Bringing IH²* Cycloparaffinic Kerosene (CPK) to market

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Integrated Hydropyrolysis & Hydroconversion
*IH² is a registered trademark of GTI

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Agenda

- Shell Aviation's commitment
- IH^2 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.

FUTURE OF ENERGY

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 CO_2 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

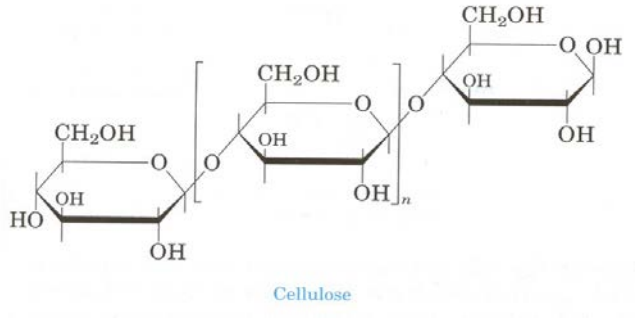
  hydrotreating steps

  to produce

  jet, diesel and gasoline fuels from various non-food biomass-type feedstocks.

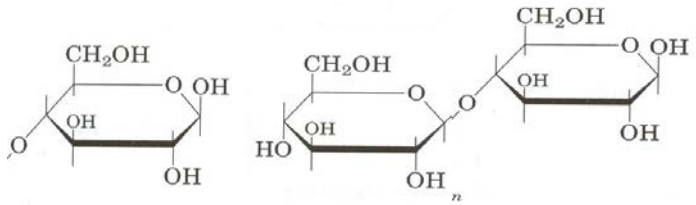
- Different mixtures and varieties of hard, and soft wood (including bark), agricultural residues such as mulberry sticks, jatropha trimmings, castor stalks, cotton stalks, bagasse, cane tops/ trash, corn stover, and municipal solid waste (MSW) samples from North America, EU and India have been processed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

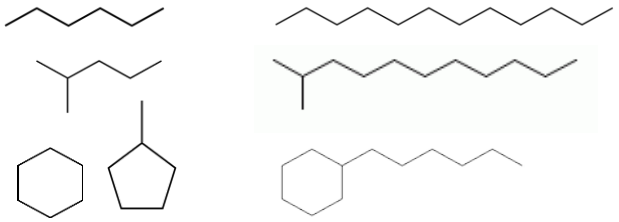
BIG Molecules with O



Cellulose

Small Molecules with O





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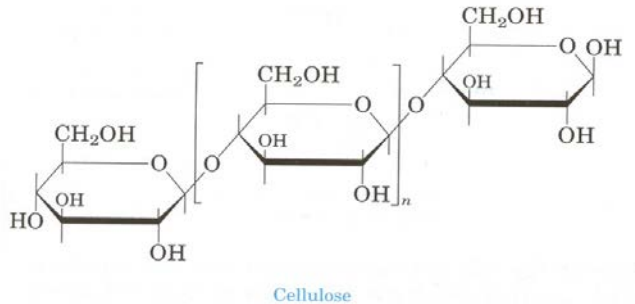
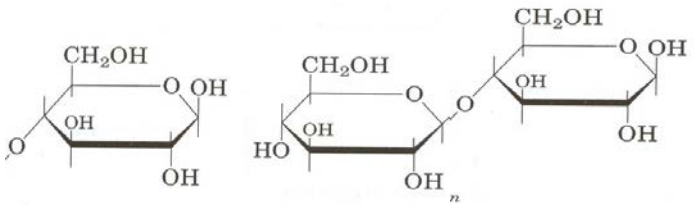
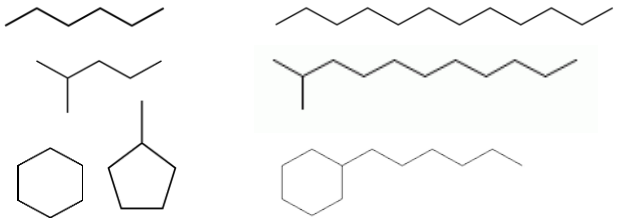


