21-15207
November 8, 2012

Honeywell CLEEN Program
FAA CLEEN Consortium

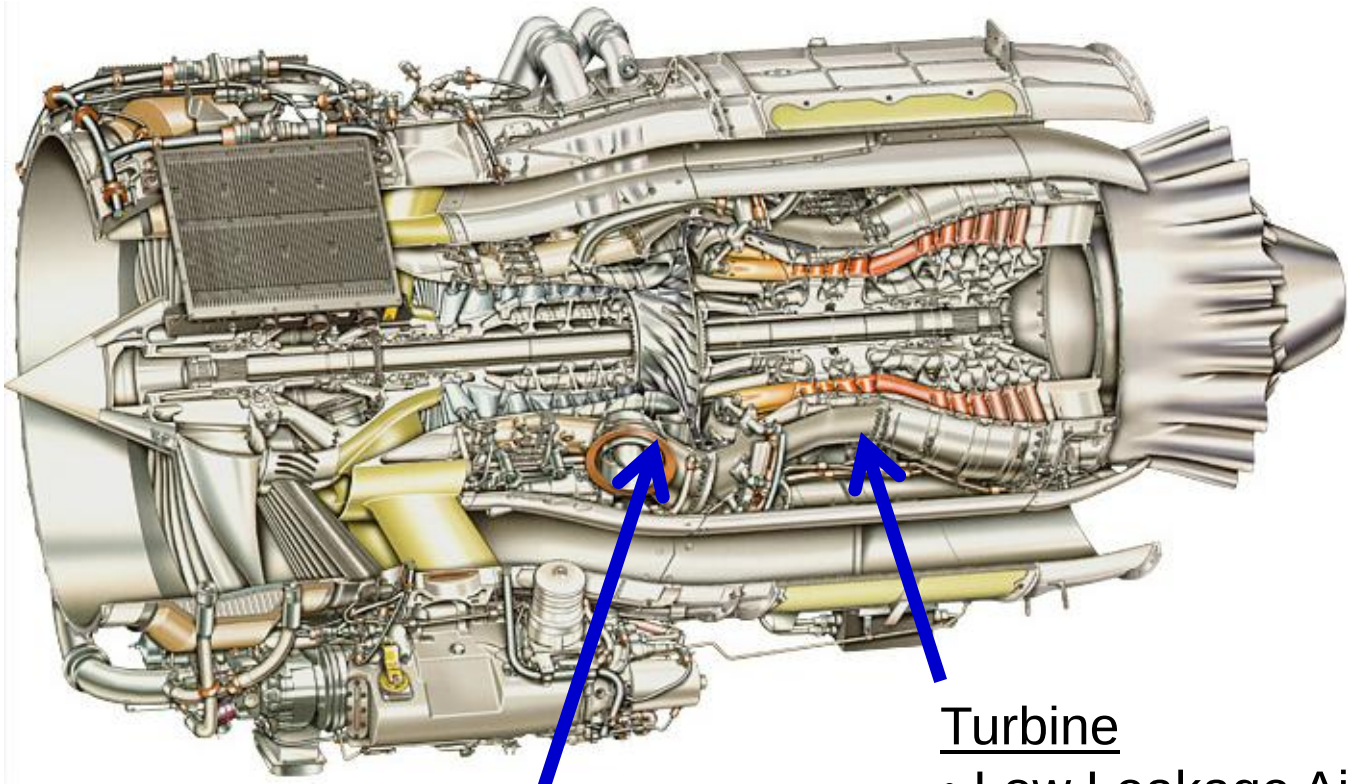
Honeywell

Agenda

- Honeywell CLEEN Technologies
- Alternative Fuels Seal Swell & Lubricity
- Alternative Fuels Phase 1 LCA

Honeywell CLEEN Technologies

Honeywell CLEEN Technologies



Turbine
- Low Leakage Air-Air Seals
- Advanced Materials
  - ✓Alloy10 Disc Material
  - ✓Low-K Blade Airfoil TBC
  - ✓Type-V HPT Shroud TBC

