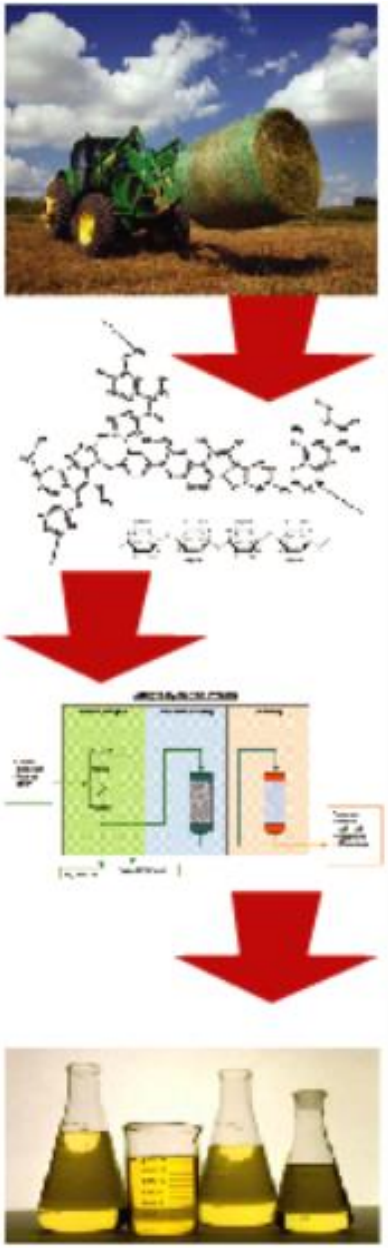


Liquid Catalytic Conversion of Biomass to Jet Fuel

BIO Pacific Rim Conference

Karl Seck
December, 2013

Mercurius Biofuels

turning biomass into value...

Biofuels Categories

Lower left quadrant:

Liquid phase = smaller equipment.

Catalytic = faster = smaller equipment.

= Lower capital costs.

	Liquid phase	Gas phase
Fermentation	Amyris Solazyme Gevo Traditional Ethanol	LanzaTech Coskata INEOS Bio
Catalytic conversion	**Mercurius** Virent Traditional Biodiesel	KiOR Enerkem Envergent Anellotech Dynamotive

Modified from Biofuels Digest, 4/18/2011

REACH Technology

Mercurius Biofuels

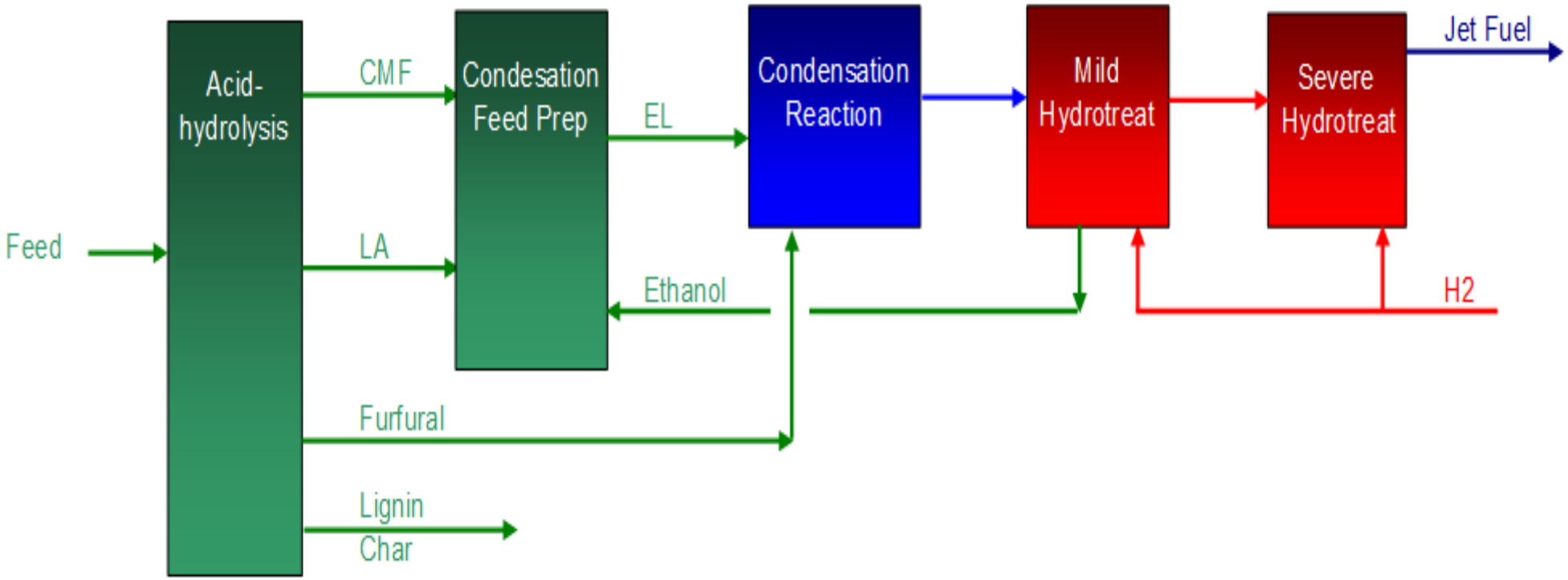
Renewable Acid-hydrolysis Condensation Hydrotreating

