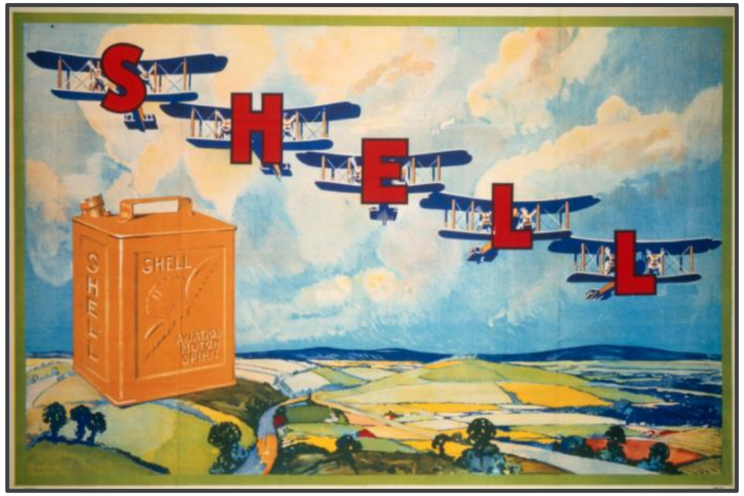
Sustainable Aviation Fuels
Shell's Activities

University of Toronto Institute for Aerospace Studies
May 19, 2021

Griffin Valentich
Aviation Fuels Engineer

Agenda

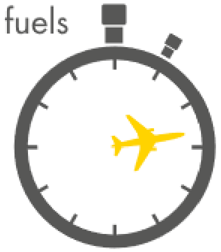
- Who is Shell Aviation?
- A history of innovation
- Sustainable Aviation Fuels
  - IH² CPK-0
  - PTL Fuel
  - Other Collaborations
- Summary



Shell Aviation

Operates in
60
COUNTRIES

On average Shell fuels an aircraft every

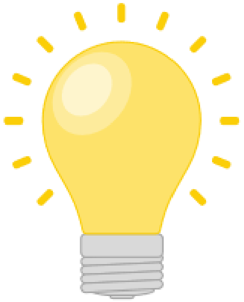


14
SECONDS

Supplier for more than
900
AIRPORTS

Each year, Shell fuels more than
2 MILLION AIRCRAFT

OVER
100
YEARS
OF INNOVATION



SAFE AND TIMELY SUPPLY OF **AVIATION FUELS**, HIGH-PERFORMANCE **LUBRICANTS AND FLUIDS**

Over 100 Years Of Innovation

1909
Louis Bleriot uses Shell fuel to cross the English channel

1919
Shell powers the first flight between England and Australia

1930s
Shell produces Avgas 100/130

1940s
Shell scientists assist Frank Whittle to develop the jet engine

1950s
Shell Water Detector developed to monitor fuel quality

1960s
Shell designs and implements the first aviation fueling hydrant system

1970s
AeroShell turbine oil 555 developed for Concorde's Rolls-Royce Olympus engines. Shell fuels its inaugural flight

1980s
AeroShell oil w15w-50 is the first semi-synthetic multigrade aviation oil

1990s
AeroShell grease 33, a multi-purpose airframe lubricant, is introduced

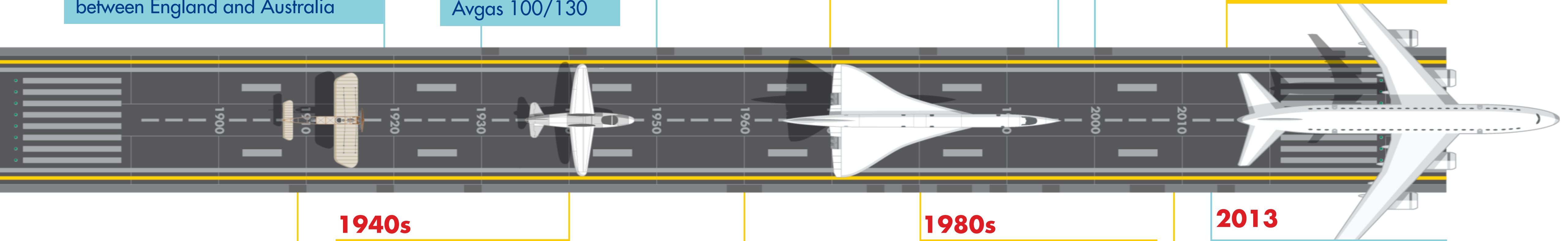
2000s
Shell develops new ways to measure cleanliness of fuels and increase the loading flow rate of fuel into an aircraft

