Virent is Replacing Crude Oil.

CAAFI SOAP- Jet Webinar
March 21, 2014
Agenda

- Introduction
- Feedstock
- Conversion Technology
- Jet Fuel Quality/Testing
- Questions
Presenters

- **Randy Cortright, PhD**
  - Chief Technology Officer and Founder

- **Brice Dally**
  - Senior Process Development Engineer

- **Kevin Kenney**
  - Director Biomass Feedstock National User Facility

- **David Thompson, PhD**
  - Biochemical Engineer, Renewable Resources Distinguished Staff Engineer

- **Cynthia Ginestra, PhD**
  - Aviation Fuels Research Engineer
Introduction
Virent at a Glance

The global leader in catalytic biorefinery research, development, and commercialization

Employees

75+ Employees

Technology

Converting plant-based feedstocks to fuels and chemicals

Partners & Investors

- Cargill
- Shell
- The Coca-Cola Company
- Honda

Infrastructure

25x Development Pilot Plants
2x Process Plants

© Virent 2014
The BioForming® Concept

Biobased feedstocks to direct replacement products

- Biomass
- Sugar Cane
- Corn

APR/HDO

Aromatics Processing
(Modified ZSM-5)

Reformate
Aromatics Gasoline

Distillate Processing
(Condensation + Hydrotreating)

Distillate
Jet Fuel Diesel

© Virent 2014
BioForming® Feedstock Advantage

Sucrose Starch

Cellulose (35-50%)

Hemicellulose (15-35%)

Lignin (15-35%)

Others (Ash, Extractives) (5-15%)

Fermentable Sugars (Glucose)

Hexose (Glucose, Mannose, Galactose)

Pentose (Xylose, Arabinose)

Oligosaccharides

Sugar Degradation (Furfurals, HMF, Organic Acids)

Lignin

Soluble Cyclics & Phenolics

Ash & Soluble Inorganics

VIRENT

Fermentation

© Virent 2014
**APR/HDO Reaction Pathways**

### Option 1: APR (In-Situ H2 Production)

**Aqueous Phase Reforming**

\[
\text{R}_1\text{OH} + \text{H}_2\text{O} \rightarrow \text{R}_1\text{H} + \text{2H}_2 + \text{CO}_2
\]

**Hydrodeoxygenation**

\[
\text{R}_2\text{OH} \rightarrow \text{R}_2\text{H} + \text{H}_2\text{O}
\]

### Option 2: HDO (Ex-Situ H2 Production)

**External Hydrogen**

\[
\text{H}_2 \rightarrow \text{(Steam Reforming)}
\]

**Hydrodeoxygenation**

\[
\text{R}_2\text{OH} \rightarrow \text{R}_2\text{H} + \text{H}_2\text{O}
\]

- Decision for APR vs. HDO based on relative cost of carbohydrate feedstock vs. NG
- HDO is currently preferred- cheap NG, improved yield- no loss of carbon to CO2
Many types of feeds can be used
Examples: Corn syrup, Sucrose, Sugar Alcohols, Biomass Hydrolyzate
Diverse mixture of components produced
Examples: Alcohols, Ketones, Cyclic Ethers, Diols
Intermediates can be tuned to achieve different final product goals
Condensation Reaction Pathways
CHASE = Carbon, Hydrogen, and Separation Efficiencies

Project Title: Fractional Multistage Hydrothermal Liquefaction of Biomass and Catalytic Conversion into Hydrocarbons (DE-EE0006286)

Objectives: Virent intends to develop an improved multistage process for the hydrothermal liquefaction (HTL) of biomass to serve as a new front-end, deconstruction process ideally suited to feed Virent’s well-proven catalytic technology, which is already being scaled up. This process will produce water soluble, partially de-oxygenated intermediates that are ideally suited for catalytic finishing to fungible distillate hydrocarbons. Virent will utilize two high impact feedstocks; debarked loblolly pine and corn stover.