- Acid-hydrolysis – breaks down biomass to non-sugar intermediates.

- Condensation – combines molecules to customize carbon chain length.

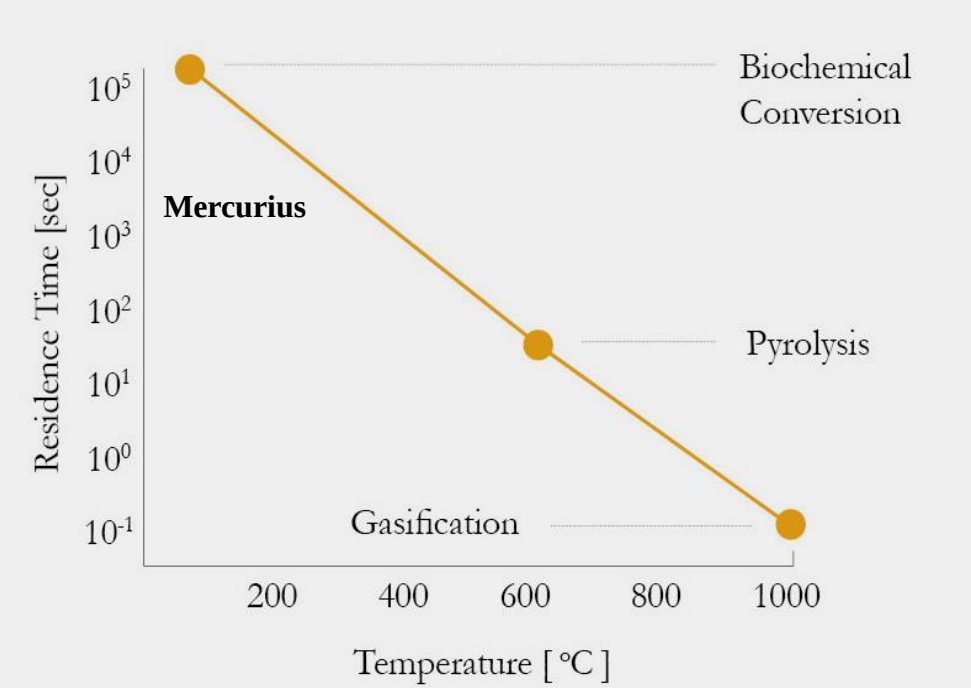
- Hydrotreating – deoxygenates to drop-in hydrocarbon fuel.

