

20 September 2023

Developments and Solutions for Renewable Fuels Testing



Presented by PAC with:

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Presenters



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Renewable Fuels



Ian Mitchell

Group Product Manager
Physical Properties



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Product Manager
Elemental Analysis



Mango Ng

Application Specialist
Gas Chromatography



Karl Kuklenz

Product Manager
Process Analytics



Dr. Gordon Chiu

Applications Specialist | Renewable Fuels

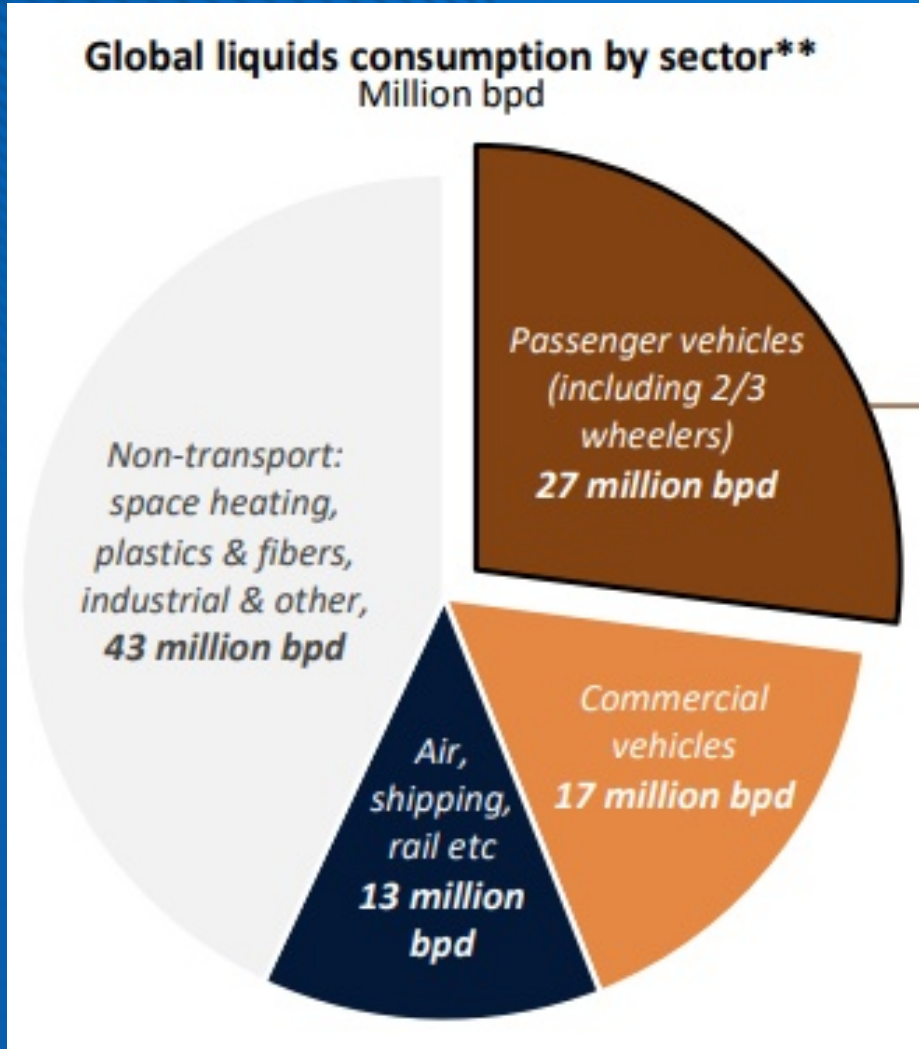
Agenda

Renewable Fuels

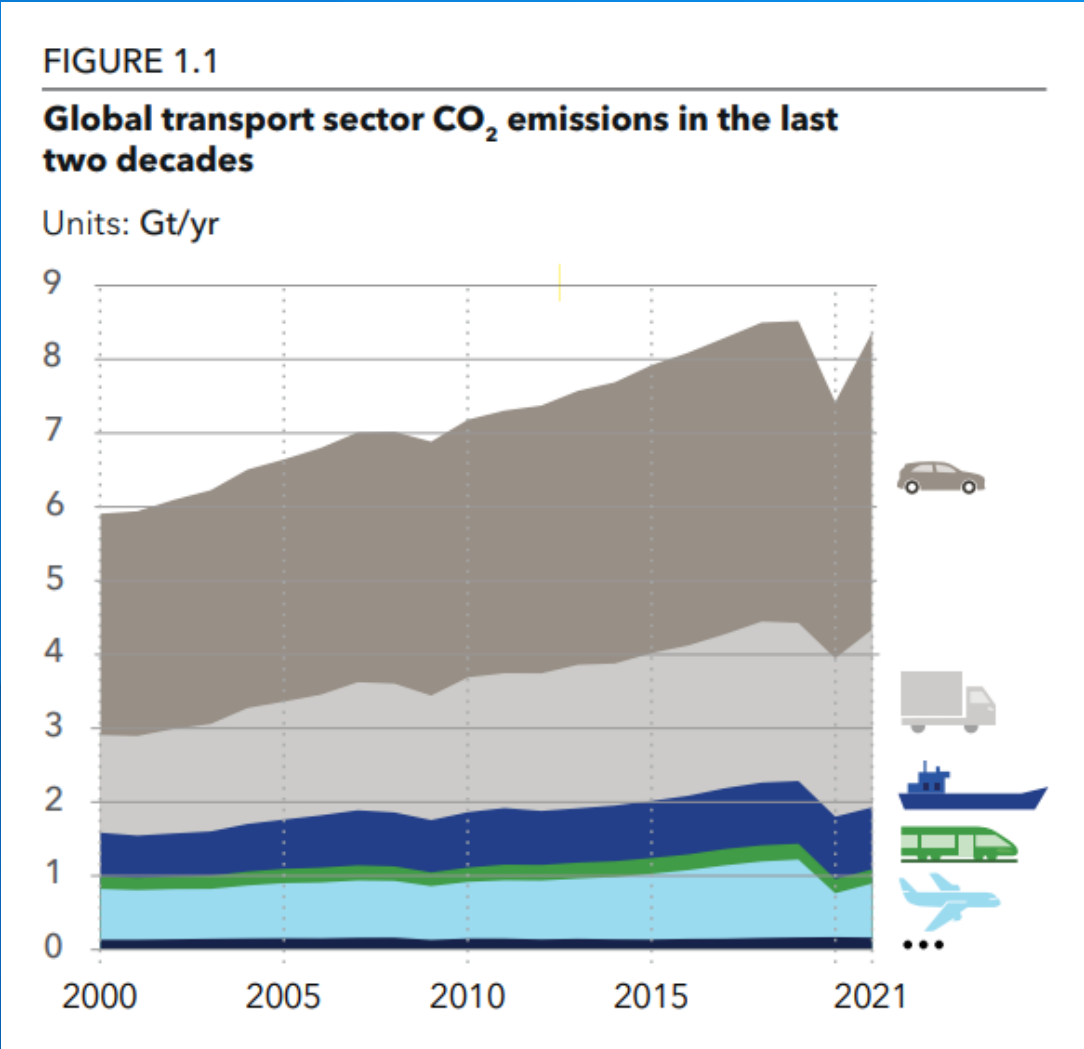
- Current market and future demand
- Bioethanol, Biodiesel & HVO, SAF
 - Hydrogen and derivatives
- Selected PAC solutions
 - Physical properties
 - Chemical properties
 - Elemental properties

Transport Sector: Currently Dominated by Fossil Oil

Ref: 2023-06 Rystad Energy – global pulse



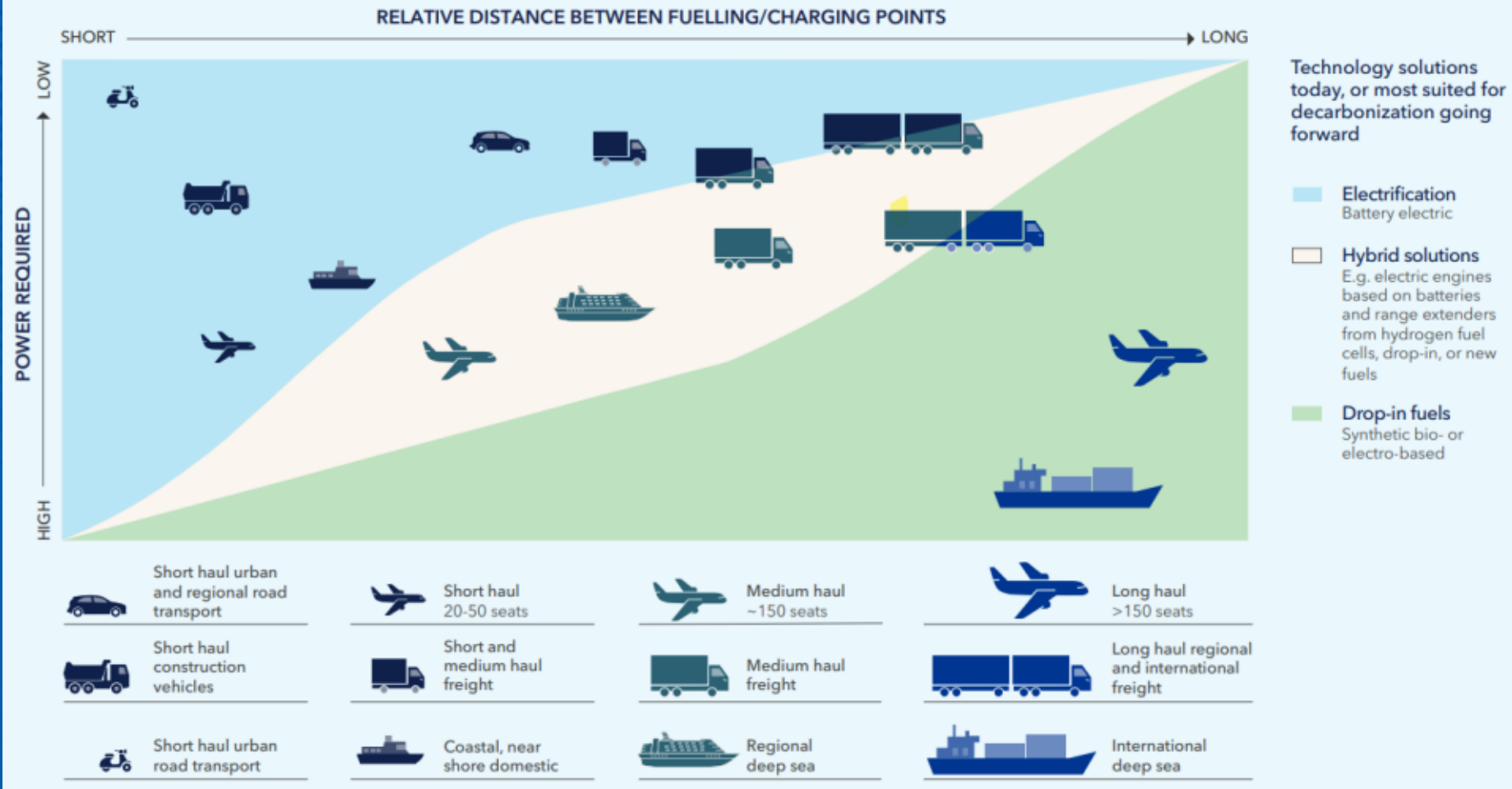
Ref: 2023 DNV – Transport in Transition



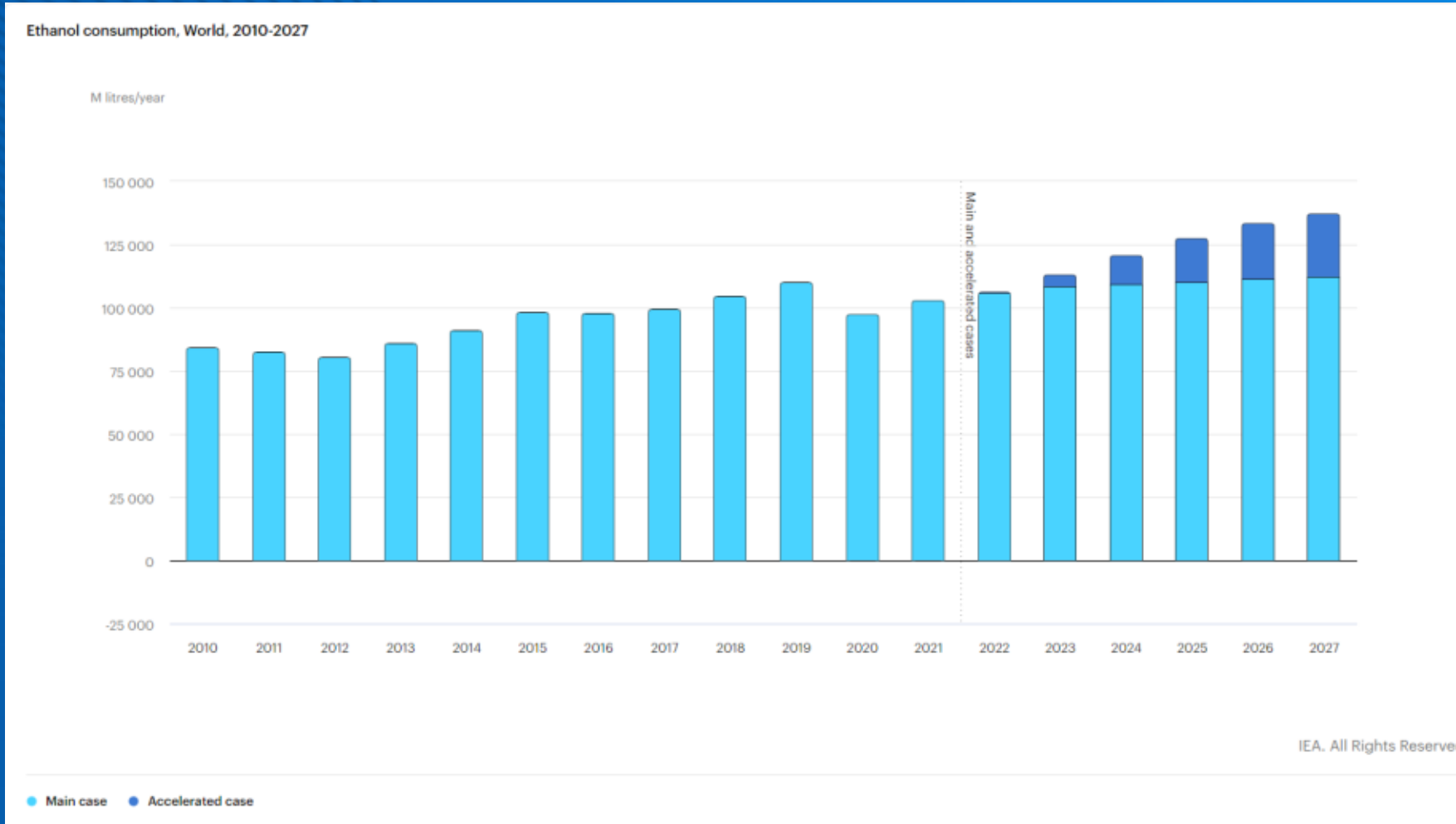
Multi-Solution, Multi-Region, Multi-Speed

FIGURE 1.2

Electric, hybrid and alternative fuel solutions towards 2050



Ethanol: Global Consumption

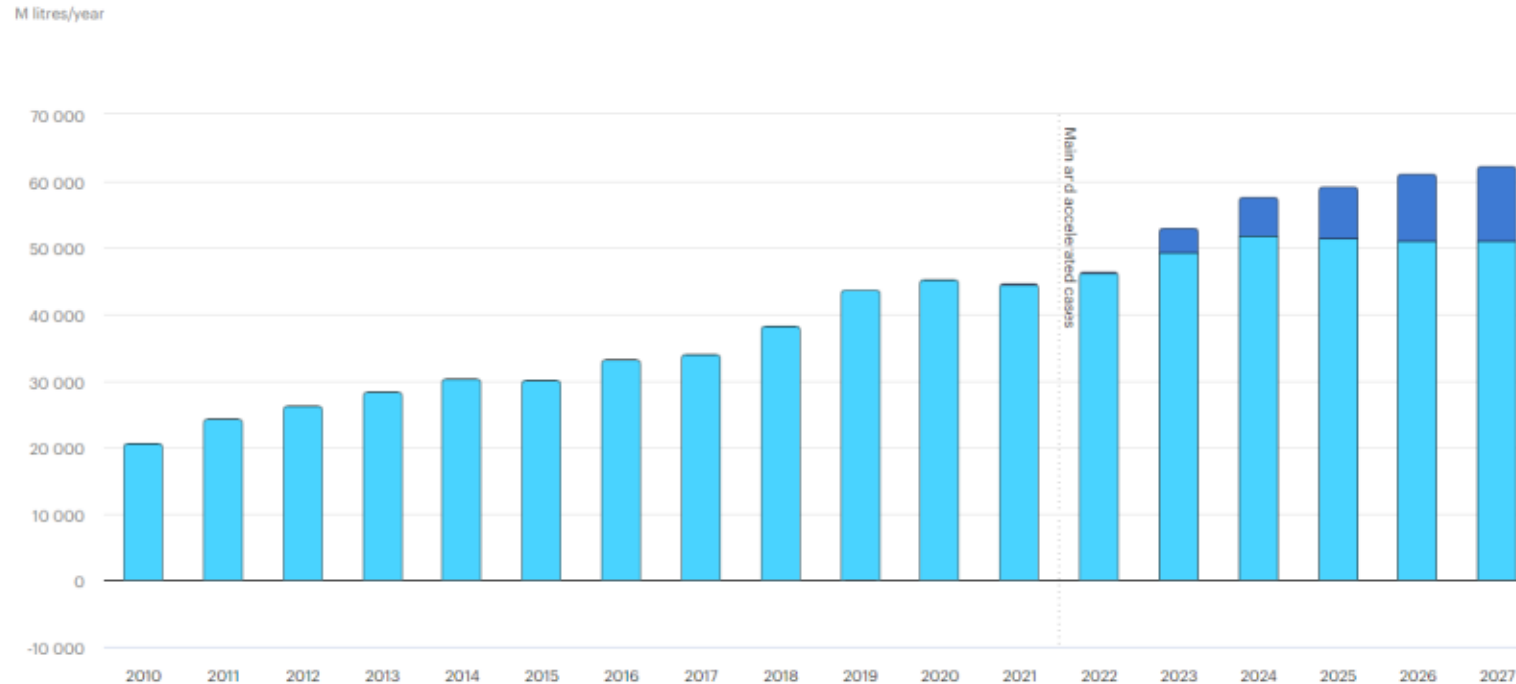


2022 Consumption		
Country	Volume (B L)	%
World	106.1	
USA	53.2	50
Brazil	28.6	27
EU	7.1	6.7
India	4.4	4.1
China	3.8	3.6
Canada	3.2	3.0