2009
Shell refuels the world's first commercial passenger flight powered by fuel made from natural gas

2013
Shell innovation enables a viable lead-free avgas for light aircraft and helicopters

2015
20 years in service – AeroShell grease 33

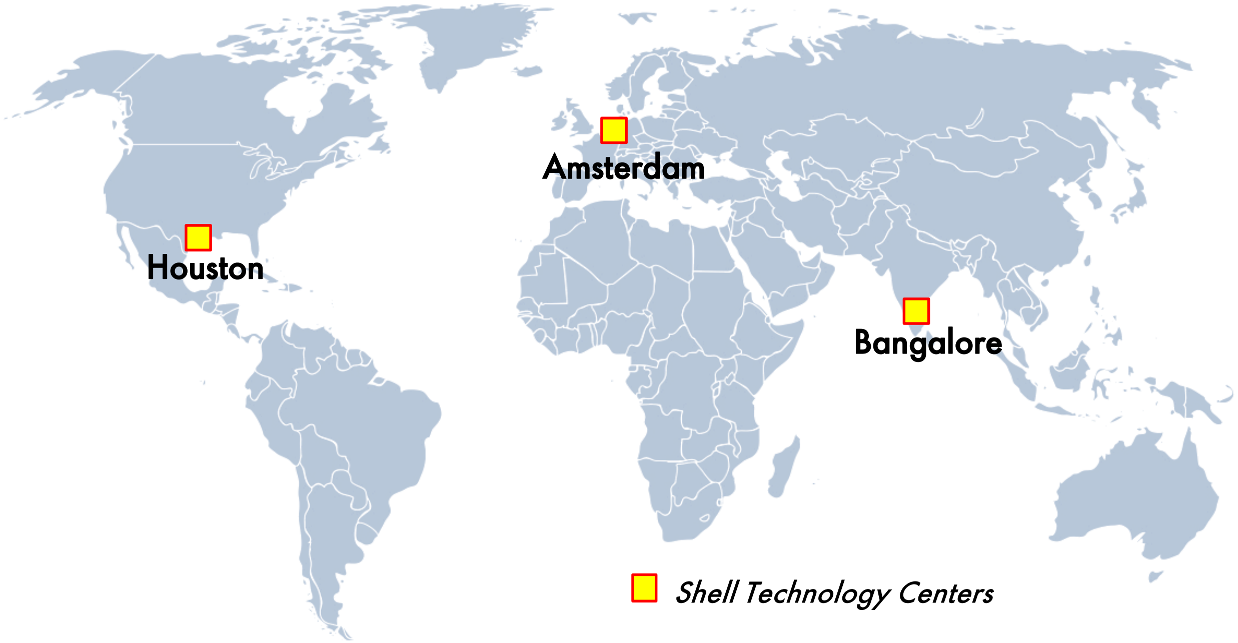
55 years in service – Shell Water Detector



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

Shell Technology Center Houston

- > 2,000 employees
- > 1 million sq.ft. (93,000 m^2) labs & offices
- Upstream & Downstream technologies



Aviation Technology Team

Sustainability Of Aviation

815
MILLION TONNES
of carbon emitted by worldwide flights in 2016

Source: IATA

Aviation responsible for
2%
of human-induced carbon emissions

Source: ATAG

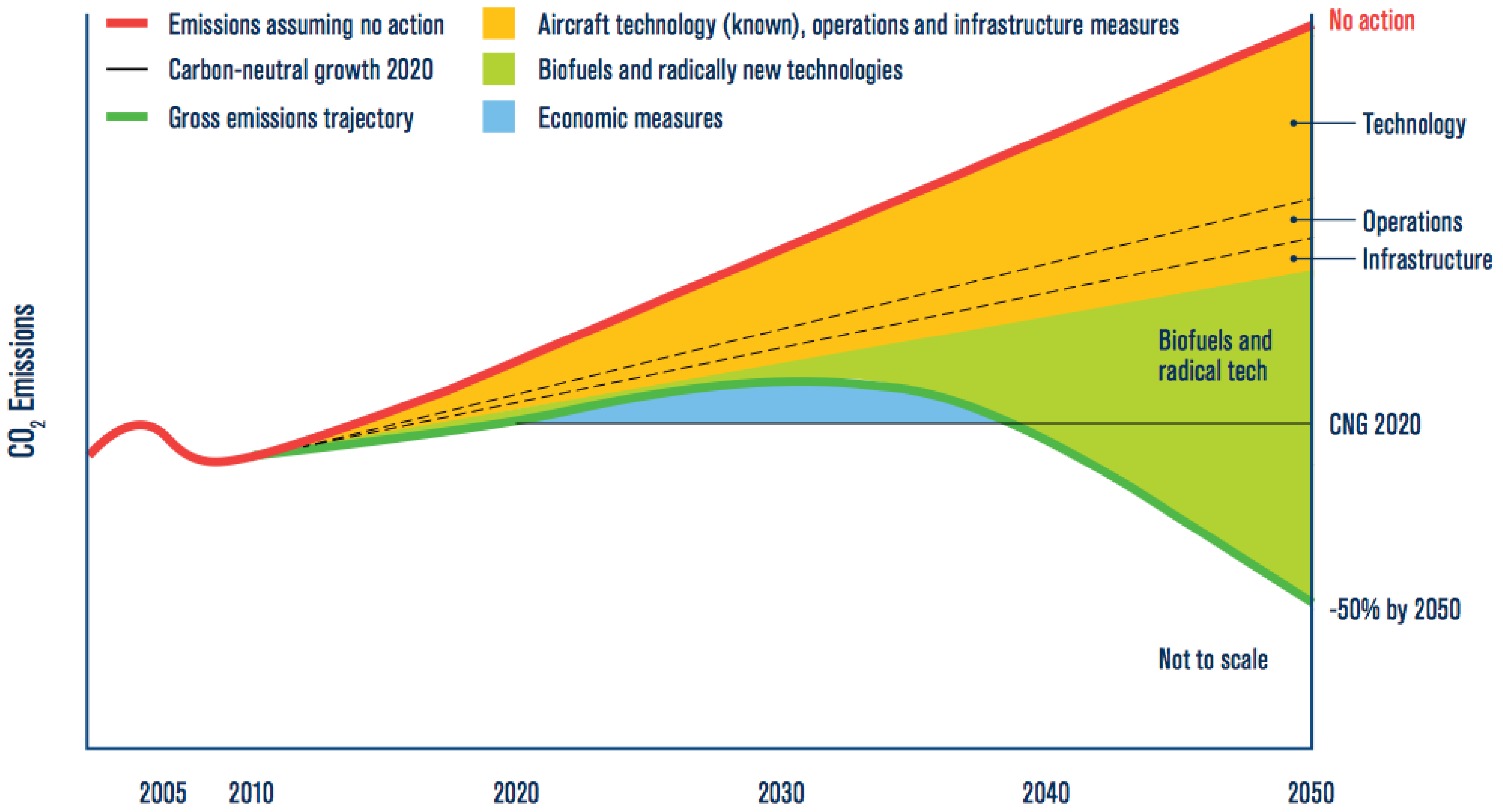
Aviation responsible for
12%
of carbon emissions from transport sources

