Sustainable Aviation Fuels
Shell’s Activities
University of Toronto Institute for Aerospace Studies
May 19, 2021

Griffin Valentich
Aviation Fuels Engineer
Agenda

• Who is Shell Aviation?
• A history of innovation
• Sustainable Aviation Fuels
  • IH$^2$ CPK-0
  • PTL Fuel
• Other Collaborations
• Summary
Shell Aviation

Operates in
60
COUNTRIES

On average Shell fuels an aircraft every
14
SECONDS

Over
100
YEARS
OF INNOVATION

Each year, Shell fuels more than
2 MILLION AIRCRAFT

Safe and timely supply of AVIATION FUELS, HIGH-PERFORMANCE LUBRICANTS AND FLUIDS

Supplier for more than
900 AIRPORTS
Shell refuels the world's first commercial passenger flight powered by fuel made from natural gas.

Shell designs and implements the first aviation fueling hydrant system.

Shell scientists assist Frank Whittle to develop the jet engine.

Louis Bleriot uses Shell fuel to cross the English channel.

AeroShell turbine oil 555 developed for Concorde’s Rolls-Royce Olympus engines. Shell fuels its inaugural flight.

AeroShell grease 33, a multi-purpose airframe lubricant, is introduced.

Shell develops new ways to measure cleanliness of fuels and increase the loading flow rate of fuel into an aircraft.

Shell innovation enables a viable lead-free avgas for light aircraft and helicopters.

Shell refuels the world’s first commercial passenger flight powered by fuel made from natural gas.

Shell Water Detector developed to monitor fuel quality.

Shell produces Avgas 100/130.

AeroShell oil w15w-50 is the first semi-synthetic multigrade aviation oil.

Shell innovation enables a viable lead-free avgas for light aircraft and helicopters.

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Aviation Technology R&D Group – Based in Houston, Texas

Shell Technology Center Houston
- > 2,000 employees
- > 1 million sq. ft. (93,000 m²) labs & offices
- Upstream & Downstream technologies

Aviation Technology Team

JET FUEL
AVGAS
FILTRATION
LUBRICANTS
GREASES
Sustainability Of Aviation

- Aviation responsible for 2% of human-induced carbon emissions. Source: ATAG
- Aviation responsible for 12% of carbon emissions from transport sources. Source: ATAG

815 MILLION TONNES of carbon emitted by worldwide flights in 2016. Source: IATA

Passenger numbers expected to reach 7.8 BILLION BY 2036. Source: IATA
Carbon Neutral Growth from 2020

- Emissions assuming no action
- Aircraft technology (known), operations and infrastructure measures
- Carbon-neutral growth 2020
- Biofuels and radically new technologies
- Gross emissions trajectory
- Economic measures

No action
Technology
Operations
Infrastructure
Biofuels and radical tech
CNG 2020
-50% by 2050
Not to scale

2005  2010  2020  2030  2040  2050
C02 Emissions
Shell’s aviation vision on carbon management solutions
- we must deploy measures in all 3 areas to support sector de-carbonisation

Avoid
Reduce
Offset
Shell’s role

Shell has a unique advantage though our technology and the multiple roles that we play.

We feel this puts us in a unique position to enable collaboration.

1. Supply Chain & Logistics
2. Technology Developer
3. Fuel Producer
4. Investor
5. Off-taker
6. Product Quality & Assurance
7. Fuel User – we also travel
## Different technology routes to SAF

7 conversion pathways (annexes) that are certified by ASTM within D7566, all ‘drop-in’ blends to re-certify as Jet A (ASTM-D1655)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Code</th>
<th>Feedstock</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; or 2&lt;sup&gt;nd&lt;/sup&gt; gen</th>
<th>Max blend</th>
<th>Technology Providers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fischer-Tropsch</td>
<td>FT</td>
<td>Biomass/Waste/Nat Gas</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>50%</td>
<td>Fulcrum, Velocys, Shell</td>
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<tr>
<td>Hydro processed Ester and Fatty Acids</td>
<td>HEFA</td>
<td>Oils, Fats &amp; Greases (Used cooking oil)</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>50%</td>
<td>UOP, Neste</td>
</tr>
<tr>
<td>Synthesized iso-paraffins</td>
<td>SIP</td>
<td>Sugars</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>10%</td>
<td>Amyris</td>
</tr>
<tr>
<td>FT Synthesized Paraffinic Kerosene plus aromatics</td>
<td>SPK/A</td>
<td>Biomass/Waste/Coal</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>50%</td>
<td>Sasol</td>
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<tr>
<td>Alcohol to Jet</td>
<td>ATJ</td>
<td>Biomass/Waste/Sugar</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>50%</td>
<td>Gevo, LanzaJet</td>
</tr>
<tr>
<td>Catalytic-HTR Hydrothermal Reactor; Supercritical Water</td>
<td>CHJ</td>
<td>Oils and Fats</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>50%</td>
<td>ARA</td>
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<tr>
<td>Hydro processed Ester and Fatty Acids</td>
<td>HC-HEFA</td>
<td>Algae</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>10%</td>
<td>IHI</td>
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### Potential future pathways (2020-2022 certification timeframe if not longer)

