PAC

Fueling the Future:
The Progress of SAF Solutions for the Decarbonization of Aviation

Speakers

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Product Manager
Renewable Fuels

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Group Product Manager
Flow Behavior, R&D

Nicole Lock

Group Product Manager
Molecular & Atomic Analysis

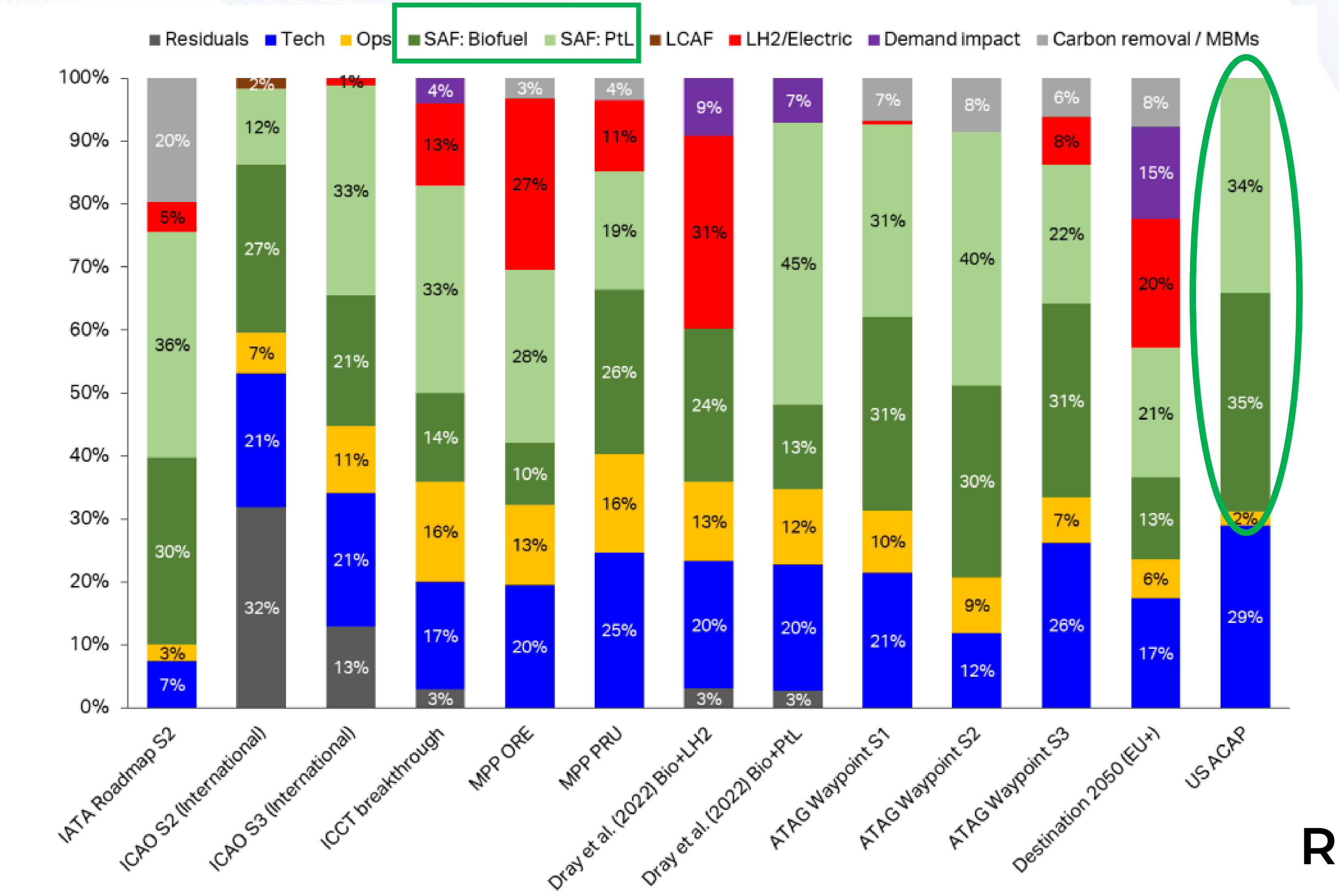
Dr. Connor Douglas

Head of Product
Process Analytics

Agenda

I. Current Market and Specification
II. Freezing point, Viscosity, Thermal Oxidation
III. Current GC methodology and how GCxGC could be the future

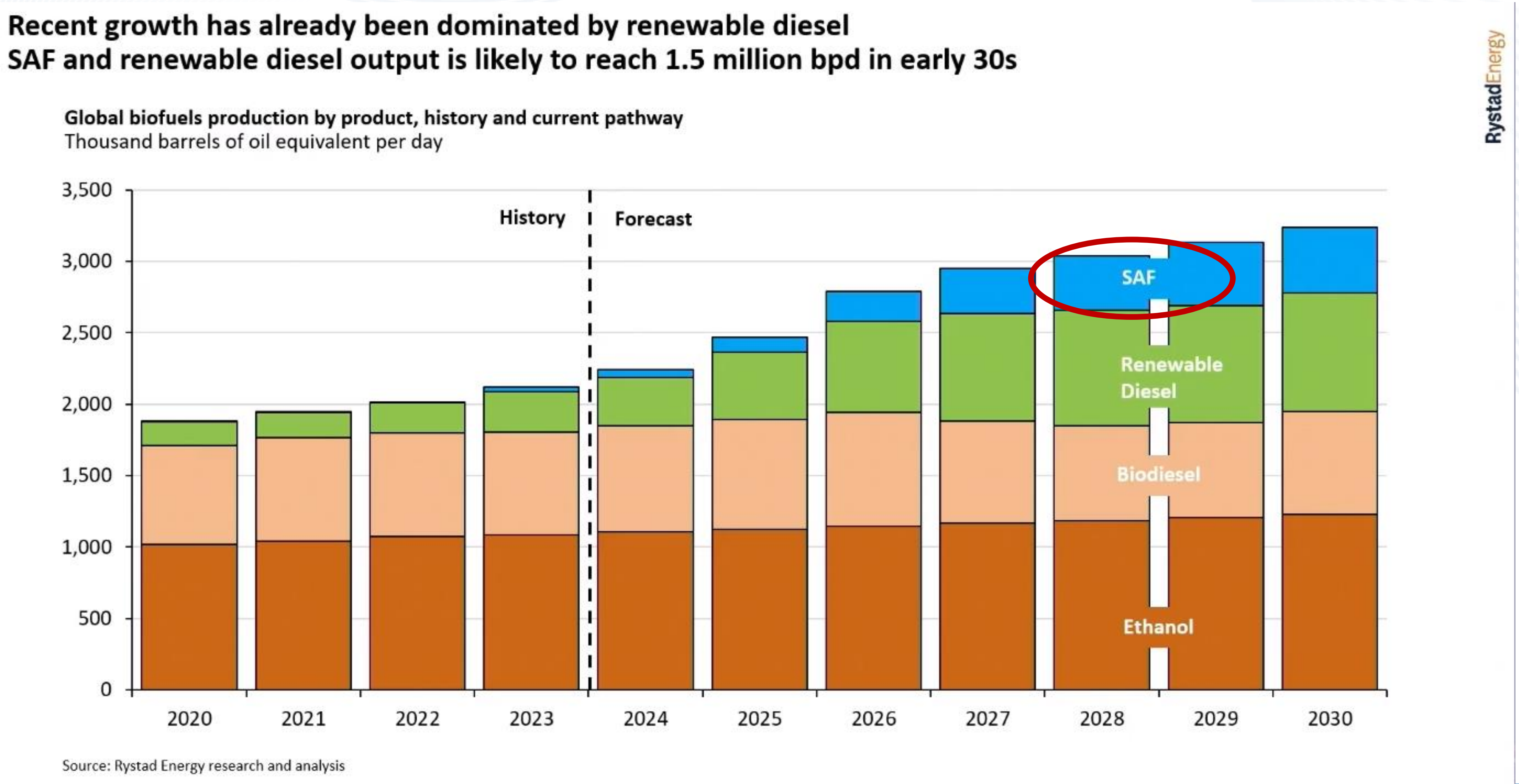
Comparative Roadmap



Ref: 2024 IATA

Growth Trajectory

Ref: 2024 Rystad Energy



Current SAF Production

Ref: 2023 IATA

Year	2019	2020	2021	2022	2023e	2024f
Estimated SAF Output (Mt)	<0.02	0.05	0.08	0.24	**0.45-0.5**** (625 million liters or 3% RF output)	1.5*** (1.875 bn liters or 6% RF output)
Global Jet Fuel (Mt)*	287	157	189	233	**286***	301
SAF % of Global Jet Fuel	<0.01%	0.03%	0.04%	0.1%	**0.2%***	0.5%

2023 SAF Production:
~0.5Mt of SAF in 2023
Average SAF output only ~3% of total Renewable Fuel output

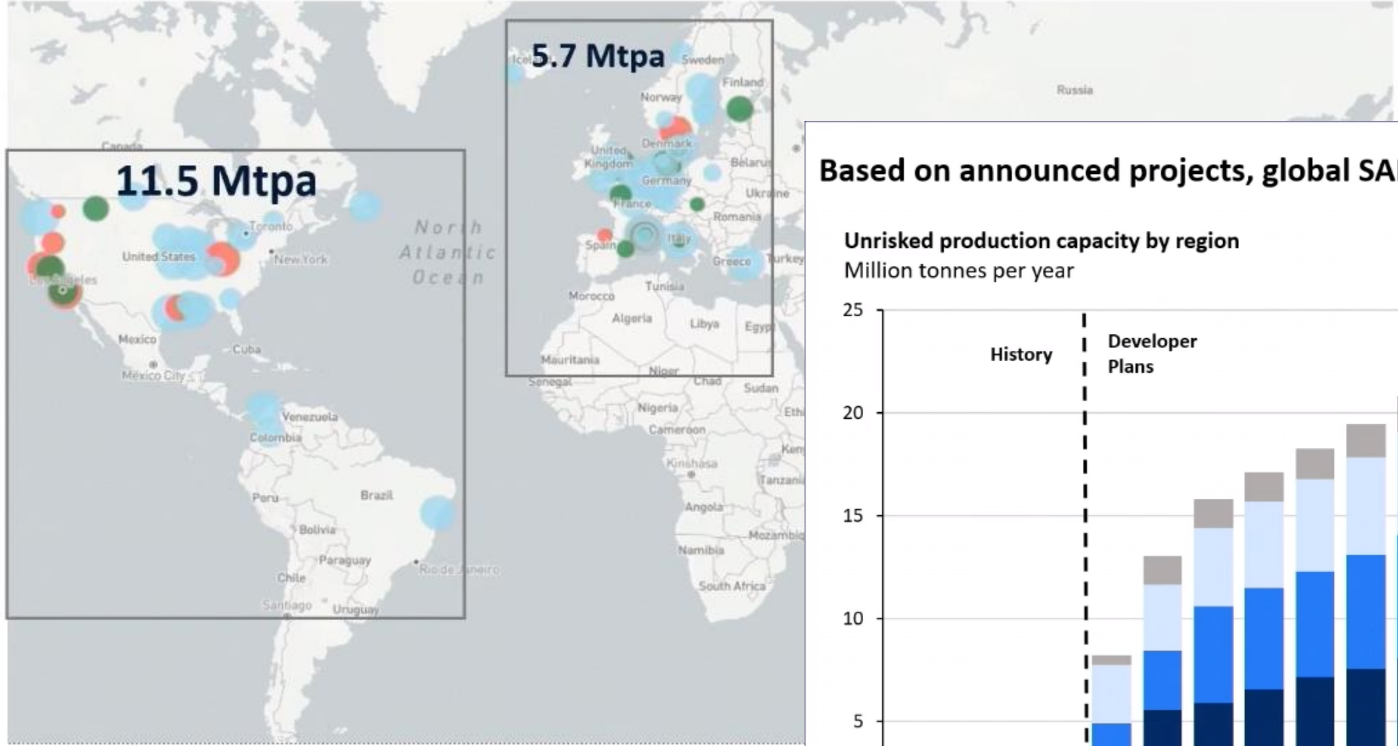
Need incentives for optimal SAF output

Future SAF Production

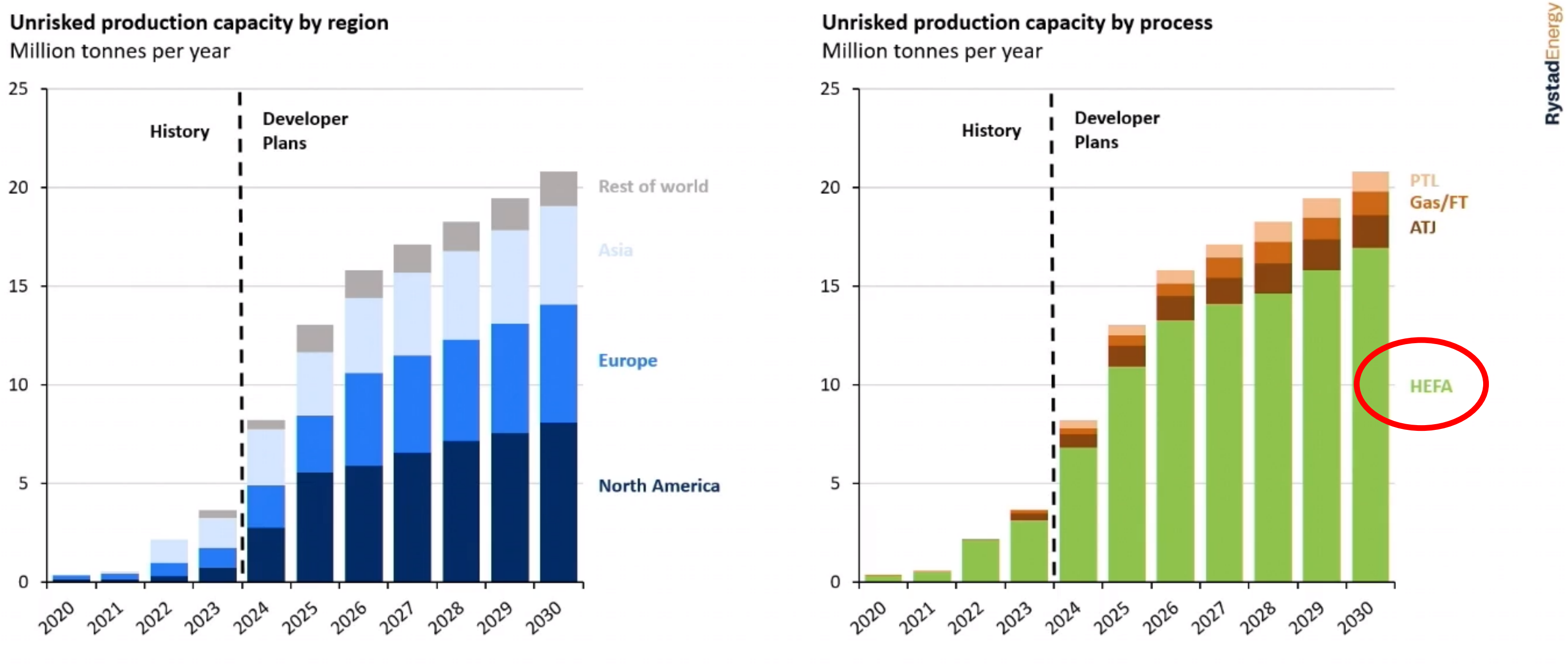
Ref: 2024 Rystad Energy

Sustainable Aviation Fuels attracted the most attention in the bioenergy space lately
~150 operational and announced projects around the world, U.S. steps up as a market leader