Cellulose

Heat
400°C

Small Molecules with O





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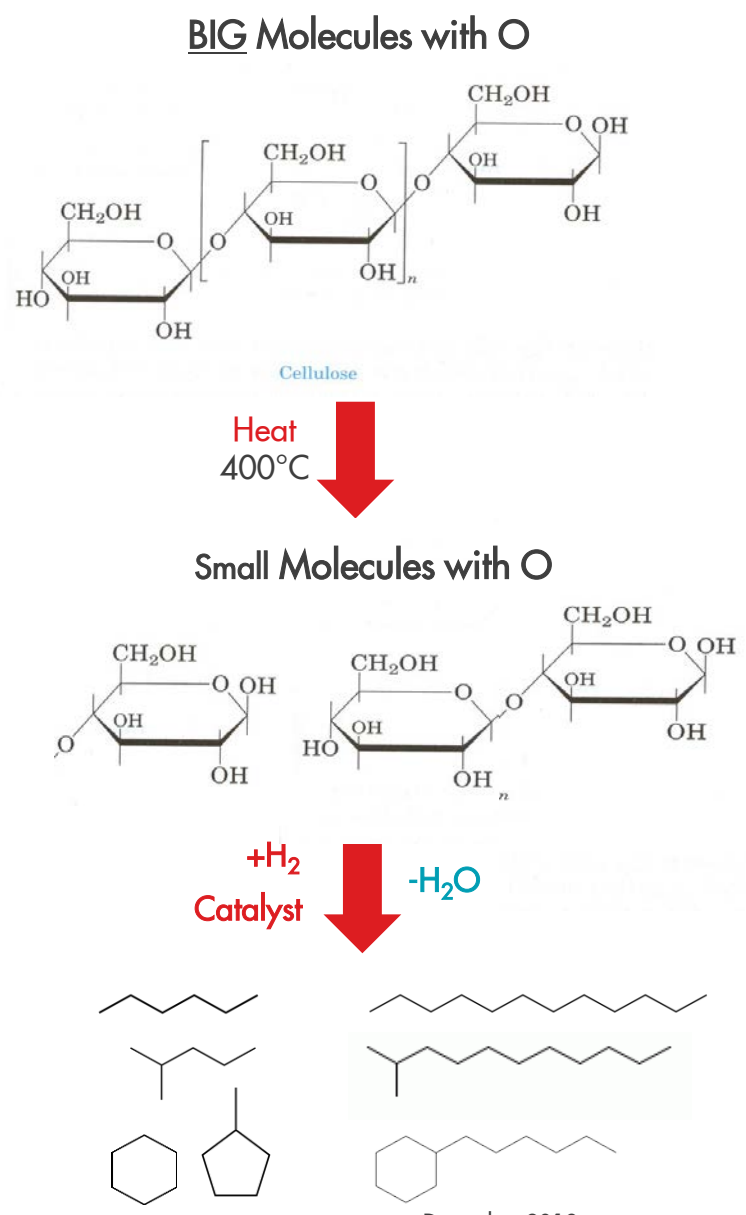