<table>
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<th>Technology</th>
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<th>1&lt;sup&gt;st&lt;/sup&gt; or 2&lt;sup&gt;nd&lt;/sup&gt; gen</th>
<th>Max blend</th>
<th>Technology Providers</th>
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<tbody>
<tr>
<td>Hydropyrolysis and Hydroconversion</td>
<td>CPK</td>
<td>Woody Biomass</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>tbc</td>
<td>Shell</td>
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<tr>
<td>Hydrotreated Renewable Diesel</td>
<td>HEFA+</td>
<td>Oil and Fats</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>Est. 10%</td>
<td>Neste, UOP</td>
</tr>
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</table>
Today, HVO/HEFA is the most commercially viable option, but Shell is working all the technology classes.
**ASTM Approval Process Landscape**

**Tier 1**
- ATJ-SKA (Byogy, Swed Biofuels)

**Tier 2**
- Phase I ASTM Research Report
- Fit-For-Purpose Properties

**Tier 3**
- Component/Rig Testing
- Engagement with ASTM Initiated
- Global BioEnergies?
- POET?
- SBI BioEnergies?
- Vertimass
- GSR/GTI?

**Tier 4**
- Engine/APU Testing

**Exploratory Discussions**
- Global BioEnergies?
- POET?
- SBI BioEnergies?
- Vertimass
- GSR/GTI?

**Engagement with ASTM Initiated**
- Virent SAK
- Virent SK

**Annex 7 HC**
- Located in D1655 Conventional Jet Fuel Specification

**Lipids Co-processing (D1655)**
- FT Co-processing (D1655)

**Currently Active**
- Shell IH2 CPK-0
- HFP-HEFA (Green Diesel)

**Currently Inactive**
- Annex A6 ARA CHJ
- Annex A4 FT-SKA
- Annex A5 ATJ SPK (Hexolanaol)
- Annex A2 HEFA
- Annex A1 FT-SPK

**FAA**
- Engagement with ASTM Initiated
- FAA Review
- ASTM Specification
- ASTM Balloting Process
- ASTM Review & Ballot
- Accept
- Re-Eval As Required
- Reject

**Rolls-Royce**
- OEM Review & Approval
- Annex 7 HC-HEFA
What is IH² Technology?

- IH² = Integrated Hydropyrolysis and Hydroconversion

- Continuous catalytic thermochemical process composed of hydropyrolysis and hydrotreating steps to produce jet, diesel and gasoline fuels from various non-food biomass-type feedstocks.

- Different mixtures and varieties of hard, and soft wood (including bark), agricultural residues such as mulberry sticks, jatropha trimmings, castor stalks, cotton stalks, bagasse, cane tops/ trash, corn stover, and municipal solid waste (MSW) samples from North America, EU and India have been processed at a bench-scale through IH2® technology.
2 Modes of Operation: On Road and Off Road

**Road fuels mode**
- Diesel: 30–45 vol%
- Petrol: 55–70 vol%
- Cut point varies: 150–200°C

**Aviation / Marine fuels mode**
- Marine Distillate: 10–20 vol%
- Jet: 35–40 vol%
- Cut points: 120–280°C
- Naphtha: 45–50 vol%
# Cycloparaffinic Kerosene (CPK-0) Composition: GC x GC