RystadEnergy



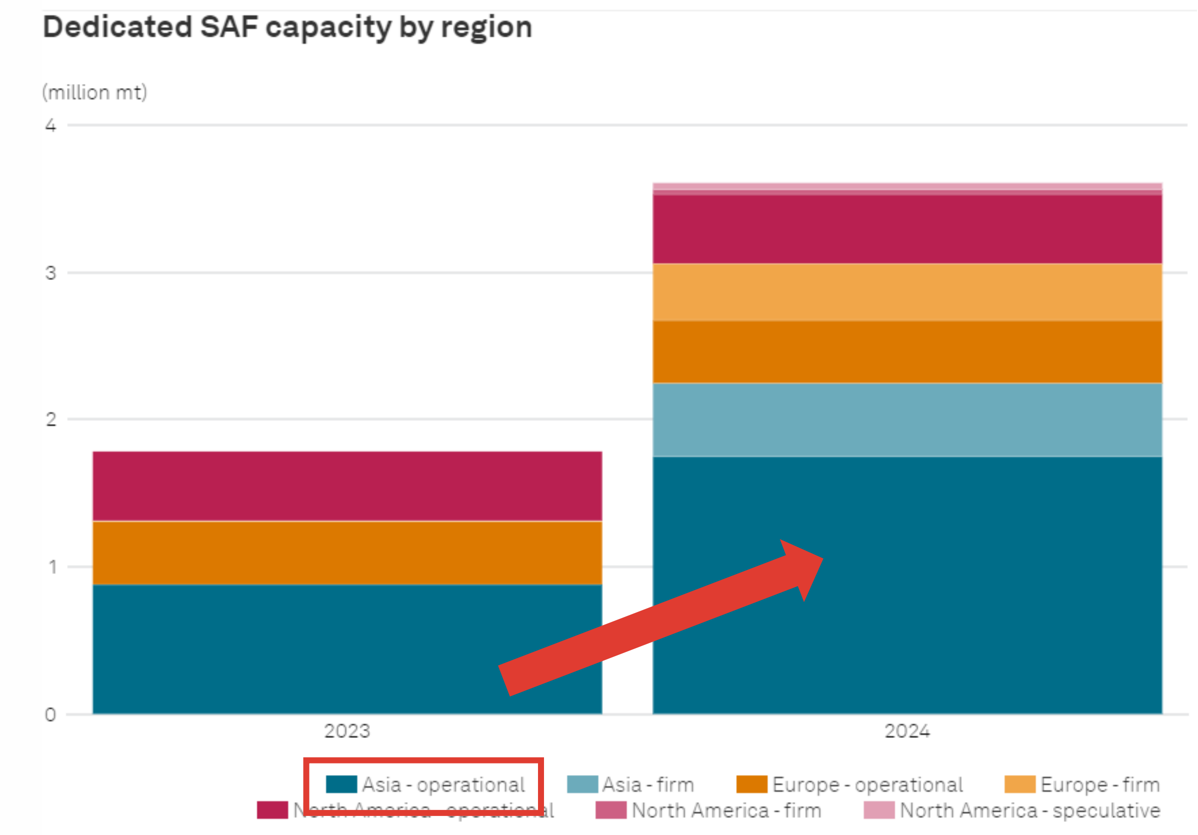
Based on announced projects, global SAF capacity might reach 20 mtpa in the second half of 20s

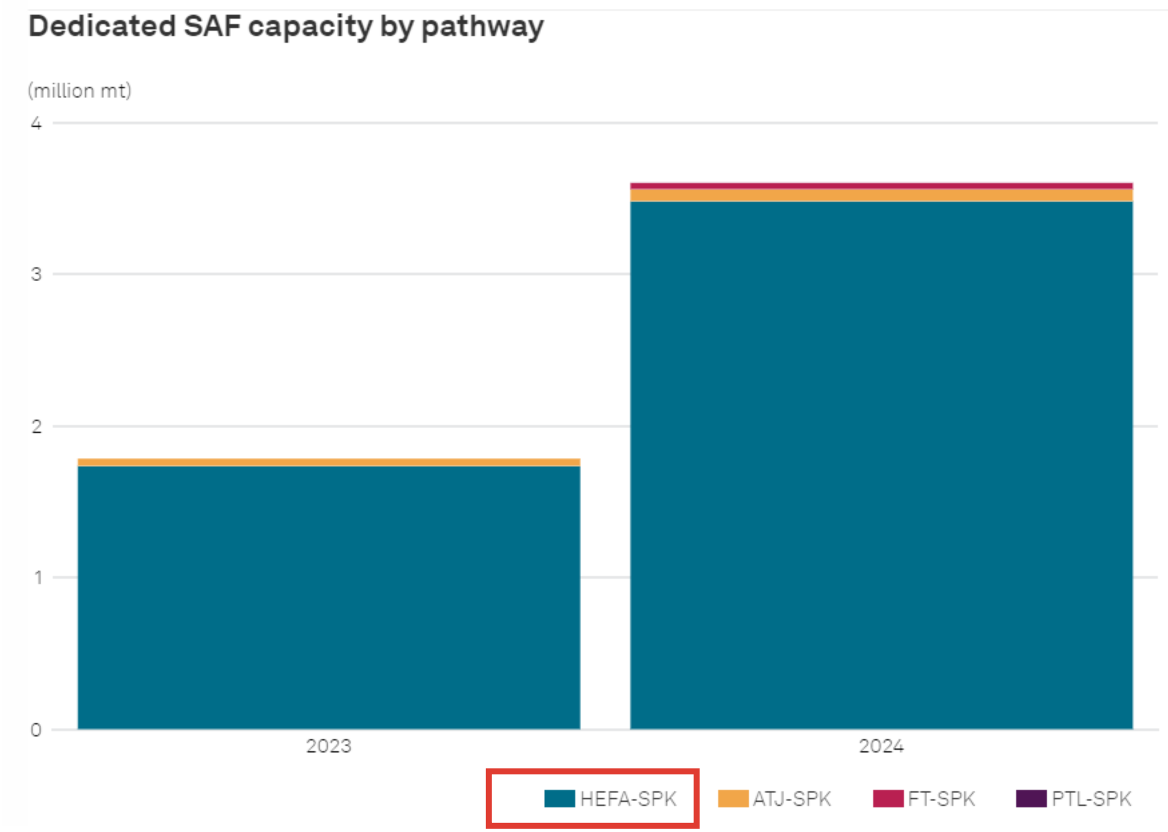


Source: Rystad Energy research and analysis

2023-4 SAF Production

Ref: 2024 S&P





ASTM D7566 Pathways

Annex	Pathway		Possible Feedstocks	Blend ratio (v)	Year of Approval	Commercialization
Annex 1	FT	Fischer-Tropsch	Coal, natural gas, biomass	50%	2009	Fulcrum, Velocys, Norsk eFuels, Infinium, Twelve
Annex 2	HEFA	hydroprocessed esters and fatty acids	Bio-oils, animal fat, recycled oils	50%	2011	World Energy, Neste, TotalEnergies, SkyNRG
Annex 3	SIP	Synthesized iso-	Biomass used for	10%	2014	TotalEnergies
Ann						
Ann						ch, Byogy, Bioenergies
Ann			camelina, carinata			
Annex 7	HC-HEFA-SPK	hydrocarbon-HEFA	Algae	10%	2020	IHI
Annex 8	ATJ-SKA	ATJ with aromatics	Biomass for alcohol production	50%	2023	Swedish Biofuels

Plant, waste fats & oils

algae

→ Hydroprocessing → HEFA-SPK

ASTM D7566 Pathways

Corn, sugarcane

Agricultural & forestry waste

→ Fermentation; ATJ: dehydration, oligomerization

→ ATJ-SPK/A

Annex	Pathway		Possible	Blend	Year of Approval	Commercialization
Annex 1						Norsk velve
Annex 2						te, NRG
Annex 3						
Annex 4	FT-SKA	Synthesized kerosene with aromatics	Coal, natural gas, biomass	50%	2015	Sasol
Annex 5	ATJ-SPK	Alcohol to jet	Biomass for alcohol production	50%	2016 (Isobutanol) / 2018 (ethanol) / 2023 (isobutene)	Gevo, Lanzatech, Byogy, Cobalt, Global Bioenergies
Annex 6	CHJ	Catalytic hydrothermolysis	Triglycerides: soybean, jatropha, camelina, carinata	50%	2020	ARA
Annex 7	HC-HEFA-SPK	hydrocarbon-HEFA	Algae	10%	2020	IHI
Annex 8	ATJ-SKA	ATJ with aromatics	Biomass for alcohol production	50%	2023	Swedish Biofuels

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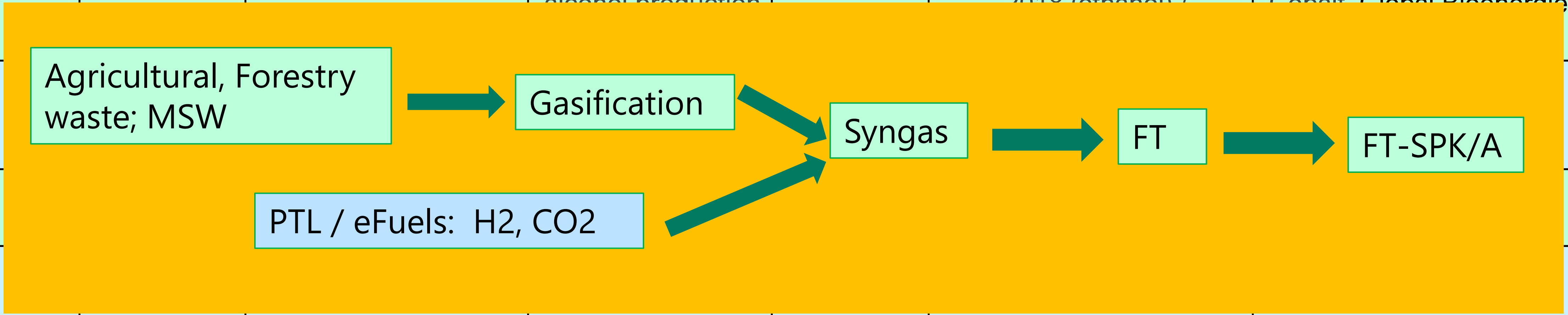
Annex 6						
Annex 7						
Annex 8						



Recent Trends

1. Airlines/Airport/Fuel traders + SAF producers : Offtake Agreements
    1. Southwest & P66 Rodeo; Air New Zealand & Neste, Ryanair & ENI, IAG & Twelve (PTL)
    2. Sumitomo + JX Nippon & Strategic Biofuels (Louisiana)]
    3. Jet2 & Shell (Stansted)
2. Direct Investments from airlines
    - Southwest – SAFFiRE Renewables (ATJ), LanzaJet
3. Oil Companies + Agribusiness partnership
    1. Diamond Green = Valero & Darling Ingredients
    2. Repsol & Bunge; ENI in Africa
    3. Bangchak & Sumitomo, BBGI; Idemitsu & Zen-noh Grain corp.
    4. Cargill (Heartwell); Ecoceres
4. National & regional green fuel standards
    - New Jersey, New Mexico, Nebraska
5. Search for new feedstock
    - Camelina, cover crops, marginal crops
6. New analytical challenges and Solutions

Freezing Point & Viscosity

ASTM Specifications

- SAF (SATF)
  - Co-Processed (up to 5% vol)
    - D1655
      - Table 1 Standard Requirements
      - Table A1.1 Extended Requirements
  - Blended (up to 50% vol)
    - D7566
      - Table 1 Part 1 Standard Requirements
      - Table 1 Part 2 Extended Requirements

*Part 1 & 2 to be combined

Co-Processed SAF – ASTM D1655

D1655 – 23a

TABLE 1 Detailed Requirements of Aviation Turbine Fuels[A]

Property		Jet A or Jet A-1	Test Methods[B] Referee	Alternative
Freezing point, °C	max	−40 Jet A[M,N] −47 Jet A-1[M,N]	D2386/IP 16	D5972/IP 435, D7153/IP 529, or D7154 or IP 528
Viscosity −20 °C, mm²/s[O]	max	8.0	D445 or IP 71, Section 1	D7042[P] or D7945

PHASE TECHNOLOGY

Innovations in phase analysis solutions

TABLE A1.1 Extended Requirements of Aviation Turbine Fuels Containing Co-hydroprocessed Esters and Fatty Acids, Fischer-Tropsch Hydrocarbons, or Hydrocarbons from Esters and Fatty Acids[A, B]

Property		Jet A or Jet A-1	Test Methods[C] Referee	Alternative
Viscosity −40 °C mm²/s[G]	max	12.0	D445 or IP 71, Section 1[H]	D7042[I] or D7945
Freezing point °C		Table 1 freezing point limits apply	D5972/IP 435	D7153/IP 529 or D7154 or IP 528

Blended SAF – ASTM D7566

D7566 – 23b

TABLE 1 Detailed Requirements of Aviation Turbine Fuels Containing Synthesized Hydrocarbons[A]

Part 1—Basic Requirements			
Property		Jet A or Jet A-1	Test Method[B]
Freezing point, °C	Max	−40 Jet A[I] −47 Jet A-1[I]	D5972/IP 435, D7153/IP 529, D7154 or IP 528, or D2386/IP 16
Viscosity −20 °C, mm^2/s[K]	Max	8.0	*D445 or IP 71, Section 1*, D7042[L] or D7945

Part 2—Extended Requirements			
Property		Jet A or Jet A-1	Test Method[B]
Viscosity −40 °C, mm^2/s	Max	12	*D445 or IP 71, Section 1*,[W] D7042,[Z] or D7945

PHASE TECHNOLOGY
Innovations in phase analysis solutions

Phase Technology JFA-70Xi

Jet Fuel Analyzer

JFA-70Xi

- The world’s first 3-in-1 analyzer that combines:
  - Freeze point (**D5972**)
  - Viscosity @ -20°C and -40°C (**D7945**)
  - Density (D7777)
- Available as 5-in-1 with additional functions:
  - Cloud point (D5773)
  - Pour point (D5949)
- Automatic sample injection
- Automatic cleaning (no solvent)