Innovation: Novel multistage hydrothermal fractionation and separation process, which improves overall carbon conversion and can be combined with Virent’s catalytic BioForming technology platform to produce distillate fuels.
Virent’s Biomass to Jet Platform

Wood to Jet

BIRD
Israel-U.S. Binational Industrial Research and Development Foundation

Sugar to Jet

Federal Aviation Administration

Corn Stover to Jet

Biological Research and Development

Hydrolysate Upgrading

APR/HDO

Condensation/Hydrotreating

Fuels

Naphtha

Diesel

CHASE
Wood to Jet
Corn Stover to Jet

Fractionated Liquefaction

© Virent 2014
Feedstock
National Challenge

• Replacing the whole barrel
  – US spends $1 billion/day on oil imports
  – Reducing dependence on oil requires replacing the whole barrel
  – Climate change mitigation by replacing fossil fuels
• Feedstock costs represent up to one-third current biofuel production costs

Feedstock Cost Challenge

Feedstock Quality Challenge

Feedstock Break Point to Achieve $3/gal Target

Temporal changes in %Moisture
Hydrocarbon Pathways

FEEDSTOCKS
- Terrestrial
  - Ag Residues
  - Pulpwood
  - Forest Residues
  - Dedicated Energy Crops
- Algal
  - Monocultures
  - Polycultures
- Municipal Solid Waste
  - Construction & Demolition Waste
  - Yard Waste
  - Food Waste
  - Paper/Cardboard

CHARACTERIZATION
- Composition
- Energy Content
- Moisture
- Ash/Elemental Species
- Contaminants
- Performance Screening

PREPROCESSING
- Drying
- Size Reduction
- Separations
- Ash Reduction
- Blending

CONVERSION PATHWAYS
- Bio. Fermentation of Sugars
- Catalytic Upgrading of Sugars
- Fast Pyrolysis
- In-Situ Catalytic Fast Pyrolysis
- Ex-Situ Catalytic Fast Pyrolysis
- Syngas Upgrading
- Algal Lipid Upgrading
- Whole Algae Hydro. Liquefaction

CONVERSION INTERMEDIATES
- Syngas
- Bio-Oil

PRODUCTS
- Hydrocarbon Biofuels (gas, diesel, jet)
- Co-products
Feedstock Quality Challenge

Sugars

- Conversion specs shown (vertical lines) represent DOE biochem (BC) and thermochem (TC) pathway quality specs.

- Distributions represent variability in biomass properties relative to spec.

- Distributions likely greater if broader range of resources are considered.

- Illustrates challenge associated with diversity.

Moisture

Ash

- N = 339

- TC: 10%  BC: 20%

- 2009 Harvest  2010 Harvest

- TC: 1%  BC: 7%

- N = 840

- Corn Stover  Miscanthus  Wheat
• Challenge: Understanding impacts of variability
  – Supply chain logistics
  – Biomass preprocessing
  – Conversion performance
• Our Approach
  – Logistics modeling & sensitivity analysis
  – Preprocessing R&D
  – Conversion performance screening

Impact of Variability

- Frequency
- Cost to Refinery ($/dry ton)

BC* 5%

- Frequency
- Cost to Refinery ($/dry ton)
Sources of Variability

• Challenge: Understanding sources of variability
  – Genetic
    • Feedstock type, variety
  – Environmental
    • Soil type
    • Weather
    • Agronomic practices
  – Annual
  – Supply Chain Practices
• Our Approach
  – Biomass Feedstock Library: database consisting of more than 60,000 samples (and growing)
  – INL biomass field research
Solutions to Variability

- Challenge: Developing cost effective solutions to variability
- Our Approach: a graded approach
  - Best Management Practices
  - Preprocessing Technology R&D

![Chart showing frequency distribution of ash content in Corn Stover, Miscanthurus, and Wheat with specified limits of ThermoChem and BioChem specs.]