Ref: 2022-12 IEA Renewables forecast to 2027 [www.iea.org/reports/renewables-2022/transport-biofuels]

Biodiesel (FAME): Global Consumption

Biodiesel consumption, World, 2010-2027



IEA. All Rights Reserved

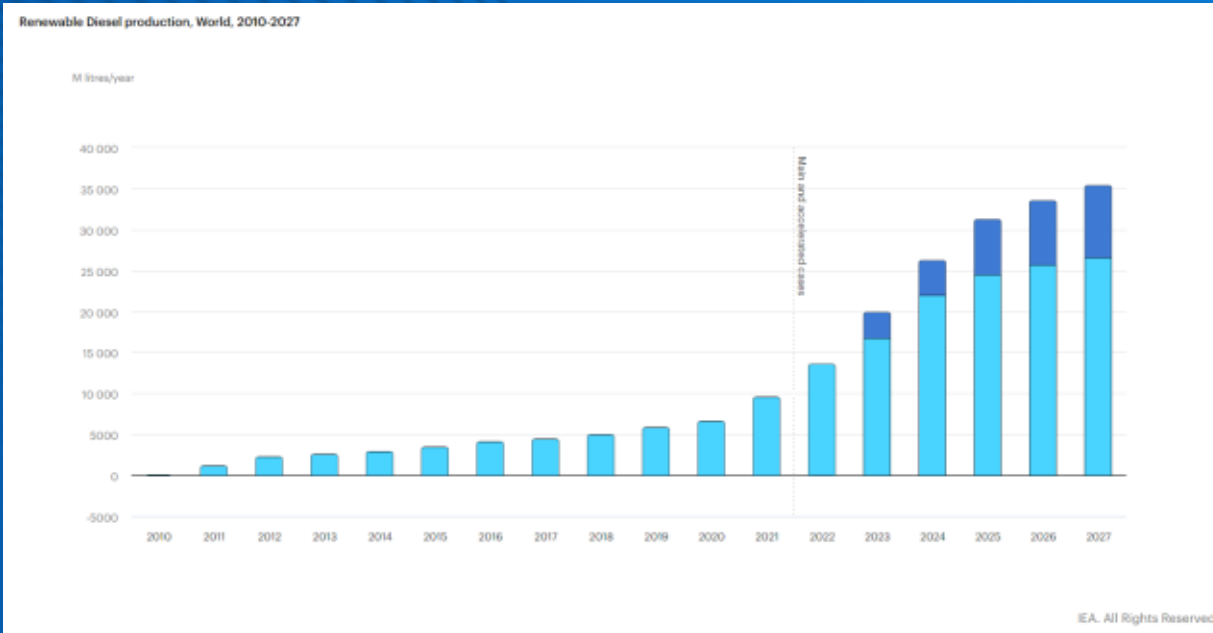
● Main case ● Accelerated case

2022 Consumption

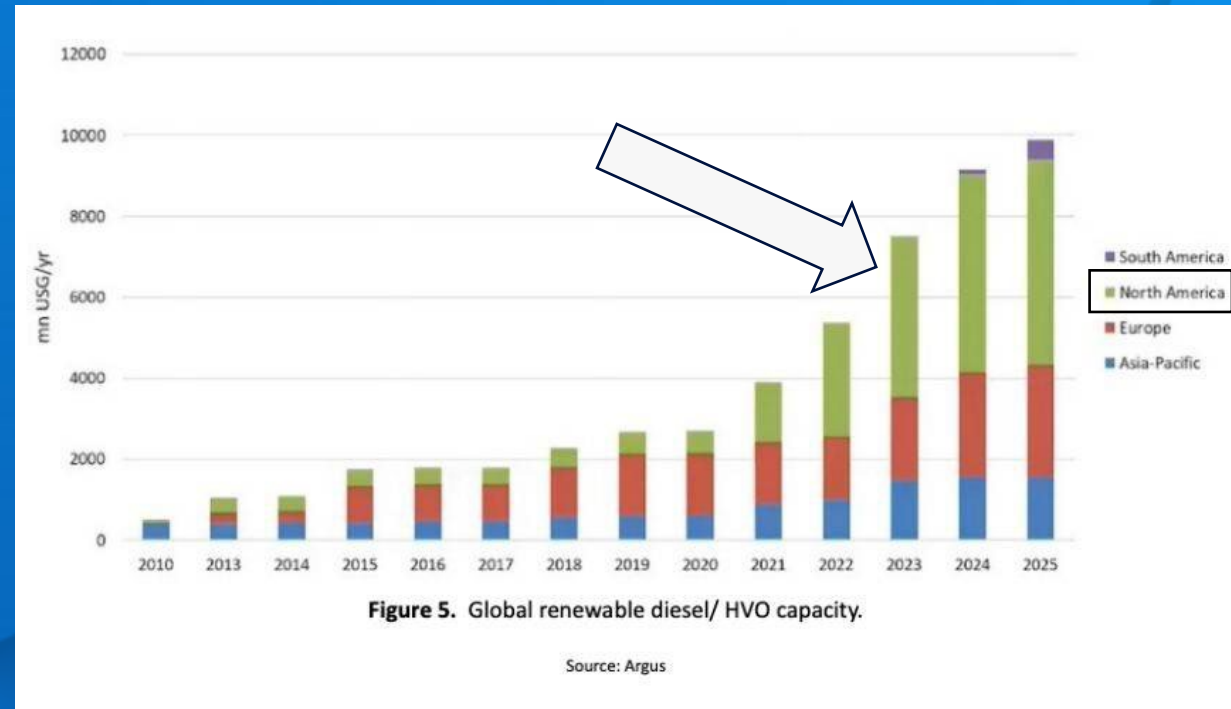
Country	Volume (B L)	%
World	46.2	
EU	15.9	34
Indonesia	10.6	23
Brazil	6.4	14
USA	5.9	13
Thailand	2.1	4.5

Ref: 2022-12 IEA Renewables forecast to 2027 [www.iea.org/reports/renewables-2022/transport-biofuels]

Renewable Diesel (HVO): Global Production



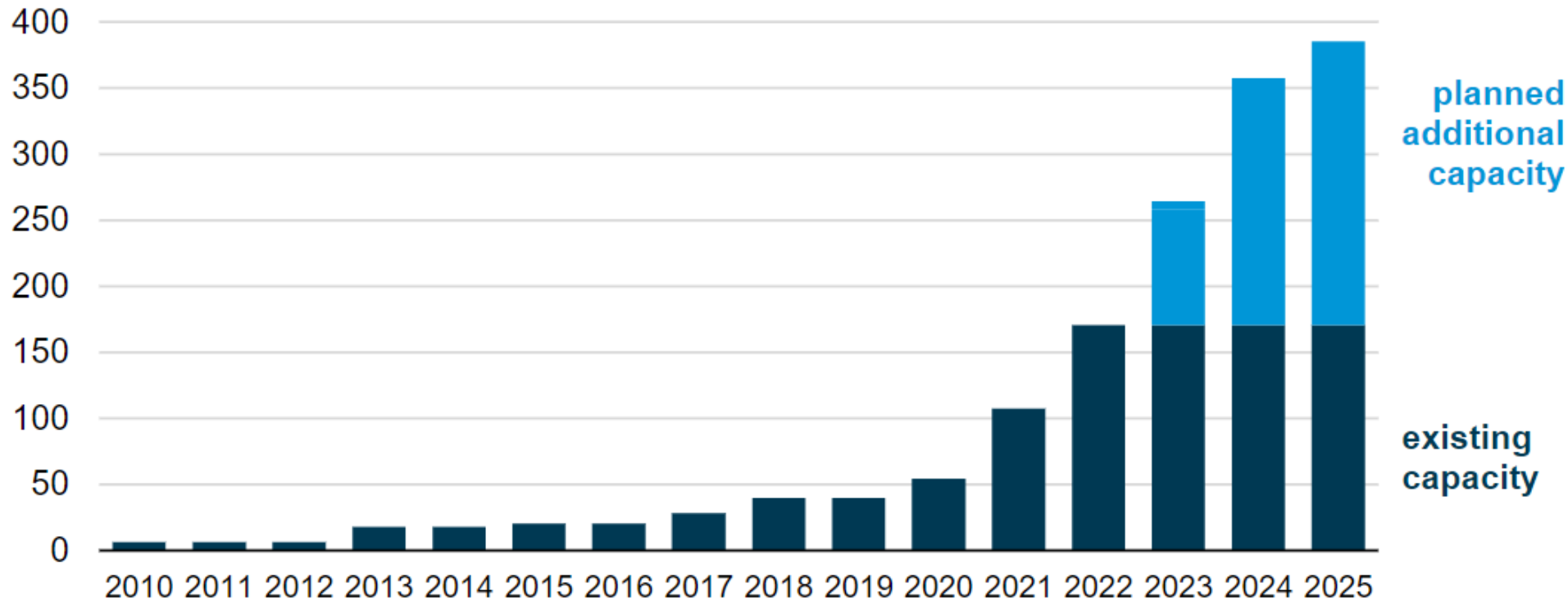
Ref: 2022-12 IEA Renewables forecast to 2027
[\[www.iea.org/reports/renewables-2022/transport-biofuels\]](https://www.iea.org/reports/renewables-2022/transport-biofuels)



2022 Argus

Strong Growth in US Production Capacity

Annual existing and expected U.S. renewable diesel production capacity (2010–2025)
thousand barrels per day



Data source: Company announcements and trade press

2023-02 EIA

Pace of SAF/RD in Aviation Transport

2023



2023 IATA

2028



SAF Mandates Drive Demand

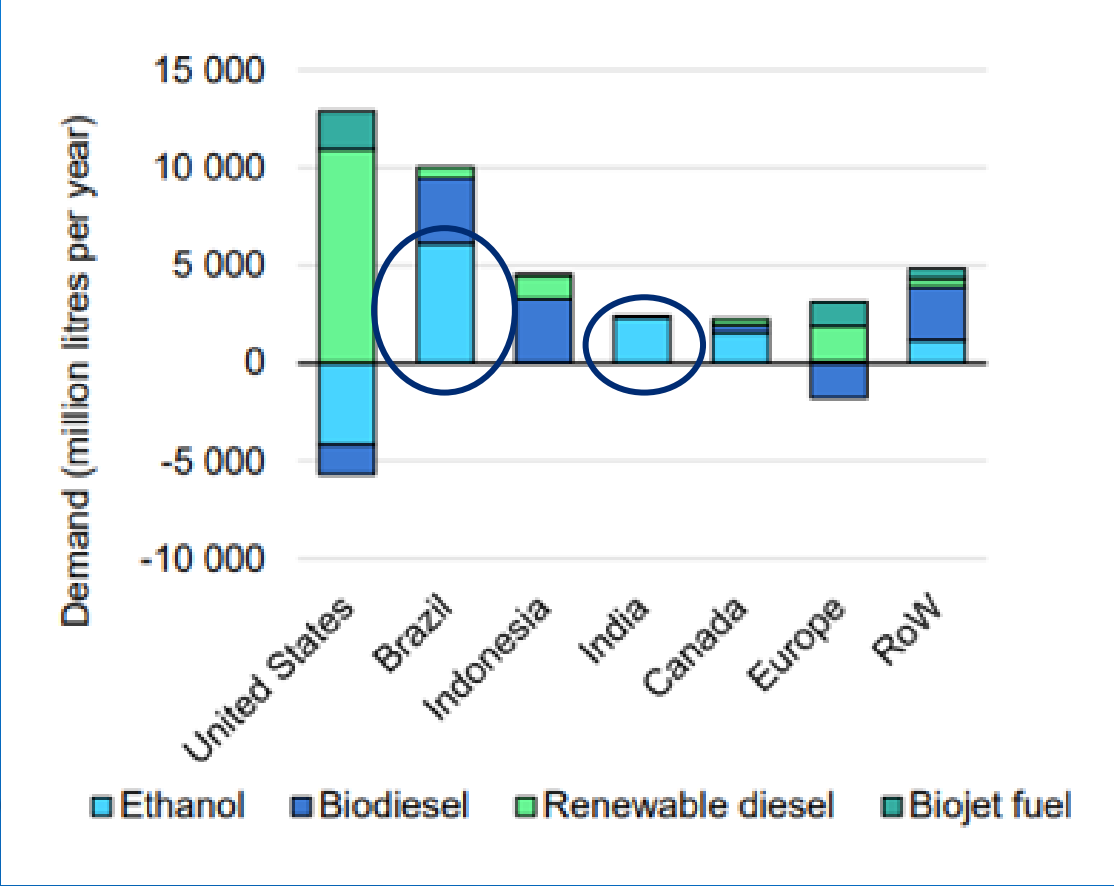
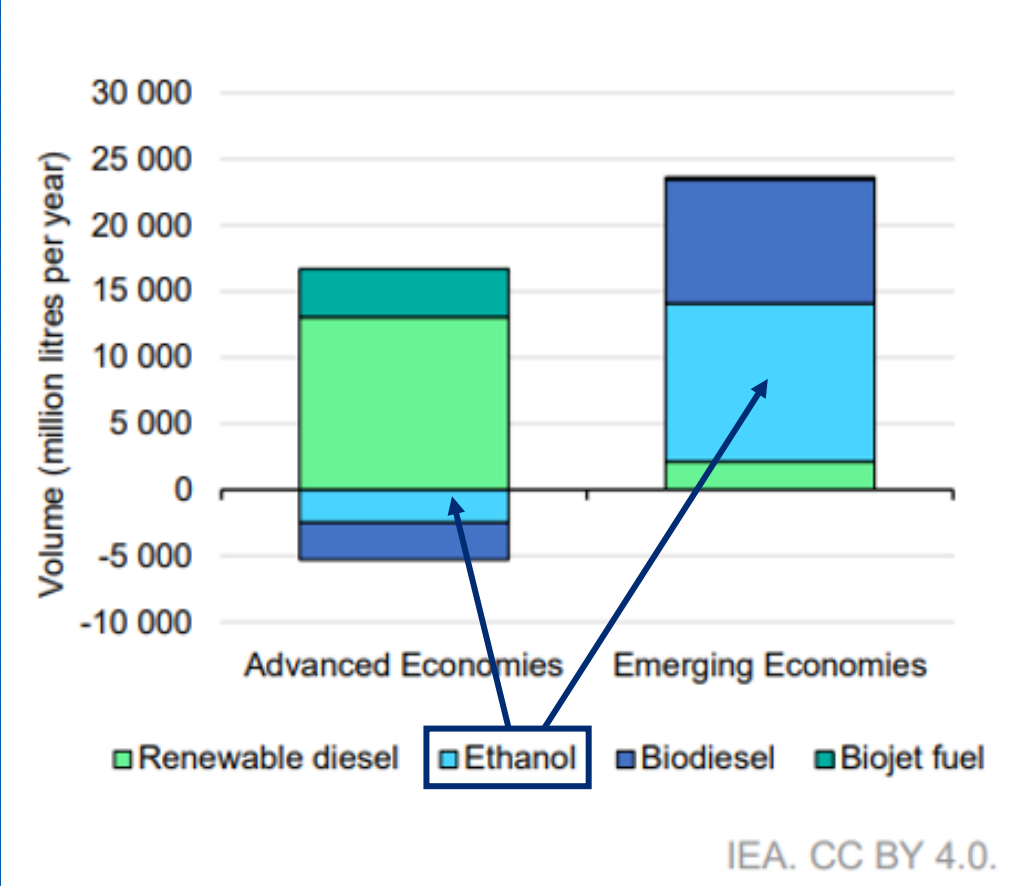
Minimum shares of SAF and synthetic aviation fuel required in the EU