Alternative Fuels
- 100% Bio Based

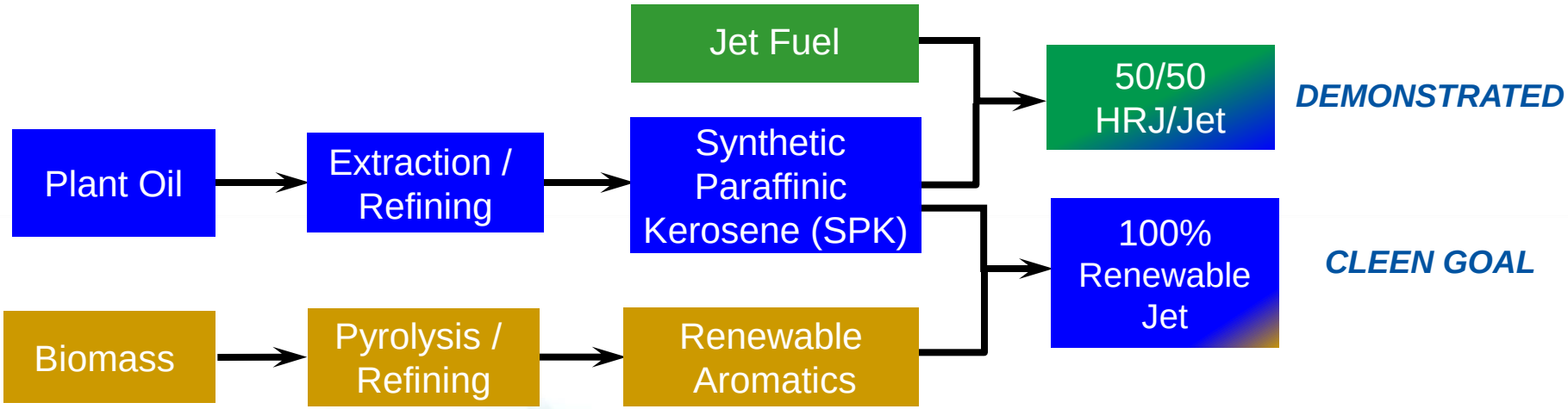
Compressor
- High T3 impeller

Alternative Fuels

Alternative Fuels

Technology Overview

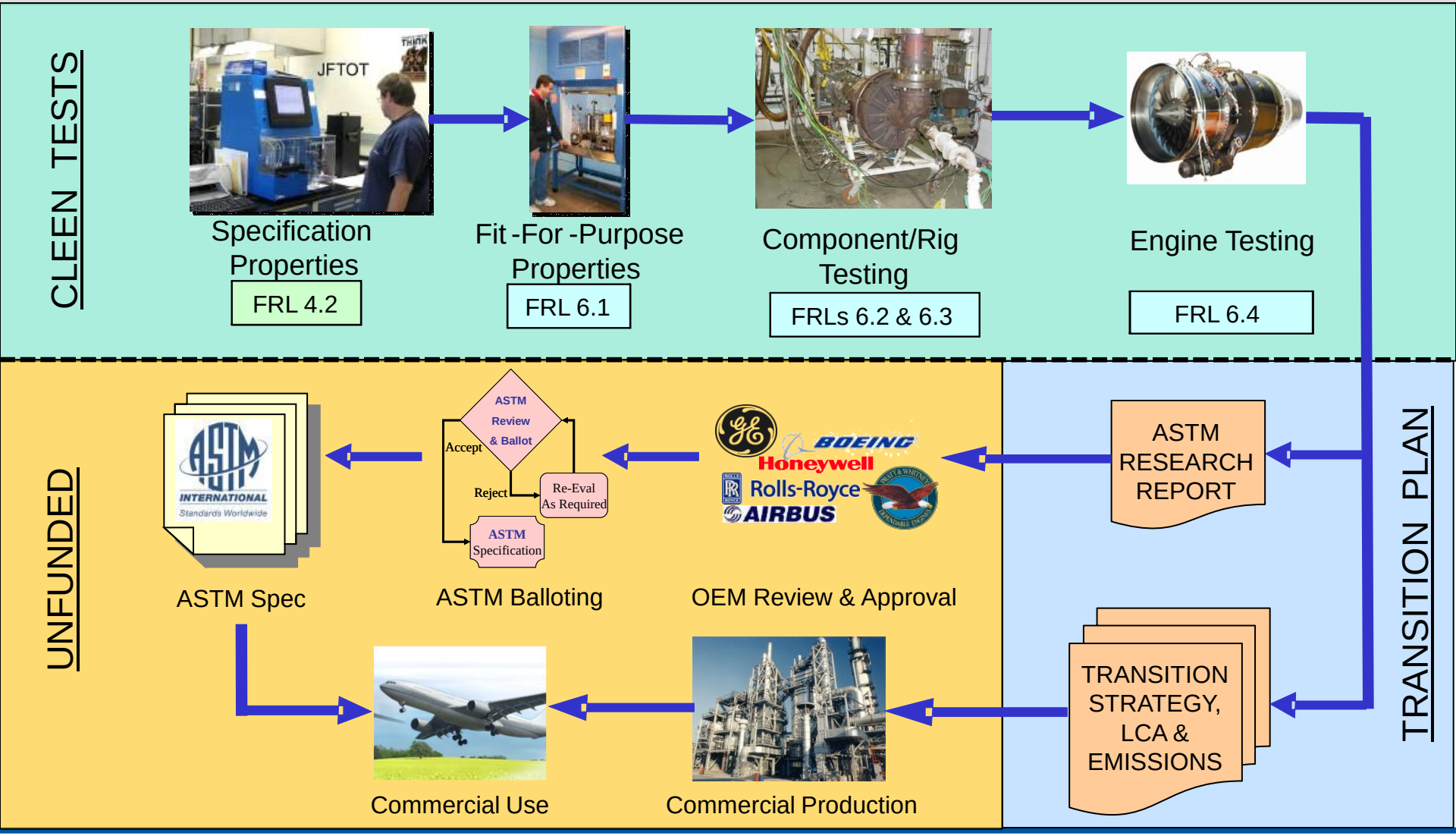
High-Level Technology Description



Selection of Renewable Aromatics

- Seal swell – Clastomers
- Emissions – Particulate emissions
- Density – Calibration of fuel gauges
- Composition – Match Jet A/JP-8
- Lubricity – Bearing life

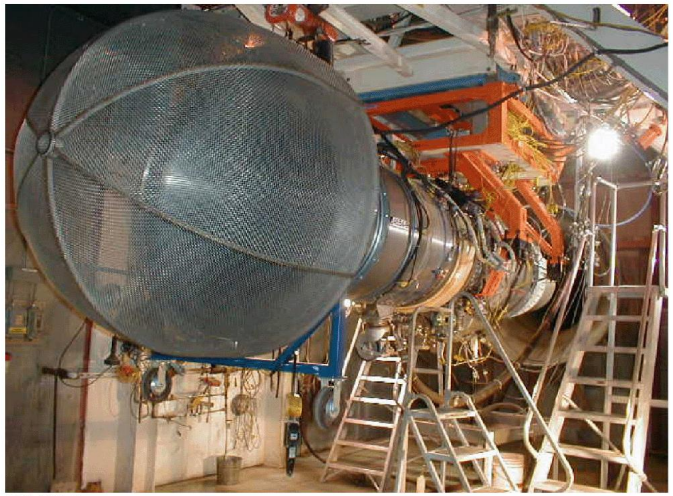
Technology Maturation Approach



CLEEN Alt Fuel Summary

- Assess required aromatic content
  - Start evaluation with petroleum-based aromatics (PBAs) blended with HRJ SPK
  - Specification analyses, fit-for-purpose testing, atomizer bench testing, combustor rig testing, GHG LCA, emissions
  - Select renewable aromatic content
- Renewable jet fuel evaluation
  - Fully renewable fuel will be tested in a combustor rig, followed by a HTF7000 demonstrator engine