- ThermoChem Spec: 1%
- BioChem Spec: 7%

- Mechanical Preconversion
- Formulation/Blending
- Chemical Separations

Best Management Practices
Examples of Ash Reduction to Meet Specifications

• Mechanical separations
  – Screening to separate rocks and soil from biomass
  – Classification by density or color to separate plant tissue fractions
  – Fractional milling to separate size fractions with higher ash
  – Triboelectrostatic separation of finely ground biomass to reduce silica

• Chemical separations
  – Simple washing to remove soil
  – Leaching with water/acid to remove alkali metals/alkaline earth metals
  – Limited structural disruption with hot water or acid to remove cell-bound nitrogen and sulfur
  – Dissolution of silica with alkali

• Formulation strategies
  – Blending the same feedstock from different sources/harvest methods
  – Blending different feedstocks of varying qualities
INL Ash Reduction in Support of Nighthawk

• Nighthawk approach to biomass conversion
  – Fractionate biomass into its individual polymers using various chemistries
  – Utilize fraction-specific reaction conditions and catalysts to convert each fraction to hydrocarbon fuels and chemical intermediates

• Utilize the CPS remove ash and effect structural modifications
  – Goal: Make corn stover look like clean stemwood in a feedstock depot
  – Simple washing or mechanical screening to remove soil
  – Dissolution of silica and lignin with alkali followed by lignin recovery
  – Additional structural disruption with dilute acid to remove cell-bound nitrogen and sulfur together with alkali metals & alkaline earth metals

• Advantages over direct hydrothermal fraction
  – Fouling agents removed before reaching conversion facility
  – Less non-convertible material delivered to conversion facility
  – Less severe fractionation conditions required at conversion facility
INL Chemical Preconversion System (CPS)

- Designed to effect limited structural modifications
  - Structural ash removal
  - Reduced grinding & pelleting energy usage
- Unique in its applicability to
  - large particle sizes
  - low bulk densities
  - high or low pressure operation
  - high or low temperature operation
  - widely varying chemistries

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size (in)</td>
<td>&lt; 2.0</td>
</tr>
<tr>
<td>Temperature range (°C)</td>
<td>40-200</td>
</tr>
<tr>
<td>Pressure range (psig)</td>
<td>0-200</td>
</tr>
<tr>
<td>pH range</td>
<td>0.5-13.5</td>
</tr>
</tbody>
</table>
Lignocellulosic Biomass
Depolymerization of Lignocellulosic Biomass

Lignocellulose

Hemicellulose

Cellulose

Lignin

© Virent 2014
CHASE Multistage HTL Concept

Virent’s Catalytic BioForming® Process

Drop-in Hydrocarbon fuels (Distillates, Naphtha, Fuel oil)
CHASE Work Plan

1. Sand bath: small scale, rapid testing
   - Temperature
   - Pressure
   - Solvent
   - Residence Time

2. Small-scale flow-through system
   - Kinetic Modeling

3. Prototype unit
   - 1-5 kg/hr throughput

4. Existing BioForming pilot plant to finished jet fuel
**Objective:** The funding provided by this proposal has supported Virent’s efforts to complete specification and fit-for-purpose testing on HDO-SK through at least CAAFI Fuel Readiness Level (FRL) 6.1 (100 gallons).

**Funding:** FAA/DOT/Volpe (Contract DTRT57-11-C-10060)

**Duration:** 2 years, Q4 2011 - Q3 2013

---

**“Project Thunderbird”**
(Q4 2011 – Q3 2013)

- **Soluble Sugars**
- **APR**
- **Condensation**
- **Finishing**
- **Separations**
- **Jet Fuel**
  - Gasoline
  - Diesel
Virent Demonstrated Yields

Yield (kg product/kg feed)

Start of Development → Current

Physical Theoretical Conversion Limit

Theoretical Conversion Limit – Fermentation & APR without External H₂

Naphtha
Distillate
BioForming® Distillate Platform

- Mini-Distillate Pilot Plant
  - 15 gal/day Liquid Fuel (20x lab)
  - 100 gal Jet Fuel produced
  - Scalable Yield and Product Quality Proven
  - ASTM Certification ongoing
Jet Composition

- Broad boiling point range
- Cycloparaffins from condensation + hydrotreating chemistry
- No composition differences from biomass derived fuels = feedstock agnostic
- Fuel testing important to gain industry support
Jet Fuel Quality and Testing
DEFINITIONS & CAUTIONARY NOTE

Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

Organic: Our use of the term Organic includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.