<table>
<thead>
<tr>
<th>Carbon Number</th>
<th>Aromatics</th>
<th>Di-Aromatics</th>
<th>Cyclo-Aromatics</th>
<th>Isoparaffins</th>
<th>Normal Paraffins</th>
<th>Cyclo-paraffins</th>
<th>Di-Cyclo Paraffins</th>
<th>Tri-Cyclo Paraffins</th>
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<tr>
<td>6</td>
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<td>0.02</td>
<td>0.12</td>
<td>0.16</td>
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<td>2.11</td>
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<tr>
<td>16</td>
<td>0.01</td>
<td>0.08</td>
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<tr>
<td>Total</td>
<td>0.03</td>
<td>0.00</td>
<td>0.02</td>
<td>1.68</td>
<td>2.55</td>
<td>47.11</td>
<td>40.33</td>
<td>8.20</td>
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</table>

*represents > 1 wt%*
### Properties | Unit | Test Method | D7566 | Jet A | 50:50 | CPK-0
---|---|---|---|---|---|---
Acidity, total | mg KOH/g | D3242 | 0.10 Max | 0.01 | 0.000 | 0.000 | 
Aromatics | vol% | D6379 | 26.5 Max | 16.4 | 8.0 | <0.2 | 
Sulfur, mercaptan | mass% | D3227 | 0.003 Max | 0.001 | 0.000 | 0.000 | 
Sulfur, total | mass% | D2622 | 0.30 Max | 0.0376 | 0.0188 | 0.00014 | 
10 % recovered | °C | D86 | 205 Max | 155 | 168 | 161 | 
50 % recovered | °C | D86 | Report | 205 | 198 | 190 | 
90 % recovered | °C | D86 | Report | 244 | 246 | 249 | 
FBP | °C | D86 | 300 Max | 271 | 270 | 271 | 
Residue | % | D86 | 1.5 Max | 1.4 | 1.3 | 1.2 | 
Loss | % | D86 | 1.5 Max | 0.5 | 0.4 | 0.5 | 
Flash point | °C | D56 | 38 Min | 48 | 42 | 40 | 
Density (at 15 °C) | kg/m³ | D4052 | 775-840 | 803 | 818 | 832 | 
Viscosity at -20 °C | mm²/s | D7945 | 8.0 Max | 4.6 | 4.4 | 4.6 | 
Net heat of combustion | MJ/kg | D4809 | 42.8 Min | 43.1 | 43.1 | 43.1 | 
Hydrogen Content | vol % | D7171 | - | 14.2 | 14.0 | 14.1 | 
Smoke point | mm | D1322 | 25 Min | 26 | 26 | 28 |
Shell IH²: CPK-O

- Made from agricultural wastes and residues
- Majority mono- and di-cyclo paraffins
- Meets all of ‘Table 1’ properties in neat form
- Practically no aromatics
  - Improved specific fuel consumption and particulate emission
  - Early tests indicate cycloparaffinic molecules can satisfy seal swell requirements without aromatics
- Excellent thermal stability
- Good low temperature properties
- Nominally equivalent specific energy
- Improved energy density

Example cycloparaffin molecules
Converting green energy, water and CO₂ into Synthetic Kerosene
500 litres in 2020
Some of Shell’s other SAF Collaborations

Working with World Energy, Shell Aviation secured an agreement to supply up to six million gallons of SAF to Amazon Air in July 2020.

Shell Aviation and World Energy are working together to develop a scalable supply of SAF in the United States. This includes an agreement to supply SAF to Lufthansa at San Francisco Airport.

In October 2020 Shell Aviation signed a collaboration agreement with SAF producer Neste that aims to significantly increase availability and supply for the aviation industry.

In 2018 Shell Aviation signed a long-term strategic collaboration with SkyNRG to promote and develop the use of SAF in aviation supply chains.

In October 2020 Shell Aviation signed a deal to distribute SAF to airline customers from Red Rock's new plant, currently under construction in Lakeview, Oregon.

Shell Aviation is working alongside World Energy and SkyNRG to supply SAF to Rolls-Royce for the first engine ground tests to use 100% SAF.

A variety of feedstocks, technologies, and offsets will be required to meet industry and global CO₂ emissions ambitions.

Active in all areas of future transportation (Hydrogen, Electrification, LNG, etc.) and helping to understand how these technologies will shape the future of aviation.

Working throughout the entire supply chain to deliver low carbon solutions.

Actively pursuing approval of new sustainable aviation fuel molecules via novel processes.

Demonstrated PTL at a small scale and delivered fuel for use on a commercial flight.

Working with established and emerging industry partners to supply SAF today and tomorrow.