Tech7000 Demonstrator Installed in In-Door Test Cell



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Alternative Fuels

Seal Compatibility & Lubricity Results

Test Description

- Fuel system compatibility with synthetic aromatics
  - Measure effect of fuel aromatic content on fuel lubricity, hardness, tensile strength, and change in elastomer volume
  - Fuel lubricity
    - Utilize D5001 BOCLE (Ball on Cylinder Lubricity Evaluator) and D6078 Scuffing Load BOCLE (SLBOCLE) to evaluate impact of fuel aromatic content on fuel lubricity
  - Elastomer material compatibility
    - Evaluate impact of fuel aromatic content on nitrile (Buna-N, NBR), fluorosilicone (FVMQ), and fluorocarbon (Viton, FKM) materials
      - Materials are typical of fuel system o-ring seals and have been examined in past using a variety synthetic fuels and blends
    - Check for impact to tensile strength, volume swell, and hardness
      - Past efforts have shown significant impact on volume swell in nitrile seals

SPK & Aromatic Blend

- Blend HEFA-SPK (tallow feedstock) with petroleum-derived aromatic
- Aromatic blend based on AFRL Jet Reference 3 formula
  - 2:1 Blend of Aromatic 150 and Aromatic 100
  - Mix primarily contained C9 and C10 aromatics
    - C9 benzenes (trimethyl, ethyl-methyl, propyl, etc…)
    - C10 benzenes (tetramethyl, dimethyl-ethyl, butyl, etc…), some naphthalene
- Aromatic blend then mixed with HEFA-SPK to desired ratios
  - Under this study, only aromatic quantity was varied, not type of aromatics

Test Fuel Properties

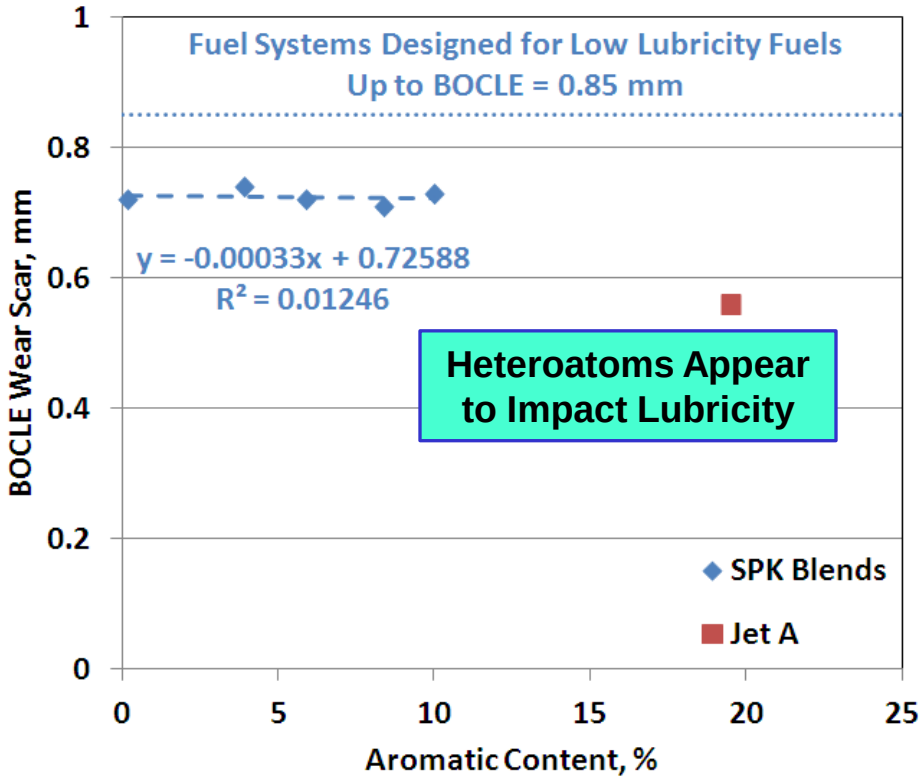
	Specific Gravity	Viscosity @ 25°C	Aromatics	Sulfur	Mercaptan Sulfur
Units		mm^2/s	Vol %	ppmw	mass %
Jet A Spec (D7566)	0.775 to 0.840		8 to 25	< 3,000	< 0.003
100% SPK	0.756	1.64	0.2	0.5	< 0.0003
4% Aromatics	0.762	1.60	3.9	0.3	< 0.0003
6% Aromatics	0.764	1.58	5.9	0.4	< 0.0003
8% Aromatics	0.767	1.56	8.4	0.2	< 0.0003
10% Aromatics	0.769	1.54	10.0	0.2	< 0.0003
100% Aromatics	0.890	1.10	100*	0.0	< 0.0003
Jet A	0.814	1.68	19.5	971	0.0015