	2025	2030	2032	2035	2040	2045	2050
SAF	2%	6%	6%	20%	34%	42%	70%
Synthetic aviation fuel	-	1.2%	2%	5%	15%	20%	35%

India – 1% (2025) to 5% (2030); Indonesia – 5% by 2025
Japan; Korea by 2026; Brazil by 2027, UK – 10% by 2030

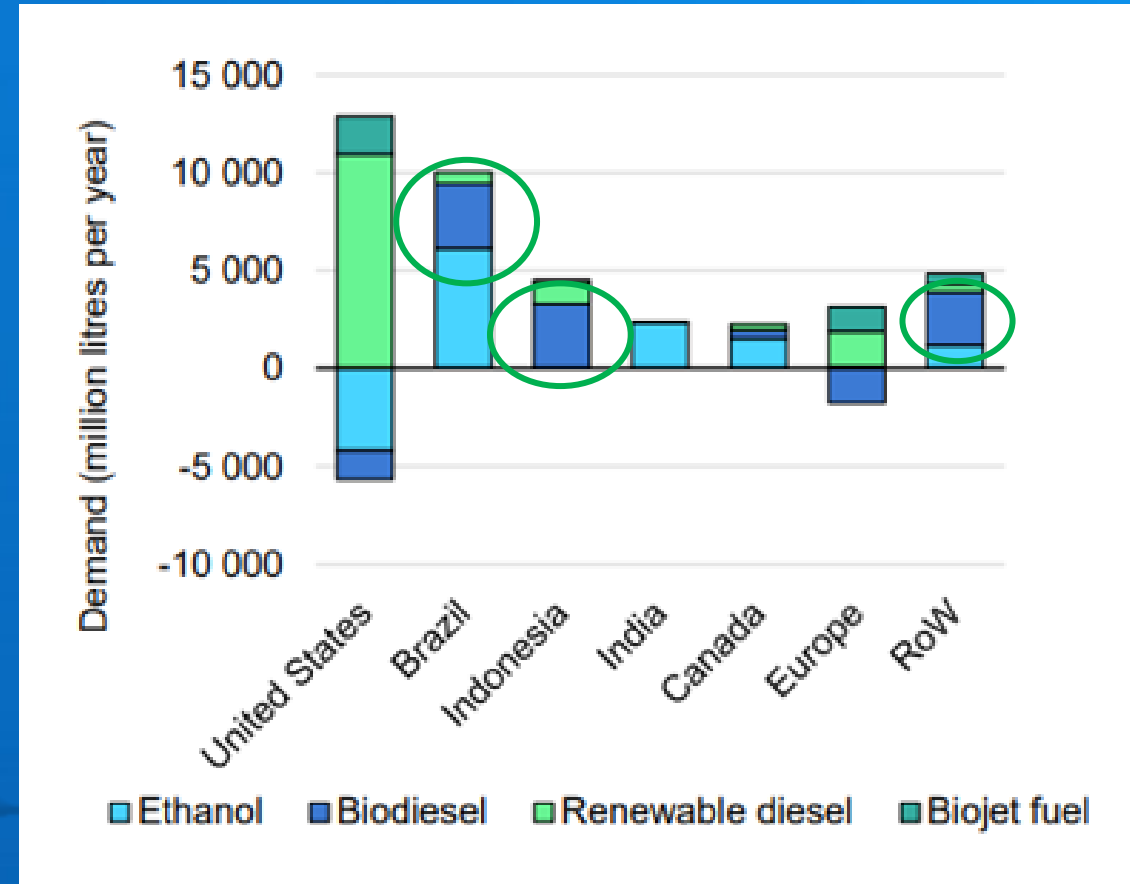
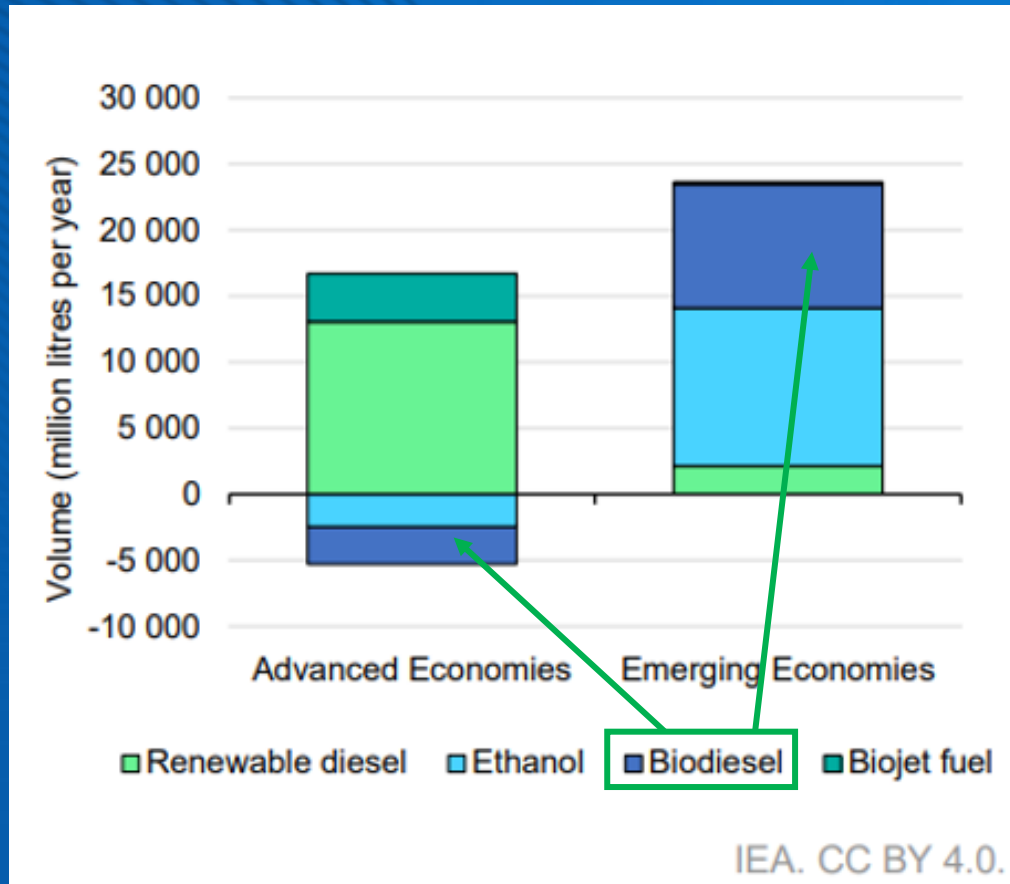
In study: Singapore, Argentina, Malaysia – 1% to 47% (2050)

Ethanol Growth by Economies & Countries 2021-2027



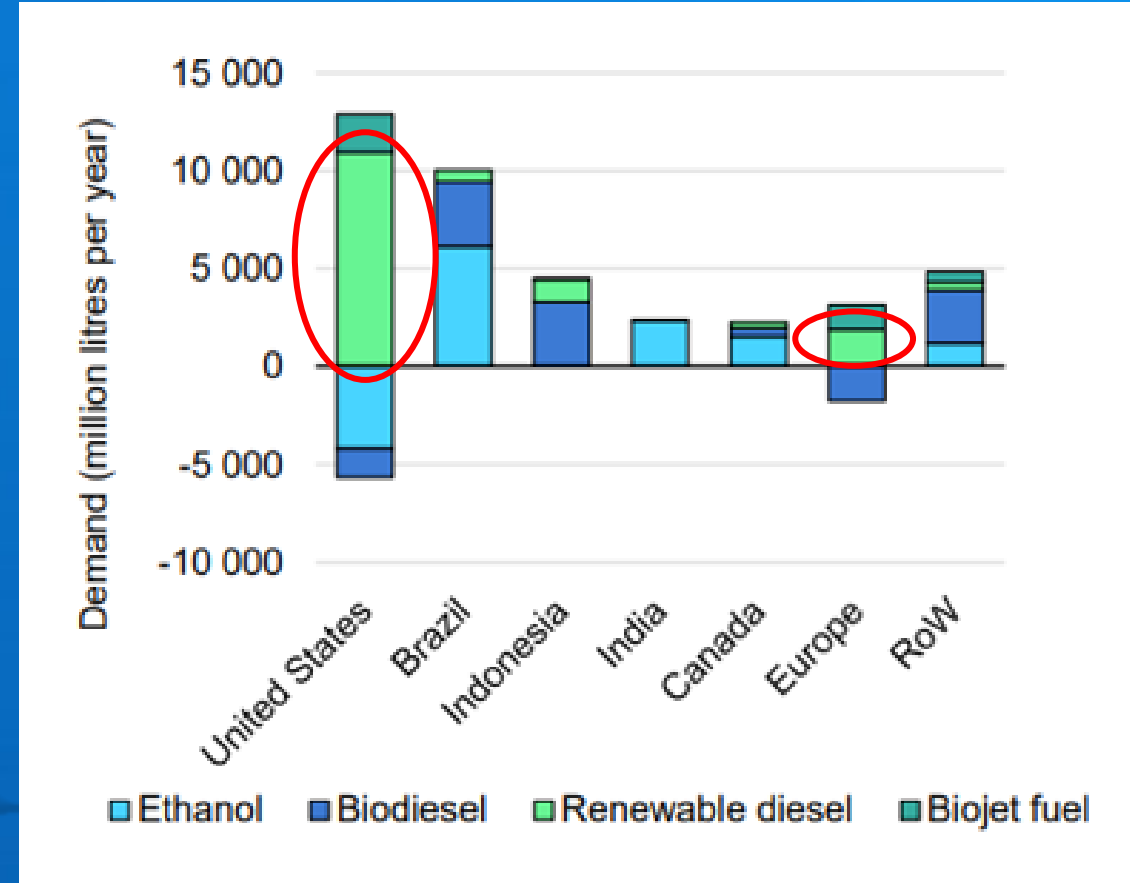
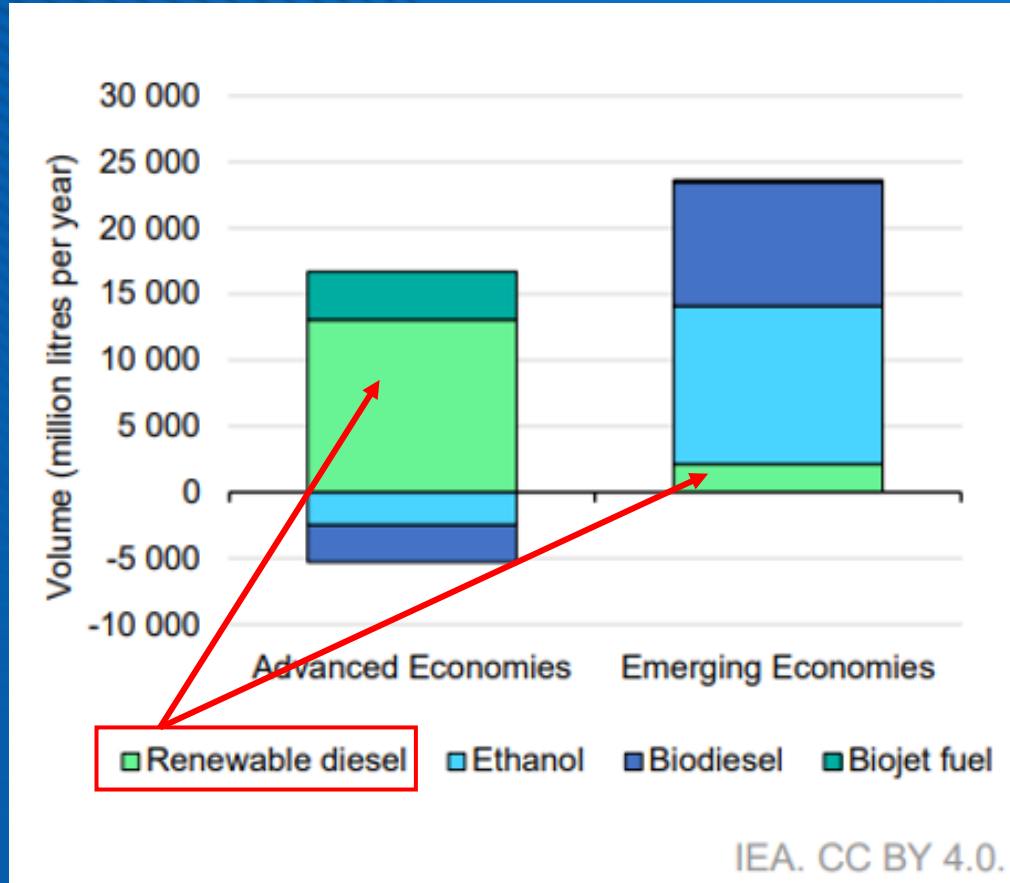
Ref: 2022-12 IEA Renewables forecast to 2027

Biofuel Growth by Economies & Countries 2021-2027



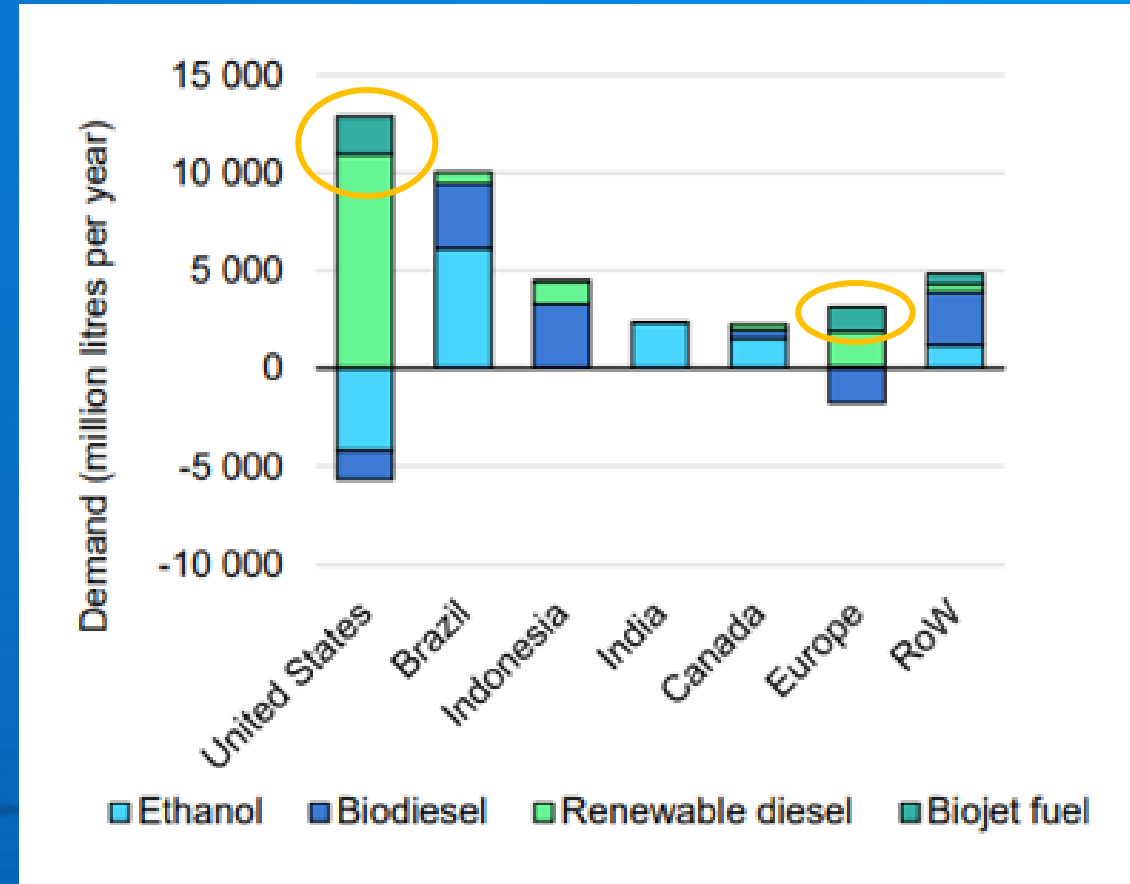
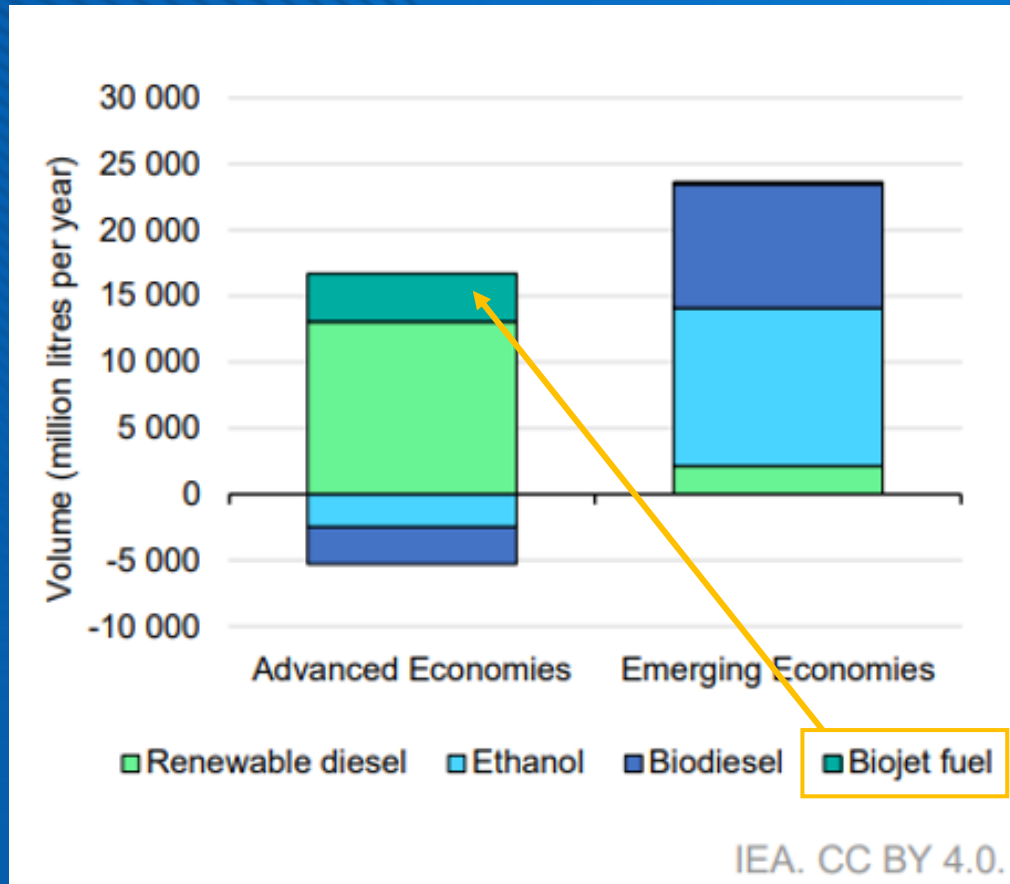
Ref: 2022-12 IEA Renewables forecast to 2027