Resources plays: our use of the term 'resources plays' refers to tight, shale and coal bed methane oil and gas acreage.

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate entities. In this presentation “Shell”, “Shell group” and “Royal Dutch Shell” are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words “we”, “us” and “our” are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. “Subsidiaries”, “Shell subsidiaries” and “Shell companies” as used in this presentation refer to companies in which Royal Dutch Shell either directly or indirectly has control, by having either a majority of the voting rights or the right to exercise a controlling influence. The companies in which Shell has significant influence but not control are referred to as “associated companies” or “associates” and companies in which Shell has joint control are referred to as “jointly controlled entities”. In this presentation, associates and jointly controlled entities are also referred to as “equity-accounted investments”. The term “Shell interest” is used for convenience to indicate the direct and/or indirect (for example, through our 23% shareholding in Woodside Petroleum Ltd.) ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

This presentation contains forward-looking statements concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management’s current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management’s expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as “anticipate”, “believe”, “could”, “estimate”, “expect”, “intend”, “may”, “plan”, “objectives”, “outlook”, “probably”, “project”, “will”, “seek”, “target”, “risks”, “goals”, “should” and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this presentation, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell’s products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including potential litigation and regulatory measures as a result of climate changes; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. All forward-looking statements contained in this presentation are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional factors that may affect future results are contained in Royal Dutch Shell’s 20-F for the year ended 31 December, 2013 (available at www.shell.com/investor and www.sec.gov ). These factors also should be considered by the reader. Each forward-looking statement speaks only as of the date of this presentation, 21 March, 2014. Neither Royal Dutch Shell nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this presentation. There can be no assurance that dividend payments will match or exceed those set out in this presentation in the future, or that they will be made at all.

We use certain terms in this presentation, such as discovery potential, that the United States Securities and Exchange Commission (SEC) guidelines strictly prohibit us from including in filings with the SEC. U.S. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov.

Copyright of Shell Global Solutions (US) Inc.