Source: ATAG

Passenger numbers expected to reach
7.8
BILLION BY 2036

Source: IATA

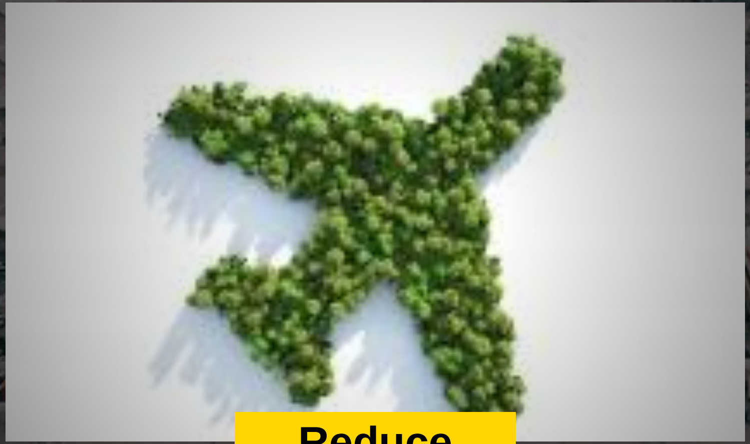
Carbon Neutral Growth from 2020



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

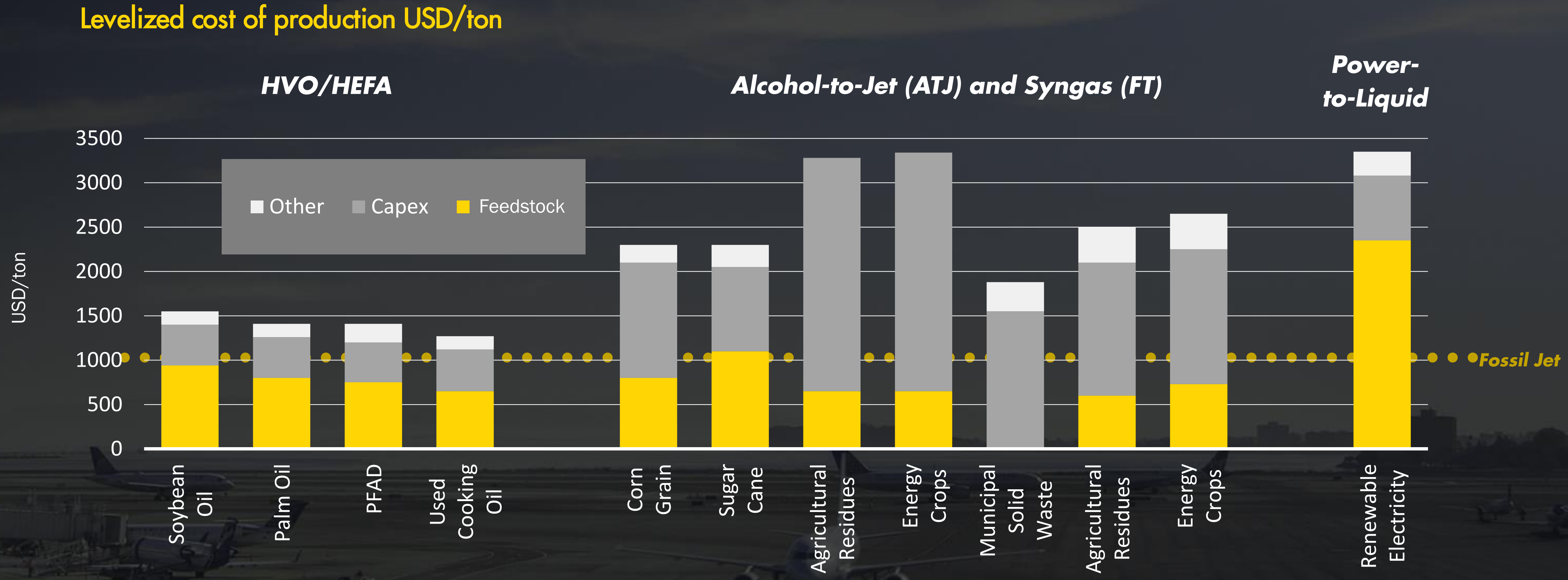
7 conversion pathways (annexes) that are certified by ASTM within D7566, all ‘drop-in’ blends to re-certify as Jet A (ASTM-D1655)