Biofuel Growth by Economies & Countries 2021-2027



Ref: 2022-12 IEA Renewables forecast to 2027

Biofuel Growth by Economies & Countries 2021-2027

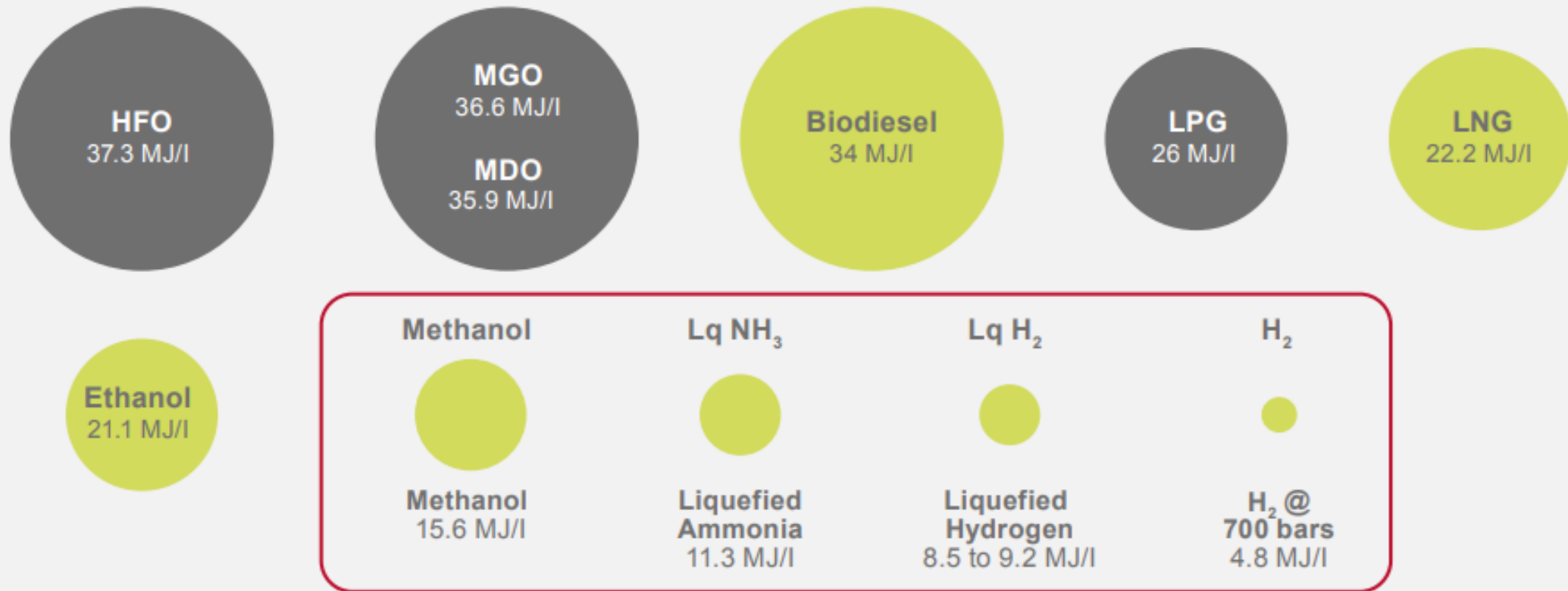


Ref: 2022-12 IEA Renewables forecast to 2027

Multiple Options for Maritime Fuels

And hydrogen is represented:

FIGURE 29: VOLUMETRIC ENERGY CONTENT OF ALTERNATIVE FUELS



Source: Bureau Veritas

Ref: 2022-09: Bureau Veritas – Alternative Fuels Outlook for Shipping



Ian Mitchell

Group Product Manager | Physical Properties

Physical Properties Measurements for Renewables

JFA 70-Xi Jet Fuel Analyzer

Phase JFA-70Xi Jet Fuel Analyzer

The world's first 3-in-1 analyzer that combines:

- Freeze point
- Viscosity @ -20°C and -40°C
- Density

Available as 5-in-1 with additional functions:

- Cloud point
- Pour point

Automatic sample injection

Automatic cleaning



ASTM D7945 Viscosity Method

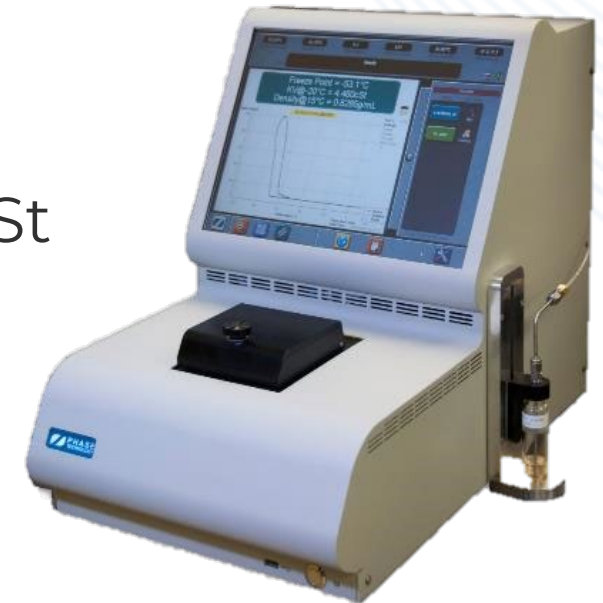
-20°C precision	Reproducibility	Repeatability	Bias
D7945 (Phase Technology)	0.4%	0.2%	No
D445 (Manual)	1.9%	0.7%	-
D7042	3%	1.7%	Yes

Has full precision at -40°C

The only ASTM test method that calculates Temp@12 cSt

Accepted into ASTM D1655 and D7566 in 2016

Included in UK Def Stan 91-91 (Issue 10) in 2018



Renewable/Sustainable (SAF) Fuels

Jet viscosity @ -40°C is a requirement in the ASTM bio-jet specification ASTM D7566. Measurement @ -20°C is not in the specification.

For co-processed jet fuel, refineries must follow D1655 specification.

- The specification requirement for co-processed fuel only allows -40C. Phase method (D7945) and manual method (D445) are the only two methods allowed. D7042 is not included.

For freeze point of co-processed jet fuel, Phase freeze point method (D5972) is the referee!

Phase 70Xi Advantage

Speed Advantage

Fastest test speeds of any auto or manual methods.
Quick and easy to use

Increased Productivity

Multiple test methods in one single unit



Accurate & Reliable

Best precision of any automatic or manual method

Versatility

Upgradable to include functions and options

JFTOT-IV

Jet Fuel Thermal Oxidation Tester

Jet Fuel Thermal Oxidation Tester

JFTOT IV

- Enhanced safety features
- Smaller, streamlined package
- Significantly increases operator productivity
- Large, global installed base of > 1,000 JFTOT instruments
- Strictly following ASTM D3241, IP 323, and ISO 6249



JFTOT Evolution

The Erdco Fuel Coker
(Not an Alcor product)

1957



JFTOT® 215

1984



JFTOT® 230, 240 CE
(JFTOT® II) (Stainless cabinet)

1996



JFTOT® IV

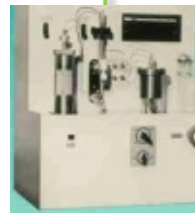


*The Worldwide
Recognized Leader
of Jet Fuel Thermal
Oxidation Testing*



1972

JFTOT® 203



1990

JFTOT® 230, 240
(JFTOT® II) (Blue and White)



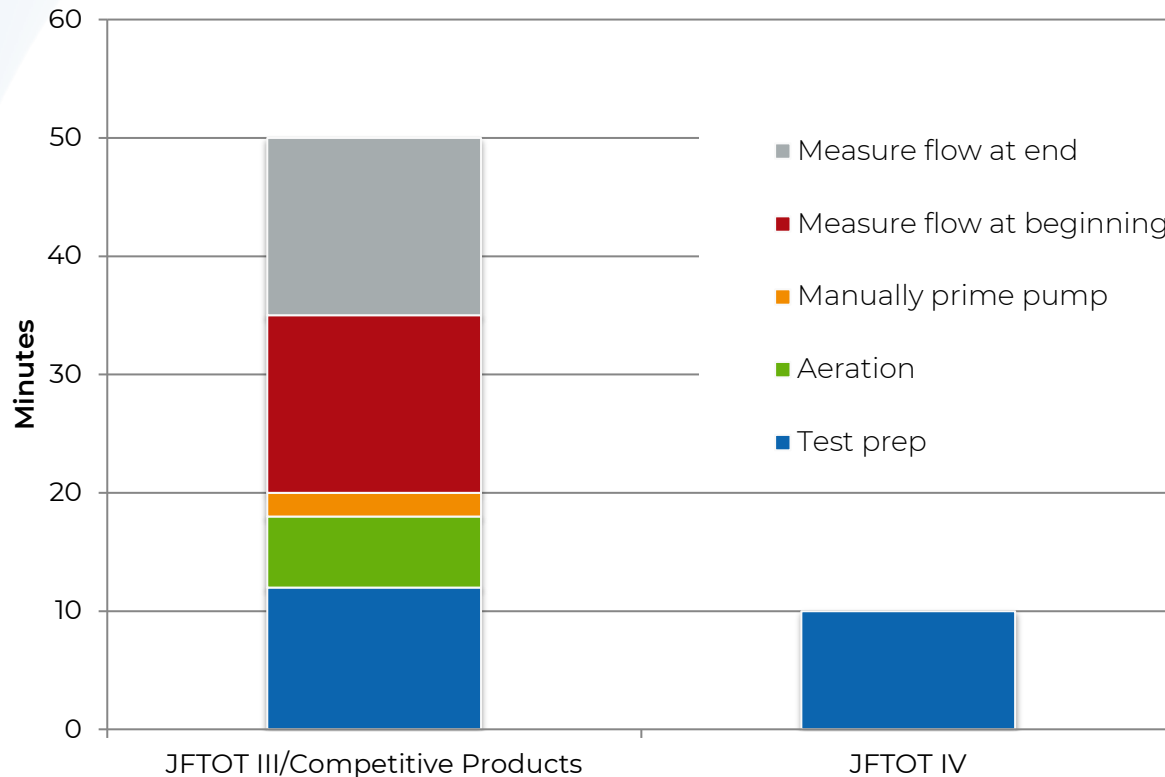
2006

JFTOT® 230 Mark III

Productivity Improvement

The JFTOT® IV increases overall lab productivity by 25%

Reduced Hands-on Time



Competition / JFTOT® III
~ 50 minutes

JFTOT® IV
10 minutes

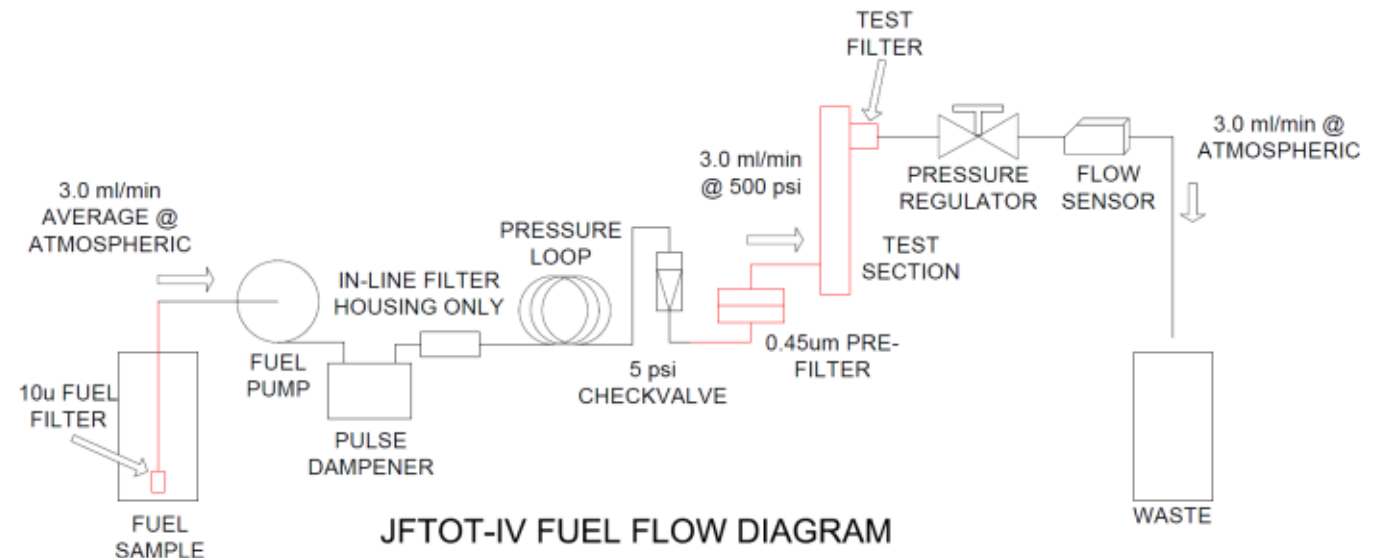
With 3 tests a day, this saves:

- 2 hours per day
- 14 hours per week
- 728 hours per year
- 91 workdays (8-hour days) per year

91/360 (total # of workdays) = 25%

JFTOT-IV Updates

- Dedicated SAF pressure loop - simple modification to reduce length of pressure loop in JFTOT to reduce system pressure (prior to the test section)
- Already proven and implemented modification for use with higher viscosity military fuels
- Filter removal completed



OptiDist Distillation

Distillation of Petchem Streams

OptiDist

- Fully automated Initial Heat, Distillation Rate, and Final Heat Regulation.
- Better precision with residue protection, and Scan Charge Volume.
- One Button testing for perfect results on the first analysis.
- Easy to operation, mistake-proof unit.



OptiDist – Product Description

Better Precision

- Fully automated Initial Heat, Distillation Rate and Final Heat Regulation
- Residue Prediction
- Scan Charge Volume to eliminate user error

One Button Testing (Optimizer)

- Select distillation group and push start button
- No sample specific heat parameters
- Perfect result on first analysis even for “unknown” samples

Easy to use mistake proof unit

- Easy flask installation
- Heater Base Plate detection
- Pt100 position without adjustment



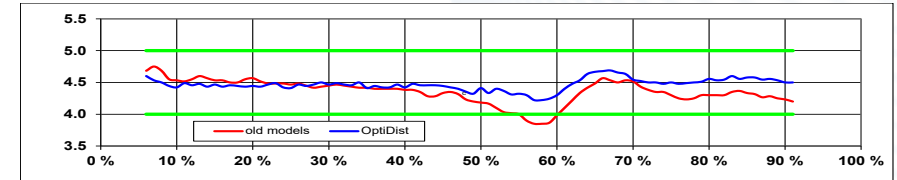
Better Precision

Better precision for IBP and 5% temperatures because the unique Optimizer automatically adjusts the Initial Heat settings and gives always correct Initial Heat time and 5%-time for any sample

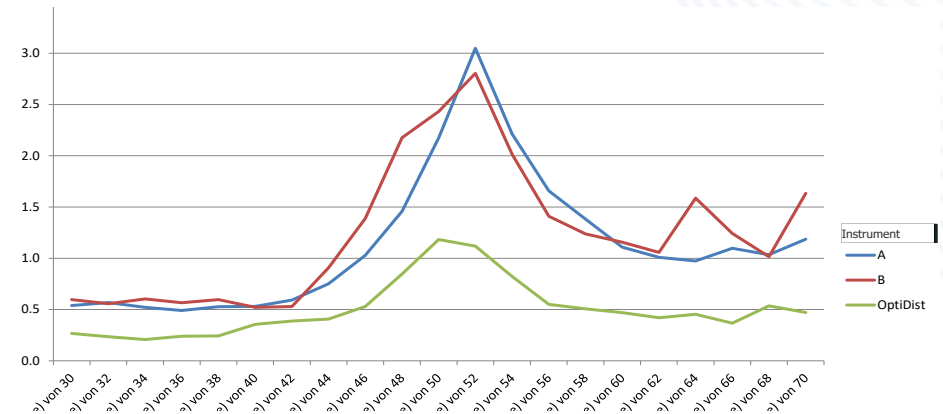
Better Precision for FBP because the Optimizer automatically calculates the optimal Final Heat settings

Better Precision for “Evaporated Values” because the Optimizer automatically calculates residue and loss

Better precision for the whole distillation curve because the Optimizer guarantees excellent Distillation Rate Regulation for all samples e.g., for Ethanol Blends



Distillation Rate is better regulated



ASTM round robin clearly demonstrated better precision that other instruments

One Button Testing

Get perfect results from the first run even for “unknown” samples by just entering the Distillation Group.