CAAFI SOAP-Jet

21 March 2014

3

3
What Makes a Good Jet Fuel?

Typical Jet A-1

Virent Synthetic Kerosene

n-paraffin

iso-paraffin

cycloparaffin = naphthene = cycloalkane

dicycloparaffin = di-naphthene = di-cycloalkane

monoaromatic

naphthenic

mono-aromatic

diaromatic = naphthalene
### US Jet Fuel Spec: ~ 25 properties

#### TABLE 1 Detailed Requirements of Aviation Turbine Fuels

<table>
<thead>
<tr>
<th>Property</th>
<th>Jet A or Jet A-1</th>
<th>ASTM Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPOSITION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidity, total mg KOH/g</td>
<td>max 0.10</td>
<td>D3242</td>
</tr>
<tr>
<td>1. Aromatics, vol %</td>
<td>max 25</td>
<td>D1319</td>
</tr>
<tr>
<td>2. Aromatics, vol %</td>
<td>max 26.5</td>
<td>D6379</td>
</tr>
<tr>
<td>Sulfur, mercaptan, mass %</td>
<td>max 0.003</td>
<td>D3227</td>
</tr>
<tr>
<td>Sulfur, total mass %</td>
<td>max 0.30</td>
<td>D1266, D2622, D4294, or D5453</td>
</tr>
<tr>
<td>VOLATILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distillation temperature, °C:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 % recovered, temperature</td>
<td>max 205</td>
<td></td>
</tr>
<tr>
<td>50 % recovered, temperature</td>
<td>report</td>
<td></td>
</tr>
<tr>
<td>90 % recovered, temperature</td>
<td>report</td>
<td></td>
</tr>
<tr>
<td>Final boiling point, temperature</td>
<td>max 300</td>
<td></td>
</tr>
<tr>
<td>Distillation residue, %</td>
<td>max 1.5</td>
<td></td>
</tr>
<tr>
<td>Distillation loss, %</td>
<td>max 1.5</td>
<td></td>
</tr>
<tr>
<td>Flash point, °C</td>
<td>min 39°</td>
<td></td>
</tr>
<tr>
<td>Density at 15°C, kg/m³</td>
<td>775 to 840</td>
<td>D56 or D3828</td>
</tr>
<tr>
<td>FLUIDITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freezing point, °C</td>
<td>max −40 Jet A'</td>
<td>D5972, D7153, D7154, or D2386</td>
</tr>
<tr>
<td>Viscosity −20°C, mm²/s'</td>
<td>max 8.0</td>
<td>D445</td>
</tr>
<tr>
<td>COMBUSTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net heat of combustion, MJ/kg</td>
<td>min 42.8°</td>
<td>D4529, D3338, or D4809</td>
</tr>
<tr>
<td>One of the following requirements shall be met:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Smoke point, mm, or</td>
<td>min 25</td>
<td>D1322</td>
</tr>
<tr>
<td>(2) Smoke point, mm, and</td>
<td>min 18</td>
<td>D1322</td>
</tr>
<tr>
<td>Naphthalenes, vol, %</td>
<td>max 3.0</td>
<td>D1840</td>
</tr>
<tr>
<td>CORROSION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper strip, 2 h at 100°C</td>
<td>max No. 1</td>
<td>D130</td>
</tr>
<tr>
<td>THERMAL STABILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2.5 h at control temperature of 260°C min)</td>
<td>max 25</td>
<td>D3241</td>
</tr>
<tr>
<td>Filter pressure drop, mm Hg</td>
<td>3°</td>
<td></td>
</tr>
<tr>
<td>Tube deposits less than</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTAMINANTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existent gum, mg/100 mL</td>
<td>max 7</td>
<td>D381, IP 540</td>
</tr>
<tr>
<td>Microseparometer, Rating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without electrical conductivity additive</td>
<td>min 85</td>
<td>D3948</td>
</tr>
<tr>
<td>With electrical conductivity additive</td>
<td>min 70</td>
<td></td>
</tr>
<tr>
<td>ADDITIVES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical conductivity, pS/m</td>
<td></td>
<td>D2624</td>
</tr>
</tbody>
</table>

*For compliance of test results against the requirements of Table 1, see 6.2.*

*The test methods indicated in this table are referred to in Section 10.*

*The moisture sulfur determination may be waived if the fuel is considered sweet by the doctor test described in Test Method D4952.*
Industry Jet Fuel Qualification Process (ASTM D4054)

- Specification Properties
- Fit-For-Purpose Properties
- Component/Rig/APU Testing
- Engine Testing

Current status of Virent Synthetic Kerosene (SK)

ASTM Specification

ASTM Balloting Process

- Accept
- Reject & Re-Eval As Required

ASTM Review & Ballot

Airbus
Boeing
GE
Honeywell
Pratt & Whitney
Rolls-Royce
Etc...

OEM Review & Approval

ASTM Research Report

*Courtesy Mark Rumizen (FAA)*
# Virent SK: Test Results

<table>
<thead>
<tr>
<th>Composition</th>
<th>Test Method</th>
<th>ASTM D1655</th>
<th>10-gal SK (Neat)*</th>
<th>Jet A / SK 50/50 Blend</th>
<th>Jet A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity, Total (mg KOH/g)**</td>
<td>D3242</td>
<td>Max.</td>
<td>0.10</td>
<td>&lt;0.003</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Aromatics (vol %)</td>
<td>D1319</td>
<td>Max.</td>
<td>25</td>
<td>8</td>
<td>16.0</td>
</tr>
<tr>
<td>Sulfur, Mercaptan (mass %)</td>
<td>D3227</td>
<td>Max.</td>
<td>0.003</td>
<td>&lt;0.0003</td>
<td>&lt;0.0003</td>
</tr>
<tr>
<td>Sulfur, Total (mass %)</td>
<td>D4294</td>
<td>Max.</td>
<td>0.30</td>
<td>0.00</td>
<td>0.034</td>
</tr>
</tbody>
</table>