Technology	Code	Feedstock	1st or 2nd gen	Max blend	Technology Providers
Fischer-Tropsch	FT	Biomass/Waste/Nat Gas	2nd	50%	Fulcrum, Velocys, Shell
Hydro processed Ester and Fatty Acids	HEFA	Oils, Fats & Greases (Used cooking oil)	1st	50%	UOP, Neste
Synthesized iso-paraffins	SIP	Sugars	1st	10%	Amyris
FT Synthesized Paraffinic Kerosene plus aromatics	SPK/A	Biomass/Waste/Coal	2nd	50%	Sasol
Alcohol to Jet	ATJ	Biomass/Waste/Sugar	2nd	50%	Gevo, LanzaJet
Catalytic-HTR Hydrothermal Reactor; Supercritical Water	CHJ	Oils and Fats	2nd	50 %	ARA
Hydro processed Ester and Fatty Acids	HC-HEFA	Algae	2nd	10%	IHI

Potential future pathways (2020-2022 certification timeframe if not longer)

Technology	Code	Feedstock	1st or 2nd gen	Max blend	Technology Providers
Hydropyrolysis and Hydroconversion	CPK	Woody Biomass	2nd	tbc	Shell
Hydrotreated Renewable Diesel	HEFA+	Oil and Fats	1st	Est. 10%	Neste, UOP

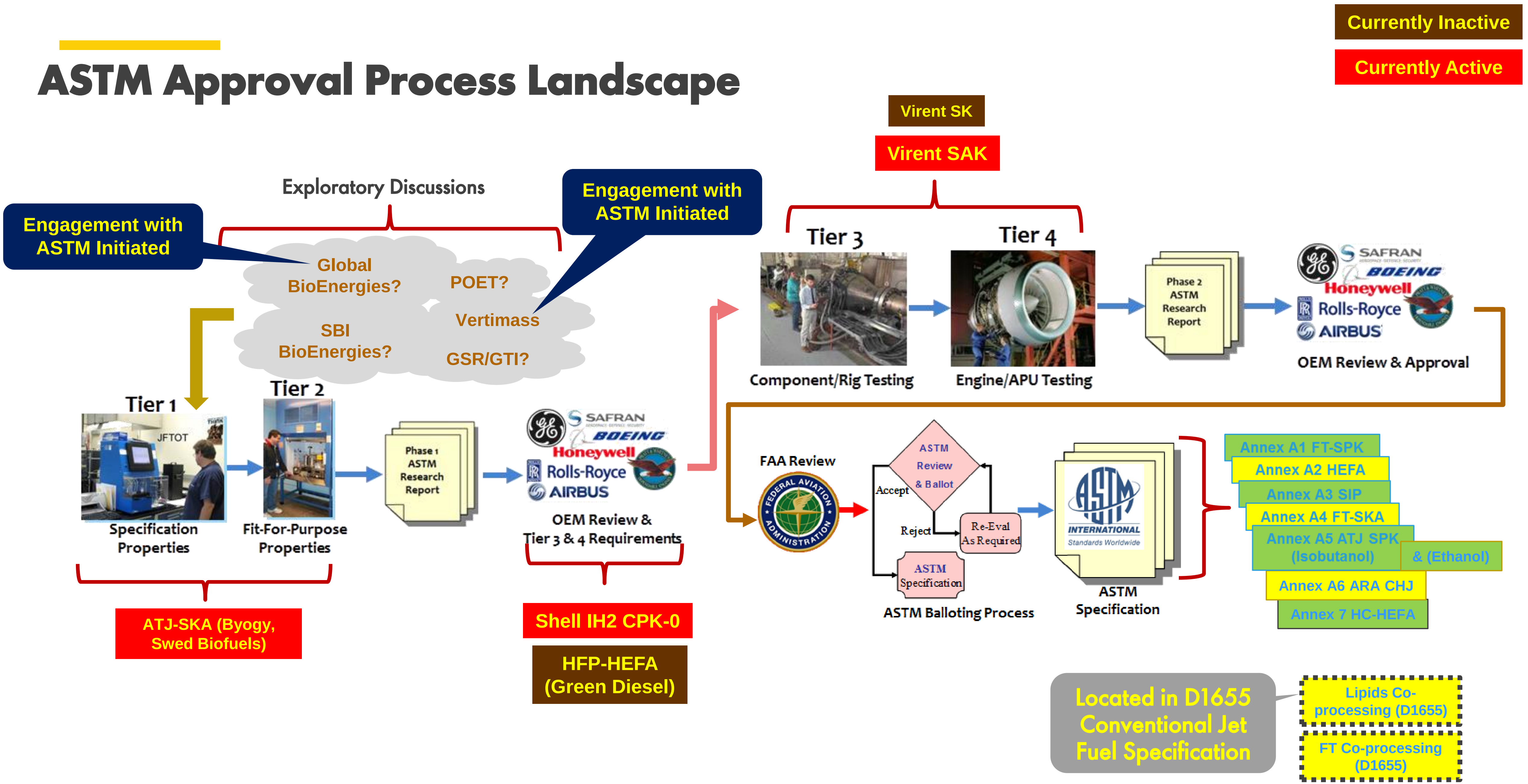
Today, HVO/HEFA is the most commercially viable option, but Shell is working all the technology classes