- Fully automatic initial heat regulation
- Improved Distillation Rate regulation
- Fully automatic final heat adjustment for the last 5 ml to distillate
- Automatic residue and loss calculation
- Time saving up to 60%
- Patent protected algorithm

Access level:	ready	PC link		22/08/06
Operator	25.91°C	0.0 %	Unitname:	Unit 5

Local Results:		Volume	dist.rate	obs.temp.	corr.temp.
Operator:		IBP 0	498.0 s	99.9 °C	100.3 °C
Joe Brown		5	75.0 s	104.1 °C	104.5 °C
Sample No.:		10	4.6 ml/min	105.3 °C	105.7 °C
DER1243654645		15	4.6 ml/min	105.9 °C	106.3 °C
		20	4.6 ml/min	106.1 °C	106.5 °C
		30	4.4 ml/min	107.5 °C	107.9 °C
		40	4.6 ml/min	109.0 °C	109.4 °C
Product:		50	4.6 ml/min	110.7 °C	111.1 °C
Gasoline tank 431		60	4.7 ml/min	113.1 °C	113.5 °C
		70	4.6 ml/min	115.9 °C	116.3 °C
		80	4.7 ml/min	119.5 °C	119.9 °C
Notes:		85	4.6 ml/min	121.8 °C	122.2 °C
		90	4.8 ml/min	124.8 °C	125.2 °C
		95	4.6 ml/min	129.4 °C	129.8 °C
Date: 22.08.06		FBP 97.6	294.0 s	146.0 °C	146.5 °C
Time: 14:56:32		DP 98.7	71.0 s	132.0 °C	132.4 °C

Residue:	0.5 ml	Loss:	0.2 %	Recovery:	99.3 %
Total Recovery:	99.5 %	P:	101.2 kPa		

Navigation: 1/100

OptiPMD Micro Distillation

Micro-Distillation of Petrochem Streams

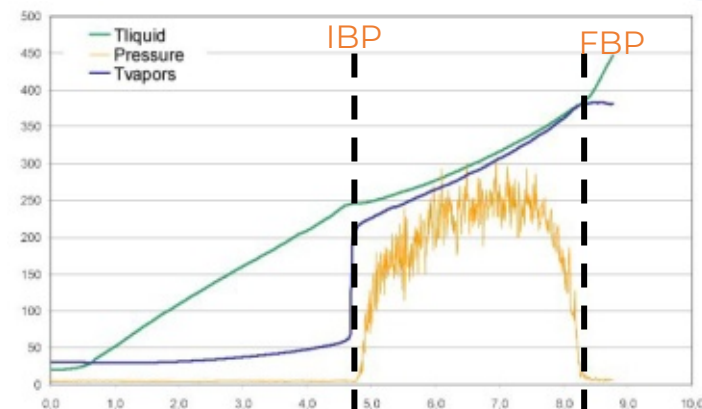
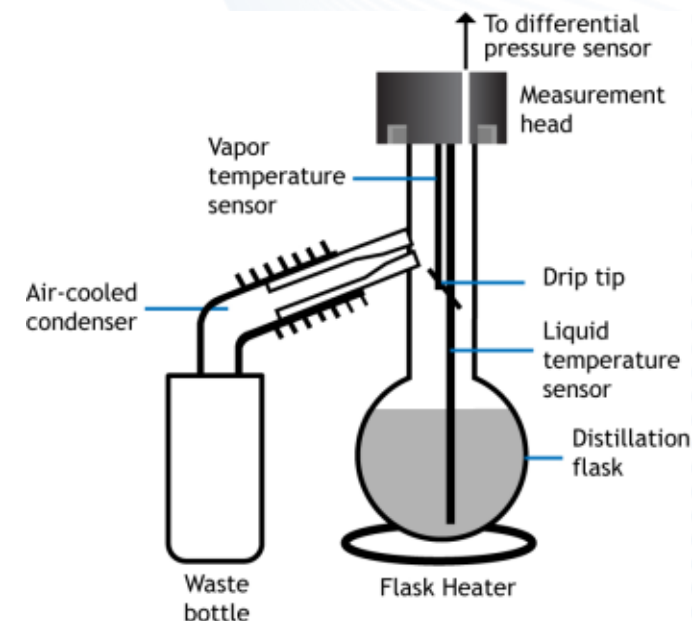
OptiPMD

- Analysis of petrochemical samples, gasoline, gasoline blends, jet fuel, diesel, and biodiesel.
- Compliant with: ASTM D7345 and IP 596
- In perfect correlation to: ASTM D86, D1160, ISO 3405 & IP123
- Included in at least ten ASTM fuel specifications as an alternative to D86.



OptiPMD for Micro-Distillation

- Measurement principle uses data from liquid to vapor evaporation
 - Same flask, heater, condenser
- Eliminates condensation from measurement
- Volume not physically measured
- Algorithm based on pressure and temperature
- Previous generation instrument in use since 2005, same analytical engine with modernized interface



OptiPMD for Micro-Distillation

Greatly reduced emissions
1-button operation

Results in
10
minutes

10
mL sample

More than
10
Fuel Specs





Manish Kalika

Product Manager | Elemental Analysis



Biofuels in transportation

- Biofuel components:
 - Gasoline → Ethanol  2033
 - Diesel
 - Fatty acid methyl esters (FAME) and /or
 - hydrogenated vegetable oils (HVO)  2050
- Shipping: Methanol is an option to meet long term targets
- Aviation: SAF

Source:
S&P Global – Commodity Insights –
Annual strategic Workbook 2023

Featured Solutions

Total Sulfur & Nitrogen analysis
FT-IR analysis

Total Sulfur and Nitrogen Analysis

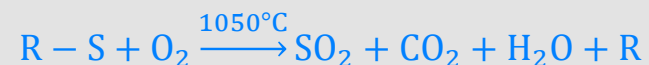
ElementS

- Combustion analyzer for (simultaneous) analysis of total sulfur and/or total nitrogen in 1 single run
- Based on UV Fluorescence (Sulfur) and Chemiluminescence (Nitrogen)
- Solution for Solids, Liquids and Gas analysis in one single instrument.
- Availability of vertical and horizontal configurations

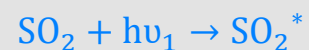


Measuring Principle

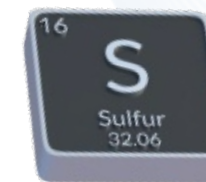
Oxidation:



Excitation (UV abs.):



Emission (Fluoresc.):



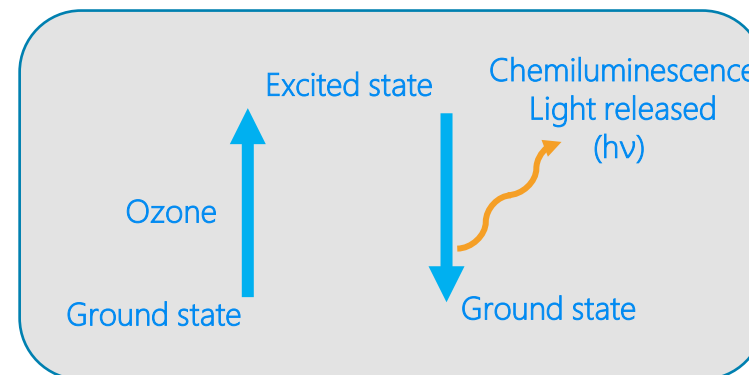
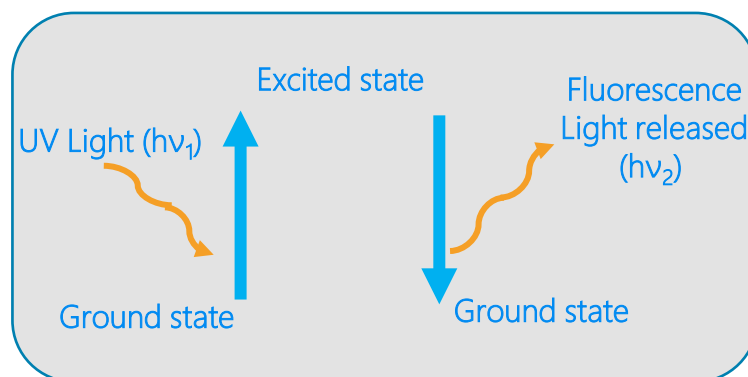
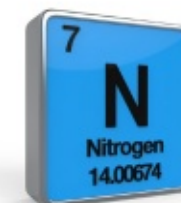
Oxidation:



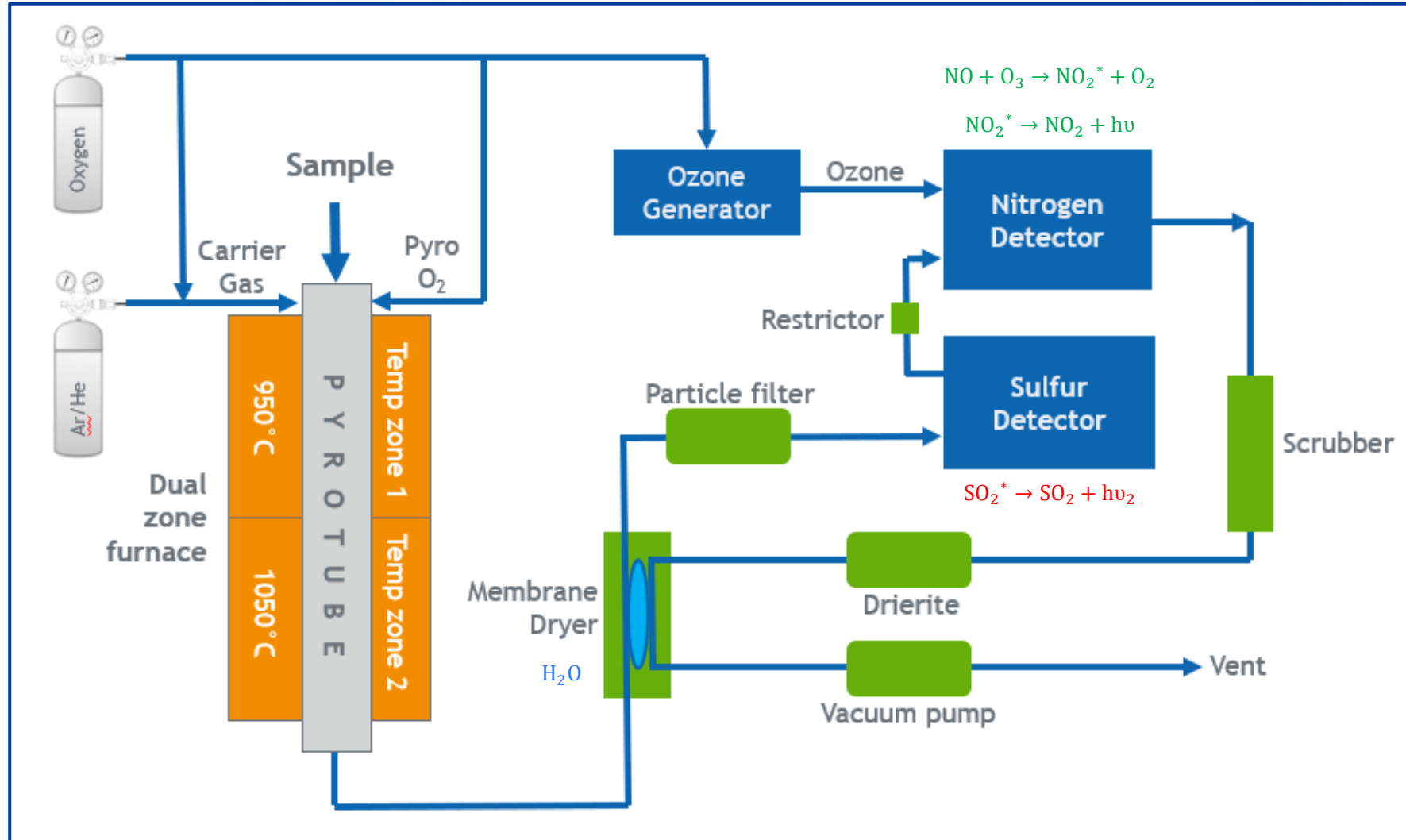
Excitation:



Emission:



Simplified System Diagram

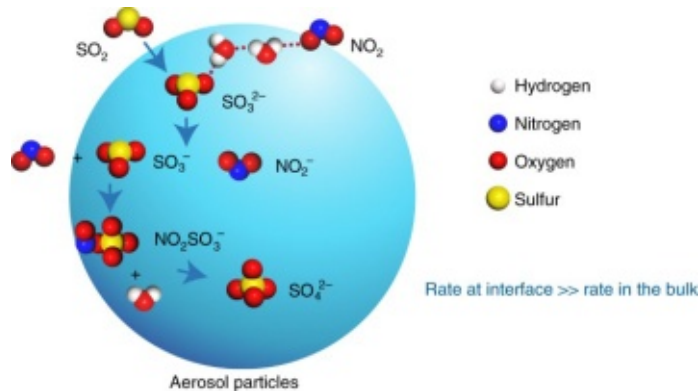


Why would you measure sulfur and nitrogen?

Reduce emissions



Prevent corrosion



Ref: Oxidation of sulfur dioxide by nitrogen dioxide accelerated at the interface of deliquesced aerosol particles, Nature Chemistry

ElementS and Renewables

Sulfur and Biodiesels (ASTM D5453)

- 1st and 2nd Generation Feedstock
- Intermediate blending components (FAME & EtOH)
- End-products: Gasoline, Diesel, SAF
- No oxygen interference as compared to X-Ray analysis

Nitrogen in SAF blending components (ASTM D4629)

- ASTM D7566 states a max. limit of 2 mg/kg nitrogen in SAF blending components.
- Precision for Nitrogen in SAF samples



Key Takeaways



Complete scope of biofuels analysis

- Solids
- Liquids
- Gases

Compliance

- Well known sulfur and nitrogen test methods
- Meet and exceed

Fast commissioning

- Factory tested
- Start-up kit

Large sample throughput

- Liquid autosampler
- Boat inlet drive
- Analysis time of 5 min.

Oxygen correction?

- Combustion analyzer
- No oxygen correction needed
- X-Ray technique does



We can provide demonstrations and the analysis of your samples, so you can observe the performance of our Sulfur and Nitrogen analyser yourself.