* Test method (D1319) did not run properly but no saturates were detected

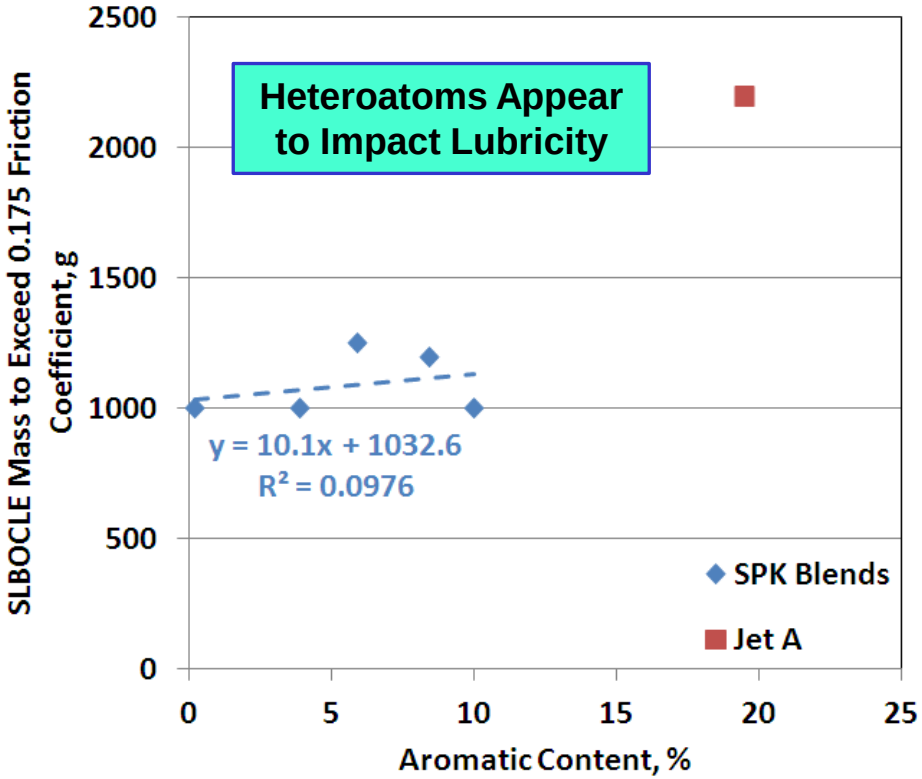
Aromatic Blends Evaluated Within and Below the Jet-Spec Range

Fluid Lubricity Results

BOCLE (D5001)



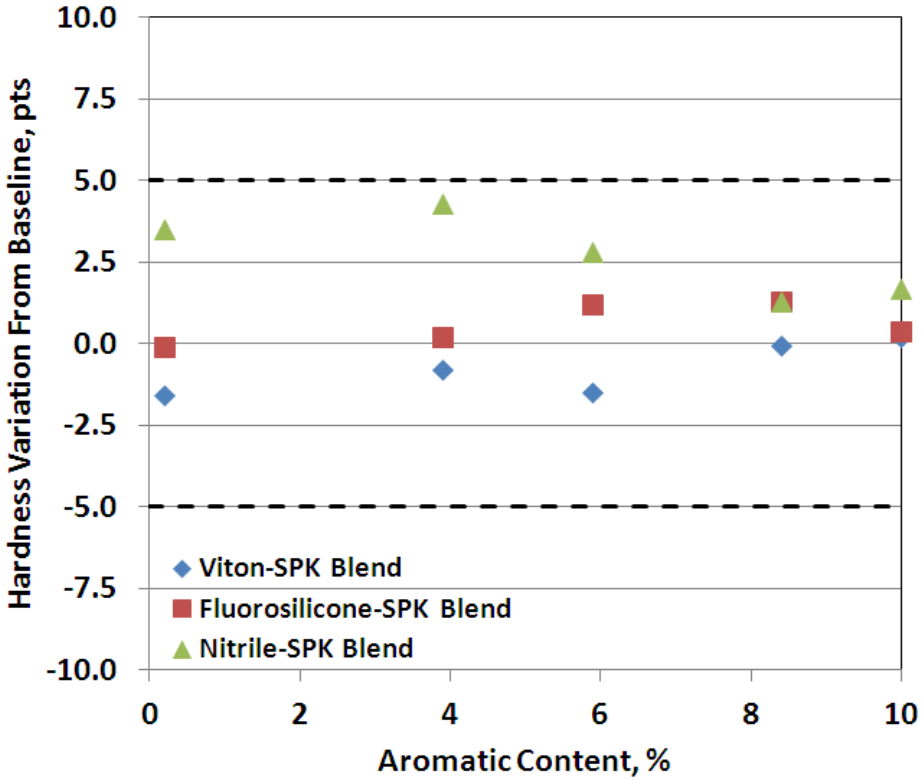
SLBOCLE (D6078)



Aromatic Content Has Minor Influence On Fuel Lubricity
Neat SPK and SPK Blend Wear Scars Meet Fuel System Requirements

Change in Material Hardness

- Change in hardness depends on material evaluated (D2240)
  - D4054 requires test fuel results to be within ±5 points from baseline fuel
- Nitrile
  - Decreases in hardness with increase in aromatic content
- Fluorosilicone
  - Minimal impact from aromatics on material hardness
  - Slight increase in durometer with aromatic content
- Fluorocarbon (Viton)
  - Slight increase in durometer with aromatic content