REACH Block Flow



Time is Money

- Liquid Phase
- Catalytic
- Short Residence Time
- Feedstock Flexible



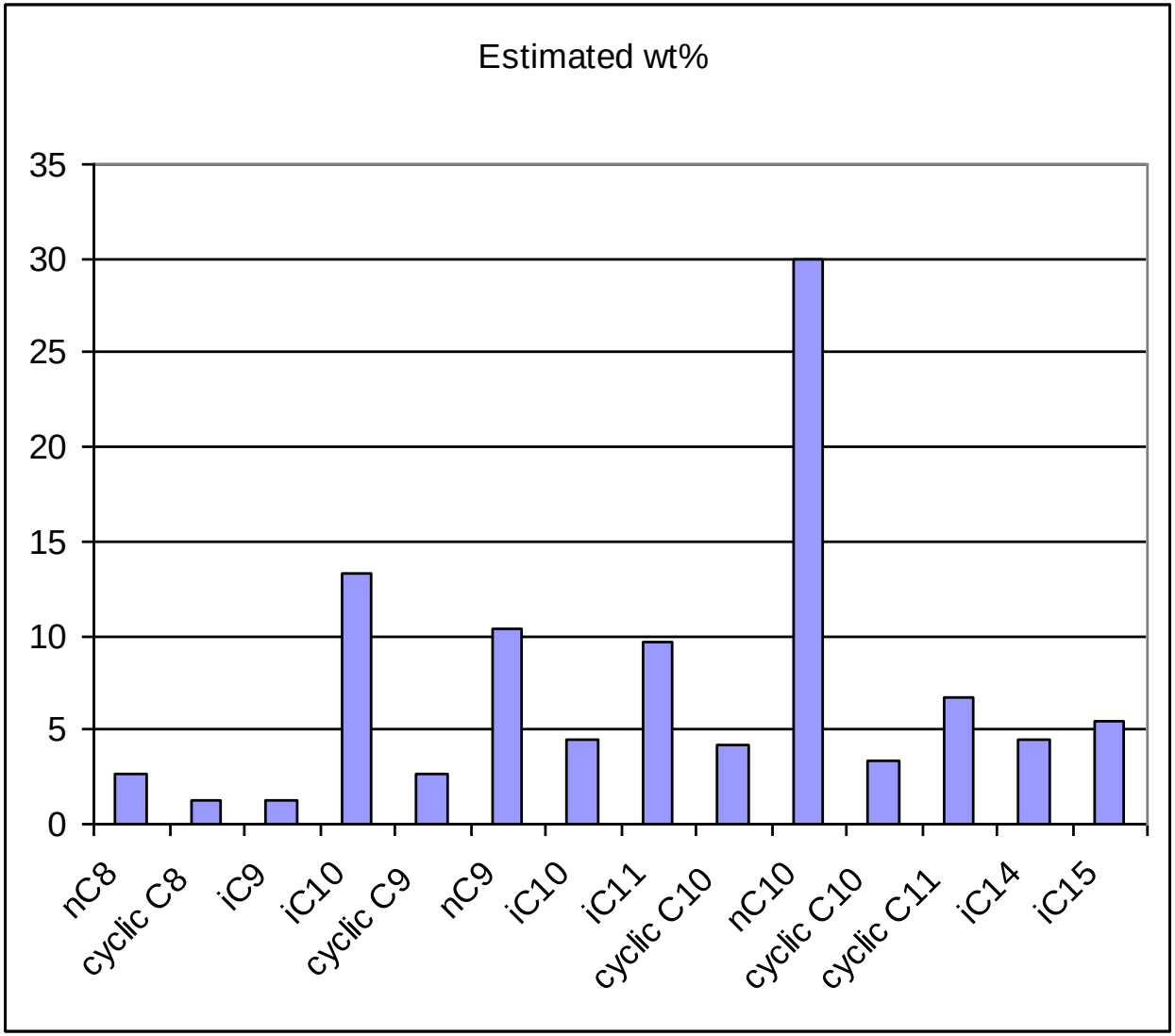
- $0.90 /Gal ($38/bbl) OpEx
- $3-5 /GPY CapEx

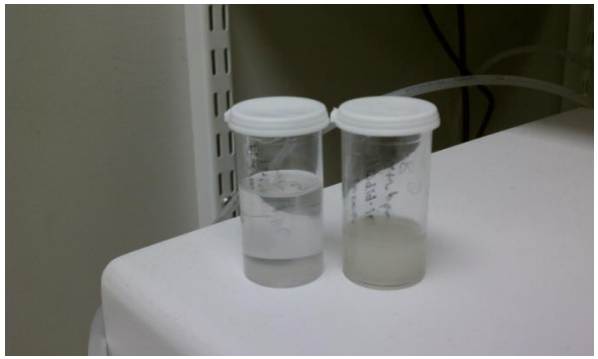
Fuel Product

Cellulosic Jet Fuel / Diesel

- Remove all oxygen for hydrocarbon fuel product.
- Total number of carbons will range from 8 to 15.
- Iso, cyclic, and normal alkanes for freeze point control.