Featured Solutions

Total Sulfur & Nitrogen analysis
FT-IR analysis

FT-IR Analysis of Renewables

OptiFuel

- Fully Calibrated for multi-parameter analysis upon delivery
- Superior precision and accuracy for compliance and correlation methods.
- Easy to Use One Button testing for efficient and reliable results.
- Robust and Rugged for all lab environments



OptiFuel and Renewables

FAME – Biodiesel Analysis in Diesel

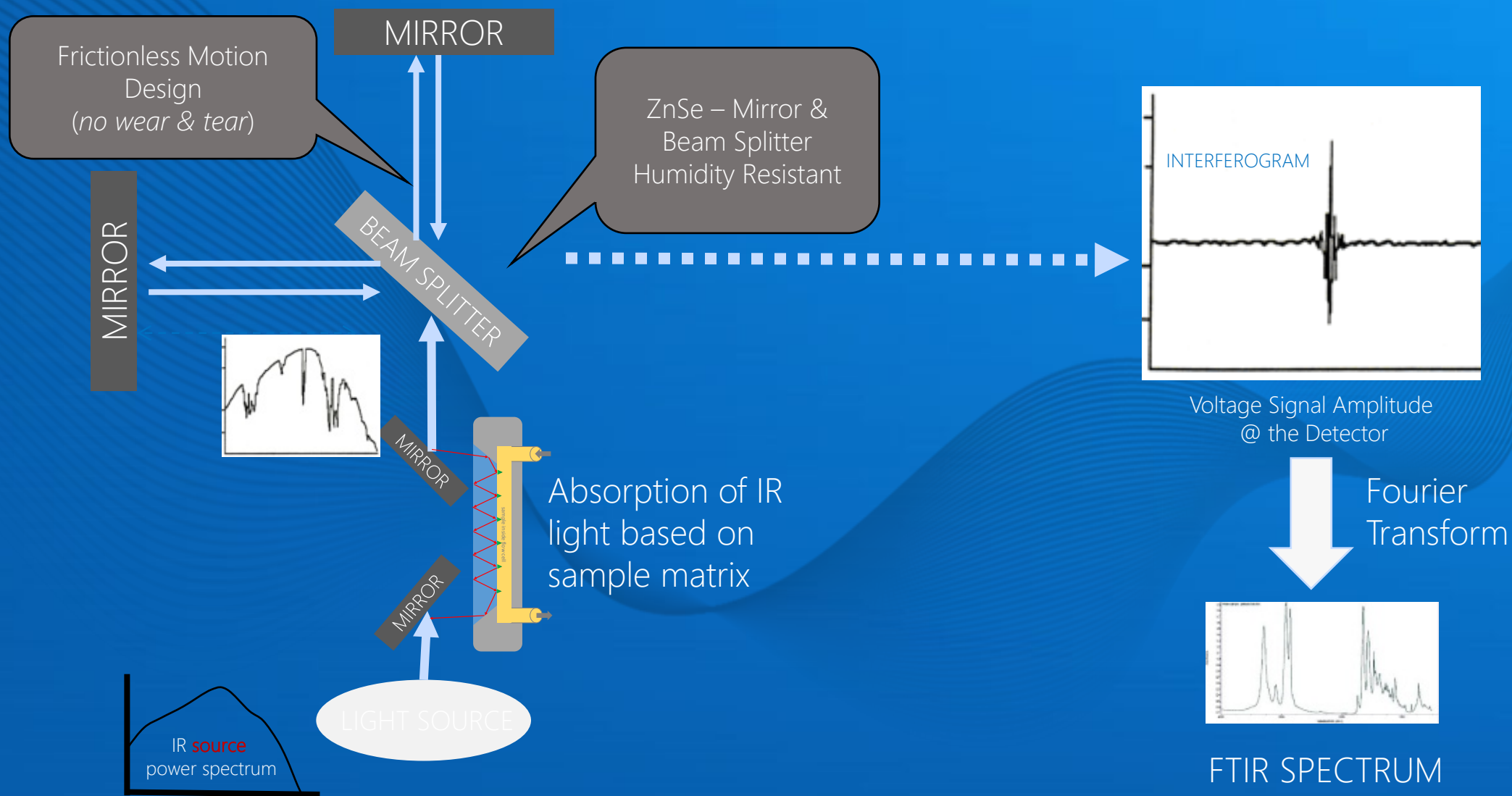
- D7371 Compliant
- 3-Tiered Calibration Matrix
 - 0 – 10%
 - 10 – 30%
 - 30 – 100%
- Compatible with Soy, Tallow, and Palm Oil
- Perfect for biodiesel - blend analysis



EtOH + MTBE + ETBE Analysis in Gasoline

- ASTM D5845 & D4814 Compliant
- Equipped with Interference Calibration Matrix
- Oxygenate breakdown in <3 minutes
- Certify gasoline and blends with D8340

Interferometer Technology



OptiFuel Unique Features

Near-Zero Downtime

10-year Warranty on Interferometer

5-year Warranty on Light Source

Regional Model Calibration Update

On-site Model Calibration Transfer

Performance

Humidity Resistant ZnSe Mirrors & Beam Splitters

Cube Corner Mirror Design

No Partial Vaporization of Samples

Non-Moving Measurement Cell

Ease-of-Use

One-Button Push Turn-Key Solution + Low Sample Volume

Measurement of Gasoline & Diesel in One & under 3 min.

Fume Sensor and Real-Time Safety Monitoring

Auto Leak Function & Filter Replacement Notification

FAME & EtOH Model Performance

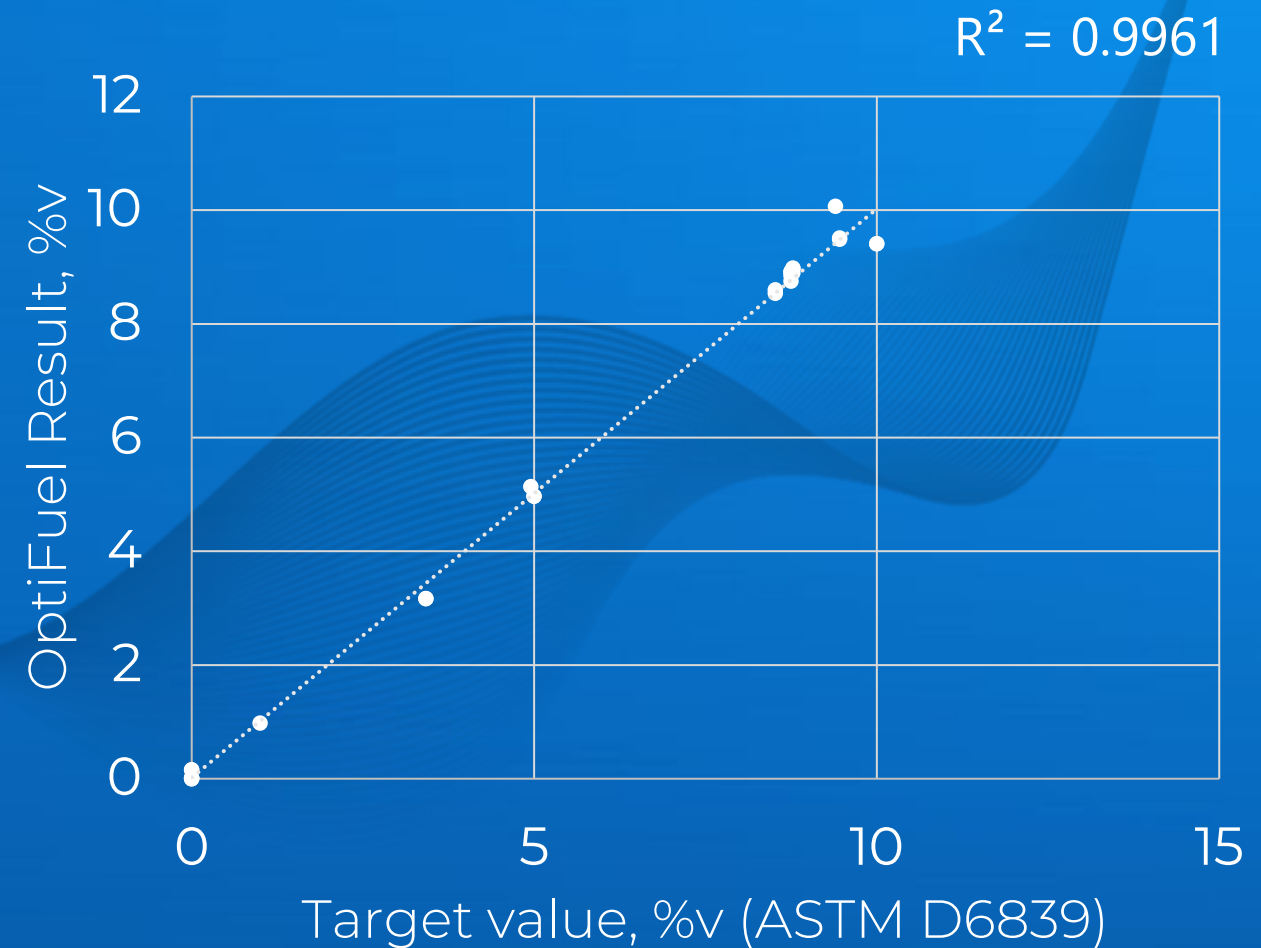
5% FAME Performance

Sample ID	FAME (%m)	Theoretical FAME (%v)	FAME (%v)	%Error
5% Tallow R1	4.97	4.80	4.94	-2.93
5% Tallow R2	4.97	4.80	4.94	-2.93
5% Palm R1	5.00	4.82	4.98	-3.15
5% Palm R2	5.00	4.82	4.98	-3.15
5% Soy R1	5.00	4.63	4.81	-3.80
5% Soy R2	5.00	4.63	4.80	-3.60

70% FAME Performance

Sample ID	FAME (%m)	Theoretical FAME (%v)	FAME (%v)	%Error
70% Tallow R1	69.59	68.80	69.24	-0.64
70% Tallow R2	69.59	68.80	69.23	-0.62
70% Palm R1	70.00	69.18	69.94	-1.08
70% Palm R2	70.00	69.18	69.93	-1.07
70% Soy R1	70.00	68.67	70.50	-2.60
70% Soy R2	70.00	68.67	70.50	-2.60

Ethanol PTP samples on OptiFuel





Mango Ng

Product Manager | Gas Chromatography

GC Use in Aviation Fuel Testing

In general, the same properties and tests are used in both standard Jet Fuel and Sustainable Aviation Fuel



GC Use in Aviation Fuel Testing

Traditional testing methods:

- GC for Simulated Distillation
- GC for FAME content
- GCxGC for composition

Simulated Distillation

D2887 can be used as an alternative to D86 (traditional distillation)

- Advantage to using D2887 is a true BP distribution where as D86 is a low-efficiency test (D1655: pg 13... section X1.6 Fuel Atomization)

GC with programable TPI inlet and FID.

- Additional software, SimDis XLNC can be used to calculate correlations to D86

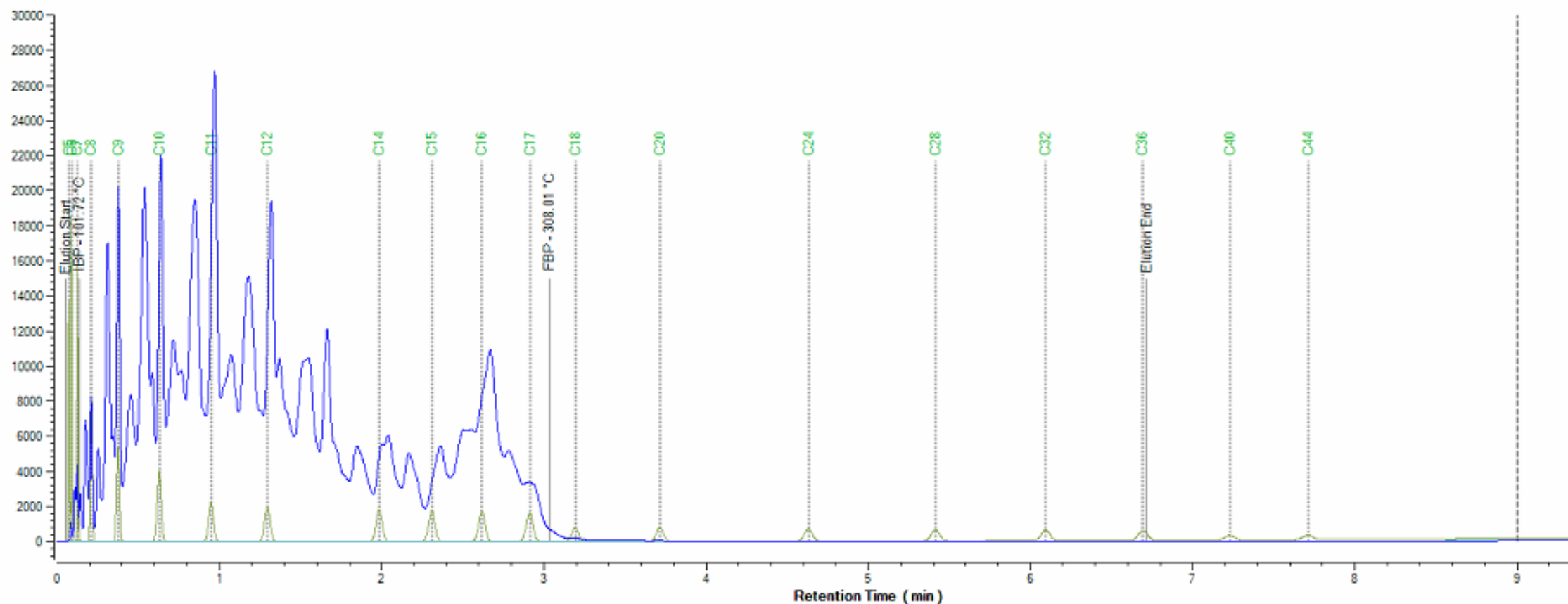
X1.6 Fuel Atomization

X1.6.1 Distillation—The fuel volatility and ease of vaporization at different temperatures are determined by distillation. The 10 % distilled temperatures are limited to ensure easy starting. The Final Boiling Point limit excludes heavier fractions that would be difficult to vaporize.

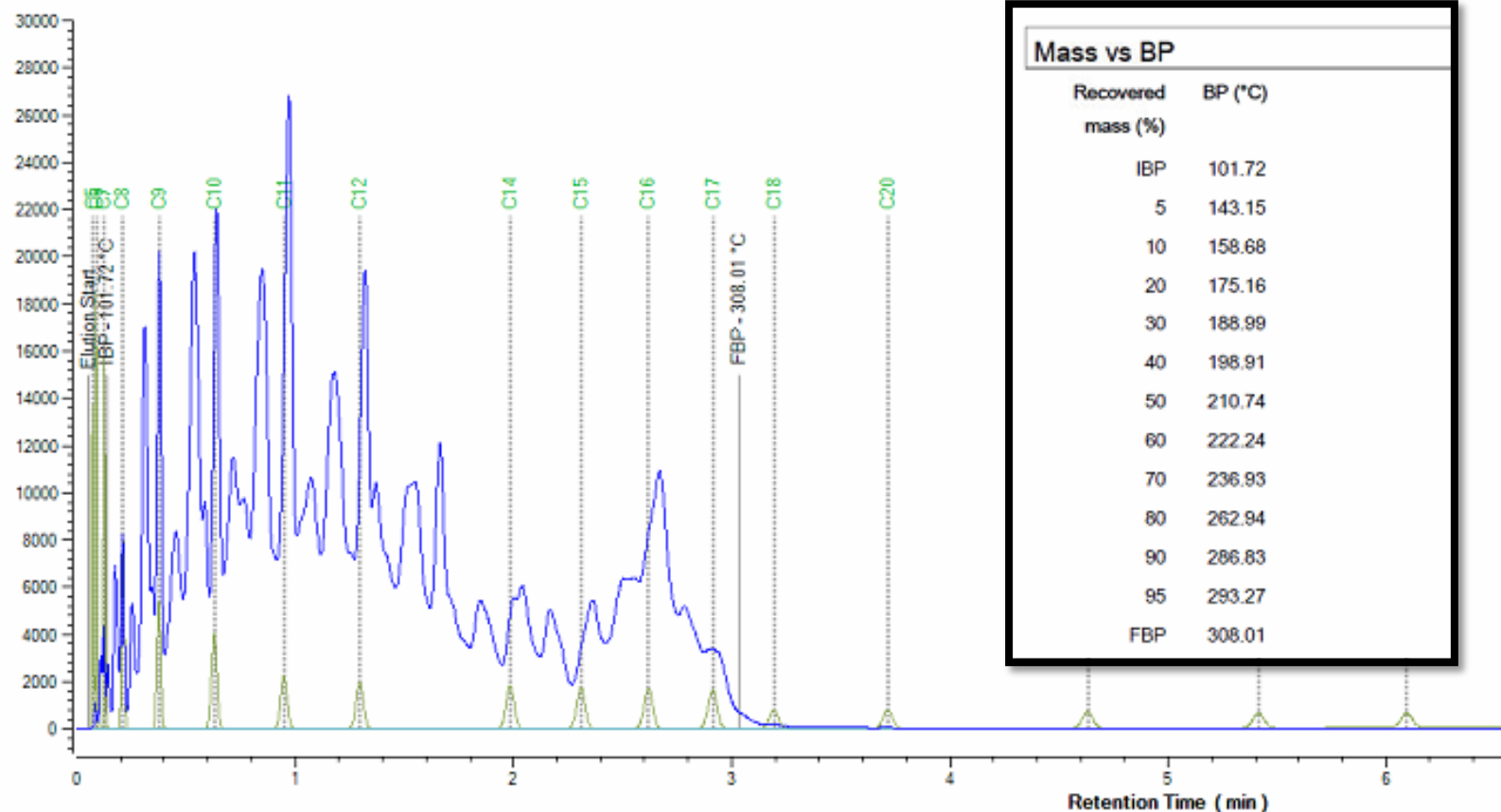
X1.6.1.1 Results from Test Method **D7344** and **D7345** shall be corrected for relative bias by applying the GRP4 corrections in each of the test method's Precision and Bias section. Test Method **D86** or IP 123 and Test Method **D2887/IP 406** do not give the same numerical results. Test Method **D2887/IP 406** always starts at a lower temperature and ends at a higher temperature than Test Method **D86** or IP 123 because Test Method **D2887/IP 406** gives true boiling point distribution (similar to Test Method **D2892**), as opposed to Test Method **D86** or IP 123, which is a low efficiency distillation. To avoid