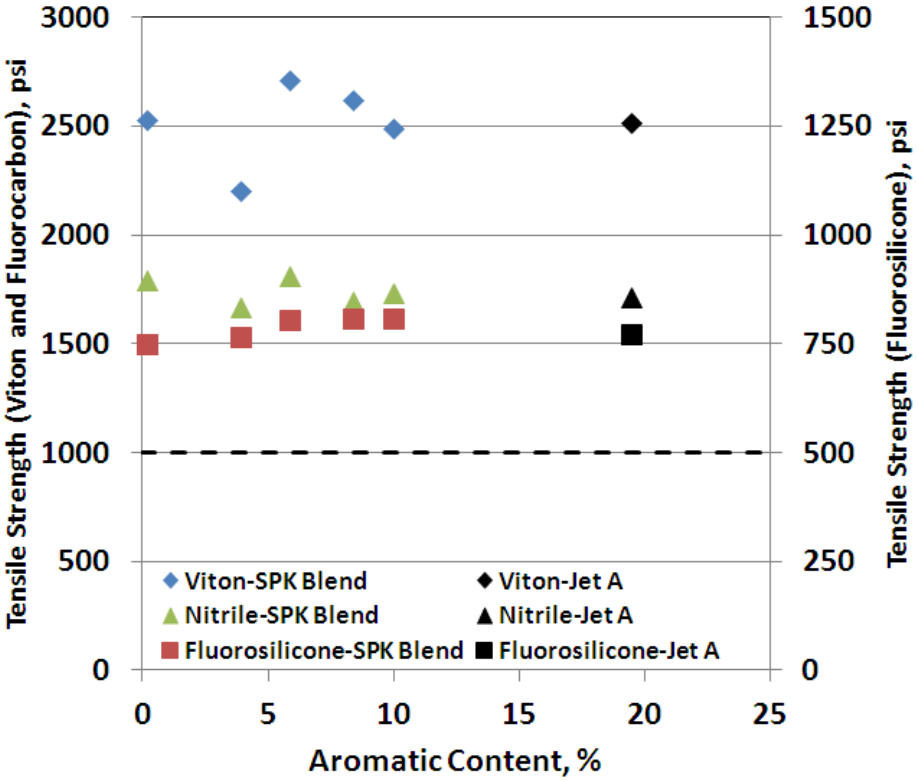


Aromatic Content Has Minor Influence on O-ring Durometer

Neat SPK and SPK-Aromatic Blends Meet O-ring Hardness Requirements

Tensile Strength

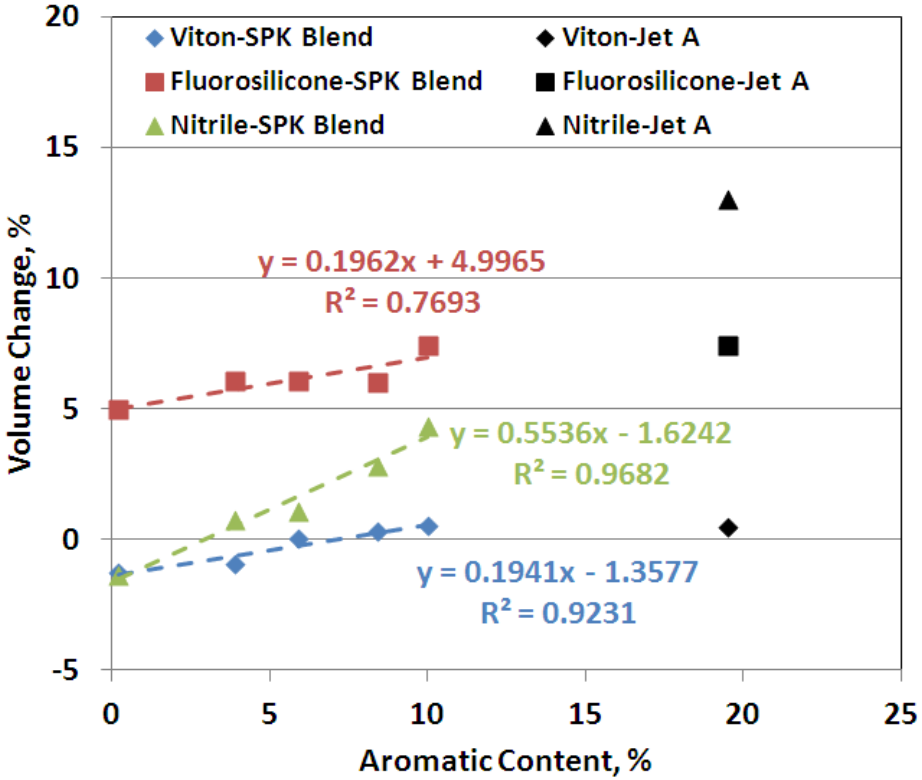
- Elastomer material tensile strengths show minimal impact from fuel aromatic content (D1414)
- Nitrile
  - D4054 requires >1000 psi
  - ~1700 psi over fuel spec range
- Fluorosilicone
  - D4054 requires >500 psi
  - ~800 psi over entire aromatic range
- Fluorocarbon (Viton)
  - D4054 requires >1000 psi
  - ~2500 psi over fuel spec range



Minor Impact on Tensile Strength With Aromatic Content Less than 25%
Neat SPK and SPK-Aromatic Blends Meet O-ring Tensile Strength Requirements

Seal Swell

- Change in volume depends on material evaluated (D471)
- Nitrile
  - Very sensitive to fuel aromatic content
  - May shrink with low aromatic fuels
  - D4054 requires <25% swell
- Fluorosilicone
  - 5 to 7% swell in all fuels
  - D4054 requires <25% swell
- Fluorocarbon (Viton)
  - May shrink with low aromatic fuels
  - D4054 requires <10% swell