Jet Fuel Composition

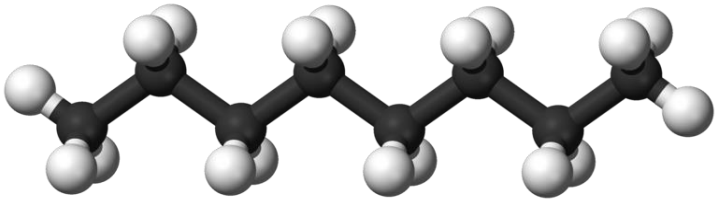


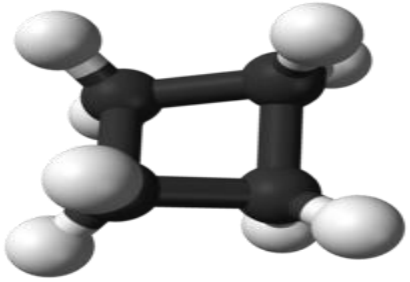


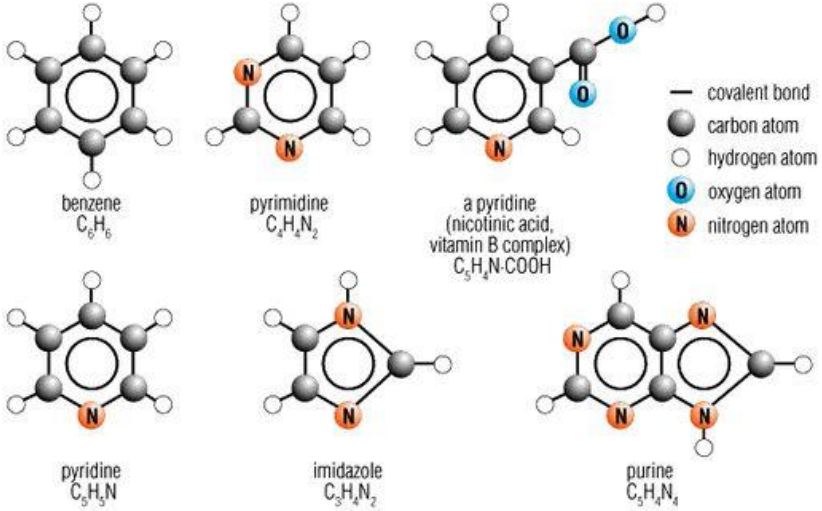
Freeze Point = - 48.4 C
JP-8 (Mil.) spec < -47 C

Main Components in Jet Fuel (Jet A)

COMPONENT	FORMULA	CHEMISTRY
n-Octane	C_8H_{18}	n-Paraffin
2-Methylheptane	C_8H_{18}	Isoparaffin
1-Methyl-1-ethylcyclopentane	C_8H_{16}	Naphthene
Ethylcyclohexane	C_8H_{16}	Naphthene
o-Xylene	C_8H_{10}	Aromatic
p-Xylene	C_8H_{10}	Aromatic
Cis-Decalin	$C_{10}H_{18}$	Naphthene
Tetralin	$C_{10}H_{12}$	Aromatic
Naphthalene	$C_{10}H_8$	Aromatic
n-Dodecane	$C_{12}H_{26}$	n-Paraffin
2-Methylundecane	$C_{12}H_{26}$	Isoparaffin
1-Ethylnaphthalene	$C_{12}H_{12}$	Aromatic
n-Hexylbenzene	$C_{12}H_{18}$	Aromatic
n-Hexadecane	$C_{16}H_{34}$	n-Paraffin
2-Methylpentadecane	$C_{16}H_{34}$	Isoparaffin
n-Decylbenzene	$C_{16}H_{26}$	Aromatic