Chromatogram with BP



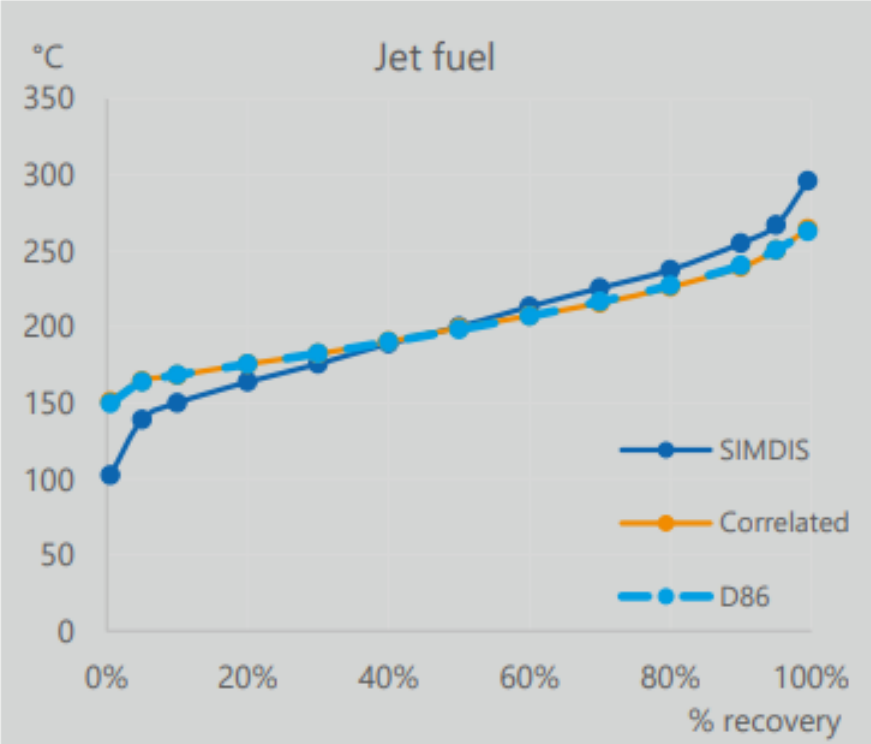
Chromatogram with BP



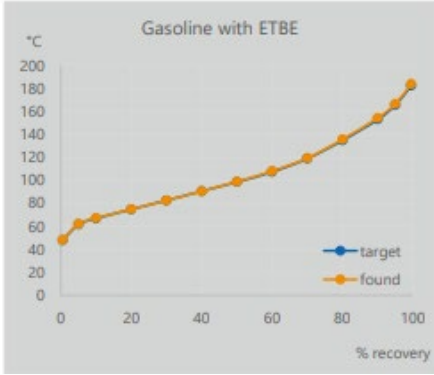
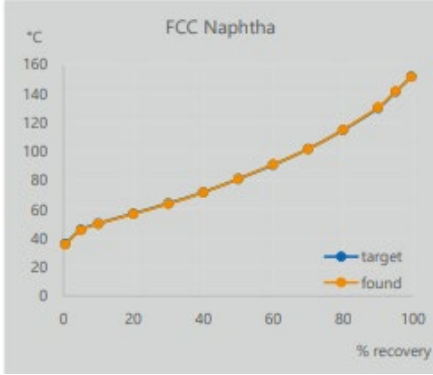
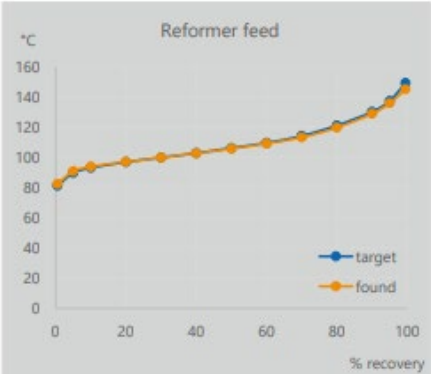
Elution End C36 C40 C44

ASTM D86 Correlation (STP577) (Vol vs BP)	
Recovered	BP
Vol (%)	(°C)
IBP	152.53
5.00	169.06
10.00	177.10
20.00	187.21
30.00	194.29
50.00	207.96
70.00	234.35
80.00	251.17
90.00	267.59
FBP	280.78

Correlation of SIMDIS to D86



% evaporated	SIMDIS	Correlated	D86	delta
0.5%	102.40	151.0	149.7	-1.3
5.0%	138.99	164.4	163.9	-0.5
10.0%	150.02	168.1	168.4	0.3
20.0%	163.80	175.6	175.5	-0.1
30.0%	175.65	182.3	182.5	0.2
40.0%	188.98	190.4	190.1	-0.3
50.0%	200.11	199.3	198.3	-1.0
60.0%	213.4	207.3	207.1	-0.2
70.0%	225.54	215.7	216.7	1.0
80.0%	237.55	226.2	227.2	1.0
90.0%	255.04	239.4	240.4	1.0
95.0%	266.99	250.5	250.6	0.1
99.5%	295.99	264.5	262.8	-1.7



FAME in AVTUR

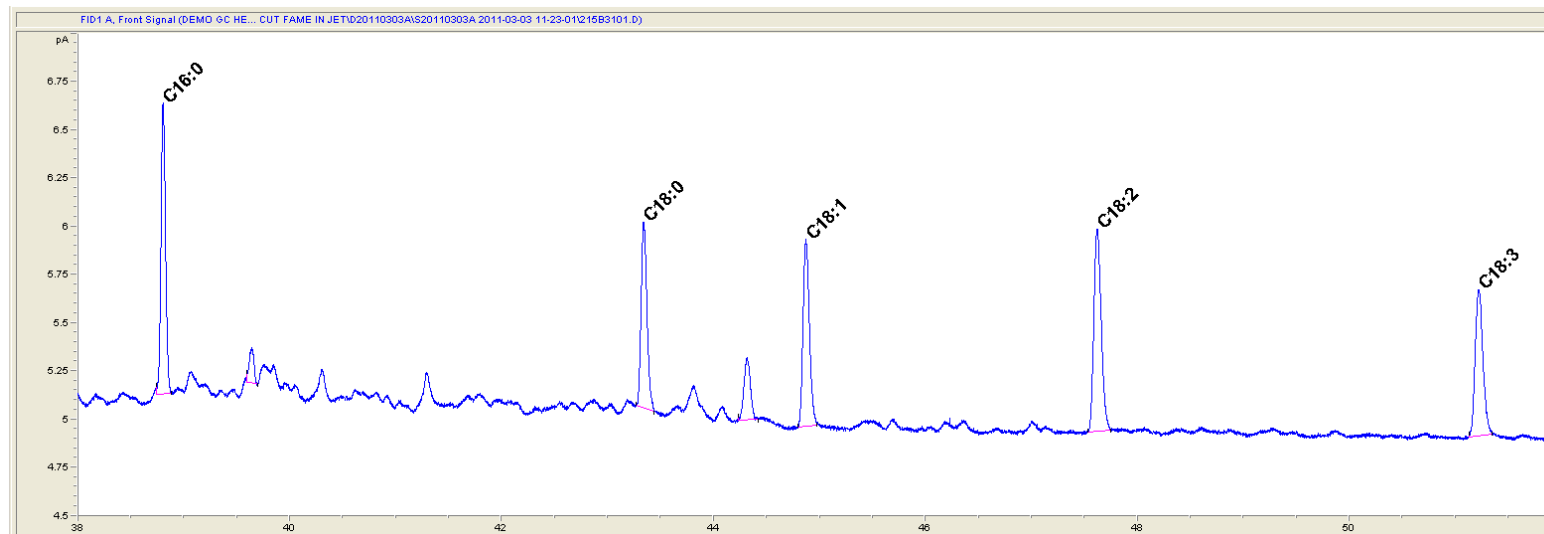
FAMEs in Aviation Turbine Fuel

IP599 is allowed per D1655 as an alternative to FTIR, GC-MS, and HPLC-ELSD

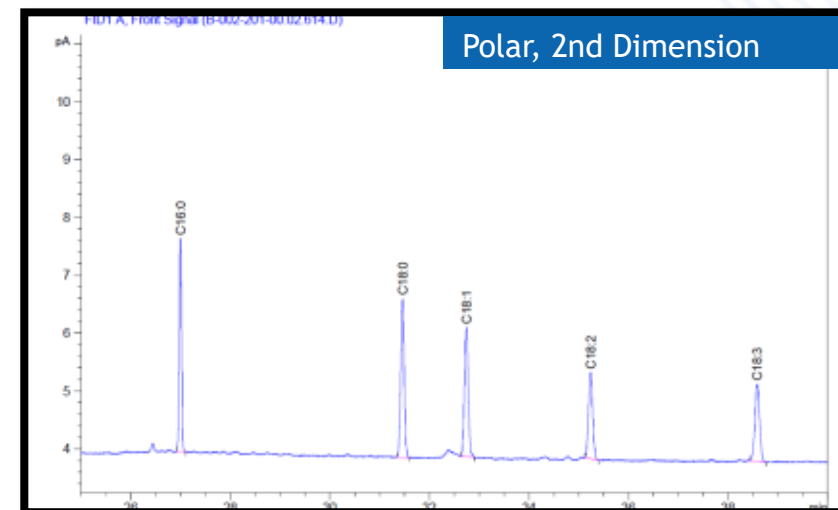
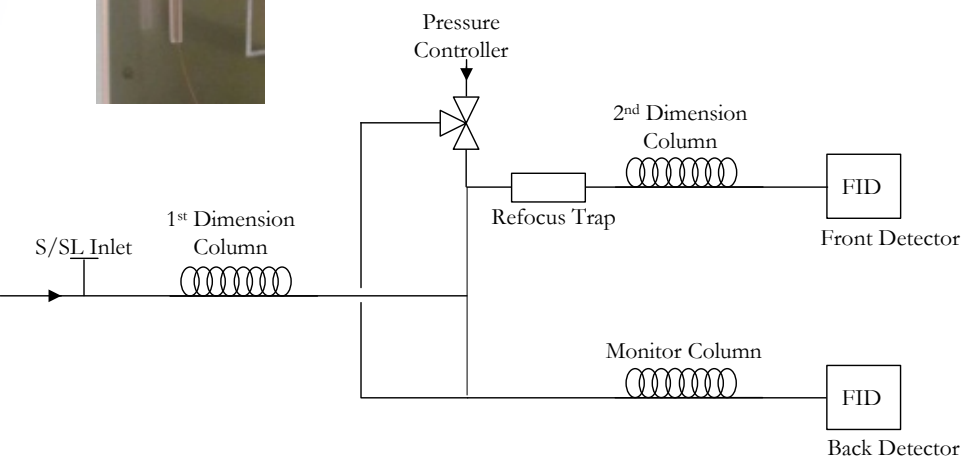
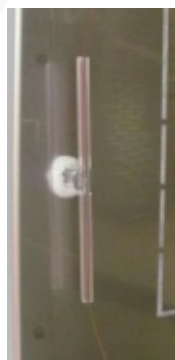
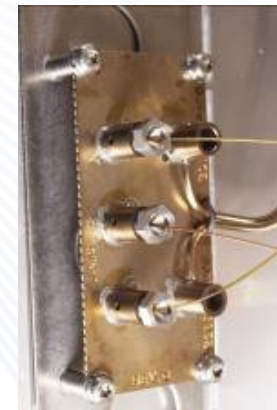
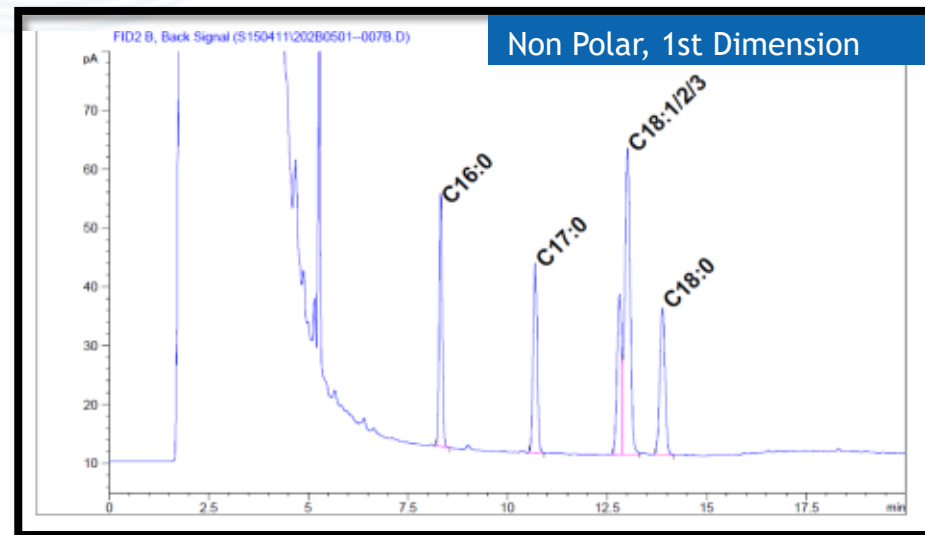
TABLE 3 Identified Incidental Materials

Material	Permitted Level	Test Methods ^A	
		Referee	Alternative
Fatty Acid Methyl Ester (FAME), ^B max	50 mg/kg ^{C,D}	IP 585	D7797/IP 583, IP 590, IP 599
Pipeline Drag Reducing Additive (DRA), ^E max	72 µg/L ^F	D7872	

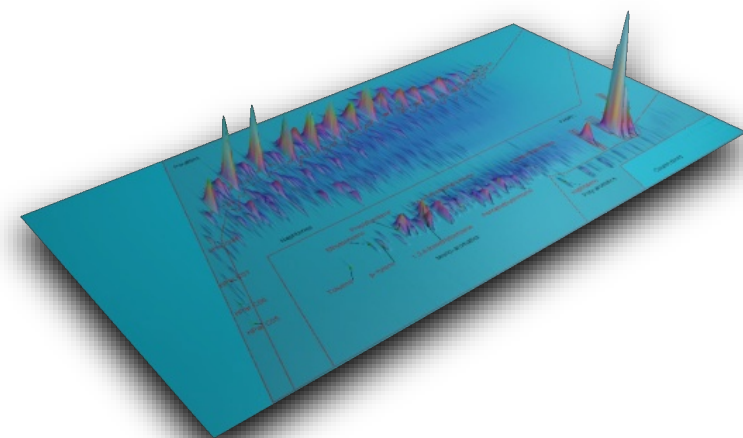
Not required to be analyzed every batch unless there is risk of contamination that would exceed the limits
GC using heart-cut and non-cryo refocusing