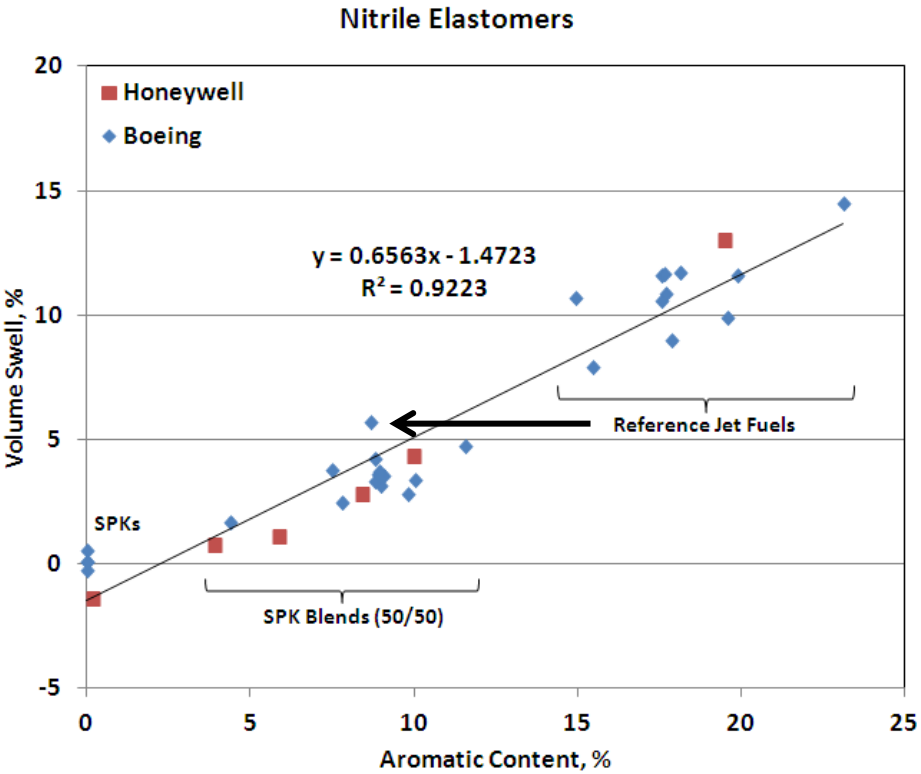
Aromatic Content Does Influence Seal Volume Swell Trends Like Jet-A

Seal Swell – Boeing Data Comparison

- Boeing data from FAA-CLEEN report
  - OTA DTFAWA-10-C-0030
- Boeing Evaluated Reference Jet Fuels, 100% SPKs, and 50/50 SPK/Jet A Blends
  - One reference fuel had 8.7% aromatic content
  - Reference fuel and 100% SPK data from data tables in report appendices
  - 50/50 Blend data from obtained from report plots
- Honeywell evaluated a baseline Jet A fuel and SPK blended with varying amounts of petroleum-derived aromatic content

Nitrile – Honeywell/Boeing Data Comparison

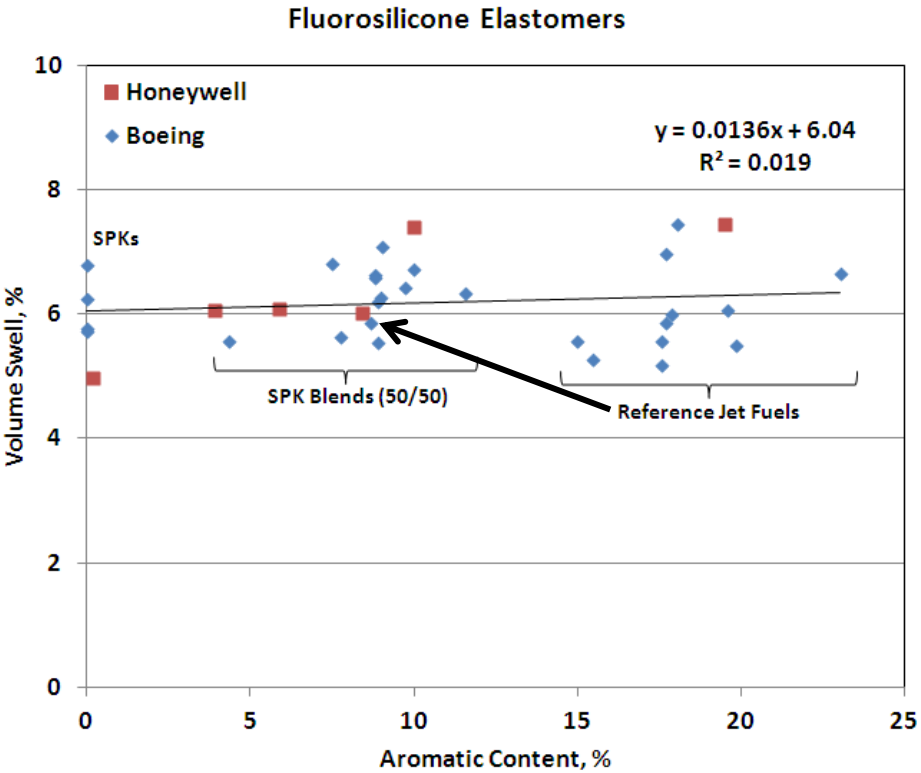
- Nitrile significantly impacted by aromatic content in fuel
  - Volume more than doubles with pure aromatic fluid (not shown)
  - D4054
- Nitrile material may shrink in fuel with low aromatic content
  - ~2% aromatics to prevent nitrile seal shrinkage (according to linear regression)
  - 8% aromatic content provides approximately 4% seal swell