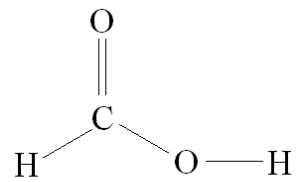




Byproducts

Ethyl Formate –or- Formic Acid

- Food safe fumigant/animal feed supplement
- Environmentally friendly de-icer
- Fuel cell feed



Formic Acid

Char

- Solid Fuel
- Fertilizer / Soil Enhancer
- Potential On-site Hydrogen Production

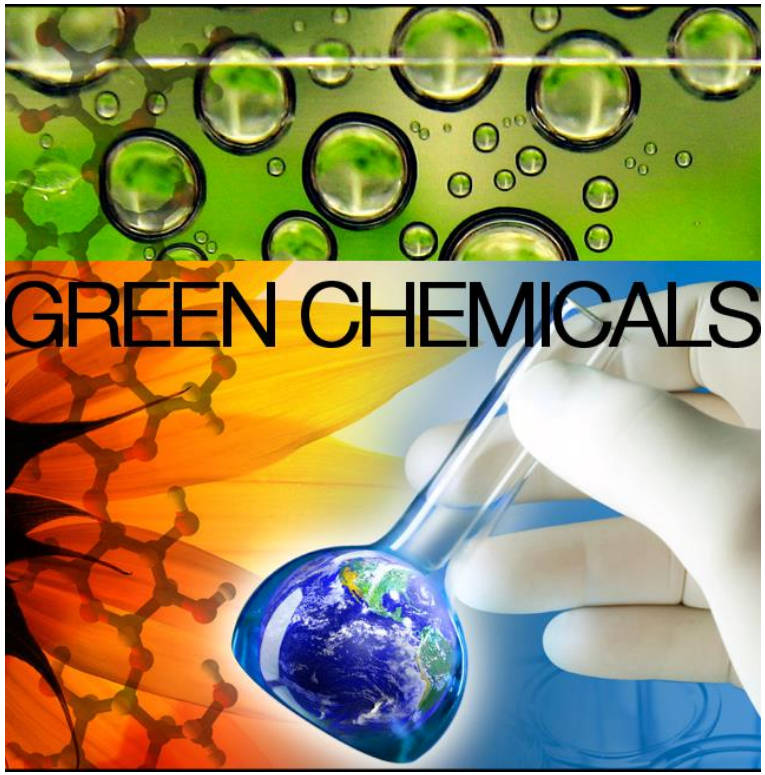
Optional Chemical Products

Ethyl Levulinate (EL)

- Many chemical uses: e.g. plasticizer production.
- Renewable home heating oil.

Furfural

- Solvent for diene extraction
- Resin manufacturing



Processing Advantages

- Lower Capital and Operating Expenses.
- Feedstock / product flexibility.
- Fuels match performance of petroleum products.

Does not:

- Depend on sugar intermediates.
- Depend on enzymes or fermentation.
- Directly produce a CO2 byproduct.

Market

- U.S. Liquid fuels sales in 2011 was estimated at over 200 Billion gallons where just under 22 Billion was Jet and just under 45 Billion was Diesel (Source: US Energy Information Association)

- RFS2 mandates biofuels must ramp up to a minimum of 21 Billion gallons annually by 2022 (@$4.00 per gallon) or $84 Billion market for 2nd generation biofuels

- A 2% market share would translate to revenue of nearly $2 Billion for Mercurius in 2022, with an $84 Billion market assuming $4/gallon

Customers

- Prompted by the Navy and Air Force, the DOD is committed to supply 50% of fuel needs with non-petroleum fuels by 2020
- Many airlines, including **Alaska**, Delta and Virgin Australia have committed to using increasing amounts of biofuels
- Diesel vehicle fleets are potential high volume customers
- Customers for Optional Chemicals and By-Products include not only fuel customers but also agricultural and specialty chemical companies

Scale-up Strategy

REACH™ Pilot Plant

- 10 MTPD (dry metric tons per day)
- Target 2014 start-up
- Hydrotreating - Existing facilities available

REACH™ Commercial scale-up ~ 50:1

- 500 MTPD
- Target 2016 start-up
- US Department of Defense, DPA grant for military fuel
- Other grants and loan/bond guarantees available
- Plan to have in place off-take agreements with customers

DOE Innovative Pilot Plant

- ✓ Build and operate in Michigan.
- ✓ 4.6 mil$ grant from the US DOE.
- ✓ 10 Dry Metric Tons/day Hydrolysis/Condensation.
- ✓ Hydrotreating - existing small scale units.
- ✓ Initial feedstock – local corn stover.