** Volatility

<table>
<thead>
<tr>
<th>Distillation</th>
<th>D86</th>
<th>Initial BP (°C)</th>
<th>159</th>
<th>160</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Temp @ 10% Rec. (°C)</td>
<td>205</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temp @ 50% Rec. (°C)</td>
<td>Max.</td>
<td>Max.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temp @ 90% Rec. (°C)</td>
<td>Max.</td>
<td>Max.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final BP (°C)</td>
<td>Max.</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T50-T10 (°C)</td>
<td>Min.</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T90-T10 (°C)</td>
<td>Min.</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residue (vol %)</td>
<td>Max.</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss (vol %)</td>
<td>Max.</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flash Point (°C)</td>
<td>D93</td>
<td>Min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Density, 15°C (kg/m³)</td>
<td>D4052</td>
<td>775 - 840</td>
</tr>
</tbody>
</table>

** Fluidity

| Freezing Point (°C) | D5972       | Max.      | -40/-47          | < -80                | -52.7           | -44               |
| Viscosity @ -20°C (cSt) | D445 | Max. | 8.0           | 6.1                  | 5.1              | 4.9              |

** Combustion

| Smoke Point (mm)** | D1322 | Min. | 18 | 27.0 | 26.0 | 25 |

** Thermal Stability

| JFTOT Breakpoint (°C) | D3241 | Min. | 260 | > = 325 | 335 | 290 |

** NB: Specs apply only to final fuel blends, not neat SK

** DEF STAN 91-91 more constrained:
- TAN max 0.015 mg KOH/g
- Smoke point max 25mm or 19mm with Naphthalenes max 3.00% v/v
# Virent SK: Fit-For-Purpose Properties

## Chemistry
- Hydrocarbon Chemistry (carbon number, type and distribution)
- Trace Materials

## Bulk Physical and Performance Properties
- Boiling Point Distribution
- Vapor/Liquid Ratio
- Thermal Stability Breakpoint
- Lubricity
- Response to Lubricity Improver
- Viscosity vs. Temperature
- Specific Heat vs. Temperature
- Density vs. Temperature
- Surface Tension vs. Temperature
- Thermal Conductivity vs. Temp.
- Water Solubility vs. Temperature
- Solubility of air (oxygen/nitrogen)

## Electrical Properties
- Dielectric Constant vs. Density
- Electrical Conductivity and Response to Static Dissipator

## Ground Handling/Safety
- Effect on Clay Filtration
- Filtration (coalescers & monitors)
- Storage Stability
  - Peroxides
  - Potential Gum
- Toxicity
- Flammability Limits
- Autoignition Temperature
- Hot Surface Ignition Temperature

## Compatibility
- With other Approved Additives and Fuels
- With Engine and Airframe Seals, Coatings and Metallics
Virent SK: Status

- Specification and Fit-For-Purpose Testing Complete
- Report Available Soon
- All Properties within Experience
- Rig Testing at Honeywell – in progress
  - Atomizer Cold Spray
  - Combustor Rig
  - Cold & Altitude Starting
- Seeking opportunities to produce additional volumes for certification
Thank You. Questions?

Randy Cortright, PhD, CTO and Founder
Brice Dally, Sr. Process Development Engineer
Kevin Kenney, Director Biomass Feedstock National User Facility
David Thompson, PhD, Biochemical Engineer, Renewable Resources Distinguished Staff Engineer
Cynthia Ginestra, PhD, Aviation Fuels Research Engineer