Good Correlation Between Honeywell/Boeing Data

Fluorosilicone – Honeywell/Boeing Data Comparison

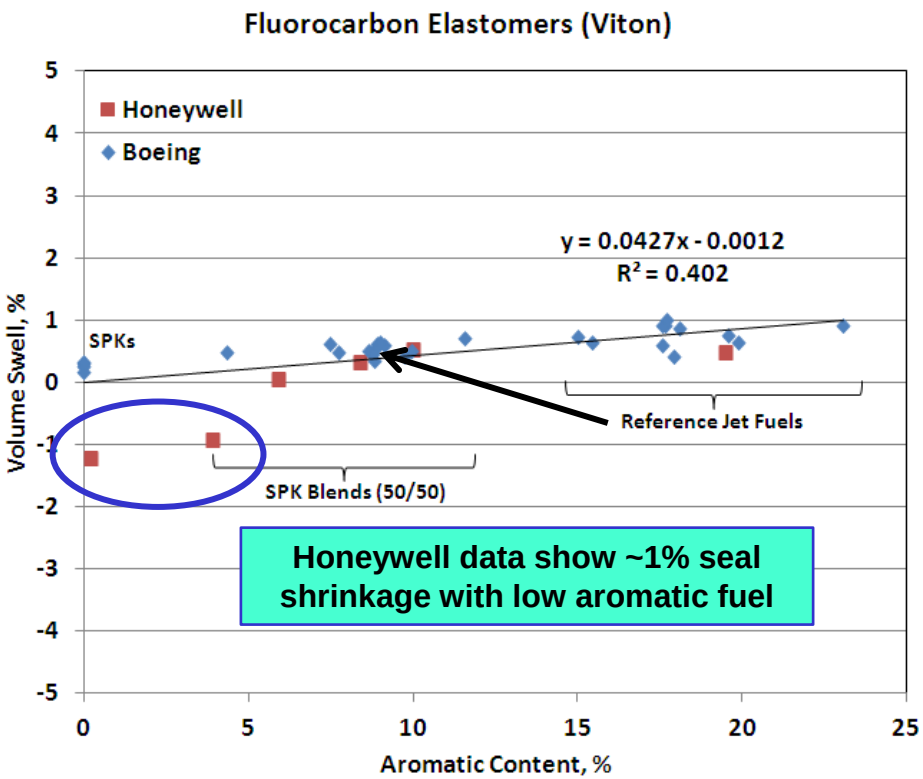
- Data shows minimal impact by fuel aromatic content
  - Both data sets display similar data scattering
- 5-7% swell in all fuels regardless of aromatic content
  - Small correlation to aromatic content
  - Approximately 6% swell in fluids with less than 25% aromatics



Good Correlation Between Honeywell / Boeing Data

Fluorocarbon – Honeywell/Boeing Data Comparison

- Data indicates slight impact of aromatic content to seal swell
  - 0-1% swell
  - Less than 1% swell in fluids with less than 25% aromatics
- Fluorocarbon material may shrink slightly in low aromatic fuels
  - Linear regression of complete data set indicate no seal shrinkage



Good Correlation Above 5% Between Honeywell / Boeing Data

Summary

- Evaluated fuel system compatibility of HEFA-SPK blended with petroleum-derived aromatics at varying concentrations
  - Compared results to baseline Jet A
- Lubricity
  - Neat SPK provided sufficient lubricity for fuel system components
  - Heteroatoms Appear to Impact Lubricity
- Seal Swell
  - Nitrile material significantly impacted by aromatic content in fuel
    - Doubles in size in pure aromatics, may shrink in fuel lacking aromatics
  - Fuel aromatic content has slight effect on fluorosilicone and fluorocarbon materials
  - Honeywell and Boeing data show good correlation

Alternative Fuels

Green House Gas Life Cycle Modeling

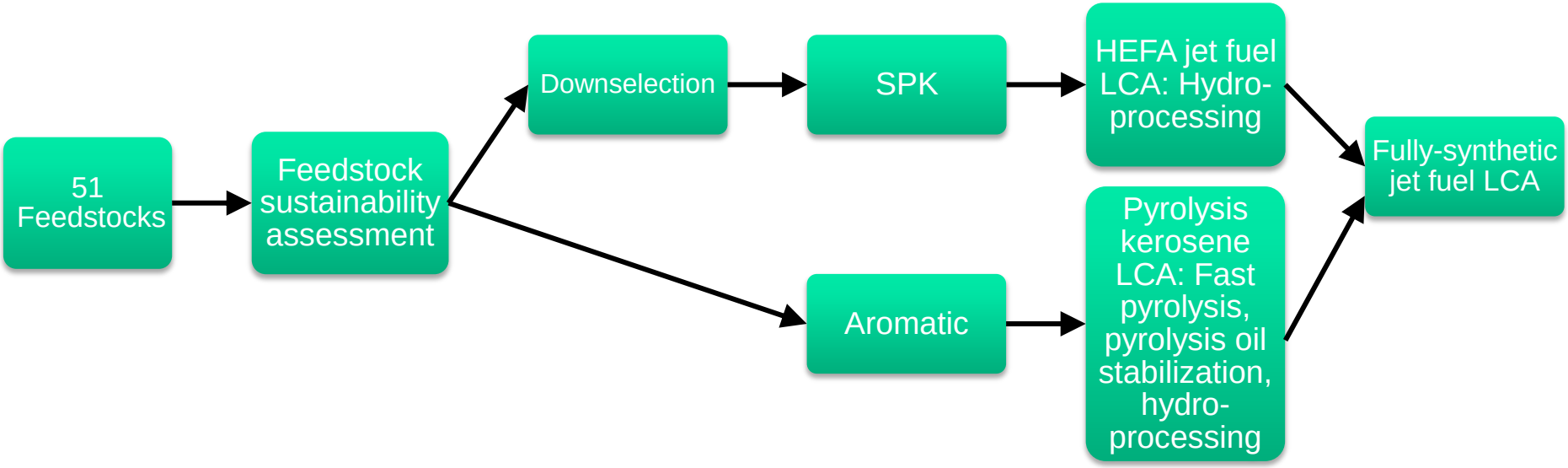
Focus of Phase I and Phase II

- Phase I *(Completed Effort)*
  - Investigation of different feedstocks in terms of sustainability and downselection of feedstocks to be used for GHG lifecycle analysis (LCA)
  - First-order LCA for blend of HEFA jet from Camelina, and of pyrolysis kerosene from sawmill residues