Key Partners

- CSIRO (Australia) – process optimization research
- Purdue University – scientific/engineering/aviation expertise
- UC Davis – Hydrolysis technology and IP
- Pacific Northwest National Laboratory (PNNL) – past hydrotreating and catalyst development
- Haldor Topsoe - catalyst / hydrotreating technology
- Michigan State University Bioeconomy Institute

Purdue Overview

- Purdue Team Members supporting Mercurius
- Overall Project Approach & Integration
- Feedstock: Type, Supply, Logistics & Economics
- Conversion: Hydrolysis Optimization Support
- Primary Pilot Plant Location & Regional Support Facilities
- **Fuel Validation: Chemical characterization, testing and emissions**
- Synthesis:
  - GHG and LCA modeling using GREET
  - Techno-economic modeling
- Estimated Budget & Cost-share

Support & Testing Facilities

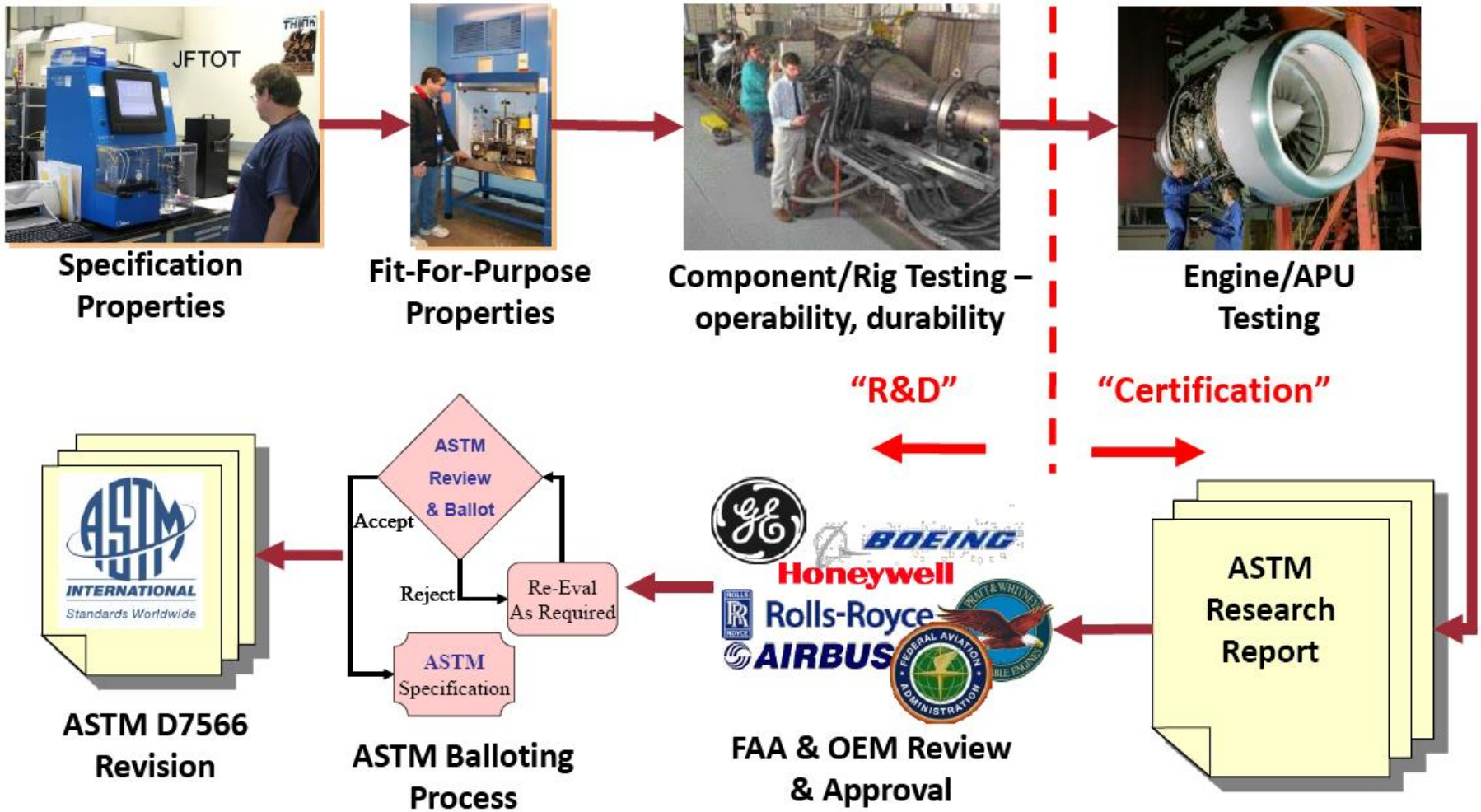
- AirTIES, Air Transport Institute for Environmental Sustainability is co-located at the Purdue airport
  - A unique advantage for accessibility to fuels, components and aircraft
- AirTIES provides the coordinating link between:
  - Academic researchers
  - Industry partners (upstream & downstream)
  - End-users
  - DoD and regulating bodies
- Expertise includes:
  - Fuel requirements,
  - Major market and policy drivers,
  - FAA regulations,
  - Techno-economic analyses
  - Technological testing

