What Are Fats/Oils?

- Fats & Oils Have the Same Chemistry
  - Fats are solid
  - Oils are liquids
- Triglycerides
  - 3 Carbon tri-alcohol, glycerin
  - 3 Long-Chain (typically C<sub>16</sub>-C<sub>18</sub>) fatty acids attached to glycerin – ester linkage
Animal Fat vs. Vegetable Oil

- Animal Fat
  - More highly saturated
- Vegetable Oil
  - More unsaturation (>50% di & poly)
  - Lower melting point

Soy Oil
Renewable Diesel Process

Crude Distillation

- Straight Run Gasoline
- Straight Run Diesel
  - Cycle Oil, etc

Hydrogen

Diesel Hydrotreater

- Renewable Fats/Oils
- Renewable Diesel Mixture

Note: Capital investment is required at refineries to modify infrastructure to enable renewable fats & oils processing.
Renewable Diesel Chemistry

Fat or Oil (Triglyceride)

Hydrotreating

Heat, Hydrogen, Catalyst

Renewable Diesel

Propane

ConocoPhillips
Biodiesel Chemistry

\[ \text{Fat or Oil (Triglyceride)} + 3 \text{MeOH} \rightarrow \text{biodiesel} + \text{glycerin} \]

R = C_{17}H_{31} (typical)

Works Best With Virgin Vegetable Oils
Renewable Diesel Process

- Co-feed Renewable Oils to Diesel Hydrotreater
  - 150-2400 psi Hydrogen, 600-800°F
  - Normal reaction is sulfur removal (HDS)

- At HDS Conditions Fat Or Oil Conversion To Renewable Diesel Is 100%
  - Glycerin converted to propane, glycerin is not a co-product of renewable diesel
  - Oxygen converted to $\text{H}_2\text{O}$ or $\text{CO}_2$
100 % Renewable Diesel From Beef Tallow

n-paraffins = 86%
i-paraffins = 6.0%
c-paraffins = 7.7%
aromatics = 0.3%

ConocoPhillips
Typical Renewable Diesel

- Paraffinic (C_{13}-C_{18})
- No Oxygen
- No Double Bonds
- In Heart of Diesel Fuel (C_{10}-C_{22})
- High Cetane
- Feedstock Independent
- Cold Flow Issues
# Low Concentration Renewable Diesel Content Effects

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM D975</th>
<th>Base Fuel</th>
<th>5% Ren Content</th>
<th>10% Ren Content</th>
<th>20% Ren Content</th>
<th>30% Ren Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>T90, F</td>
<td>540-640°F</td>
<td>559</td>
<td>565</td>
<td>568</td>
<td>571</td>
<td>577</td>
</tr>
<tr>
<td>Visc. (mm²/s at 20°C)</td>
<td>1.9-4.1</td>
<td>2.3</td>
<td>2.3</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Ash, mass %</td>
<td>0.01 max</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sulfur (ppm)</td>
<td>15 max</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Copper Strip Corrosion</td>
<td>3 max</td>
<td>1A</td>
<td>1A</td>
<td>1A</td>
<td>1A</td>
<td>1A</td>
</tr>
<tr>
<td>Ramsbottom Carbon</td>
<td>0.35 %max</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Cetane number</td>
<td>40 min.</td>
<td>41.2</td>
<td>45.8</td>
<td>47.4</td>
<td>51.2</td>
<td>54.2</td>
</tr>
<tr>
<td>Lubricity</td>
<td>520μ max.</td>
<td>591</td>
<td>598</td>
<td>603</td>
<td>597</td>
<td>586</td>
</tr>
<tr>
<td>Cloud Point, F</td>
<td>Seasonal/Regional</td>
<td>-9</td>
<td>3</td>
<td>8</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Pour Point, F</td>
<td>Seasonal/Regional</td>
<td>-24</td>
<td>-6</td>
<td>0</td>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

Note 1: Renewable diesel fuels shown here are not commercially optimized - for illustration only
Note 2: Feedstock is soy oil; results for non-soy feedstocks are similar
Renewable Diesel Compatibility

- No New Molecules
- Meets ASTM D 975
- High Level of Quality Control
- No Transportation Limitations
  - Use existing pipeline & trucking infrastructure
- Reduces Emissions & CO$_2$
Low Concentration Renewable Diesel NOx

Note: Renewable diesel fuels tested are not commercially optimized
Low Concentration Renewable Diesel CO

Note: Renewable diesel fuels tested are not commercially optimized
Low Concentration Renewable Diesel NMHC

Note: Renewable diesel fuels tested are not commercially optimized
Low Concentration Renewable Diesel PM

Note: Renewable diesel fuels tested are not commercially optimized
Similar life cycle analysis can be performed for other renewable diesel feedstocks including beef tallow, canola (rapeseed), poultry fat and yellow grease.
Relative CO$_2$ Life Cycle Emissions

<table>
<thead>
<tr>
<th>Process</th>
<th>COP (soy)</th>
<th>UOP (soy)</th>
<th>NExBTL® *</th>
<th>CONCAWE-EUCAR-JRC *</th>
<th>U.S. EPA GREET Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Diesel</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Biodiesel, B100</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Co-processed</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Renewable Diesel</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

* Rapeseed Feedstock
Renewable Diesel Summary

- Excellent Way To Incorporate Renewable Fats & Oils Into Diesel Fuel
- Feedstock Flexible
  - Converts Any Fat/Oil to Normal Diesel Fuel
- High Level Of Quality Control
- Meets ASTM D 975 Diesel Specification
- Transparent To Users
- Expands Opportunities For Farm Community