ASTM D7945 Viscosity Method

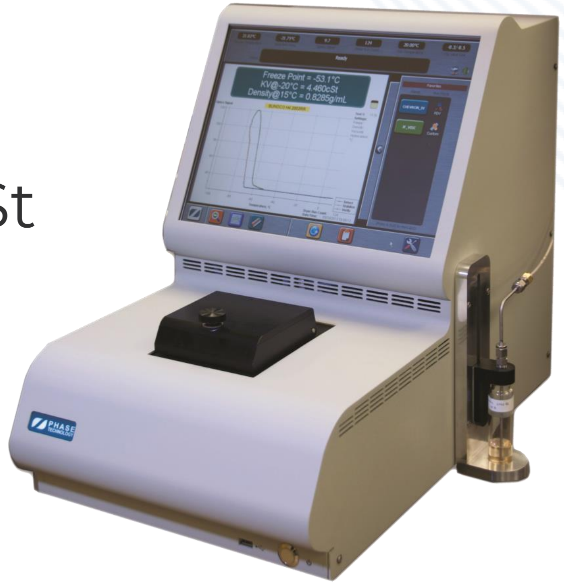
-20°C precision	Reproducibility	Repeatability	Bias
D7945 (Phase Technology)	0.4%	0.2%	No
D445 (Manual)	1.9%	0.7%	-
D7042	3%	1.7%	Yes

Has full precision at -40°C

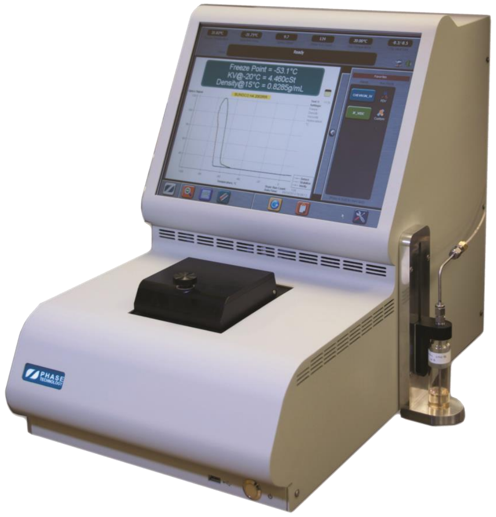
The only ASTM test method that calculates Temp@12 cSt

Accepted into ASTM D1655 and D7566 in 2016

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



JFA-70Xi and SAF



JFA-70Xi

- Co-Processed SAF — ASTM D1655
  - **Freezing Point (Referee)**
  - Viscosity @ -20°C
  - Viscosity @ -40°C
- Blended SAF — ASTM D7566
  - Freezing Point
  - Viscosity @ -20°C
  - Viscosity @ -40°C

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

Thermal Oxidation Test System

Alcor
JFTOT-IV, OptiReader & Intelligent Heater Tubes

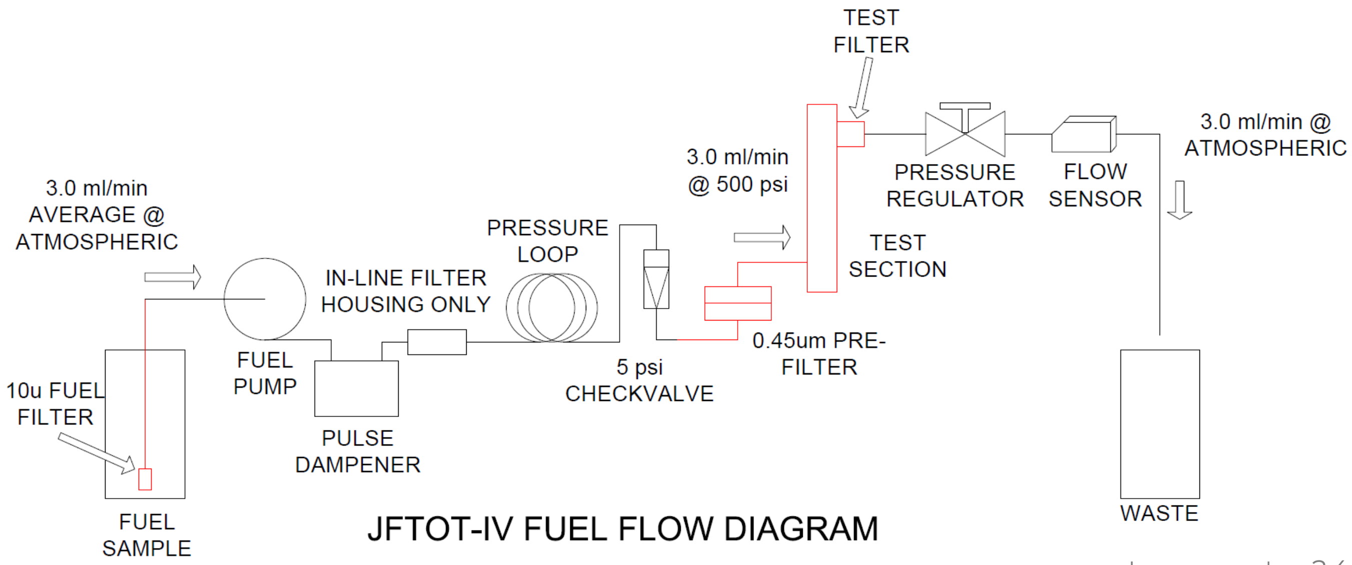
Jet Fuel Thermal Oxidation Tester

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-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



JFTOT-IV FUEL FLOW DIAGRAM

Heater Tube Scanner

OptiReader

- MultiWave Ellipsometer method
  - Unaffected by roughness variation
  - No false prediction due to periodicity
  - Excellent at handling wide dynamic range of thickness
- Fast measurement of deposits
- Unified report with Intelligent Heater Tubes
- Accepted into the D1655 and D7566 jet fuel specifications

Best-in-Class

Jet fuel Thermal Oxidation Testing System

OptiReader JFTOT IV IHT

Current GC methodology and how GCxGC could be the future

Current Specifications

D7566 *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*

Composition specifications in D7566:

property	specification		test method
Aromatics	Min 8 % volume	Max 25% volume	D2425/D8305
Aromatics	Min 8.4% volume	Max 26.5% volume	D6379

Annex specifications with method

A1. FISCHER-TROPSCH HYDROPROCESSED SYNTHESIZED PARAFFINIC KEROSINE (FT-SPK) A2. SYNTHESIZED PARAFFINIC KEROSINE FROM HYDROPROCESSED ESTERS AND FATTY ACIDS (HEFA-SPK) A5. ALCOHOL-TO-JET SYNTHETIC PARAFFINIC KEROSENE (ATJ-SPK)			
property	**specification**		**test method**
cycloparaffins		Max 15% mass	D2425
Aromatics		Max 0.5% mass	D2425
Paraffins		report % mass	D2425

A3. SYNTHESIZED ISO-PARAFFINS FROM HYDROPROCESSED FERMENTED SUGARS (SIP)			
property	**specification**		**test method**
Saturated hydrocarbons	Min 98% mass		
Farnesane	Min 97% mass		
Hexahydrofarnesol			
Olefins		M	
Aromatics			

A4. SYNTHESIZED KEROSINE WITH AROMATICS DERIVED BY ALKYLATION OF LIGHT AROMATICS FROM NONPETROLEUM SOURCES (SPK/A)			
property	**specification**		**ASTM test method**
Aromatics		Max 20% volume	D1319
Aromatics		Max 21.2% volume	D6379
Paraffins		Report % mass	D2425
cycloparaffins		Max 15% mass	D2425
Aromatics		Max 20 % mass	D2425

A6. SYNTHESIZED KEROSINE FROM HYDROTHERMAL CONVERSION OF FATTY ACID ESTERS AND FATTY ACIDS (CHJ)			
property	**specification**		**ASTM test method**
Aromatics	Min 8% volume	Max 20% volume	D1319
Aromatics	Min 8.4% mass	Max 21.2% mass	D2425/D6379
Paraffins		report % mass	D2425
cycloparaffins		report % mass	D2425

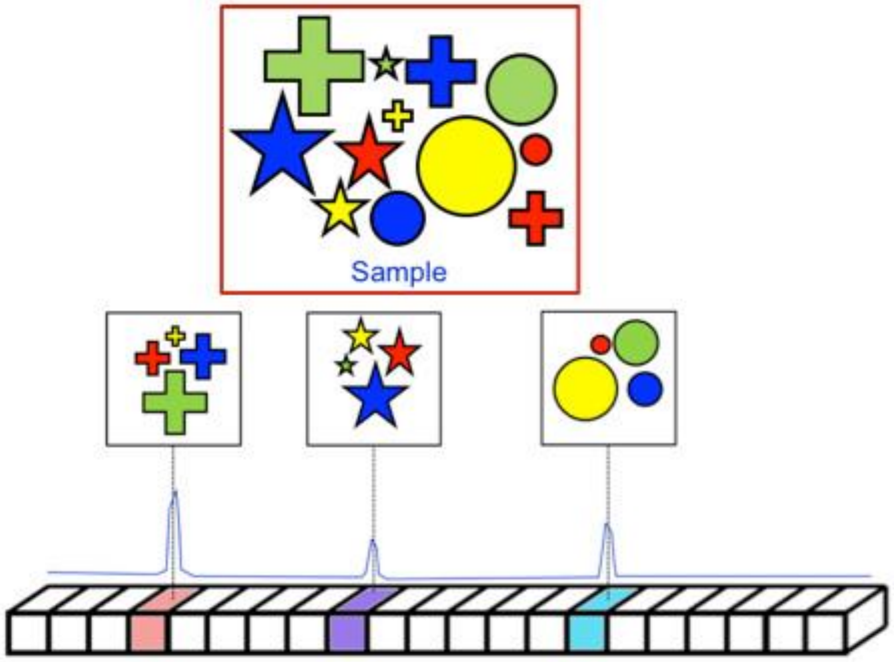
A7. SYNTHESIZED PARAFFINIC KEROSINE FROM HYDROPROCESSED HYDROCARBONS, ESTERS AND FATTY ACIDS (HC-HEFA SPK)			
property	**specification**		**ASTM test method**
cycloparaffins		Max 50% mass	D2425
Aromatics		Max 0.5% mass	D2425
Paraffins		report % mass	D2425

GCxGC fundamentals

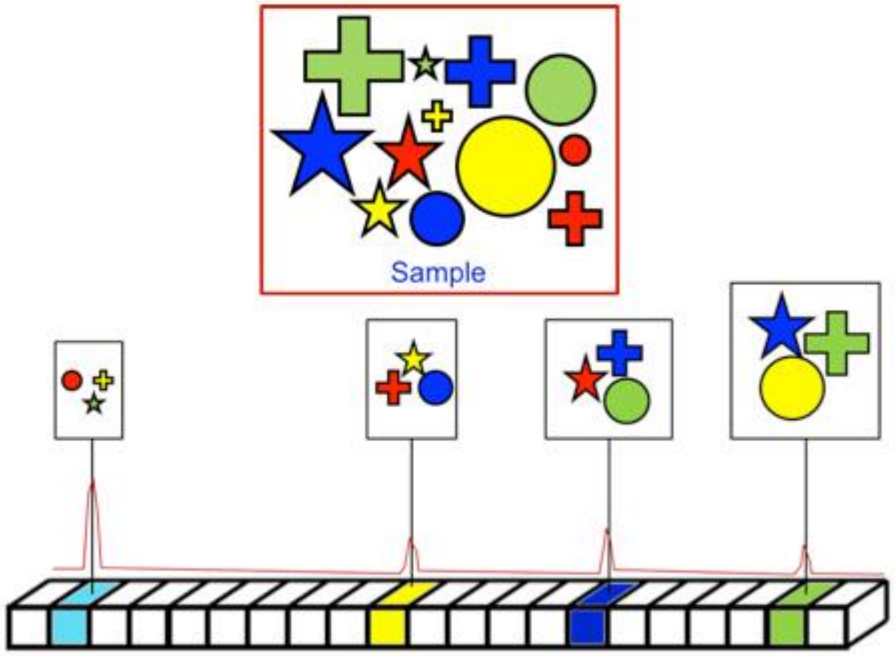
- What led users looking for alternatives?
- Why is GCxGC a strong contender for the future?

How does GCxGC work?

One dimension separation by shape
(Polarity)



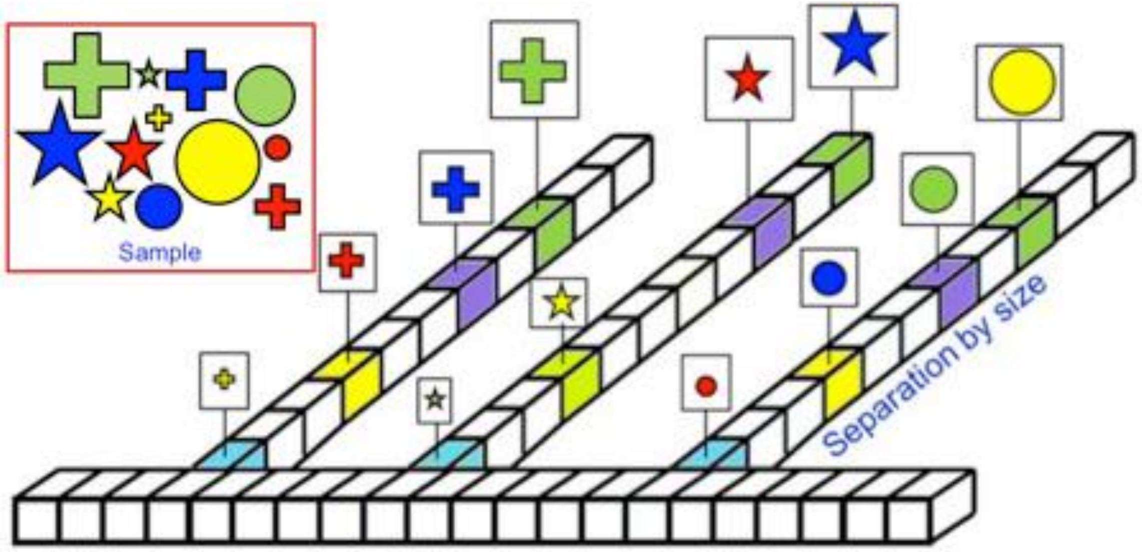
One dimension separation by size
(Boiling Point)



Note that neither of the two separations can separate all analytes within the sample.

How does GCxGC work?