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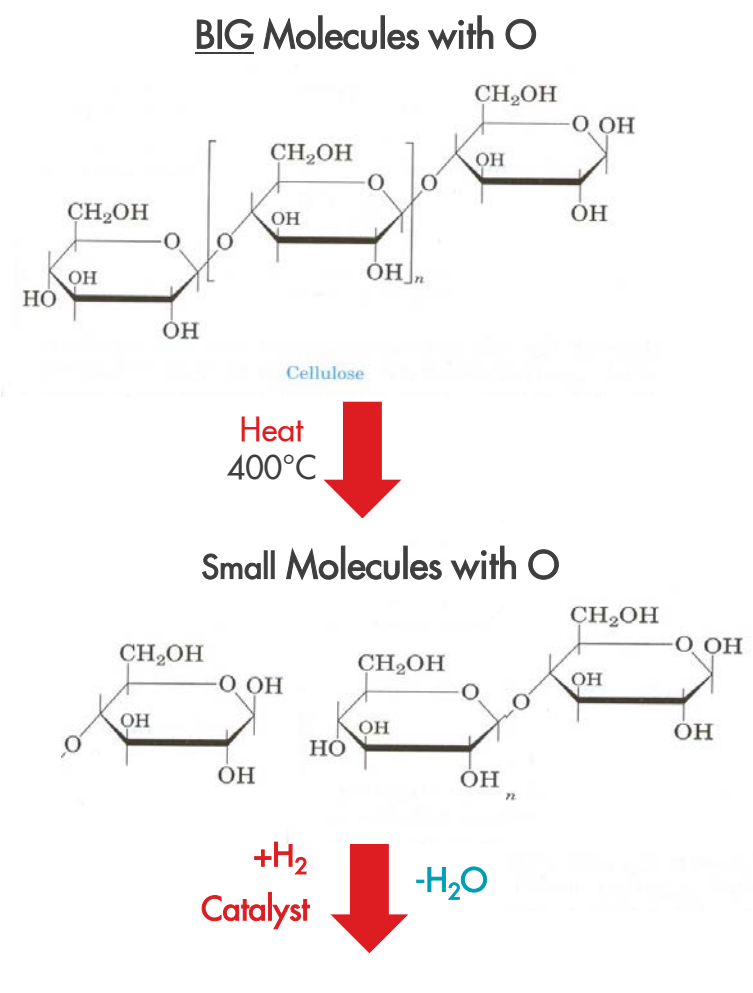
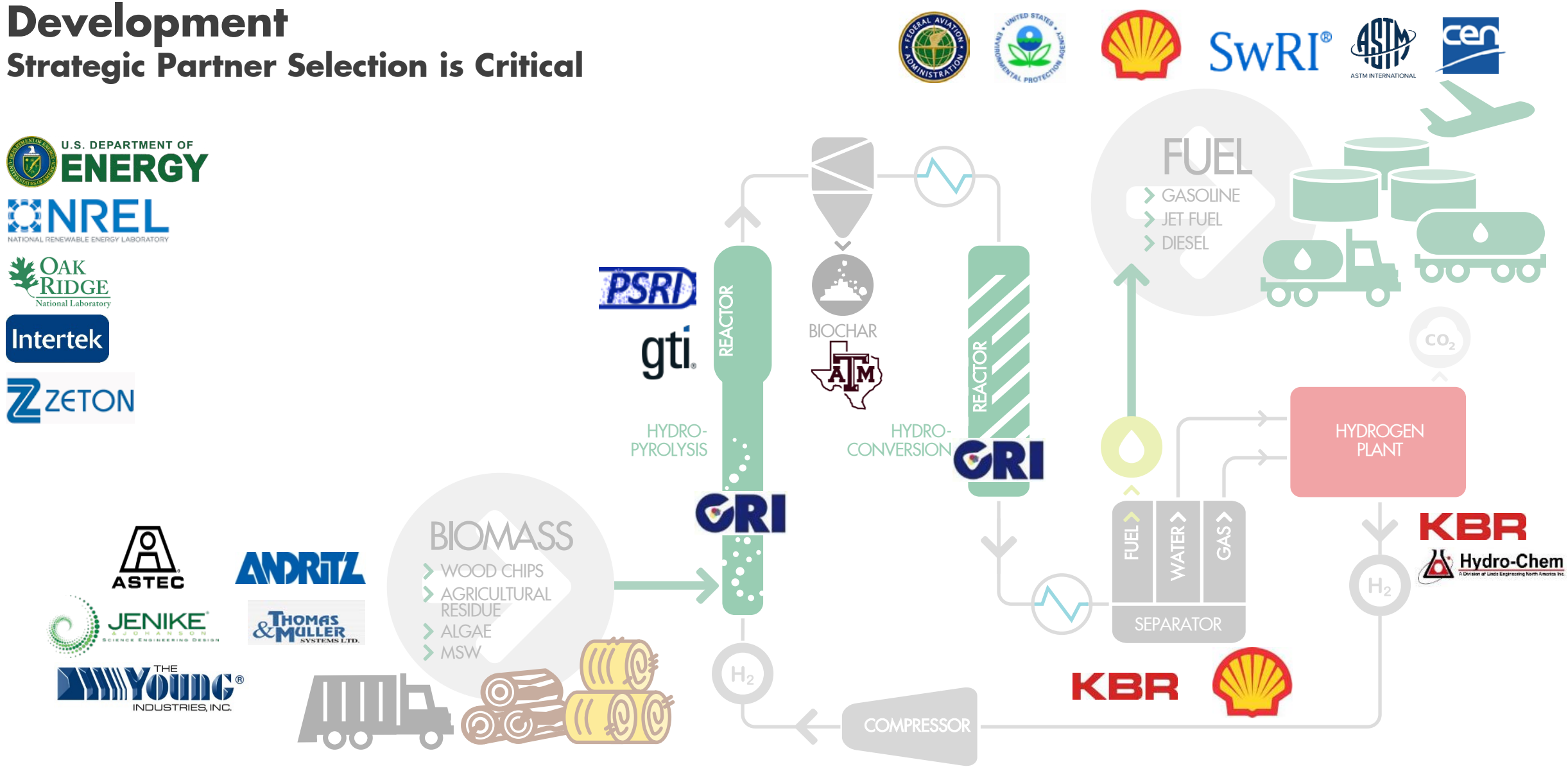