Estimates for indication only

SOURCE: PCC working paper 2019/05

ASTM Approval Process Landscape



Integrated Hydropyrolysis & Hydroconversion

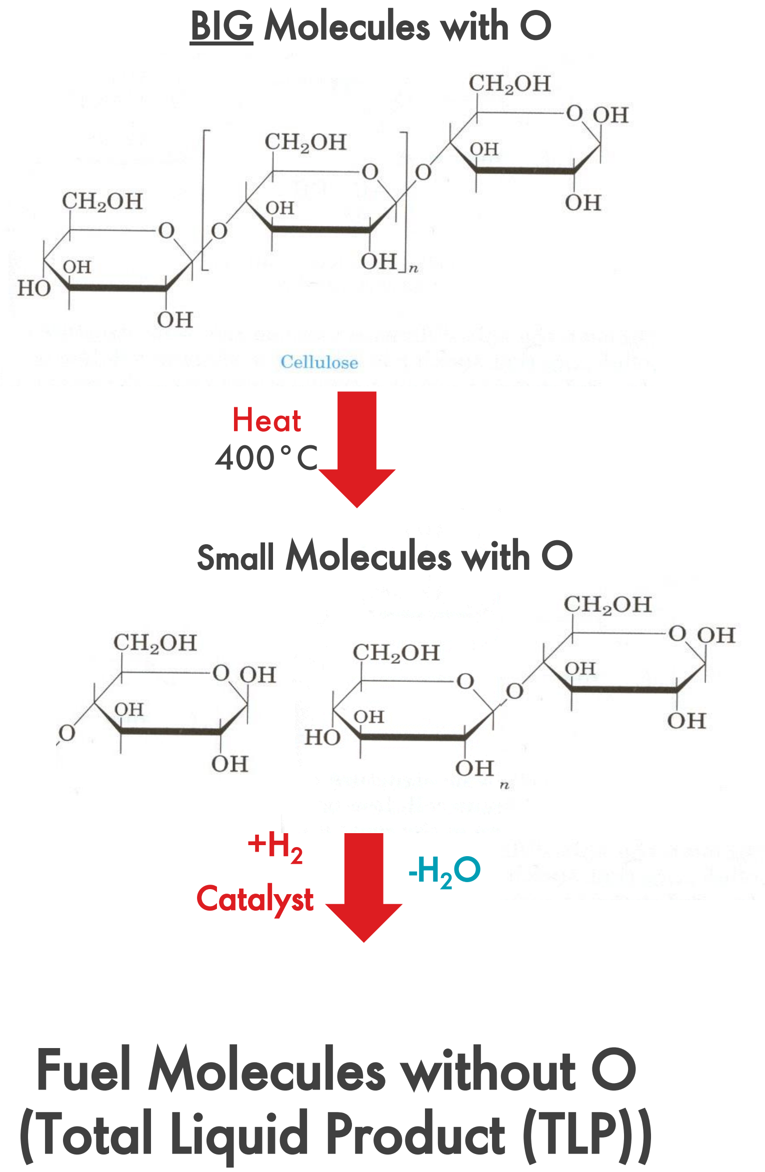
*IH² is a registered trademark of GTI

What is IH^2 Technology?

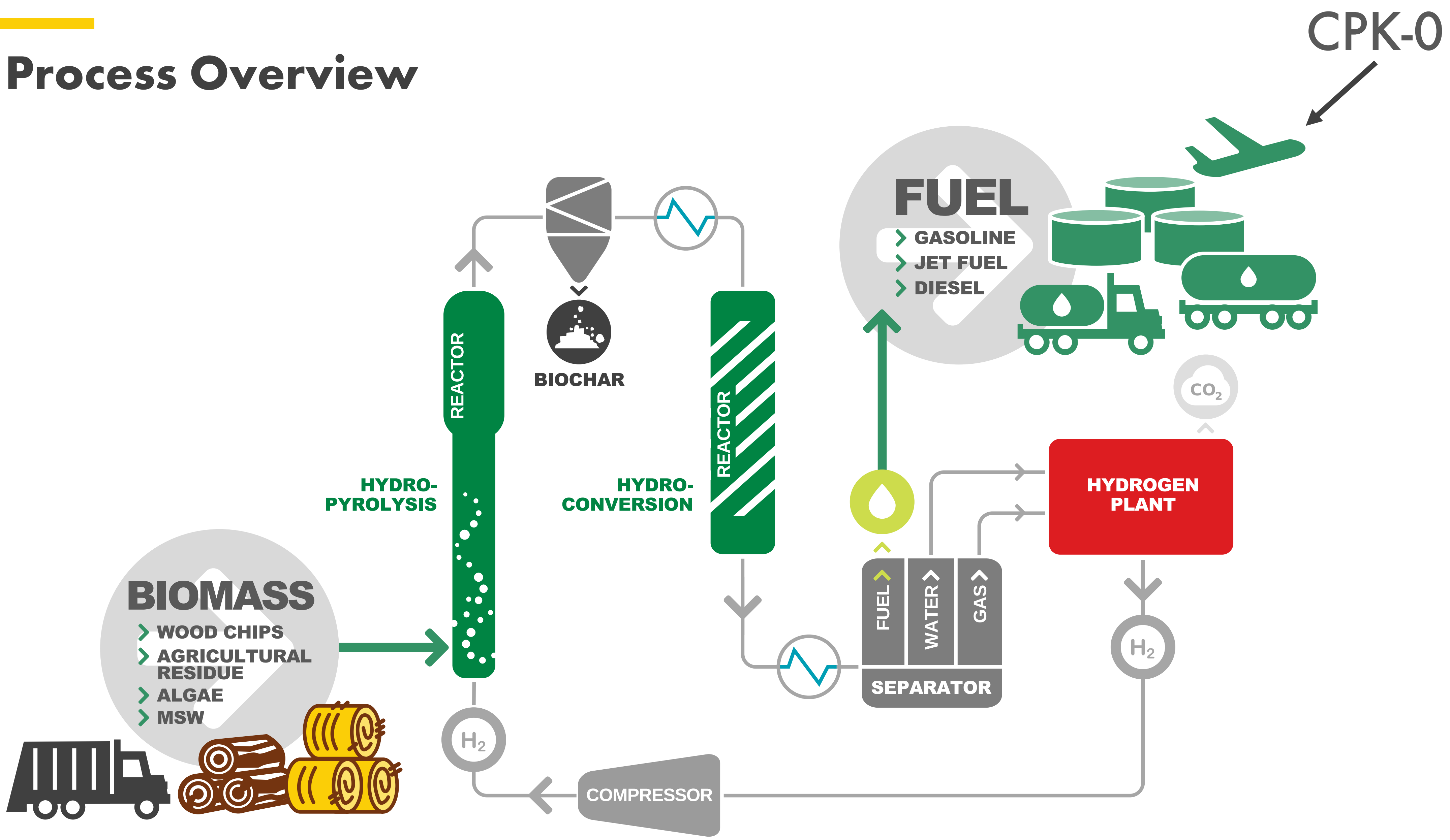
- IH^2 = Integrated Hydropyrolysis and Hydroconversion