Two-dimension separation by shape and size
(Polarity and Boiling Point)

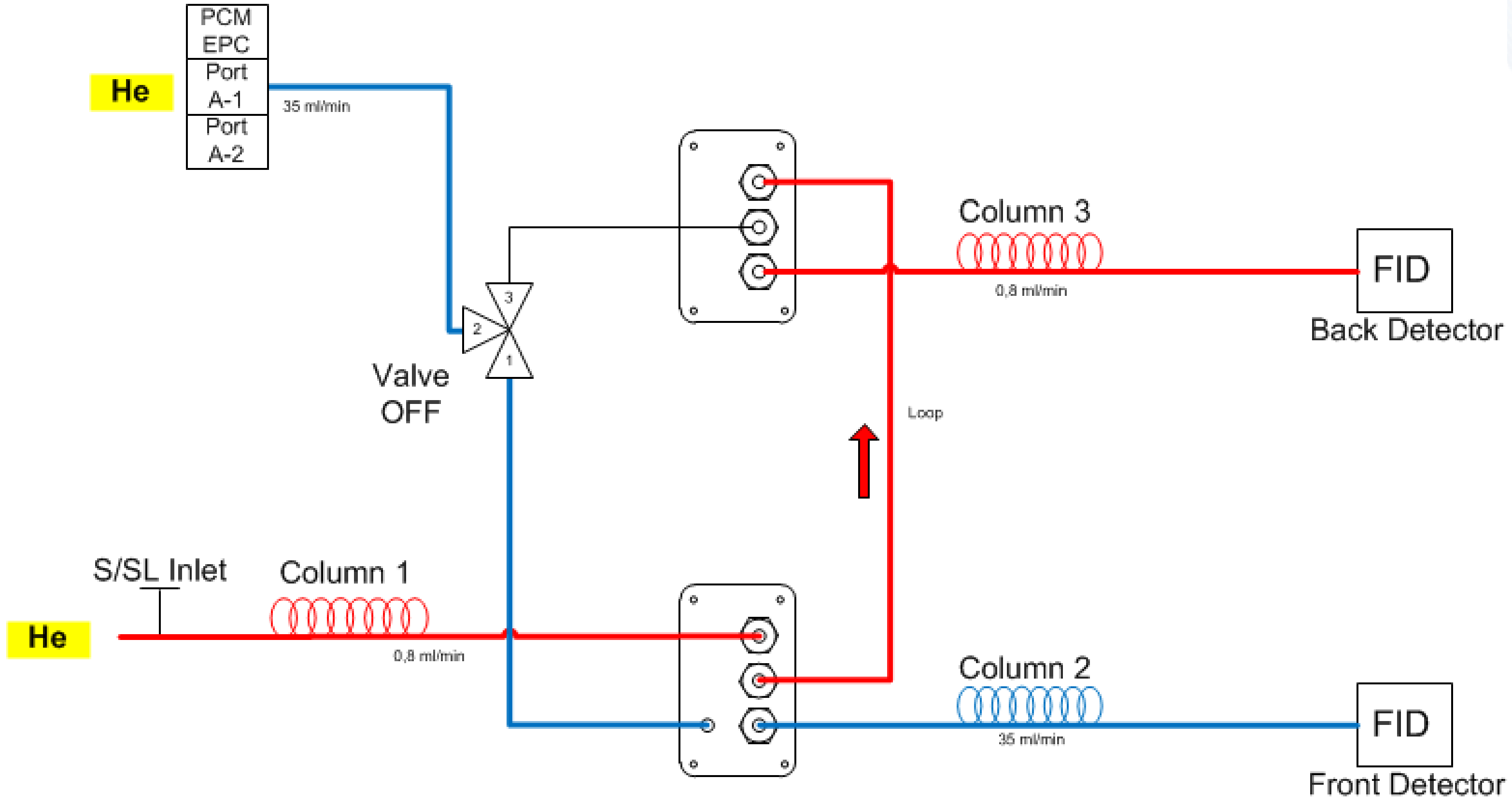


Separation by boiling point

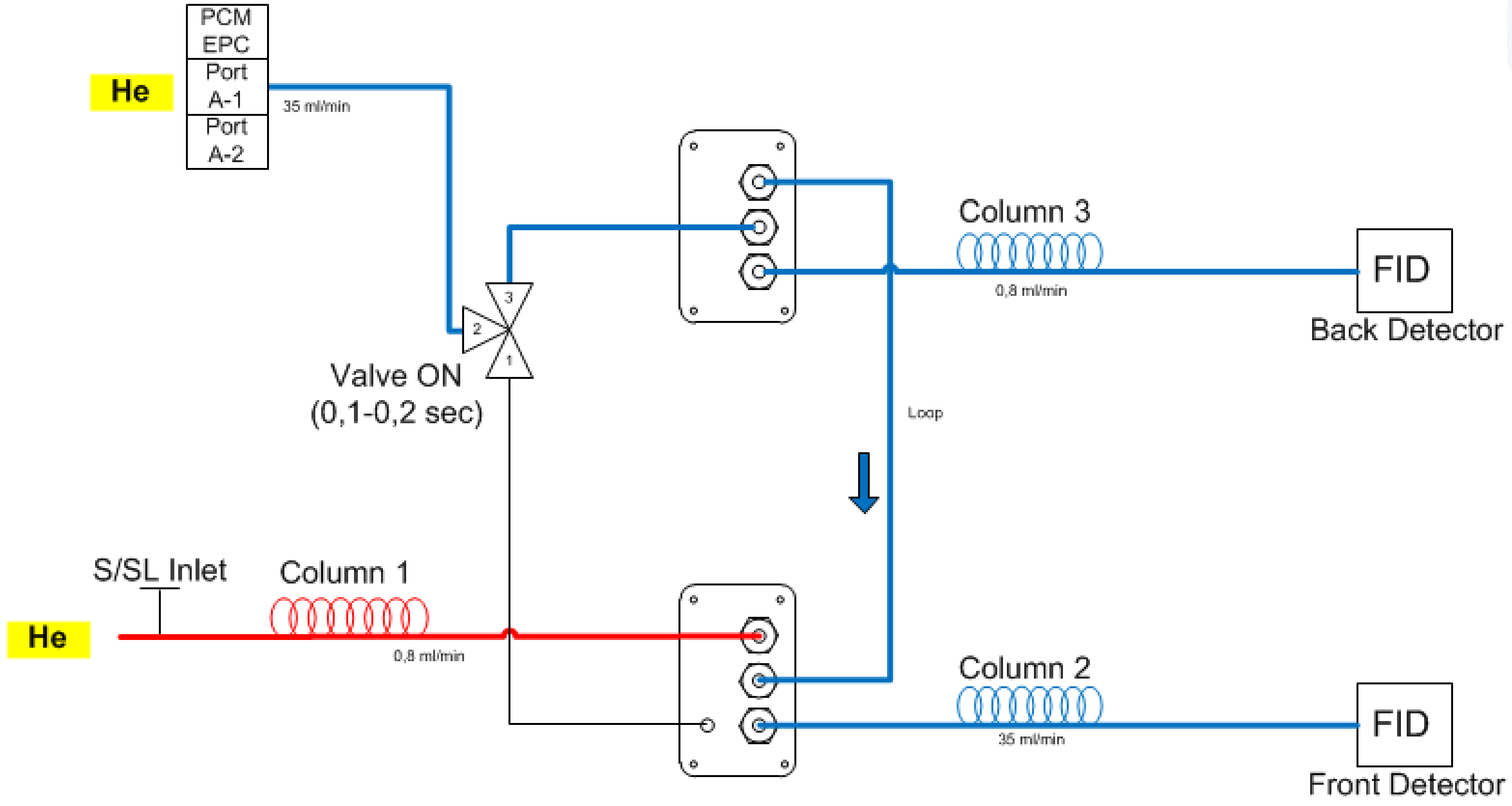
Combination of separation types:

- “Orthogonal” column chemistries – e.g. polarity & boiling point
- Every portion of the eluate coming from the 1st column undergoes a further 2nd separation
- Significantly improves separation power of the chromatographic system