Development
Strategic Partner Selection is Critical



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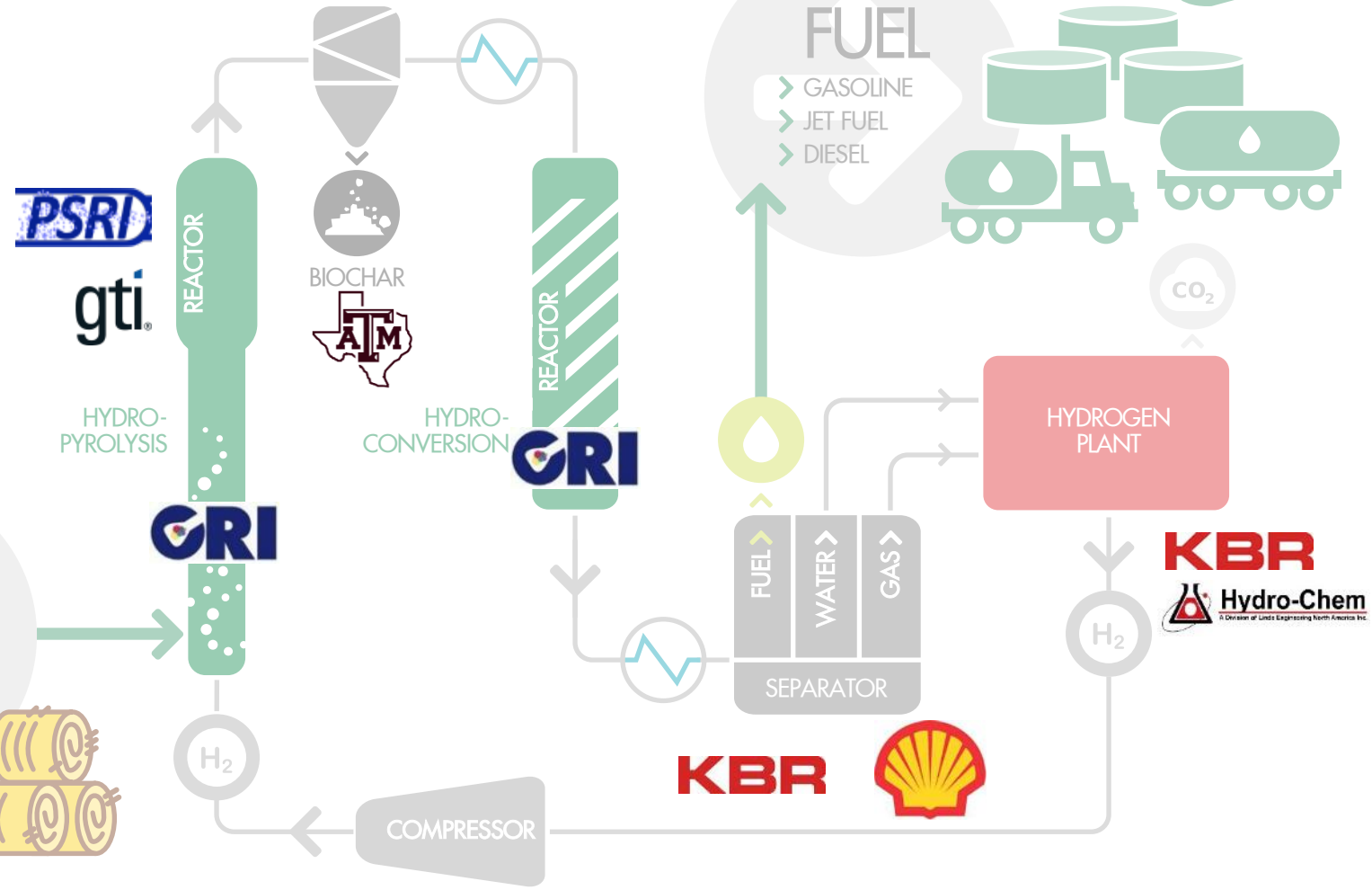
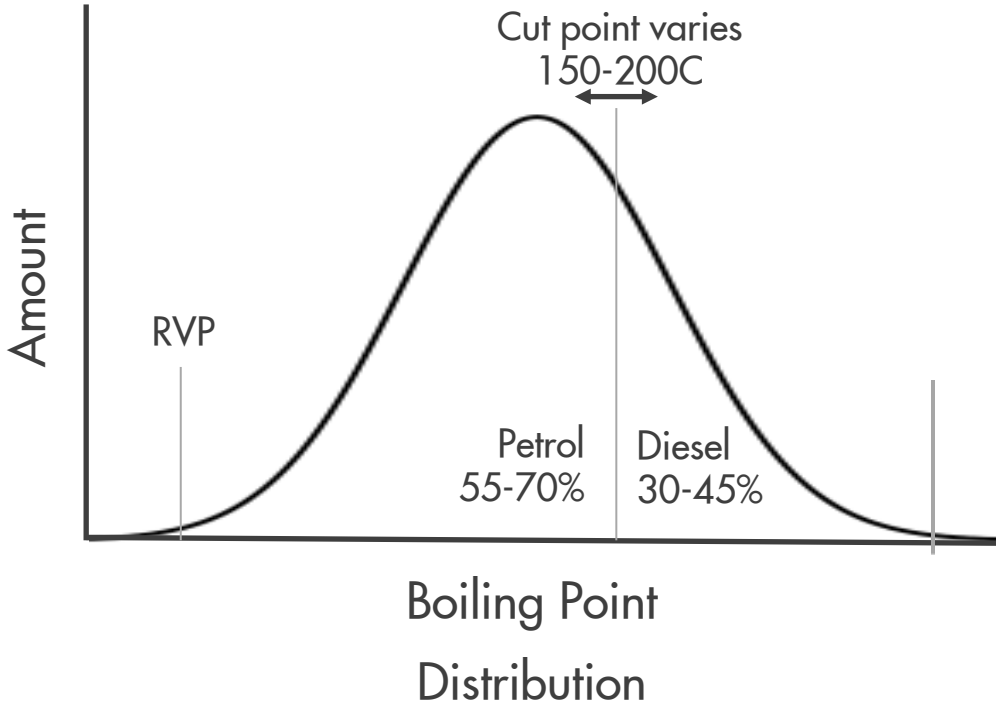
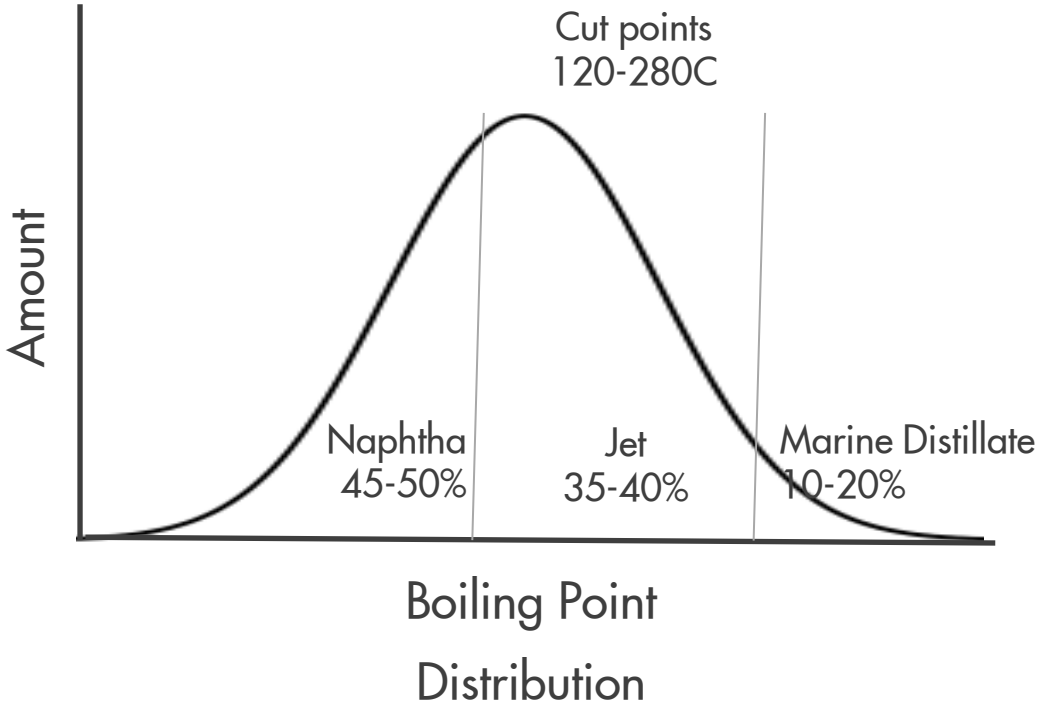