- 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.

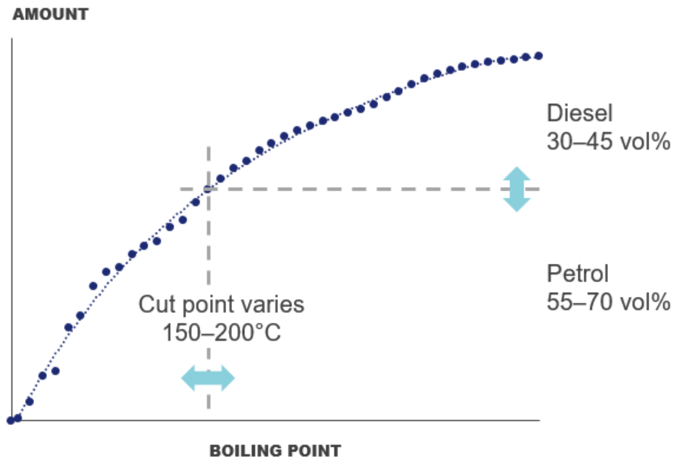


IH² Process Overview

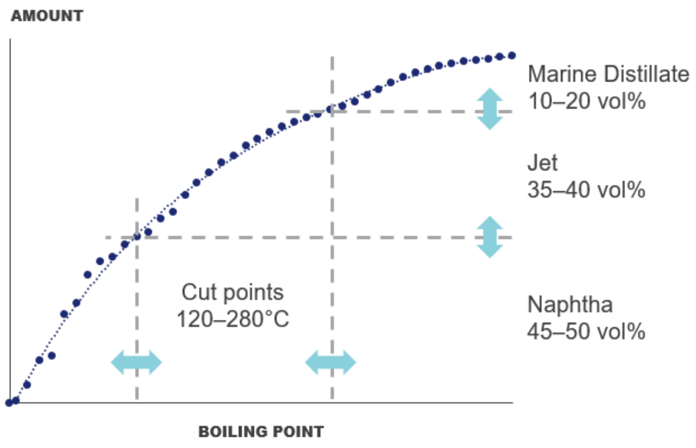


2 Modes of Operation: On Road and Off Road

Road fuels mode



Aviation / Marine fuels mode



GASOLINE / PETROL

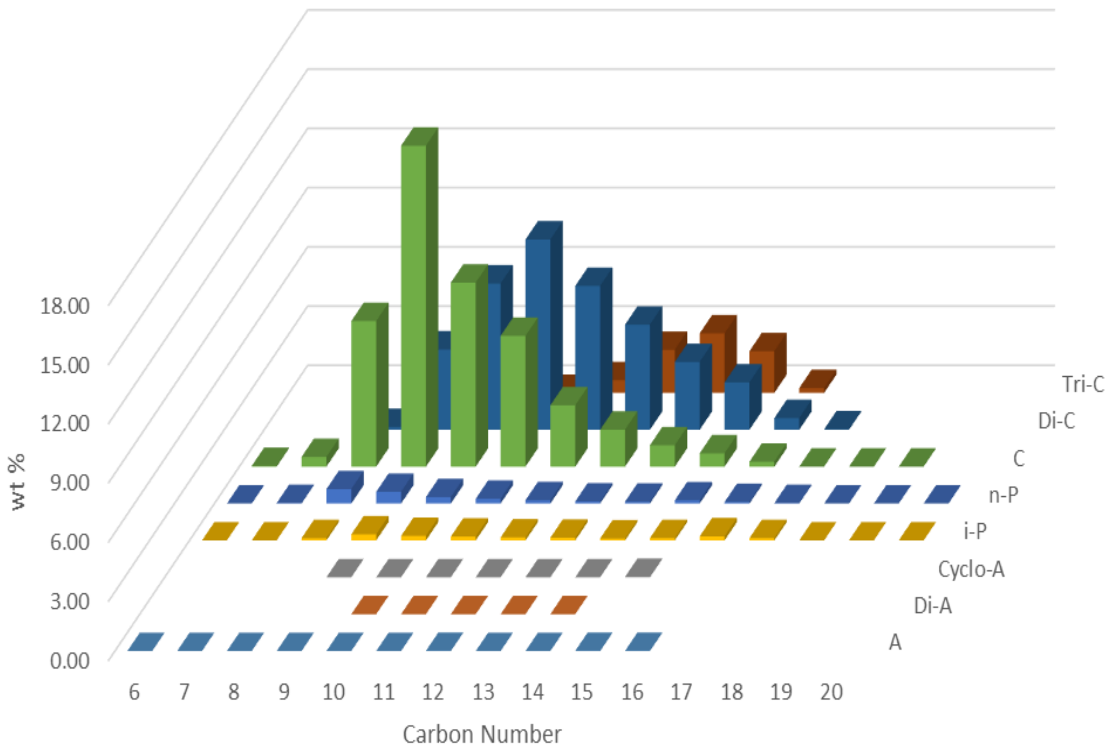
NAPHTHA

MARINE DISTILLATE

CPK-0

Cycloparaffinic Kerosene (CPK-0) Composition: GC x GC

Carbon Number	Aromatics	Di-Aromatics	Cyclo-Aromatics	Iso paraffins	Normal Paraffins	Cyclo-paraffins	Di-Cyclo Paraffins	Tri-Cyclo Paraffins
6						0.04		
7					0.02	0.49		
8				0.12	0.73	7.38	0.14	
9				0.31	0.59	16.26	4.07	