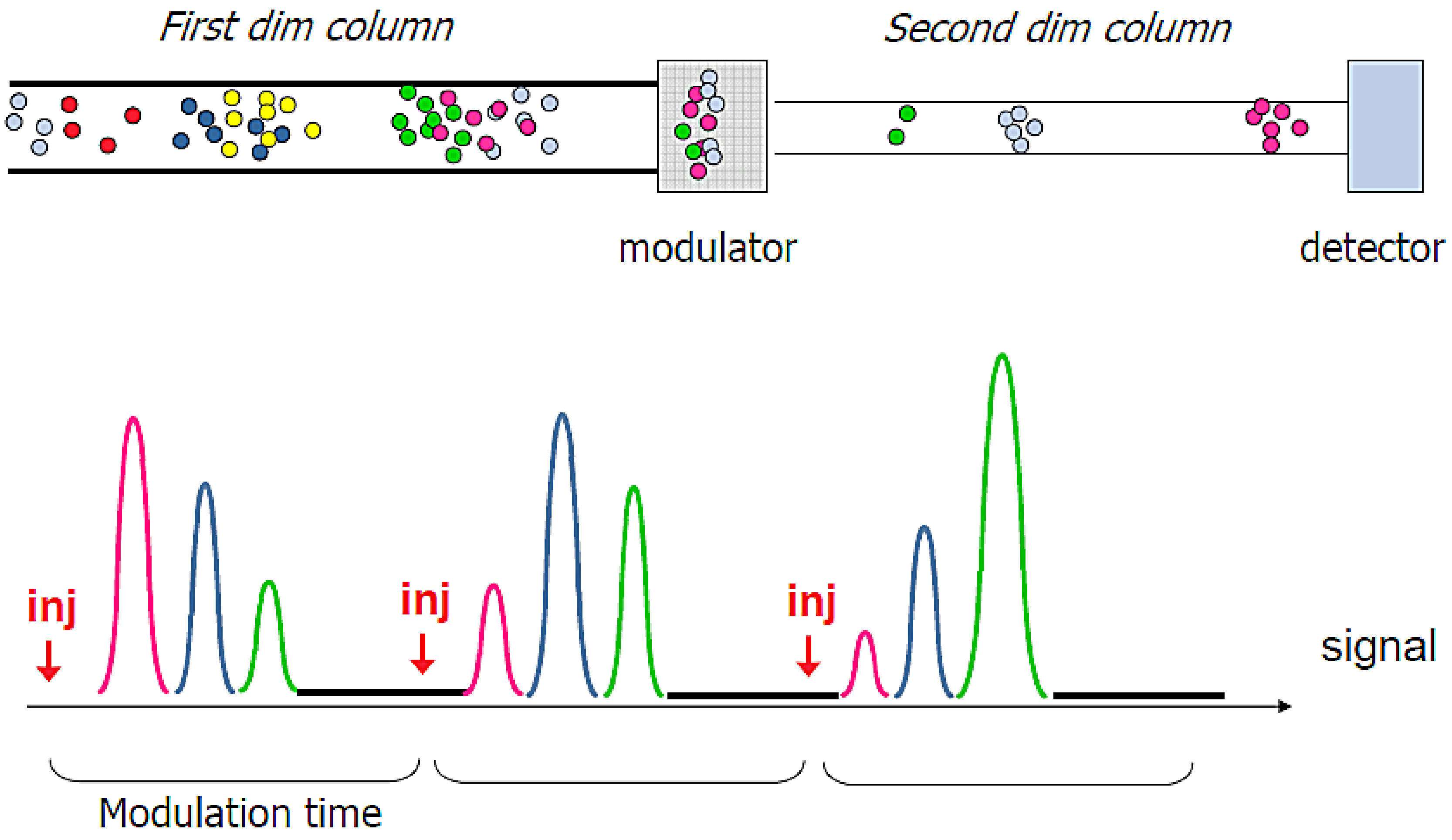
System example - Fill



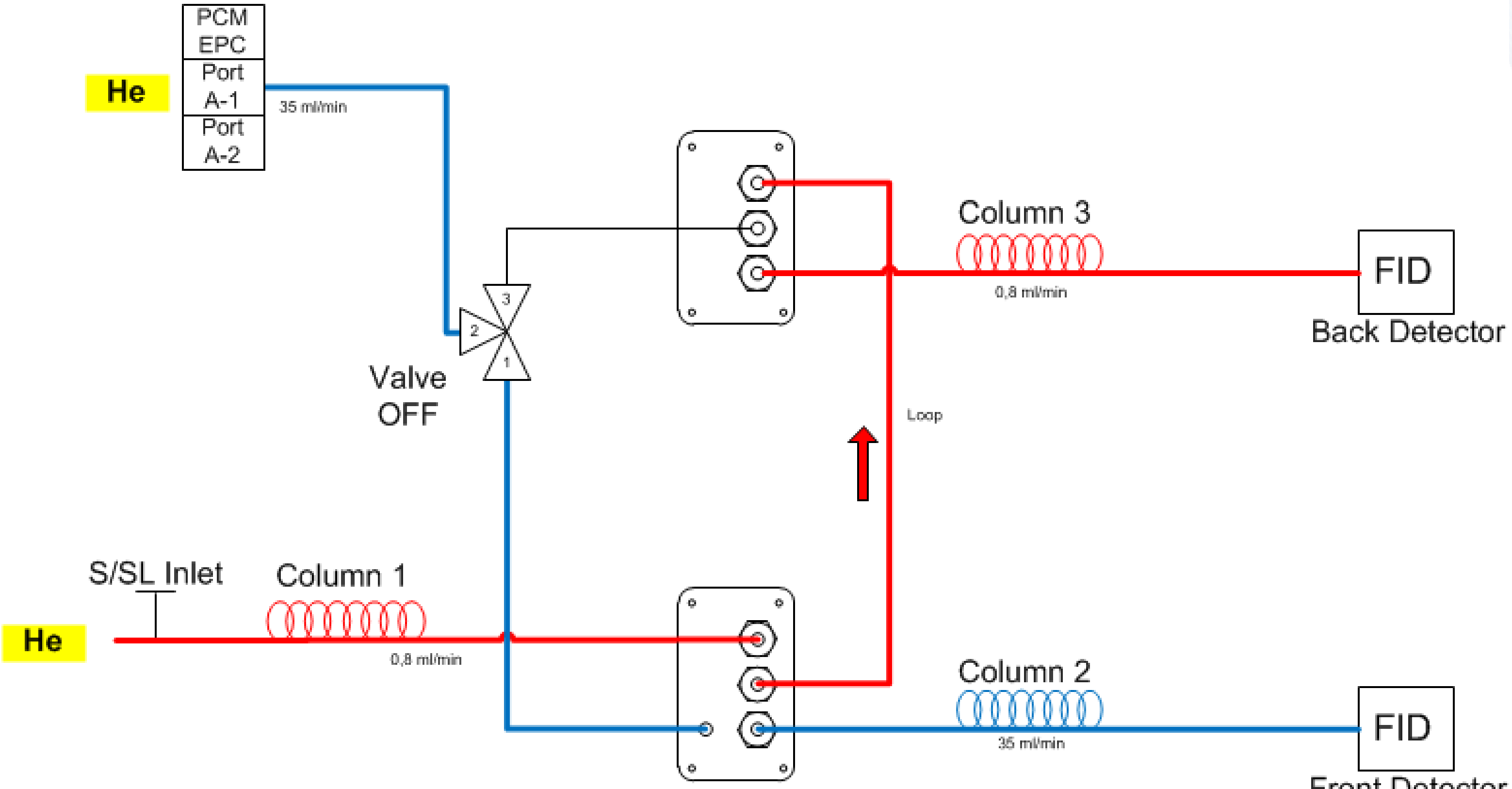
System example - Flush



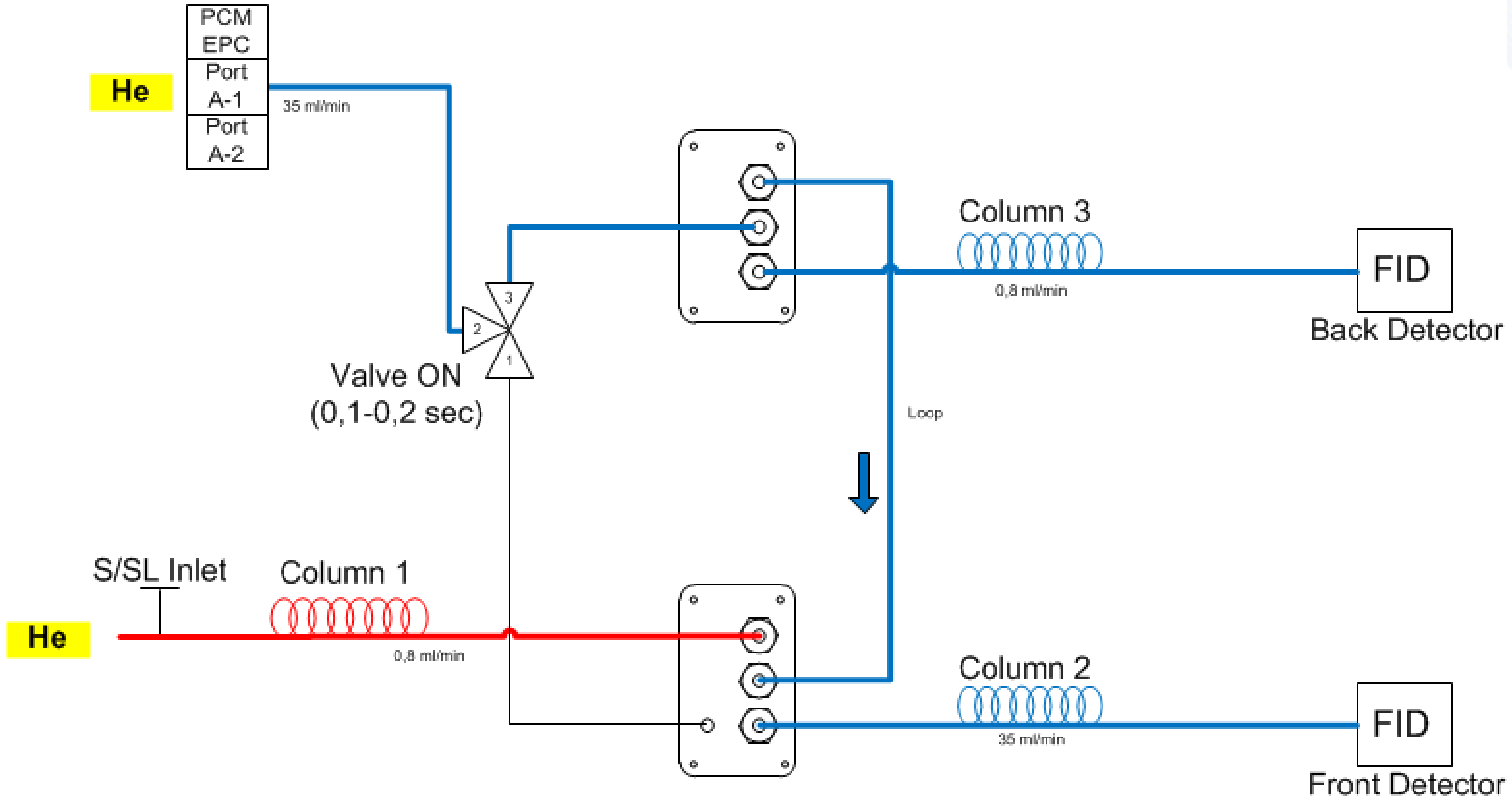
Modulation


First dim column
Second dim column
modulator
detector
inj
inj
inj
signal
Modulation time

System example - Fill

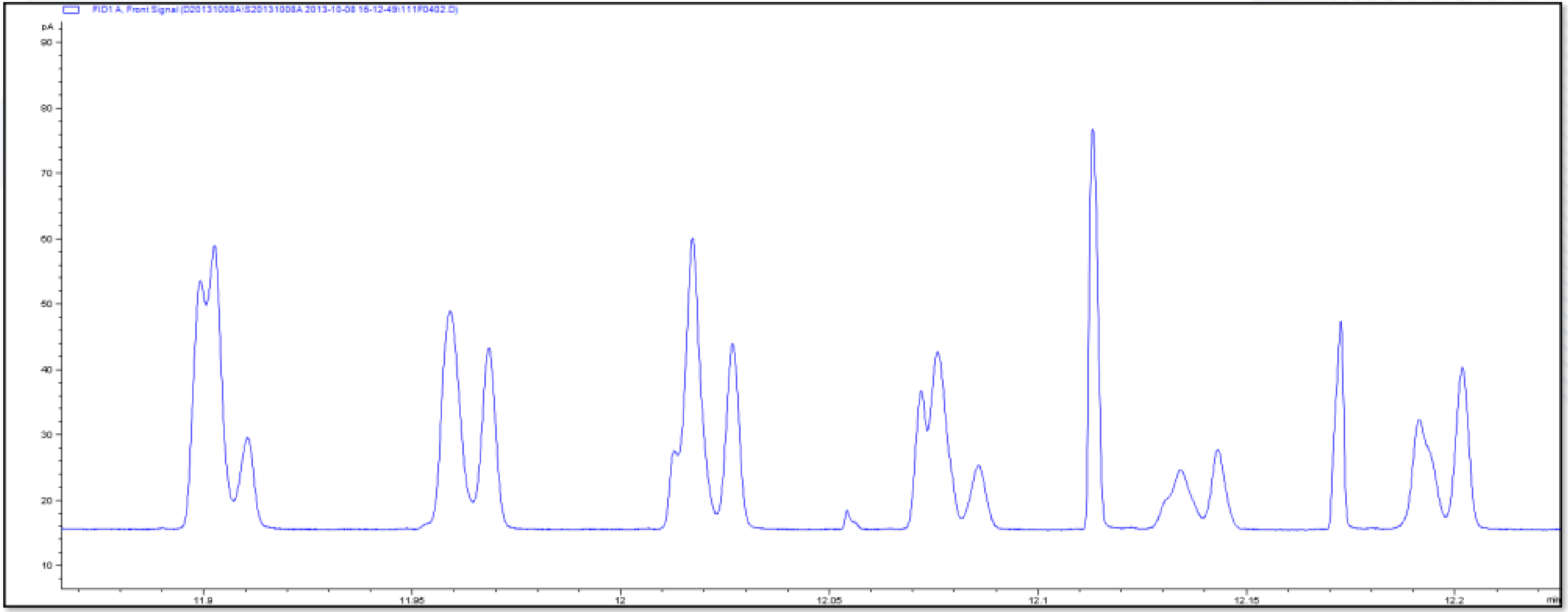


System example - Flush



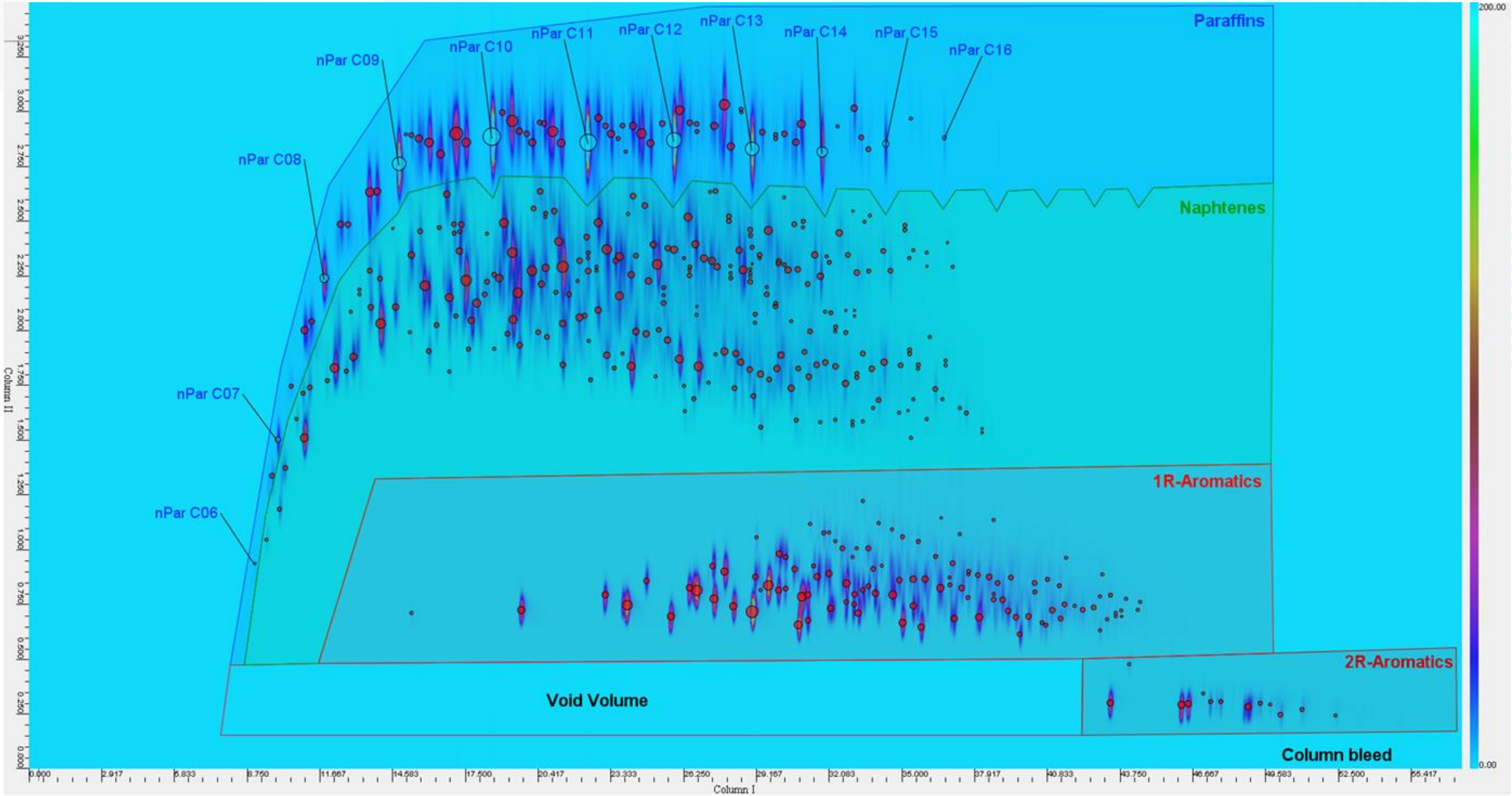
![PAC logo]

How will I see this on my data system?



Data Processing:

GCxGC software and identification example



Current ASTM work

ASTM D8396 *Standard Test Method for Group Types Quantification of Hydrocarbons in Hydrocarbon Liquids with a Boiling Point between 36 °C and 343 °C by Flow Modulated GCxGC-FID*

- Diesel and jet fuel market interested in composition information
- Group Types Quantification of Hydrocarbons in mid distillates
- Technology: GCxGC
- Generic method for flow modulation though thermal is being tested.
- Free choice of columns and software

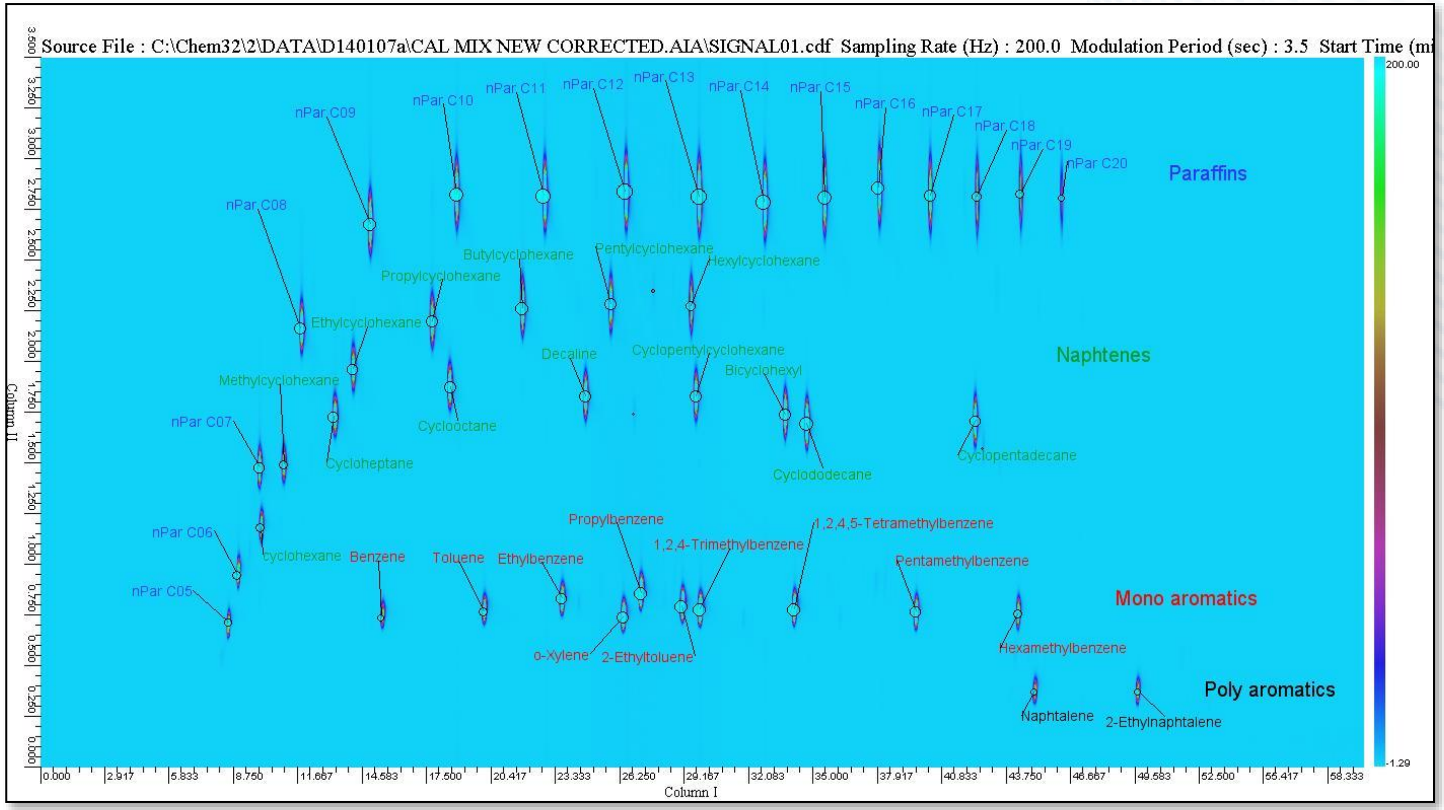
Current published method

PAC worked with ASTM on the first method for GCxGC

- Published in 2022
- Initial version of method with interim precision statement

TABLE 1 Typical Chromatographic Operating Parameters Used in Developing the Test Method