- Phase II *(Future Effort)*
  - Refinement of LCA results by analyzing impacts of different co-product allocation rules and different technology options
  - Investigate the robustness of the Phase I result in relation to methodology employed
  - Evaluate two additional feedstocks per SPK and aromatic

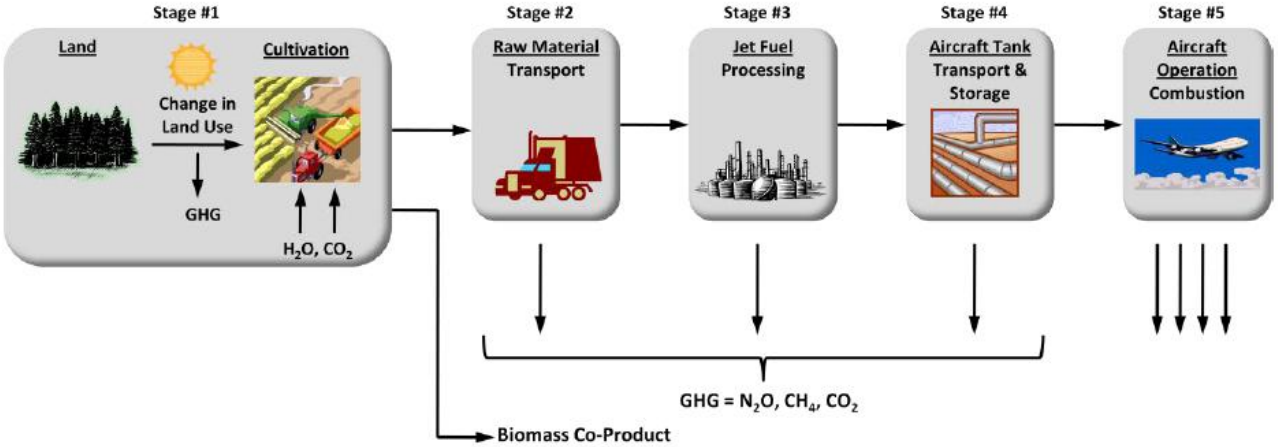
Phase I Approach

- **Conduct Sustainability Assessments**
  - 51 feedstocks evaluated
  - Included environment, economic, societal perspectives, and feedstock 'readiness'
- **Downselect Feedstock**
- **Conduct LCAs for SPK & Aromatic**



Lifecycle GHG emissions from renewable fuels

- 'Well-to-wake' analysis of greenhouse gas emissions over the entire life cycle from biomass cultivation through fuel combustion
- Material data inputs and outputs for HEFA-SPK were taken from open literature. Proprietary material inputs and outputs were used for the modeling of renewable aromatic production.
- GHG Modeling performed using GREET* software
- Considers all stages of the life cycle including LUC impacts



http://www.netl.doe.gov/energy-analyses/pubs/EstGHGFtprntsAvFuels2009.pdf

***GREET =** Green house gases, Regulated Emissions, and Energy use in Transportation

LCA Considerations

- **Co-product allocation**
  - In Phase 1, energy allocation was used to account for co-products
- **Data quality**
  - GREET1.2011was used for modeling camelina HEFA
  - Both GREET1.2011 and SimaPro 7.3.3 were used to model sawmill residue kerosene
  - UOP provided proprietary mass and energy balance data for production of sawmill residue kerosene (renewable aromatics)
- **Data variability and uncertainty**
  - Introduction of different emission cases that capture a broad range of potential outcomes
- **Emissions from land-use change**
  - Camelina can grow on fallow land – No negative change in land use induced
  - No land-use change is attributed to sawmill residues (since it is a "residue")

Summary of LCA Study Results

- Camelina chosen as HEFA feedstock after mutual agreement between MIT and UOP: (Relatively well-researched feedstock, rotation crop which can grow on fallow land, no direct competition with food etc.)
- Three cultivation scenarios were considered for camelina (low, medium and high inputs)
- Sawmill residues taken as pyrolysis feedstock
- Blends of 10%, 20%, and 30% pyrolysis kerosene were considered (source of aromatics)
- **Fully-synthetic jet fuel exhibited life cycle GHG savings of 51-58% relative to conventional jet fuel base line (87.5 gCO2e/ MJ)**
- Savings depend on camelina inputs and the content of sawmill residue kerosene

		% Blended Volume	Camelina-derived HEFA Jet Fuel		
			Low	Base	High
Pyrolysis-derived kerosene	Low	10	58.3	55.5	51.7
		20	57.9	55.5	52.1
		30	57.6	55.5	52.5
	High	10	57.9	55.2	51.4
		20	57.3	54.9	51.5
		30	56.6	54.5	51.6

MIT LCA Year 1 Summary

- Feedstock sustainability assessment completed
  - 51 renewable feed-stocks evaluated
  - Metrics developed to capture sustainability from environmental, economic, and societal perspectives
- Camelina SPK and Sawmill residue renewable feedstocks down-selected for Phase I modeling
- Preliminary Life Cycle Analysis for Fully-Synthetic Jet Fuel Production report completed based on Camelina and Sawmill residue feedstocks
  - LCA includes stages from feedstock recovery through fuel combustion
  - GHG emissions calculated with GREET1_2011 framework for low, medium, and high emission cases
  - Simulation performed for year 2017 with 10, 20, and 30 percent aromatics