10				0.23	0.33	9.32	7.41	
11				0.19	0.24	6.63	9.64	
12	0.01			0.15	0.17	3.11	7.29	0.64
13				0.14	0.11	1.87	5.32	2.18
14				0.10	0.09	1.08	3.44	3.02
15	0.01		0.02	0.12	0.16	0.68	2.40	2.11
16	0.01			0.21	0.08	0.25	0.59	0.24
17				0.12	0.02		0.02	
18								
19								
20								
Total	0.03	0.00	0.02	1.68	2.55	47.11	40.33	8.20



represents > 1 wt%

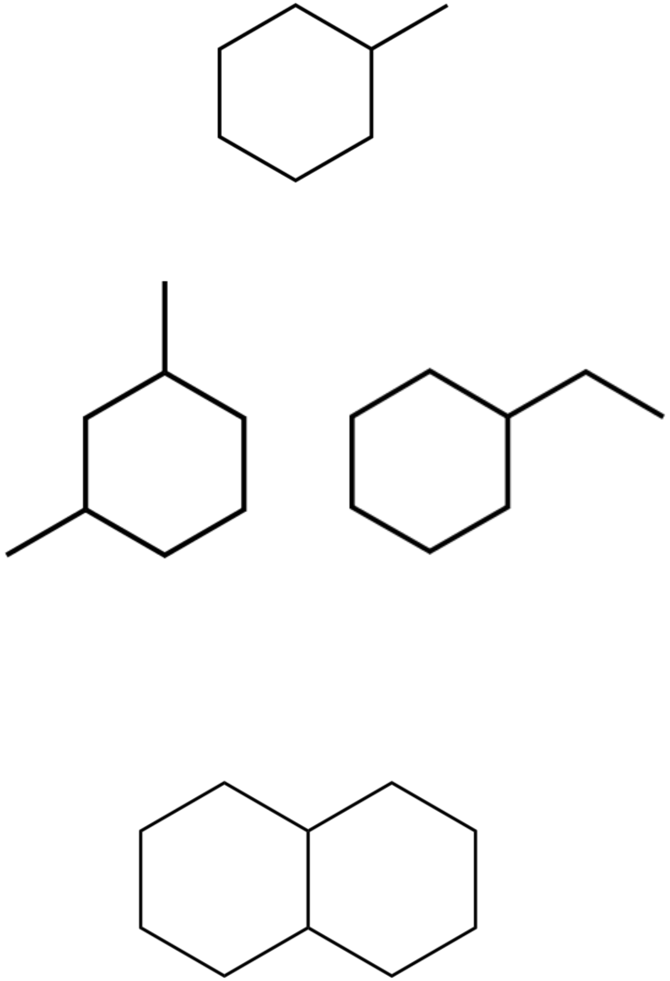
D7566 Table 1 Specification Properties

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	0.0014
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
Freezing Point	C	D5972	-40 Jet A / -47 Jet A-1	-51	-62	-61
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