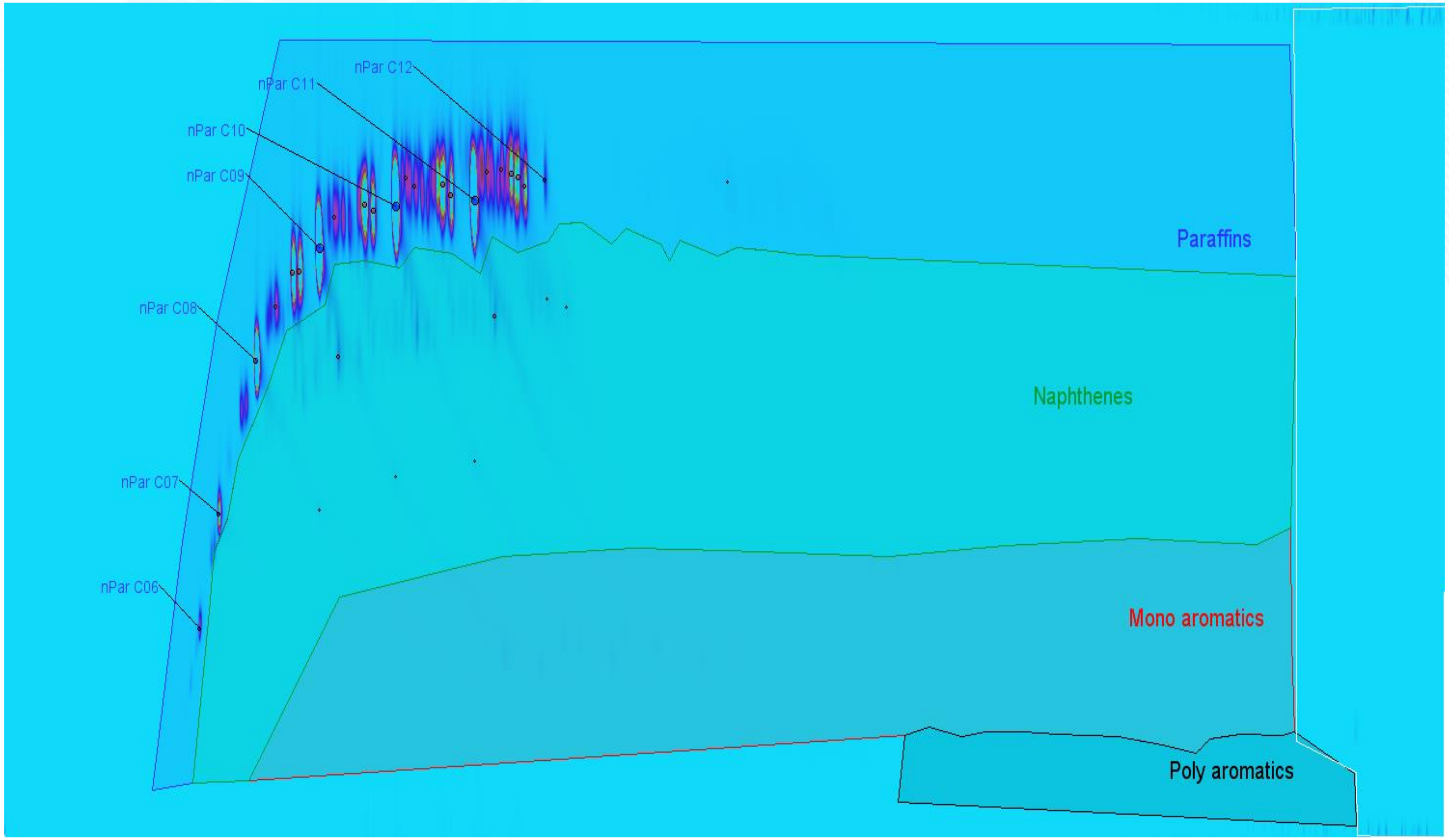
	Description			
Inlets	Front		S/SL Inlet	
	Heater		325 °C	
	Carrier Gas		Helium	
	Split ratio		1:200	
Columns	**1st dimension polar column**			
	30 m x 250 µm polar column (e.g., polyethylene glycol)			
	Flow		1 mL/min	
	2nd dimension non-polar column			
	10 m x 320 µm non-polar column (e.g., polydimethylsiloxane)			
	Flow		35 mL/min	
	Monitor column			
	Deactivated Fused Silica			
	Flow		1 mL/min	
Oven	Temperature		40 °C	
	Equilibration time		1 min	
		°C/min	Next °C	Hold min
	Oven Ramp		40	7.5
		3.2	45	0
		4.2	120	0
		4.7	165	0
		5.2	200	0
		5.7	270	3
	Total run time			57.5
Detector	Front	Front FID	Back FID	
	Heater	325 °C	325 °C	
	H2 flow	35.0 mL/min	35.0 mL/min	
	Air flow	350.0 mL/min	350.0 mL/min	
	Make-up flow	20.0 mL/min	20.0 mL/min	
Flow Modulator	Valve Idle State	Off		
	Modulation delay	0.1 min		
	Modulation period	3.5 s		
	Inject time	0.1 s		



Pilot study information

- 17 participating laboratories
- Wide variety in configurations:
    - Modulation style: Flow and Thermal tested
    - Column configuration: Normal Phase and Reversed Phase
    - Software: Commercial brands and in-house created
    - Detection type: area detection, blob detection, and both
- Reported properties:
    - Iso-Paraffins
    - normal-Paraffins
    - Naphthenes
    - 1R Aromatics
    - 2R aromatics
    - 3R aromatics

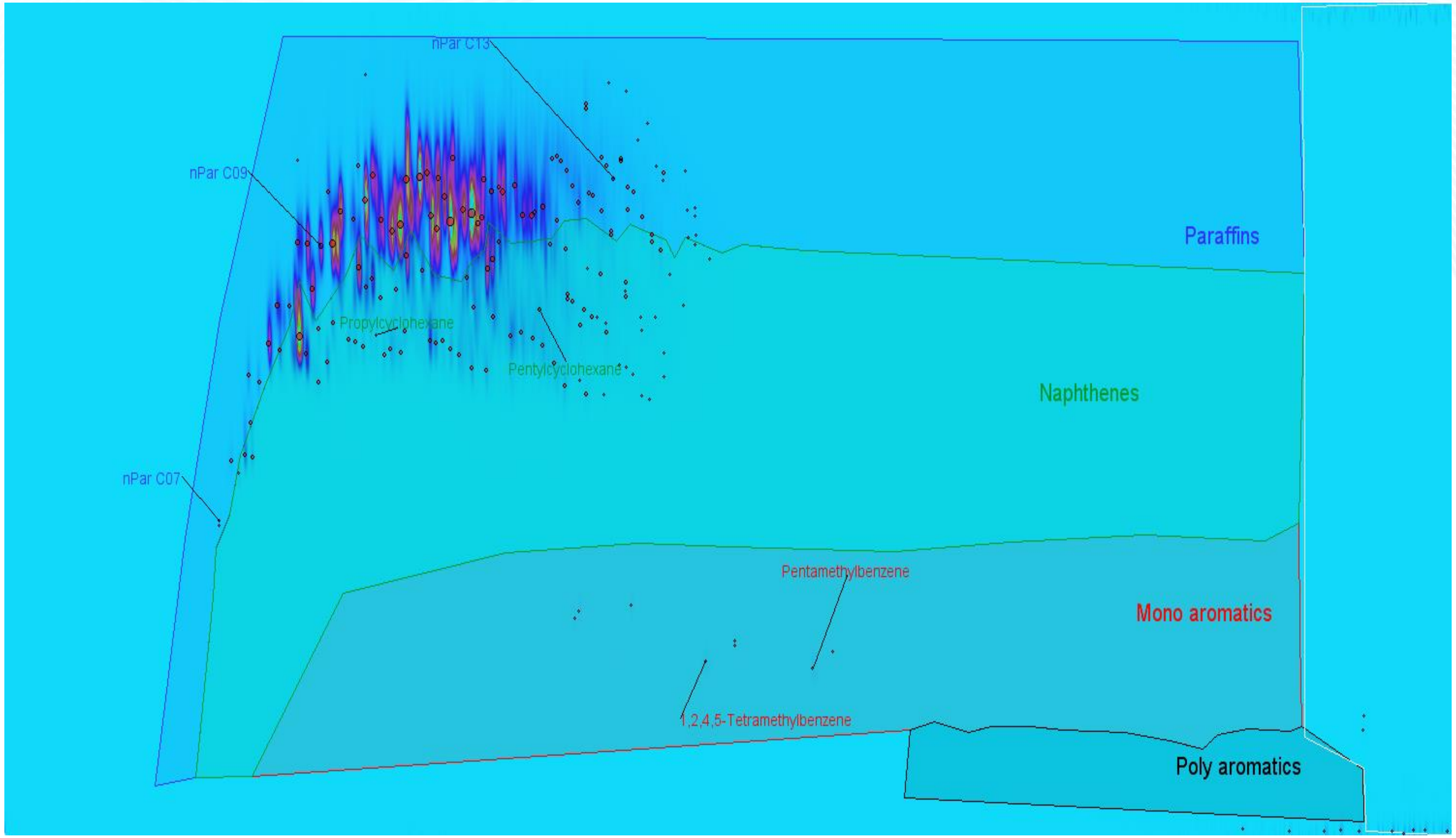
Sample 1: FT-SPK (LTFT, GTL)



Estimated composition (confirmed with D6839):

Iso-Paraffins	Normal-Paraffins	Naphthenes	1R Aromatics	2R aromatics
31%	68%	0.5%	0.2%	0%

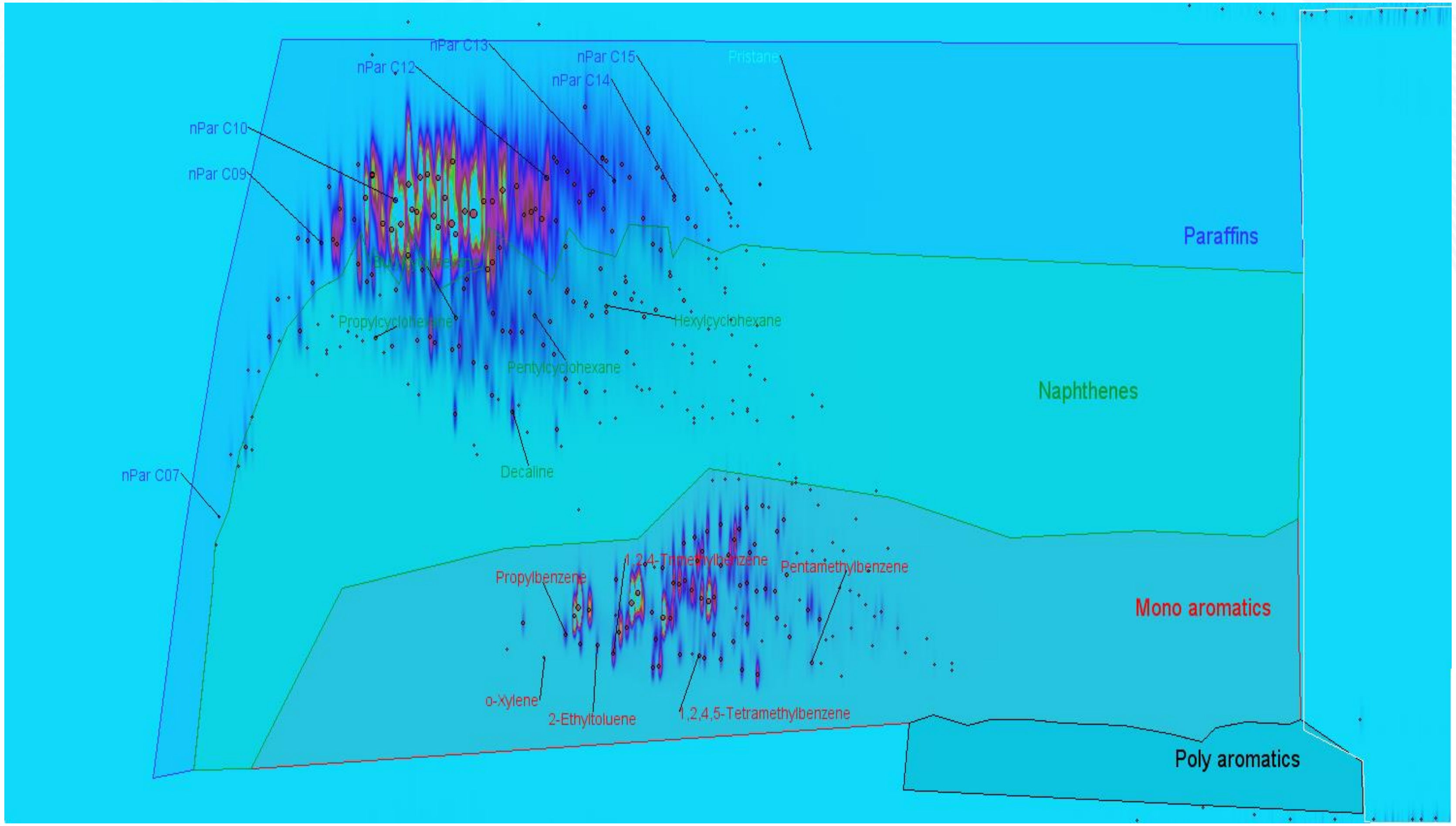
Sample 2: FT-SPK (HTFT)



Estimated composition (Confirmed with D6839):

Iso-Paraffins	Normal-Paraffins	Naphthenes	1R Aromatics	2R aromatics
96%	0.5%	3%	0.2%	0%