Two modes of operation

Road Transport Mode



Jet Mode



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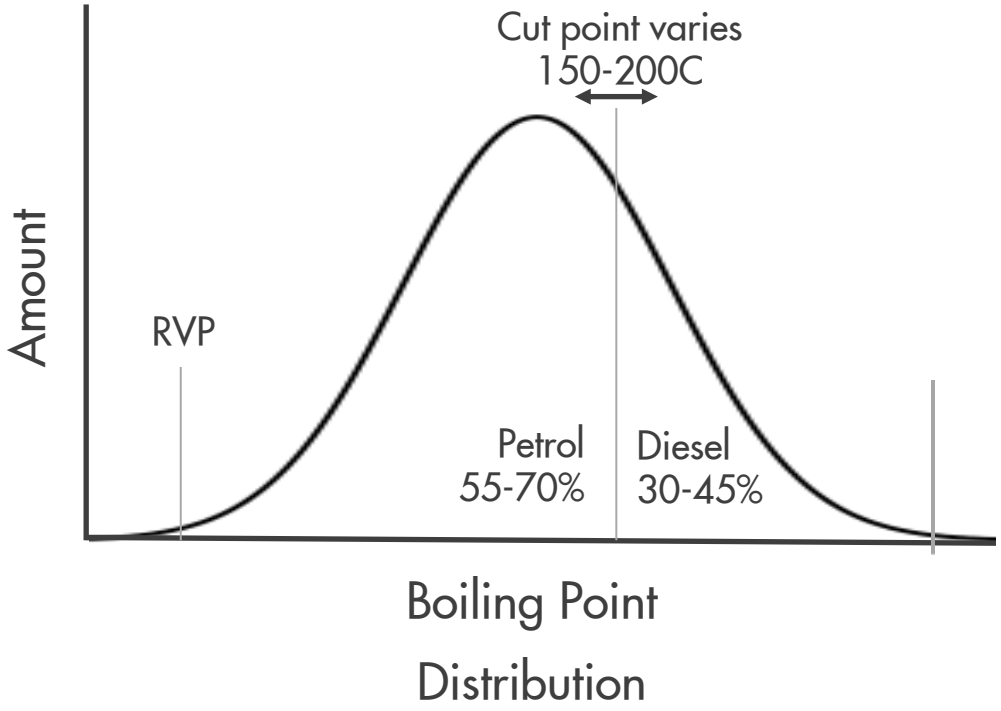