Properties	Unit	Test Method	D7566	Jet A	50:50	CPK-0
Copper Strip 2 h at 100 °C	-	D130	No. 1 Max	1a	1a	1b
Thermal Oxidation Stability Test Temp	°C	D3241	260 Min	260	260	325
JFTOT Pressure Drop	mm Hg	D3241	25 Max	0	0	0
Tube Rating	nm over 2.5 mm^2	D3241	85 Max	9	11	7
Existent gum	mg/100mL	D381	7 Max	<1	<1	<1
Microseparometer Rating w/o SDA	-	D3948	85 Min	92	91	95
Aromatics	vol%	D6379	8.4 Min	16.4	8.0	<0.2
T50 – T10	°C	D86	15 Min	50	30	29
T90 – T10	°C	D86	40 Min	89	78	88
Lubricity	mm	D5001	0.85 Max	0.61	0.61	0.80
Viscosity at -40 °C	mm^2/s	D7945	12 Max	9.2	8.7	8.8

Shell IH^2 : CPK-0

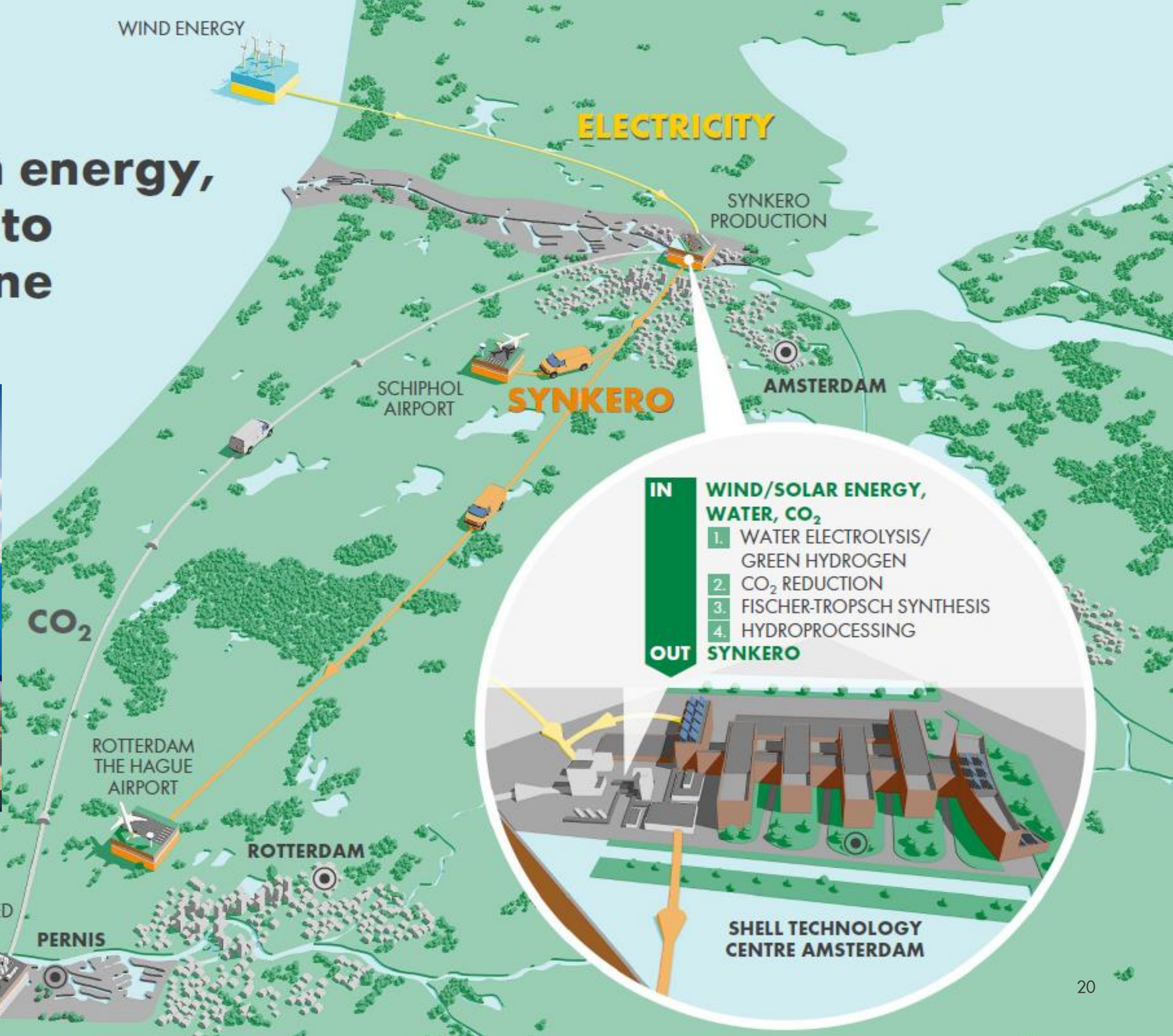
- Made from agricultural wastes and residues
- Majority mono- and di-cyclo paraffins
- Meets all of 'Table 1' properties in neat form
- Practically no aromatics
  - Improved specific fuel consumption and particulate emission
  - Early tests indicate cycloparaffinic molecules can satisfy seal swell requirements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



Example cycloparaffin molecules

Converting green energy, water and CO_2 into Synthetic Kerosene

500 litres in 2020



Some of Shell’s other SAF Collaborations

amazon Prime Air

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

world energy

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.

NESTE

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.

SkyNRG

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

RED ROCK BIOFUELS

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.

ROLLS ROYCE

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.

https://www.shell.com/business-customers/aviation/the-future-of-energy/sustainable-aviation-fuel.html

Summary

- A variety of feedstocks, technologies, and offsets will be required to meet industry and global CO_2 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