Fuel Validation

- Renewable jet fuels will be analyzed and validated in real-time
  - ✓ Chemical characteristics of key intermediates and finished fuels
  - ✓ Validation of Fuels “Fit-for-purpose”
  - ✓ Engine and component level testing
  - ✓ Gaseous and Particulate Emissions
- Strategic expertise, certification & support from Purdue, Air Force Research Lab (AFRL) and Baere Aerospace
- Candidate fuels will be tested in accordance with ASTM D4054
- High-impact, critical specifications will be prioritized to reduce technical risk and ensure efficient use of capital
- Potential to provide feedback to inform upstream chemical/engineering/design and processing steps

ASTM Alternative Fuel Evaluation,

ASTM D4054, MIL-HDBK-510



SOURCE: FAA, CRC Emerging Fuels Group, May 2010

Characterization & Certification

- Focus on 'Priority' Attributes
- "Fuel Specification" Properties:
  - Composition
  - Volatility & Density
  - Fluidity
  - Combustion
  - Thermal Stability
  - Contaminants, etc
- "Fit-for-Purpose" Properties:
  - Chemistry
  - Bulk Physical & Performance*
  - Electrical Properties
  - Ground Handling/Safety
  - Compatibility
- Component-Interface Considerations

Designation: D7566 – 12a

Standard Specification for
Aviation Turbine Fuel Containing Synthesized Hydrocarbons[1]

Designation: D1655 – 12a

Standard Specification for
Aviation Turbine Fuels[1]

*Includes: Boiling pt, Lubricity, Viscosity, Specific Heat, Density, Surface tension, Solubility of air, Thermal properties…

Fuel/Engine Test & Validation

Turboprop Test Cell

Turboshaft Test Stand

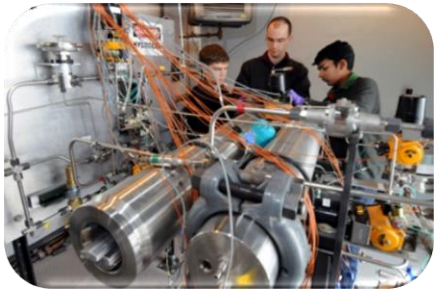
Jet Turbine Cell

Piston Engine Dynamometer Test Cell

Dynamic Flight Laboratories

Cirrus SR-20 & SR-22 Aircraft

Data Center



Zucrow Combustion Test & Design

Very Light Jet Aircraft

Experimental Beechcraft Duchess

Aircraft Materials and Components Testing

Thank you.

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