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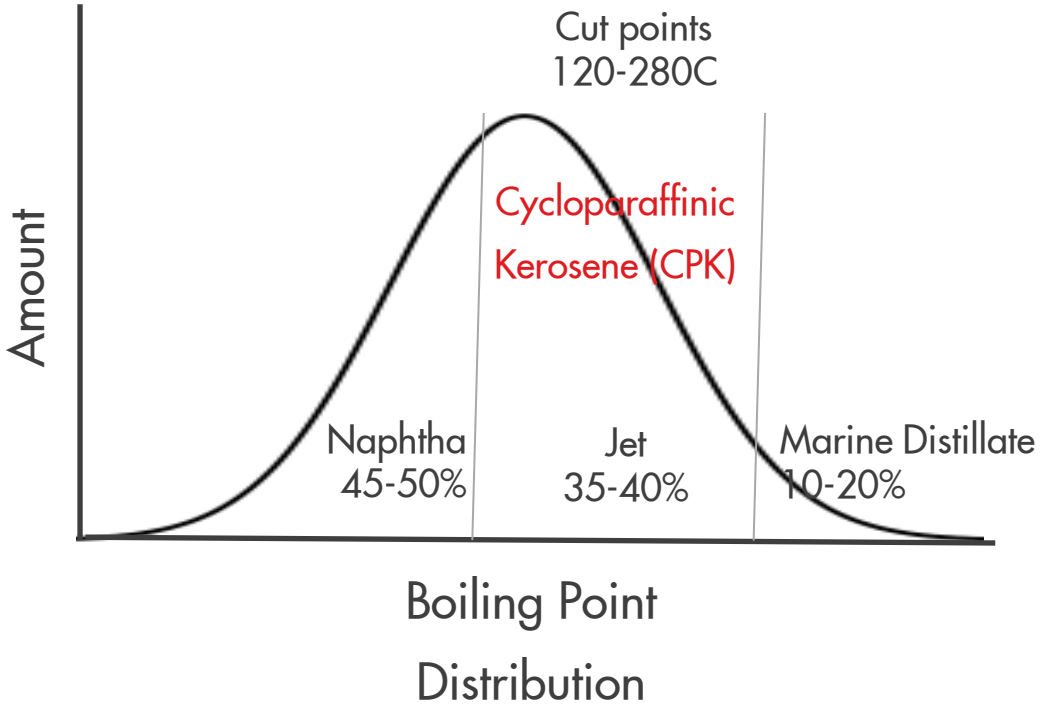
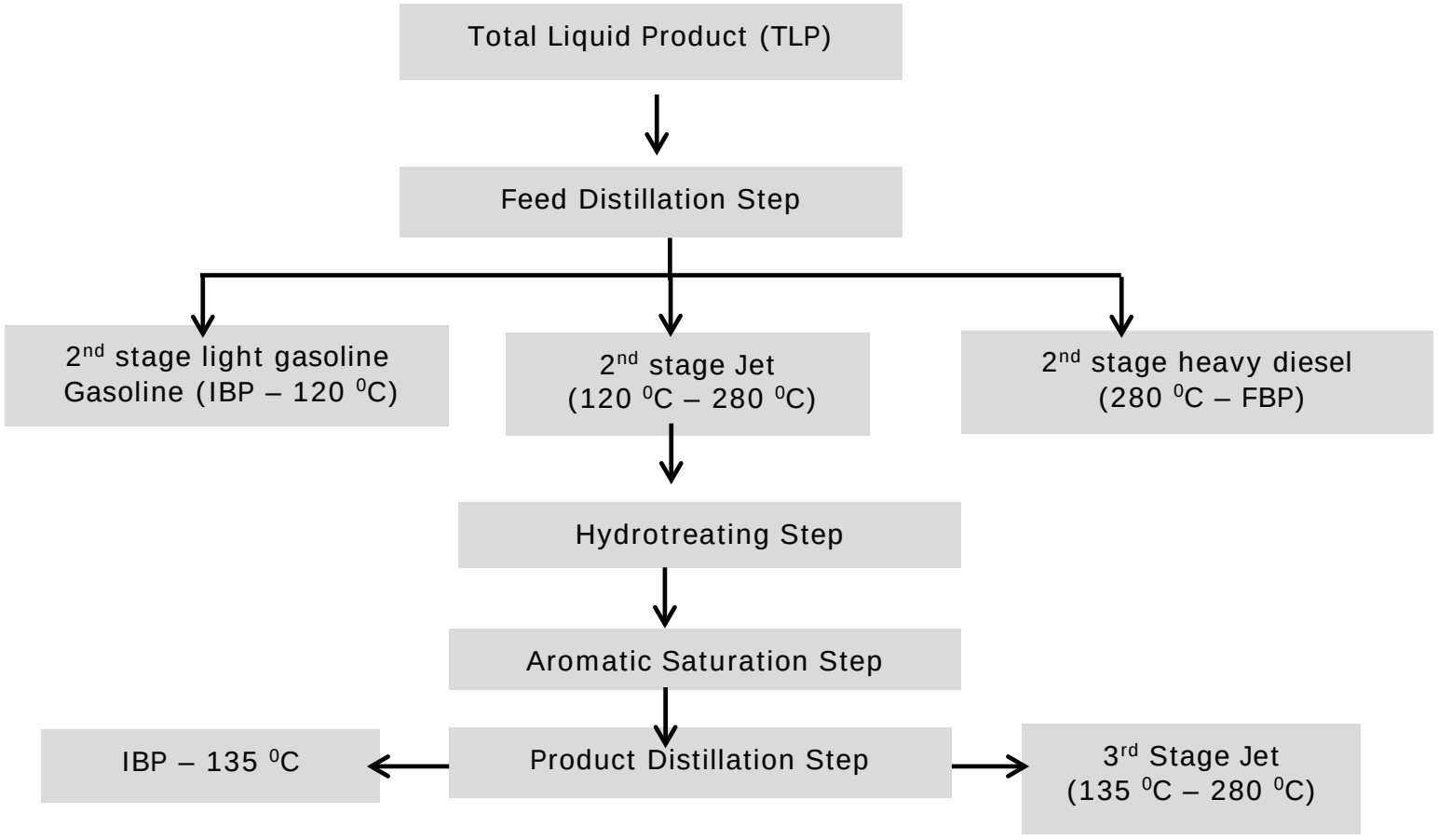


