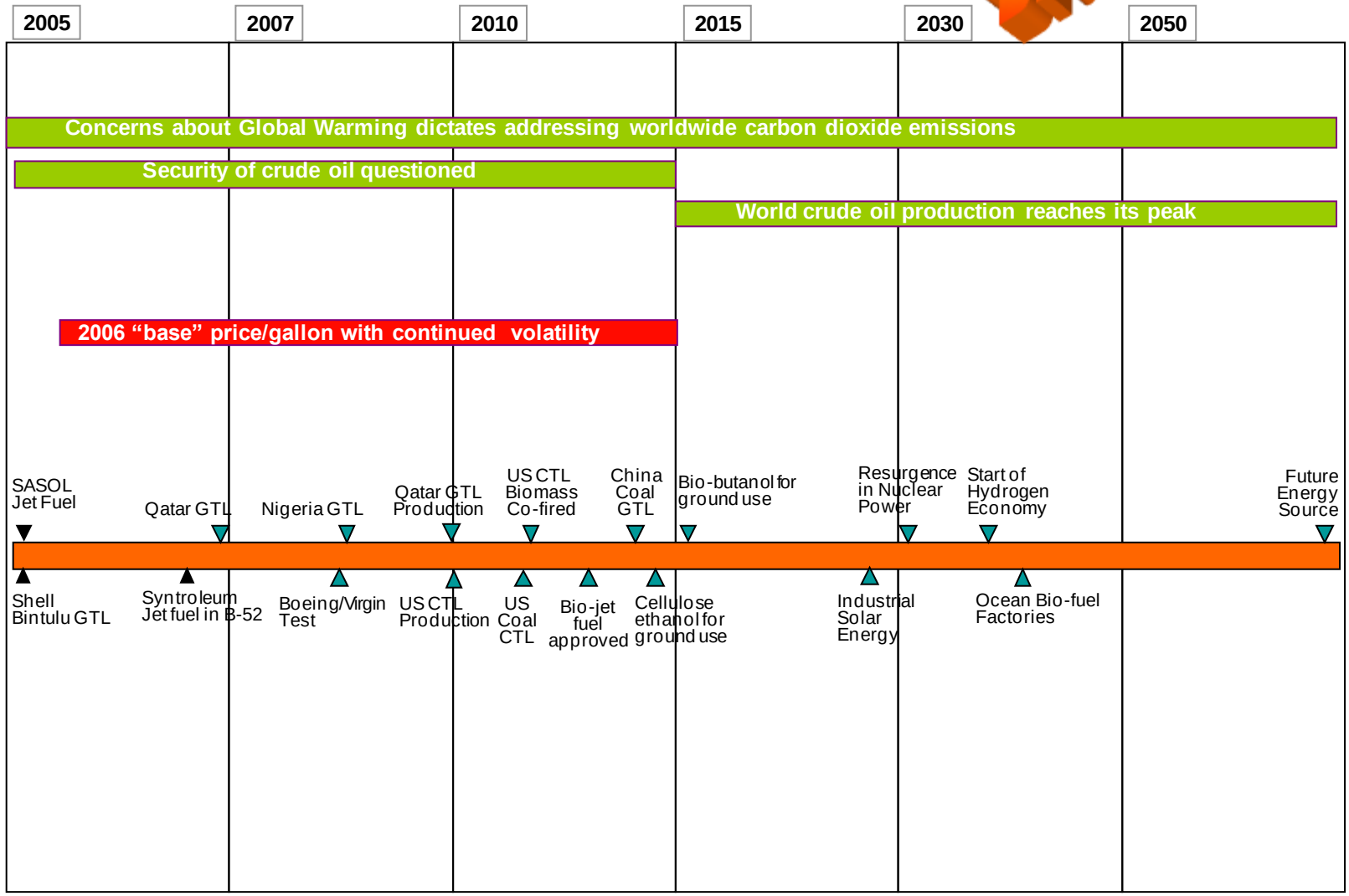
- **Army started conversion from diesel fuel to Single Fuel in the Battlefield (SFB) in 1980s, implemented in 1988**
  - Done on “no-harm” premise basis for use of aviation turbine engine fuel in Army equipment typically having compression ignition (CI) engines
- **Army equipment has generally maintained acceptable levels of performance and durability using SFB, but have been some issues**
- **Requirements in diesel fuel specs not in JP-8 spec**
  - Minimum viscosity at 40 C (1.3 mm^2/s, No. 1-D)
    - Low fuel viscosity could lead to increased wear rates in some types of fuel injectors and injection pumps
  - Minimum Cetane No. (40, No. 1-D and 2-D)
    - Better cold-starting of CI engines
    - Better CI engine performance, namely less misfire/combustion instability, for light to medium load operation
  - Army request to add these two requirements, to Table A-1 for FT SPK, during last revision to MIL-DTL-83133F was dismissed, will try again for next revision
- **Different lubricity specification for DF-2 (HFRR) vs. JP-8**

