1-Butanol as a Gasoline Blending Bio-component
BP and DuPont have joined forces to develop, produce and market next generation biofuels to help meet increasing global demand for renewable transport fuels.

These next generation fuels will harness DuPont’s advanced biotechnology capabilities, BP’s fuel market expertise and their joint process engineering know how.

We are seeking advantaged biocomponent molecules which can be:
- added to the fungible fuel pool using existing supply infrastructure
- are compatible with the existing vehicle park
- can be used at reasonable blend concentrations
- require no compromise in fuel specifications
- meet the needs of the customer without performance compromise

Biobutanol (1-butanol) will likely be first product introduced into market.
Biobutanol Technology Developments

- A biobutanol only process using advanced biotechnology currently being developed.
- Advantages:
  - Enhanced yields / lower production cost.
  - Potential to produce other biobutanol isomers with further enhanced fuel properties.
  - Targeting a value chain which is competitive versus conventional bio-components.
  - Future potential for bio-pathways to be compatible with lignocellulosic feedstocks.

Commercialisation

- BP-DuPont are evaluating commercialisation opportunities of 1-butanol in European markets and other regions.
# Fuel Properties

<table>
<thead>
<tr>
<th></th>
<th>Ethanol</th>
<th>1-Butanol</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp. Gravity, 60/60 °F</td>
<td>0.794</td>
<td>0.814</td>
<td>0.720-0.775</td>
</tr>
<tr>
<td>RON</td>
<td>106-130(^1)</td>
<td>94(^1)</td>
<td>95</td>
</tr>
<tr>
<td>MON</td>
<td>89-103(^1)</td>
<td>80-81(^1)</td>
<td>85</td>
</tr>
<tr>
<td>Rvp@ 5% /10% [psi]</td>
<td>31(^1)/20(^1)</td>
<td>6.4(^1) / 6.4(^1)</td>
<td>&lt; 7.8/15(^2)</td>
</tr>
<tr>
<td>Oxygen [%wt]</td>
<td>34.7</td>
<td>21.6</td>
<td>&lt; 2.7</td>
</tr>
</tbody>
</table>

\(^1\) Blend values of alcohol octane numbers and vapour pressure.

\(^2\) Summer / Winter specifications.
Butanol has a vapour pressure synergy with ethanol. Butanol’s DVPE in a co-blend with ethanol is negative. In this example ~ minus 35kPa.

Impact of Alcohol Content on Vapour Pressure

<table>
<thead>
<tr>
<th>Alcohol Content [%]</th>
<th>Δ Vapour Pressure [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>91-BuOH</td>
<td>5.0</td>
</tr>
<tr>
<td>91-EtOH</td>
<td>0.0</td>
</tr>
<tr>
<td>91-EtOH5-BuOH3.5</td>
<td>-4.0</td>
</tr>
<tr>
<td>95-BuOH</td>
<td>3.5</td>
</tr>
<tr>
<td>95-EtOH</td>
<td>0.0</td>
</tr>
<tr>
<td>95-EtOH5-BuOH3.0</td>
<td>-3.0</td>
</tr>
</tbody>
</table>

5% EtOH + Increasing Addition of BuOH

Ethanol Increase

Butanol Decrease
Ethanol blends (E5/E10) lead to a distillation curve abnormality.

E5 / E10: Gasoline blended with 5%/10% ethanol
B10: Gasoline blended with 10% butanol

Oxygen rich, low boiling effect can impact driveability.
Butanol does not phase-separate in the presence of water, unlike ethanol.
20% 1-Butanol Gasoline Elastomer Swelling

Percentage Swell

<table>
<thead>
<tr>
<th></th>
<th>ULR</th>
<th>ULR + 20% 1-BuOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epichlor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eth Acryl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypalon</td>
<td>35±1</td>
<td>25±1</td>
</tr>
<tr>
<td>Nitrile</td>
<td>28±1</td>
<td>15±1</td>
</tr>
<tr>
<td>Silicone</td>
<td>37±1</td>
<td>20±1</td>
</tr>
<tr>
<td>Viton A</td>
<td>10±1</td>
<td>5±1</td>
</tr>
<tr>
<td>Viton B</td>
<td>5±1</td>
<td>2±1</td>
</tr>
</tbody>
</table>

