Bringing IH²* Cycloparaffinic Kerosene (CPK) to market

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Agenda

- Shell Aviation’s commitment
- IH² Technology Introduction
- Overview of Feedstock Capability & Process Technology
- Status Today, Production Capabilities – Now, Near & Future
- Q&A
Shell Aviation is committed to:

Investing in initiatives that will Avoid, Reduce and Offset emissions across all aspects of aviation. These include:

- We have co-designed the first of its kind electric pump jet refuelling vehicle. While traditional refuellers use the truck’s diesel engine to power the fuel pump, this truck uses electric energy. This helps avoid carbon emissions at the point of use by significantly reducing the truck’s diesel consumption.

- Developing long-term solutions to make our ground operations (and our partner’s) carbon neutral.

- Investing in technologies that have the potential to establish a long-term supply source of Sustainable Aviation Fuel (SAF). Including IH2 technology that turns wood and forestry waste into jet fuel.

- Identifying opportunities to build long-term resilient supply chains, for seamless integration of SAF within existing infrastructure.

- Providing our customers with access to quality assured carbon offsets.

- Helping our customers achieve their energy ambitions and commitments by providing access to skills and expertise in new energy, sustainability and R&D, from across the Shell group.
SUSTAINABLE AVIATION FUEL
Shell has developed a number of new cleaner fuels engineered from renewable sources including: used cooking oil, municipal waste and woody biomass. We’re working with the industry to make these new and cleaner fuels more readily available.

CO2 MANAGEMENT SOLUTIONS
We offer a range of bespoke services that can help our customers offset their CO2 emissions, either to meet legislative requirements, or to offer more environmentally friendly travel to their passengers and business partners.

UNLEADED AVGAS
Most fuel consumed by piston aircraft is still leaded. So we are developing a safe unleaded fuel for all piston aircraft.
What is IH² Technology - 1?

- Invented by Gas Technology Institute (GTI) of Des Plaines, IL in 2009; further developed by CRI from 2010 onwards at Shell’s Technology Centre in Bangalore, India (STCB).

- CRI Catalyst Company is part of CRI/Criterion Inc., the global catalyst technology company of the Shell Group.
What is IH² Technology - 2?

- 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.
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Development
Strategic Partner Selection is Critical
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Two modes of operation

Road Transport Mode

- Cut point varies 150-200°C
- Petrol 55-70%
- Diesel 30-45%

Jet Mode

- Cut points 120-280°C
- Naphtha 45-50%
- Jet 35-40%
- Marine Distillate 10-20%
Two modes of operation

Road Transport Mode

- Cut point varies: 150-200°C
- Petrol: 55-70%
- Diesel: 30-45%

Jet Mode

- Cut points: 120-280°C
- Cycloparaffinic Kerosene (CPK)
- Naphtha: 45-50%
- Jet: 35-40%
- Marine Distillate: 10-20%
Final upgrading stage to produce finished CPK for jet

Batch distillation unit to fractionate TLP from demonstration plant into jet, gasoline and diesel

Total Liquid Product (TLP)

Feed Distillation Step

2nd stage light gasoline
Gasoline (IBP – 120 °C)

2nd stage Jet
(120 °C – 280 °C)

2nd stage heavy diesel
(280 °C – FBP)

Hydrotreating Step

Aromatic Saturation Step

IBP – 135 °C

Product Distillation Step

3rd Stage Jet
(135 °C – 280 °C)
Jet mode fuels are high quality ‘drop in’

Suitable components for Solvents
Steam cracker feed
Reformer feedstock – bioBTX
Gasoline blending...

Matches Table 1 Performance Criteria for:
World-wide Civil Jet Fuel Grade
Jet A/A-1
(e.g. ASTM D1655 & DEF STAN 91-091)
US & Other Military Jet Fuel Grade
JP-8 and F-34
(e.g. MIL-DTL-83133, DEF STAN 91-87)
Fuels are currently in ASTM D4054 approvals process

Meets ISO 8217 2017 specs
Meets DMB/DFB specs (Very low S)

High on DMA/DFA density (fixable);
High on DMB/DFB density (fixable)
Exceeds Residual Fuel Spec

US Navy F-76
High on density and cetane (fixable)
IH² SPK Fuel certification roadmap and Production capabilities

- ASTM D1655 Table 1 properties testing complete
- 1st batch contains 0.5 wt. % aromatics, 95% cycloparaffins, remaining iso & normal paraffins