Aviation Alternate Fuels Roadmap

Level 1 / Scenario

May 4, 2009

Draft



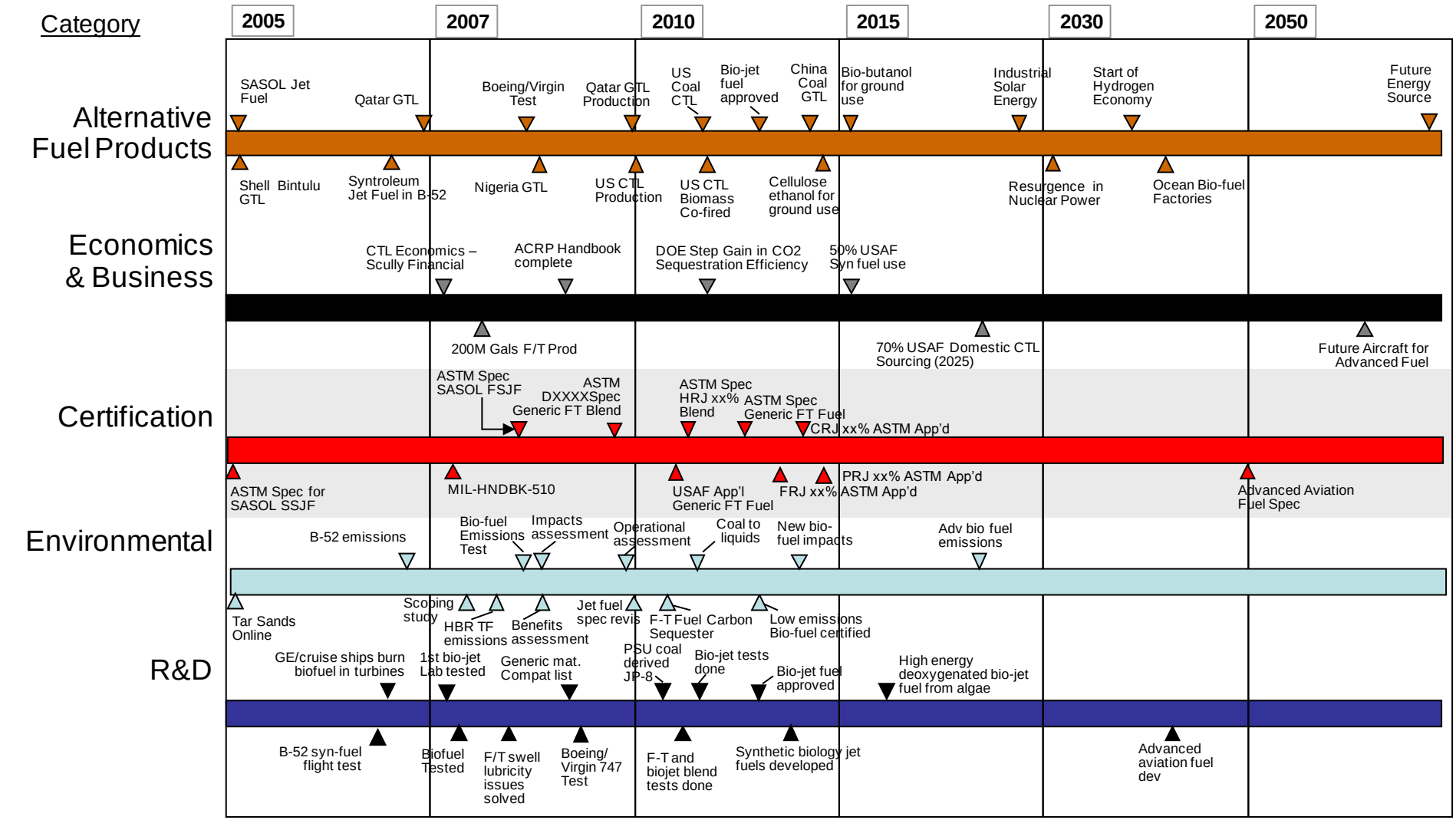
*Fuels produced from seeds and other organic sources such as Soybean Methyl Ester