Elastomer

% Swell

ULR
ULR + 20% 1-BuOH
### 6-weeks-corrosion test (water addition)

<table>
<thead>
<tr>
<th></th>
<th>10% 1-butanol (chemical grade) in gasoline</th>
<th>5% ethanol in gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>visual (compared to base fuel)</td>
<td>analytical evaluation</td>
</tr>
<tr>
<td>Copper</td>
<td>[Green] pass / no impact of alcohol compared to base fuel</td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td>[Yellow] pass / minor impact of alcohol compared to base fuel</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>[Green] pass / no impact of alcohol compared to base fuel</td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>[Yellow] pass / minor impact of alcohol compared to base fuel</td>
<td></td>
</tr>
<tr>
<td>Steel ST12</td>
<td>[Smiley] positive impact of alcohol compared to base fuel</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>[Smiley] positive impact of alcohol compared to base fuel</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- **Green:** pass / no impact of alcohol compared to base fuel
- **Smiley:** positive impact of alcohol compared to base fuel
- **Yellow:** pass / minor impact of alcohol compared to base fuel

Corrosion test will be repeated when process grade 1-(bio)-butanol is available.
Ongoing Test Work

• Protocol 1 Laboratory Testing
• Protocol 2 EVL-Test Bench
  - Testing of Fuel Pumps (EKP: Siemens, Bosch and Pierburg)
  - VW 1.6l engine test bench (Fuel BB10)
    - Inlet valve deposit
    - Combustion chamber deposits
• Protocol 3 Performance/Emissions (Fuels: RON 91, BB5, BB10, E5, E10, E5+BB2.5)
  - Acceleration, power
  - Driveability - hot/cold
  - Emissions
• Protocol 4 Field Trial
  - 6 cars, 20k km
• Protocol 5 Mileage Accumulation (Fuels: RON 91, E5, BB10)
  - 3 cars, 50k km, emissions testing
Summary Performance Test Work

• Fuels
  − Alcohols splash blended into regular fuel
    − Octane not adjusted

• Results
  − Power
    − Alcohols generally increase power, even with a limited increase in octane
  − Fuel economy
    − Alcohols generally lead to lower fuel economy
      − Butanol is better than ethanol, due to its higher energy content
• Limited investigations of four vehicles with butanol in gasoline at 11.5 vol% within current substantially similar limit of total oxygen 2.7 wt. % were performed

• Butanol in gasoline did not change CO, HC, NOx emissions in standard FTP cycle

• Fuel consumption increases are consistent with the reduced energy content of the fuel
Ethanol is a commodity chemical currently used as an intermediate in the production of other chemicals and as a gasoline blending stream.

- Low acute oral, dermal and inhalation toxicity.
- Not irritating to the skin or eyes.
- Not genotoxic.
- Evidence of developmental toxicity in animals.
- Evidence of reproductive toxicity in animals.
- Carcinogenic potential at high exposures.

1-Butanol is a commodity chemical currently used as an intermediate in the production of other chemicals (for adhesives, building material agents, cleaning agents, detergents, dyestuffs, fertilisers and surface treatment agents) and as a solvent (especially in surface coatings).

- Low acute oral, dermal and inhalation toxicity.
- Moderate skin irritant, a severe eye irritant.
- Not genotoxic.
- Not considered to be a developmental toxin.
- Studies suggest that reproductive function is not likely to be affected and carcinogenic potential is low.
- Low odour threshold, and detectable at levels below those expected to cause harm.

On release to the environment ethanol is expected to partition mainly to air, and readily move through soil to groundwater.

- Readily bio-degradable and will not persist in the environment/groundwater.
- Not expected to accumulate in biota, and is of low eco-toxicity concern.

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Thank you

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