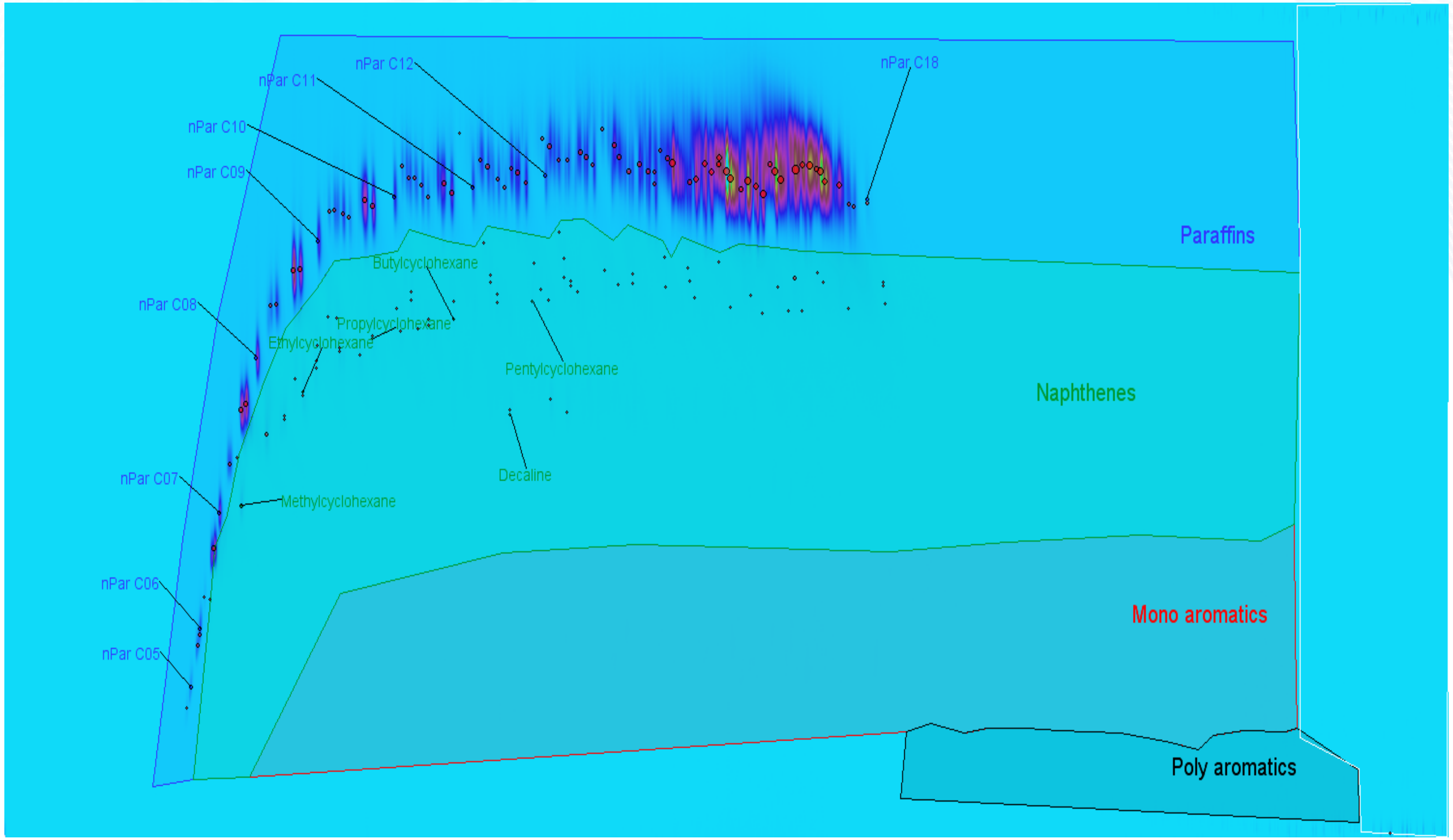
Sample 3: FT-SPK/A (HTFT)



Estimated composition (Confirmed with D6839):

Iso-Paraffins	Normal-Paraffins	Naphthenes	1R Aromatics	2R aromatics
77%	2%	4%	18%	0%

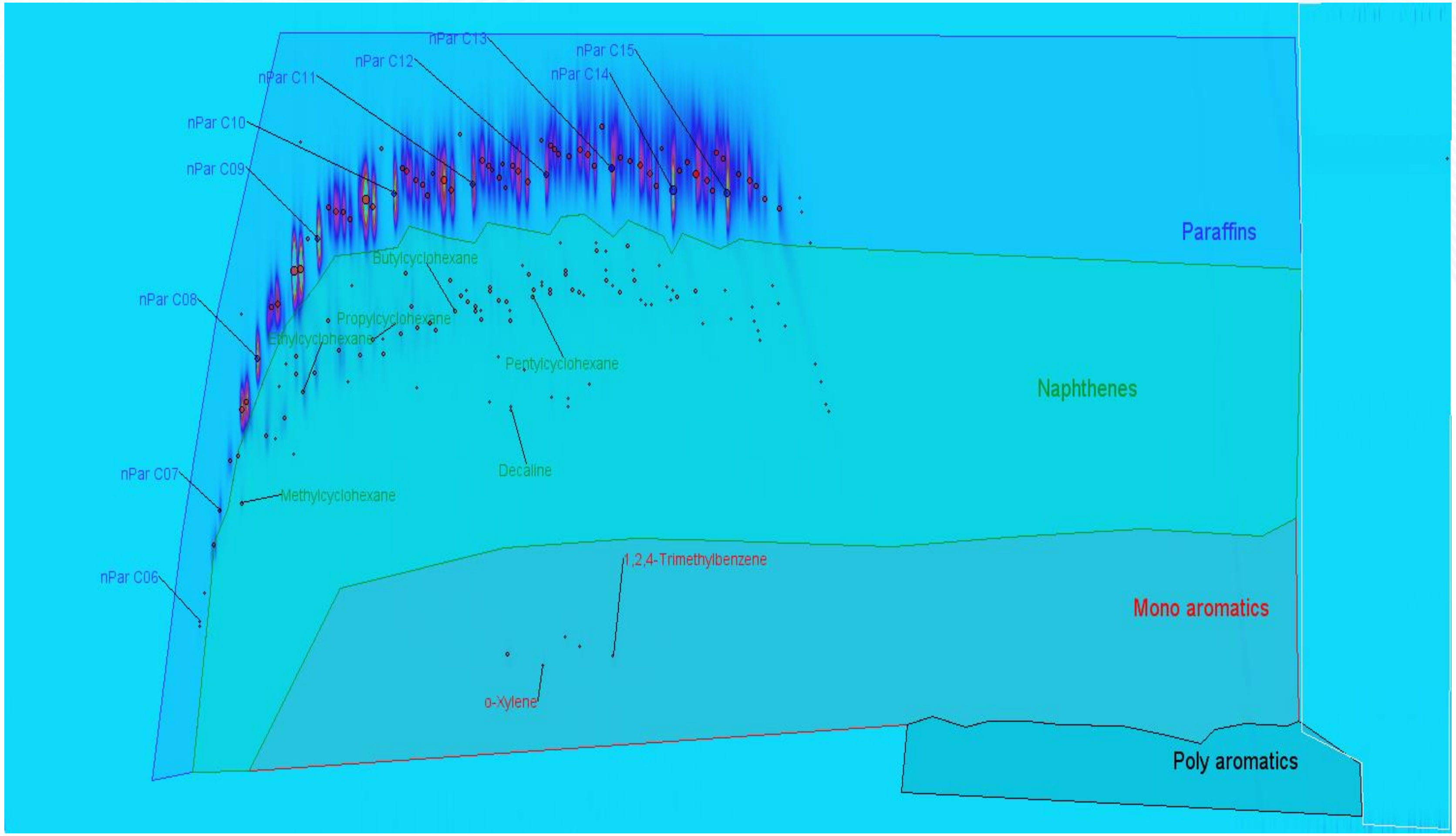
Sample 4: "SAF"



Estimated composition:

Iso-Paraffins	Normal-Paraffins	Naphthenes	1R Aromatics	2R aromatics
95%	4%	1%	0.5%	0.1%

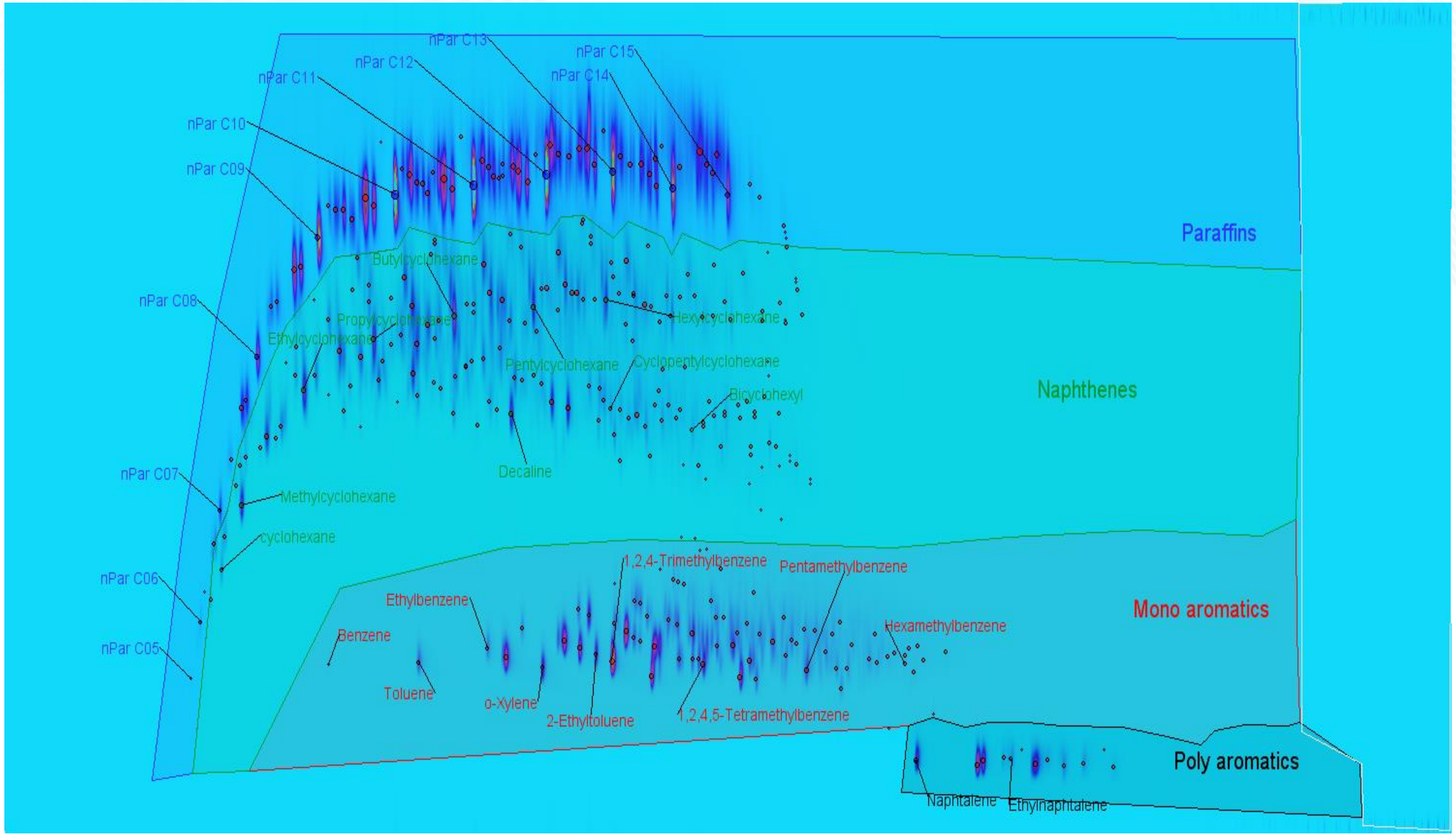
Sample 5: “SAF”



Estimated composition:

Iso-Paraffins	Normal-Paraffins	Naphthenes	1R Aromatics	2R aromatics
78%	18%	3%	0.2%	0.1%

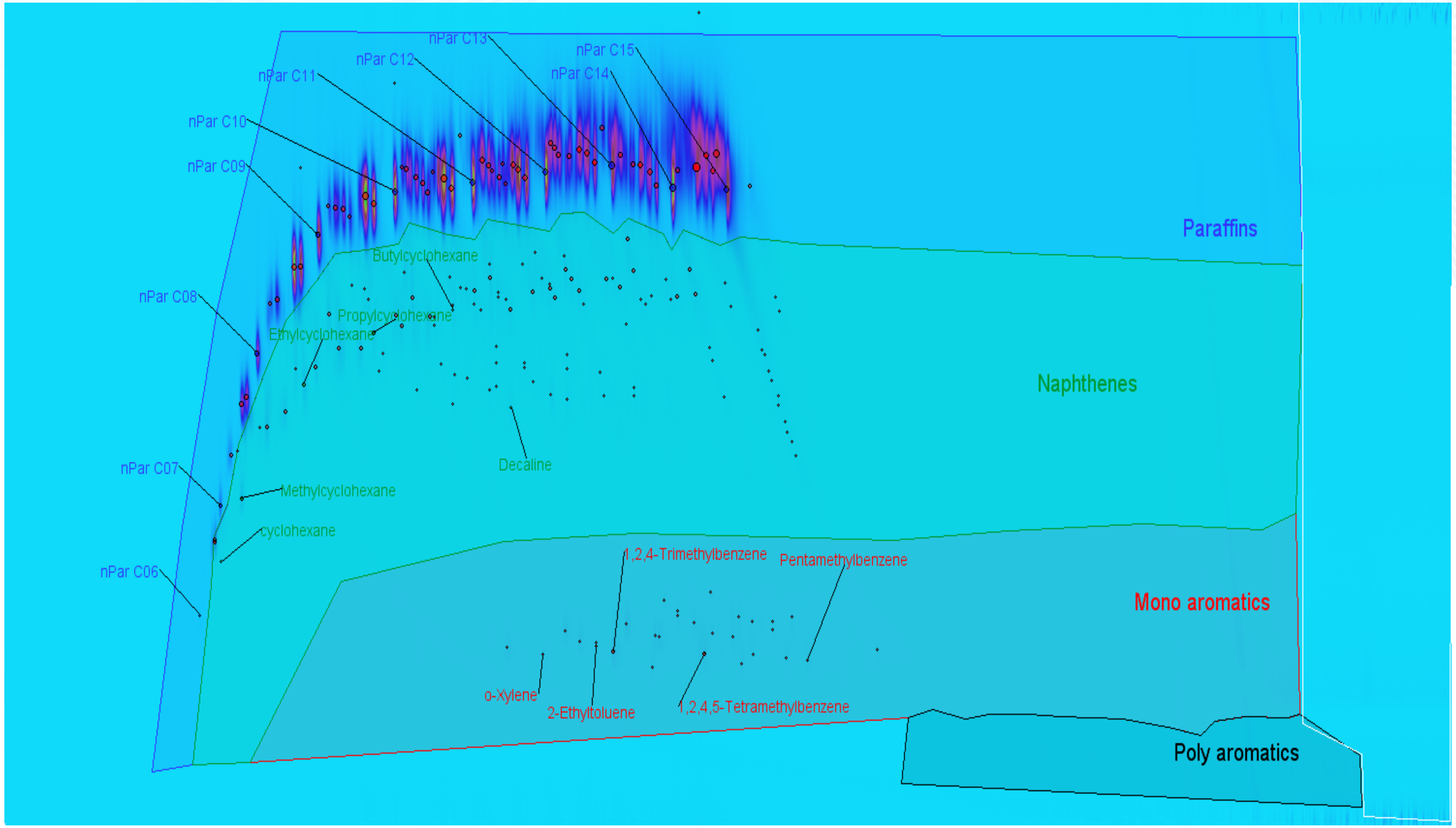
Sample 6: Jet A-1 SAF



Estimated composition :

Iso-Paraffins	Normal-Paraffins	Naphthenes	1R Aromatics	2R aromatics
42%	18%	25%	12%	2.5%