Courtesy –
Mark Rumizen, FAA

Aviation Alternate Fuels Roadmap

Level 2 / Scenario 1

May 4, 2009



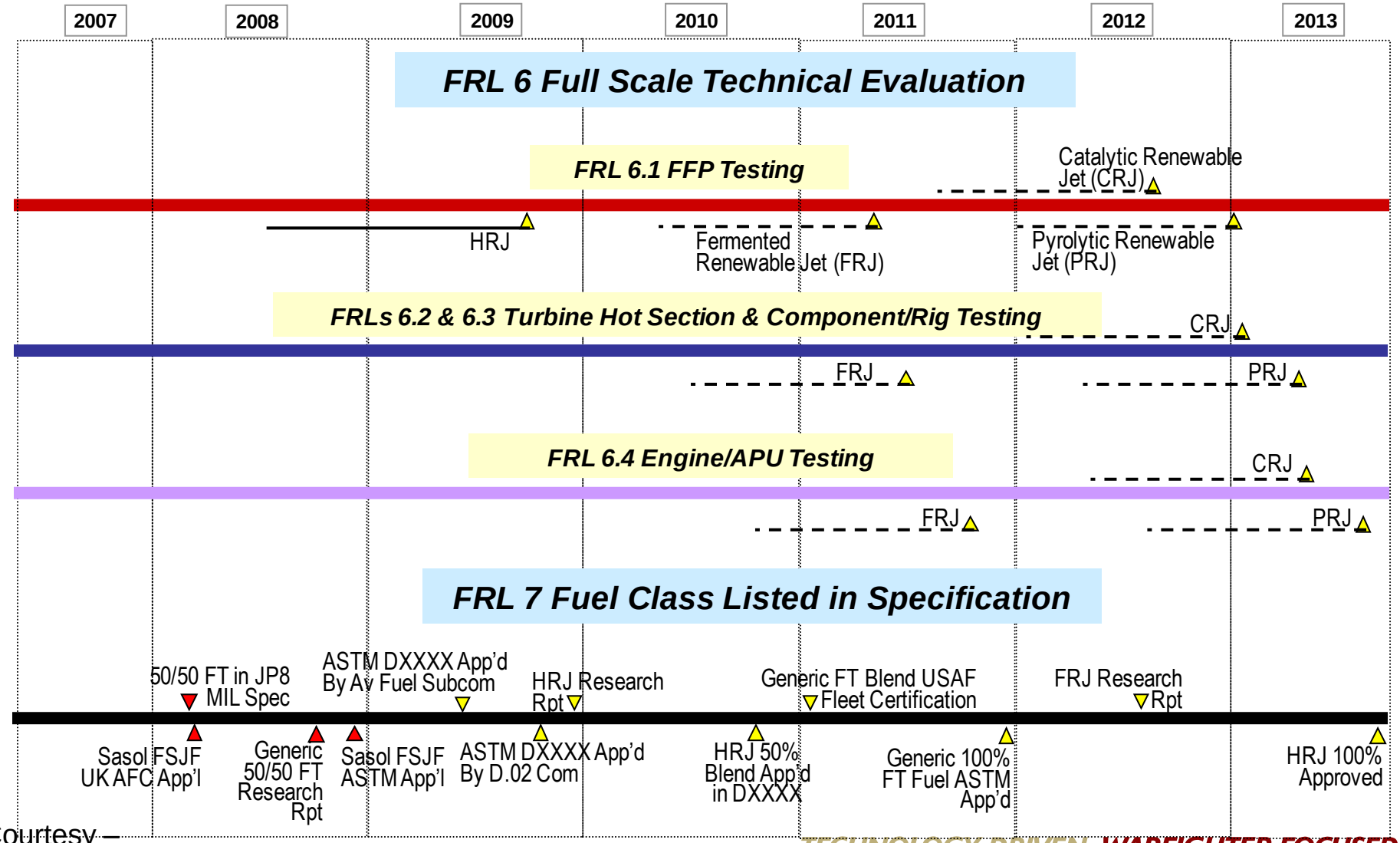
Courtesy –
Mark Rumizen, FAA

Aviation Alternate Fuels Roadmap

Level 3 / Certification and Qualification

DRAFT

May 4, 2009



Courtesy –
Mark Rumizen, FAA

Fuel Readiness Level (FRL)

Commercial Fuel Readiness Level (FRL) - Alternative Aviation Fuels

FRL	Description	CAAFI Toll Gate	FRL	Description	CAAFI Toll Gate	Fuel Qty	MI
1	Basic Principles Observed and Reported	Feedstock and process basic principles identified					1
2	Technology Concept Formulated	Feedstock and complete process concept identified					2
3	Proof of Concept	Small Fuel Sample Available from Lab Basic Fuel Properties Validated (Thermal Stability/Freezing Point)				500 ml	3
4.1 4.2	Preliminary Technical Evaluation	System Perf. & Integration Studies Entry Criteria/Specification Properties Evaluated (MSDS/D1655/MIL 83133)				10 gal	4
5.1 5.2 5.3 5.4	Process Validation	Laboratory Production Development Subscale Production Demonstrated Scalability of Production Demonstrated Pilot Plant Capability Enabled	6.1 6.2 6.3 6.4	Full-Scale Technical Evaluation	Fit-For-Purpose Prop's Evaluated Turbine Hot Section Component/Rig/Emissions Testing Engine/APU Testing	80 gal 4K gal 20K gal 225K gal	5 6 7 8
			6.5				