FAMEs in AvTur Fuel Analyzer



GC x GC Application

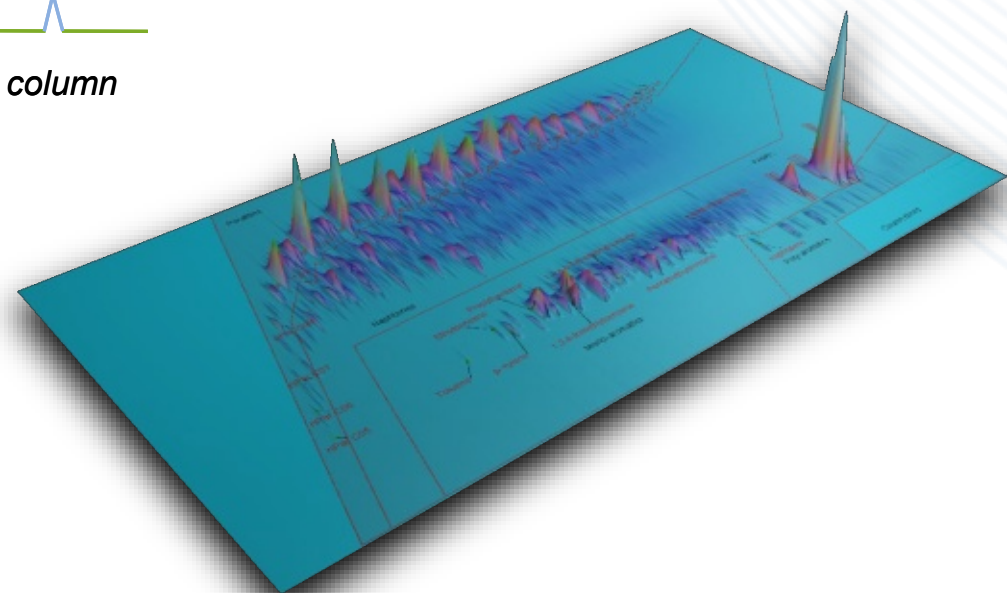
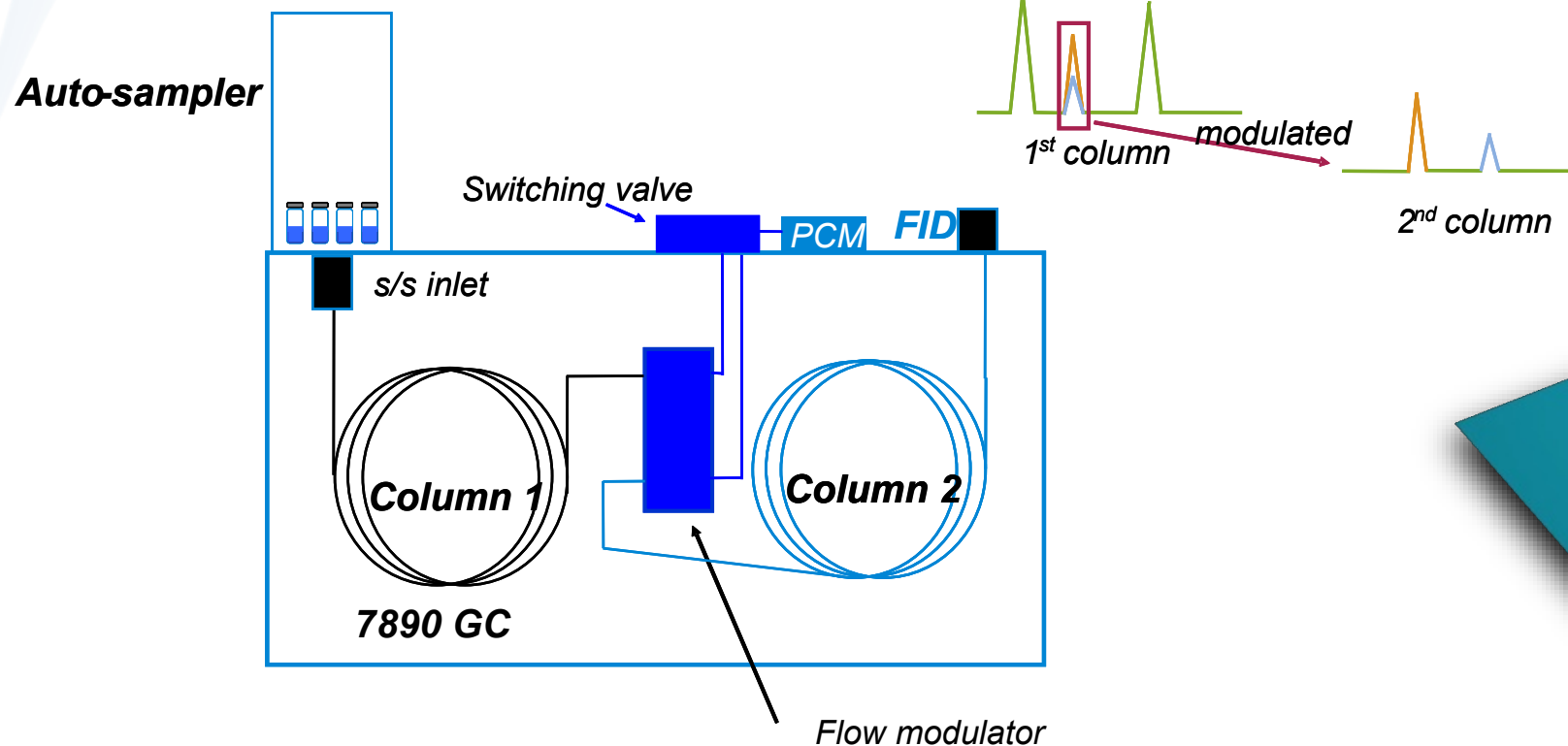


Compositional Testing by GC x GC

D8396

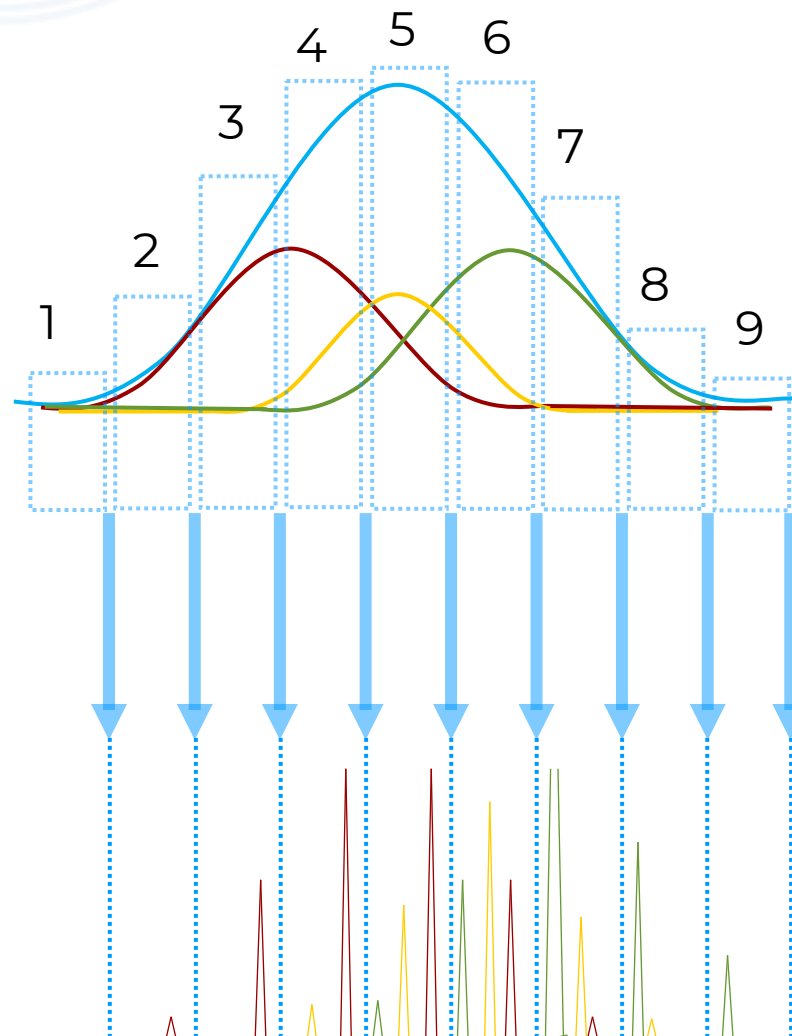
1. Scope

1.1 This test method covers the quantitative determination of total n-paraffins, total i-paraffins, total naphthenes (cycloparaffins), total one ring (1R) and total two ring plus (2R+) aromatic hydrocarbons in hydrocarbon liquids having a boiling point between 36 °C and 343 °C by GCxGC (flow modulated comprehensive two-dimensional gas chromatography). The method has been applied to aviation turbine fuels and is applicable to other low olefinic fuels in the stated boiling point range.



GC x GC Modulation Basics

1. Acquisition



1D - GC Chromatogram
at the end of the 1st column in **blue**
9 modulations shown
Coelution of 3 compounds!

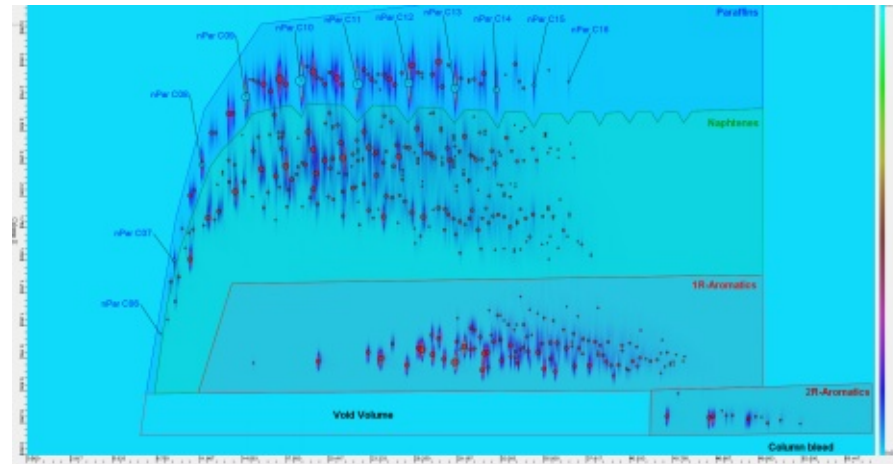
2. Transformation

Raw 2D - GC chromatograms
at the end of the 2nd column
Take “slices” of the co-eluting peaks and inject quickly to another column of different selectivity

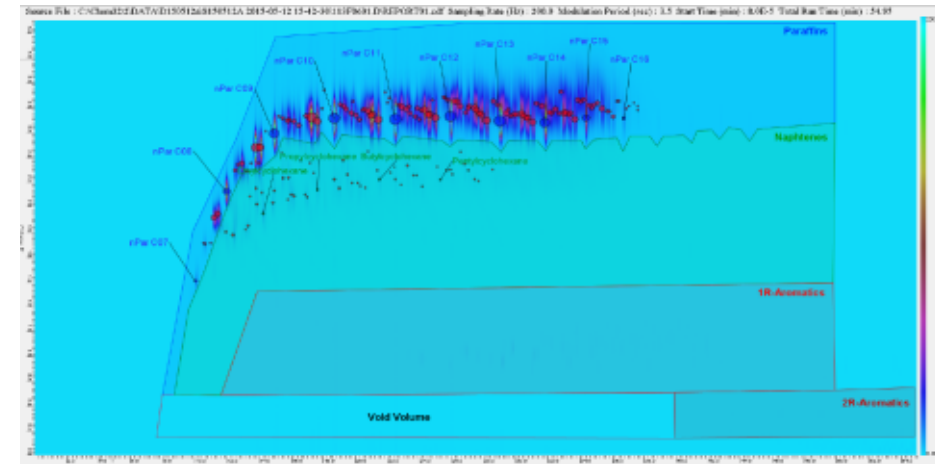
“Red” peak elutes last now
“Green” peak elutes first
All 3 completely separated!

Jet Fuel Analysis – Actual Sample Data

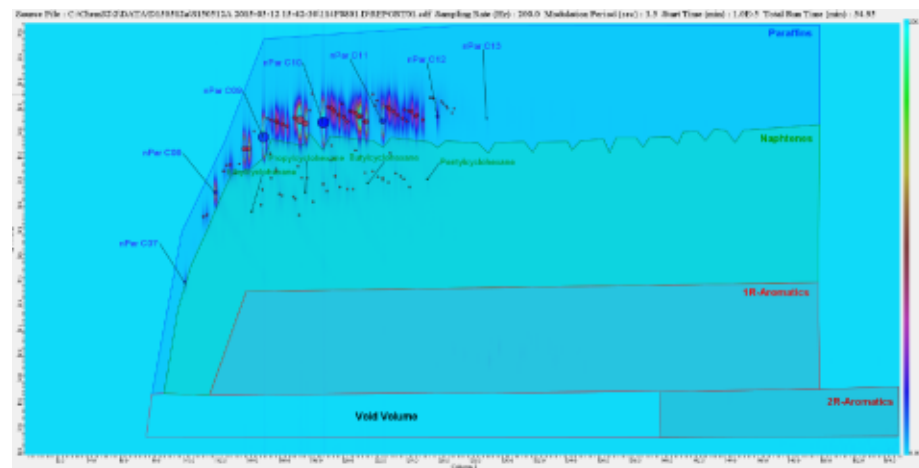
Conventional jet fuel



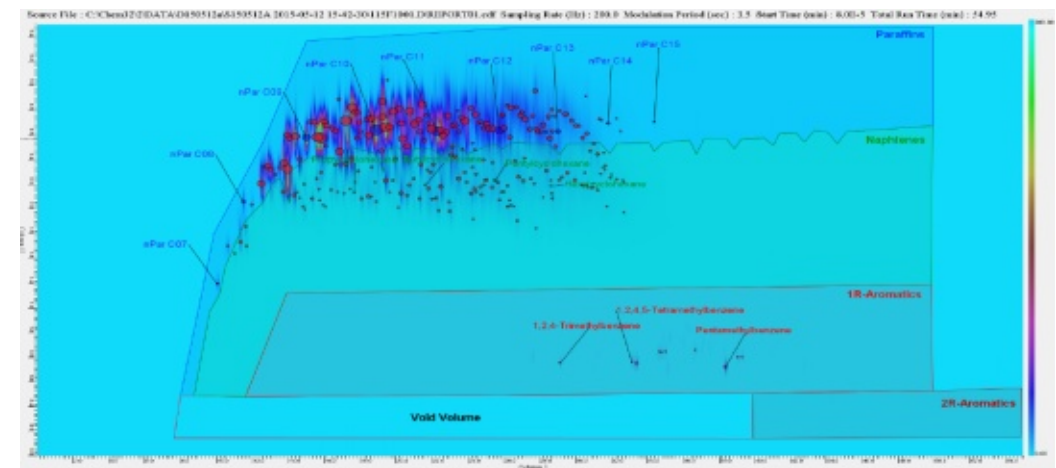
SAF SPK 5018, aromatics < 0.2%



SAF SPK 5172



SAF SPK 5642, aromatics: 0.36%



Summary

- GC application: SIMDIS, FAME in AVTUR Analyzer, GC x GC application
- Each analyzer is factory tested and comes with a start-up kit, allowing for fast commissioning.

Curious? Contact PAC for further information on the solution for GC analysis.



Karl Kuklenz

Product Manager | Process Analytics

Process Analytics



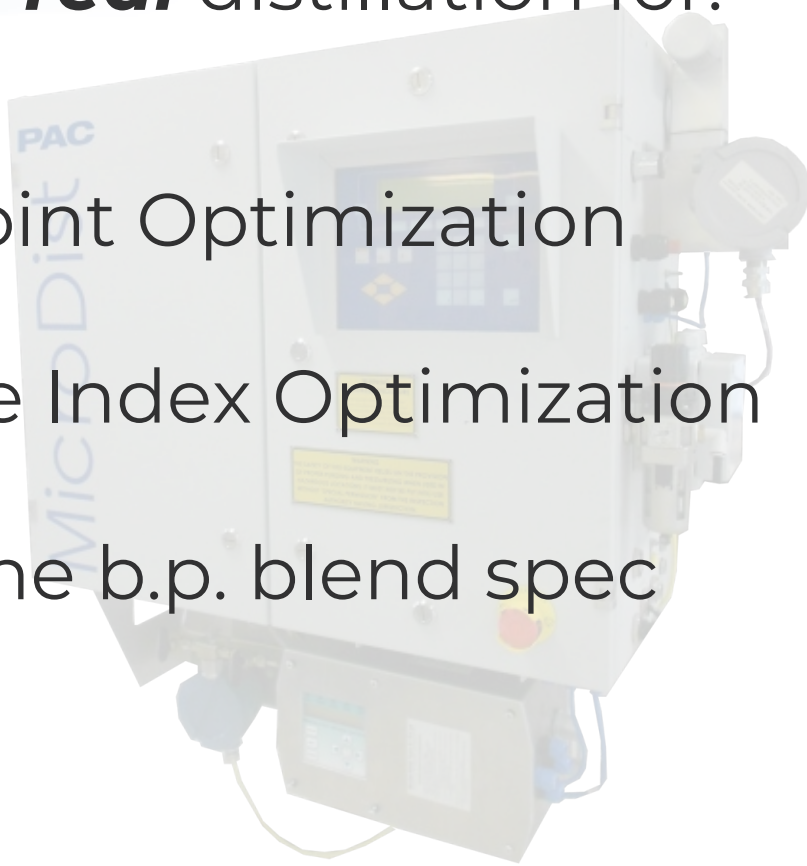
Process Analytics

Online **real** distillation for:

Cut-point Optimization

Cetane Index Optimization

Gasoline b.p. blend spec

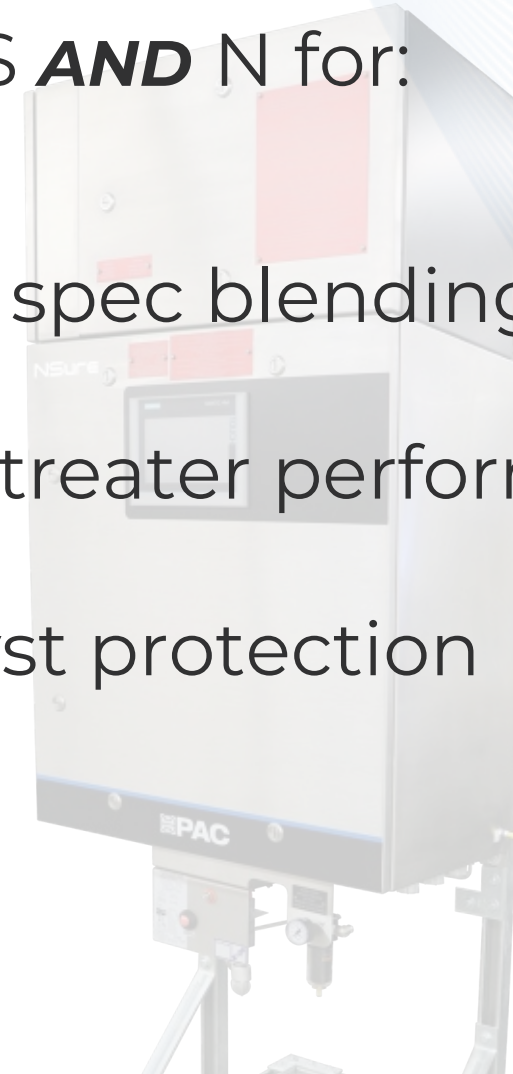


Total S **AND** N for:

Sulfur spec blending

Hydrotreater performance

Catalyst protection



The background of the slide features decorative blue wavy lines that flow from the left side towards the right, creating a sense of movement and depth.

Thank you!



Moving the World Forward, Safely and Sustainably