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Online Date</th>
<th>Feed Source</th>
<th>Finished CPK Jet Fuel Production Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell Technology Center Bangalore (STCB)</td>
<td>Micro-flow Unit (small-scale, batch upgrading to finished fuels)</td>
<td>2015</td>
<td>Total hydrocarbon product comes from processing Pinus sylvestris at IH²®-50 (Pilot Plant at GTI)</td>
<td>3.0 gallons TLP/week feed yields about 1 gallon CPK/week (~30% jet)</td>
</tr>
<tr>
<td></td>
<td>Pilot Scale CPK upgrading</td>
<td>Oct. 2017</td>
<td>Total hydrocarbon product comes from processing Pinus sylvestris at IH²®-5000 (Demonstration Plant at Shell Technology Center Bangalore)</td>
<td>1.5 gallons CPK/day</td>
</tr>
<tr>
<td></td>
<td>TLP Production with integrated CPK upgrading</td>
<td>Aug. 2019</td>
<td>Total hydrocarbon product comes from processing Pinus sylvestris at IH²®-50 (Pilot Plant at GTI)</td>
<td>24,500 gallons CPK/year</td>
</tr>
<tr>
<td>GTI (Des Plaines, IL)+ Intertek (Pittsburg)</td>
<td>Only upgrading</td>
<td></td>
<td>Total hydrocarbon product comes from processing Pinus sylvestris at IH²®-50 (Pilot Plant at GTI)</td>
<td>83 gallons TLP/week feed yields ~25 gallons CPK/week (~30% jet)</td>
</tr>
</tbody>
</table>

Current Position in D4054

- Tier 1 and 2 testing with UDRI begins
- Tier 1 and 2 testing complete with analysis and Phase 1 Research Report; OEM review commences
- Phase 1 research report feedback received; Phase 2 planning and requirements determined
- Tier 3 and 4 testing complete with analysis and Phase 2 Research Report; OEM review commences
- Phase 2 Research Report reviewed with feedback addressed; ready for ASTM ballot

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Moving Forwards

- CPK product is entry fuel into D4054 Clearinghouse; aside from minimum 8 vol. % aromatic content, CPK-0 meets all D7566 Table 1 specification requirements as a neat synthetic component (i.e. before blending).
- CPK is mix of ~C6 to ~C19 molecules, mainly C9 to C13 and predominantly naphthenics and di-naphthenics. Low levels of other normal and iso paraffins (<5%) and unsaturated compounds (mostly monoaromatic).
- Further production and testing of various aromatic level CPK’s is planned for D4054 and potential engine testing.
- Proposed ASTM certification blend: 50% blend limit with conventional jet fuel + CPK-\(x\) certification (\(x\) = aromatic content in wt. %); preferred aromatic content for initial certification is \(~0\ %\).

<table>
<thead>
<tr>
<th>Year</th>
<th>Sample Name</th>
<th>Feedstock</th>
<th>Volume</th>
<th>TLP Production Site</th>
<th>Upgrading Site</th>
<th>Test Houses</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>CPK-0</td>
<td>Pinus sylvestris (pine wood)</td>
<td>1 L</td>
<td>GTI</td>
<td>STCB</td>
<td>STCB/STCH</td>
</tr>
<tr>
<td></td>
<td>CPK-6</td>
<td></td>
<td>1 L</td>
<td>GTI</td>
<td>STCB</td>
<td>STCB/STCH</td>
</tr>
<tr>
<td></td>
<td>CPK-23</td>
<td></td>
<td>1 L</td>
<td>GTI</td>
<td>STCB</td>
<td>STCB/STCH</td>
</tr>
<tr>
<td>2017</td>
<td>CPK-0</td>
<td></td>
<td>25 gal</td>
<td>GTI</td>
<td>Intertek</td>
<td>Intertek Pittsburg/STCH</td>
</tr>
<tr>
<td>2018</td>
<td>CPK-0</td>
<td></td>
<td>30 gal</td>
<td>IH² Demo</td>
<td>STCB</td>
<td>STCB/STCH</td>
</tr>
</tbody>
</table>
Questions & Answers

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Process Development
Scale Up

Prove the Technology
2017+

GTI PILOT SCALE
20L/day
(8000+ hrs)

Prove the Engineering & Hardware
2017+

STCB PILOT SCALE
6L/day

Soft Start Up
OCTOBER 2017

DEMO SCALE
2000L/day

>200,000L/day
1H²-500tpd

Prove the Reliability & Profitability
2020+

STCB PILOT SCALE
6L/day

GTI LAB SCALE
1L/week

SBL/STCB LAB SCALE
0.10-1L/week
180+ Runs


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