Final upgrading stage to produce finished CPK for jet

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



Jet mode fuels are high quality ‘drop in’

NAPHTHA

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

JET FUEL

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

MARINE DISTILLATE

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)

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IH² SPK Fuel certification roadmap and Production capabilities

2017

Q3
- ASTM D1655 Table 1 properties testing complete
- 1st batch contains 0.5 wt. % aromatics, 95% cycloparaffins, remaining iso & normal paraffins

Q4
D4054 Clearinghouse Entry Report shared with FAA and UDRI

2018

Q1
Tier 1 and 2 testing with UDRI begins

Q2

Q3
Tier 1 and 2 testing complete with analysis and Phase 1 Research Report; OEM review commences

Q4
Phase 1 research report feedback received; Phase 2 planning and requirements determined

2019

H1
Tier 3 and 4 testing complete with analysis and Phase 2 Research Report; OEM review commences

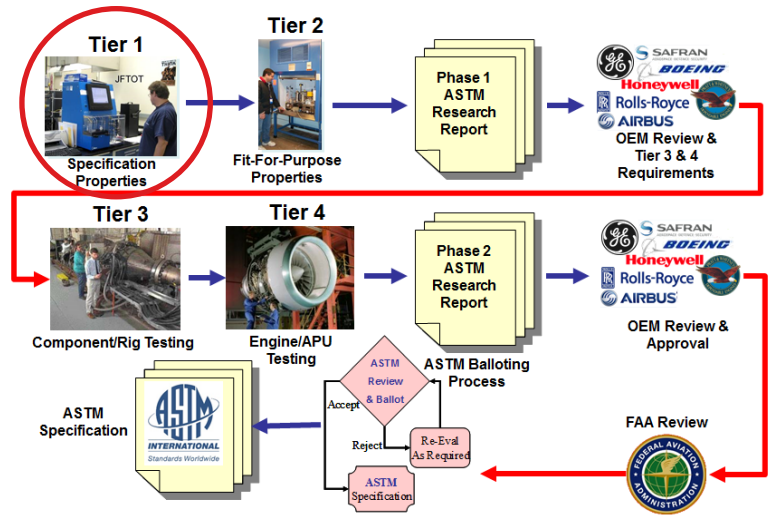
H2

2020

Q1
Phase 2 Research Report reviewed with feedback addressed, ready for ASTM ballot

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

Current Position in D4054



ASTM D4054 Qualification Process
Source: ASTM D4054 Clearinghouse Guide

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 %.

Year	Sample Name	Feedstock	Volume	TLP Production Site	Upgrading Site	Test Houses
2016	CPK-0	Pinus sylvestris (pine wood)	1 L	GTI	STCB	STCB/STCH
	CPK-6		1 L	GTI	STCB	STCB/STCH
	CPK-23		1 L	GTI	STCB	STCB/STCH
2017	CPK-0		25 gal	GTI	Intertek	Intertek Pittsburg/STCH
2018	CPK-0		30 gal	IH^2 Demo	STCB	STCB/STCH

Questions & Answers

Follow-up Contacts:

Process Technology, Commercial Opportunities:
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Fuel Science, Product Quality, Certification:
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Griffin Valentich, Griffin.Valentich@shell.com

Process Development
Scale Up

Scale

Prove the Technology
2017+

GTI LAB SCALE
1L/week

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

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

Prove the Engineering & Hardware
2017+

DEMO SCALE
2000L/day

Soft Start Up
OCTOBER 2017

STCB PILOT SCALE
6L/day

>200,000L/day
IH²-500tpd

Prove the Reliability & Profitability
2020+

2009 2012 2013 2014 2015 2017 2021