			7	Fuel Approval	Fuel Class/Type Listed in Int'l Fuel Standards		
8	Commercialization Validated	Business Model Validated for Production Go-Ahead Airline/Military Purchase Agreements					
9	Production Capability Established	Full Scale Plant Operational					9-1

see next slide for rest of chart

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Legend:	R & D	Certification/Qualification	Business & Economics

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Fuel Readiness Level (FRL)

Commercial Fuel Readiness Level (FRL) - Alternative Aviation Fuels

see previous slide for rest of chart

	FRL	Description	CAAFI Toll Gate	Fuel Qty	MRL	USAF TRL
nciples					1	
s concept					2	
om Lab ted Point)				500 ml	3	1. Basic Fuel Properties Observed and Reported
lies perties IL 83133)				10 gal	4	2. Fuel Specification Properties
ment ted nstrated	6.1 6.2 6.3 6.4	Full-Scale Technical Evaluation	Fit-For-Purpose Prop's Evaluated Turbine Hot Section Component/Rig/Emissions Testing Engine/APU Testing	80 gal 4K gal 20K gal 225K gal	5 6 7 8	3. Fit for Purpose 4. Extended Lab Fuel Property Test 5. Component Rig Testing 6. Small Engine Testing
	6.5					7. Pathfinder
	7	Fuel Approval	Fuel Class/Type Listed in Int'l Fuel Standards			8. Validation/Certification 9. Field Service Evaluations
roduction greements						
					9-10	

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