Sample 7: HEFA



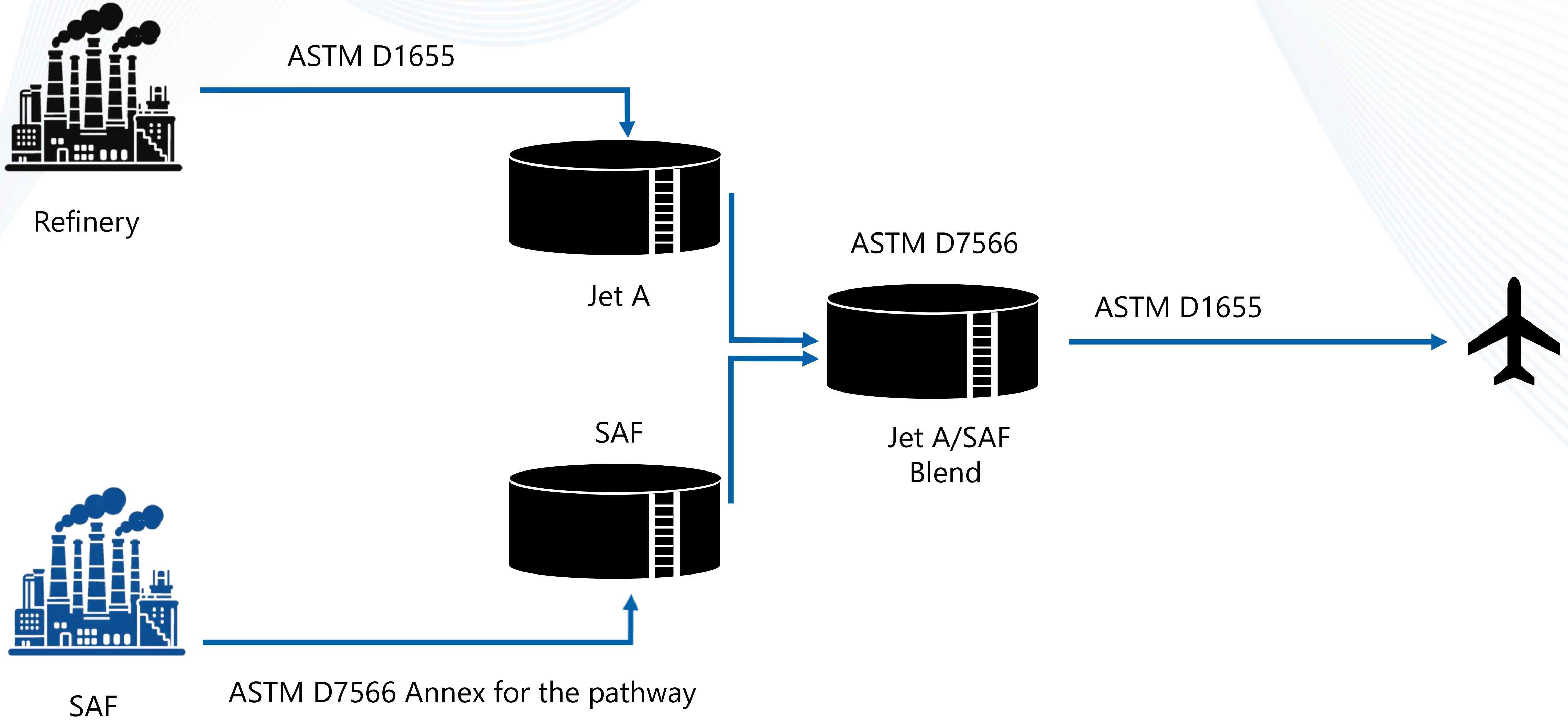
Estimated composition:

Iso-Paraffins	Normal-Paraffins	Naphthenes	1R Aromatics	2R aromatics
81%	16%	2.5%	0.4%	0.1%

ASTM ILS study next steps

- Implement the improvement we learned during the pilot study
- Joined study for aromatics in Jet A1, SAF, diesel and Avgas:
  - D1319 (FIA) precision update
  - Four different test methods for comparison against D1319
  - D8396 ILS will also report paraffins, olefins, etc.
- Based on ILS results after summer:
  - Precision for total aromatics and maybe more
  - Precision for Jet A1 and SAF, and maybe more
  - Revise D8396 around break of the year

SAF Journey


ASTM D1655
Refinery
Jet A
ASTM D7566
ASTM D1655
SAF
Jet A/SAF
Blend
SAF
ASTM D7566 Annex for the pathway

Why measure with process analysers?

Cost Savings
Optimising the blending of Kerosene streams to produce Jet A
Optimising the wide variety of feedstocks for SAF

Reduced Downtime:
Minimise downtime by monitor for process upsets

Closer to specification:
Online measurement enable the refinery to get closer to specification than just taking lab measurements alone

Meet Compliance Online
For some refineries use online instruments to meet compliance online, with the benefit of not having to wait for lab result before moving the product onwards

Solutions

	Max/Min	D1655	D7566	Method
Sulphur	Max	3000ppm	3000ppm	D5453
Distillation				D86
10%	Max	205°C	205°C	
50%		report	report	
90%		report	report	
Final Boiling Point	Max	300°C	300°C	
Flash Point	Min	38°C	38°C	D56
Freezing Point	Max	-40°C	-40°C	D2386


Total Nitrogen & Sulfur	Flash Point	Atmospheric Micro-Distillation	Atmospheric Pressure Distillation	Freeze Point
NSure	Icon Flash Point Analyser	MicroDist	Icon Distillation Analyser	Icon Freeze Point Analyser
Sulfur: D5453, D6667, ISO 20846	D56, D92, D93, IP170	D86, D7345, IP 123	D86, IP 123, ISO 3405.	D2386, D5972 and D7153.

PAC

Fz Freeze Point

Powered by Icon

Best cooling performance

Patented cryo-cooler achieves exceptional results, without the need for an external chiller. Freeze Point cools down to -100°C within 10 minutes using normal plant-cooling water.

Excellent repeatability

Advanced detection algorithms and phase angle cryo-cooler control ensure better repeatability than standard test methods, giving unrivalled measurement certainty.

Meets your test requirements

Freeze Point's measurement results are compatible with all standard freeze-point test methods including ASTM D2386, D5972 and D7153.

MicroDist

Quickest Online Physical Property Distillation

While measuring samples up to 430^{o}C, it can perform a complete distillation in under 10mins

Repeatability that better the D86

For most samples, the MicroDist is better than D86, for other it is equivalent

Match the Lab

Same physical analytical engine at the Lab Opti-PMD and provides excellent corelation to the OptiDist the benchmark measurement of atmospheric distillation using ASTM D86

Fp Flash Point

Powered by Icon

Safe Operation

Peltier-based sample cooler, ensuring that the incoming sample is safely cooled below the flash point temperature
An internal camera enables flash point observation without the need to open the explosion-proof box

Low Maintenance

Solvent wash cycle to wash away in waxy/gum build up.
Electrode are sparked to remove deposits on them

Meets your test requirements

The results are compatible with those produced by any standard flash point test methods, such as IP170, ASTM D92 and ASTM D93

Eb Ethanol Blender

Powered by Icon

There has never been an accurate way to be absolutely certain that gasoline will be on spec after ethanol has been added.

There has always been uncertainty, with refineries naturally erring on the side of caution to make sure the product hits spec.

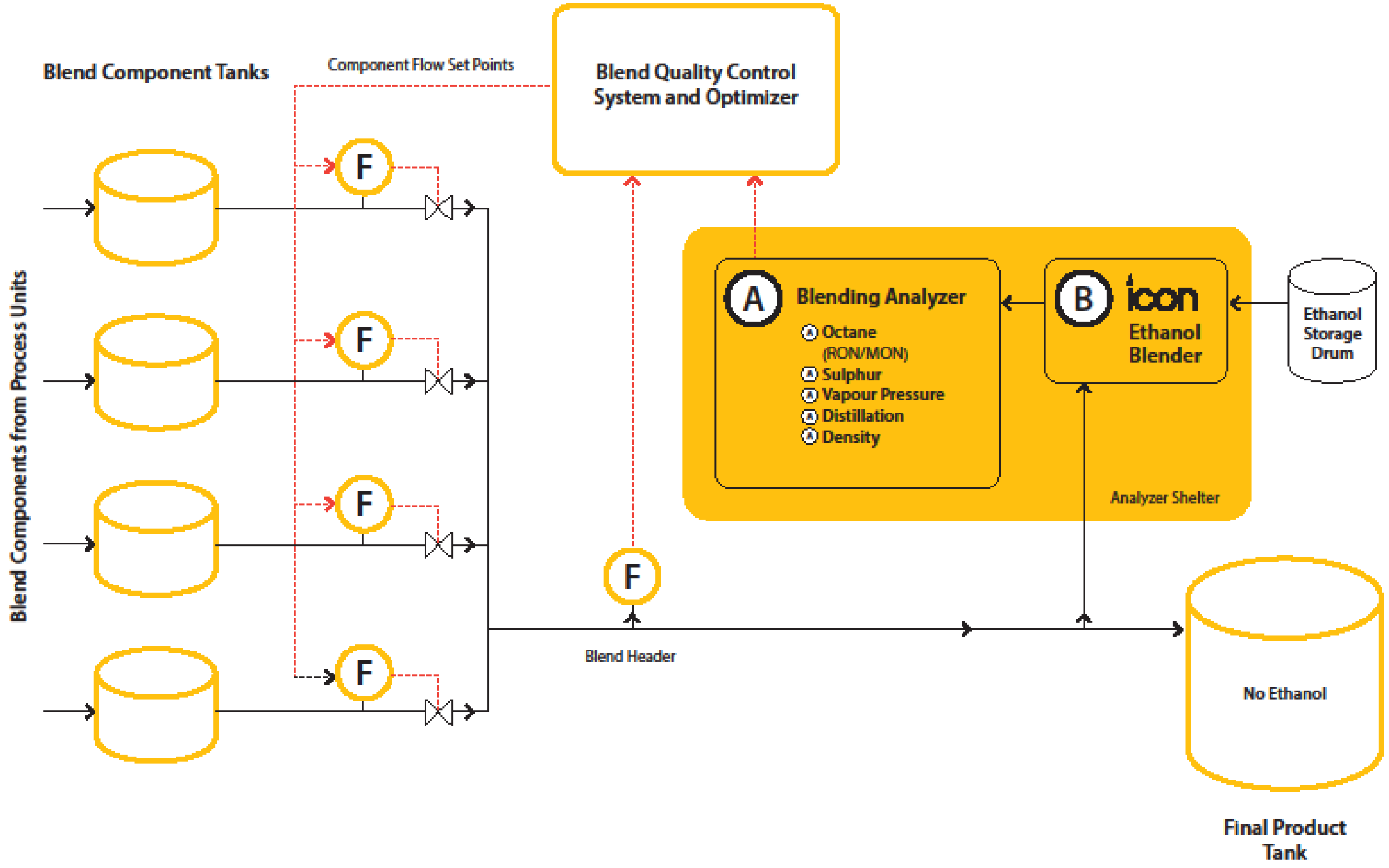
Until now.

Reduction in Give Away

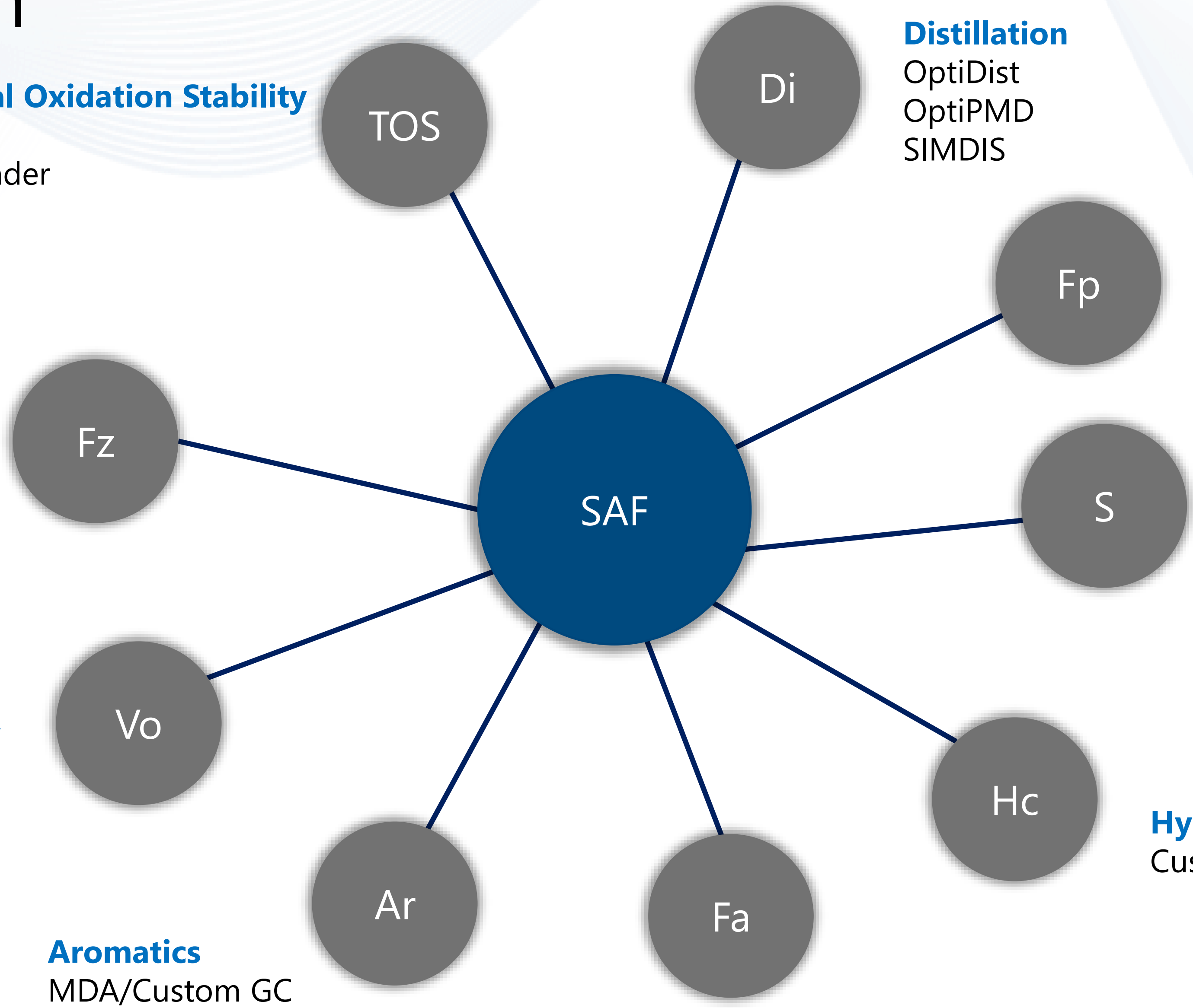
The Ethanol Blend Optimiser, situated within the blending control system, takes a sample of the BOB and mixes it with the precise (better than± 0.05%) amount of ethanol at the required ratio to flow to the analysers.

This is no estimation.

You're testing the final blend – with ethanol.



SAF Ecosystem Lab



Thermal Oxidation Stability
JFTOT
OptiReader

Distillation
OptiDist
OptiPMD
SIMDIS

Flash Point
OptiFlash

Freeze Point
JFA 70Xi
OptiFZP

Sulphur
ElemeNts

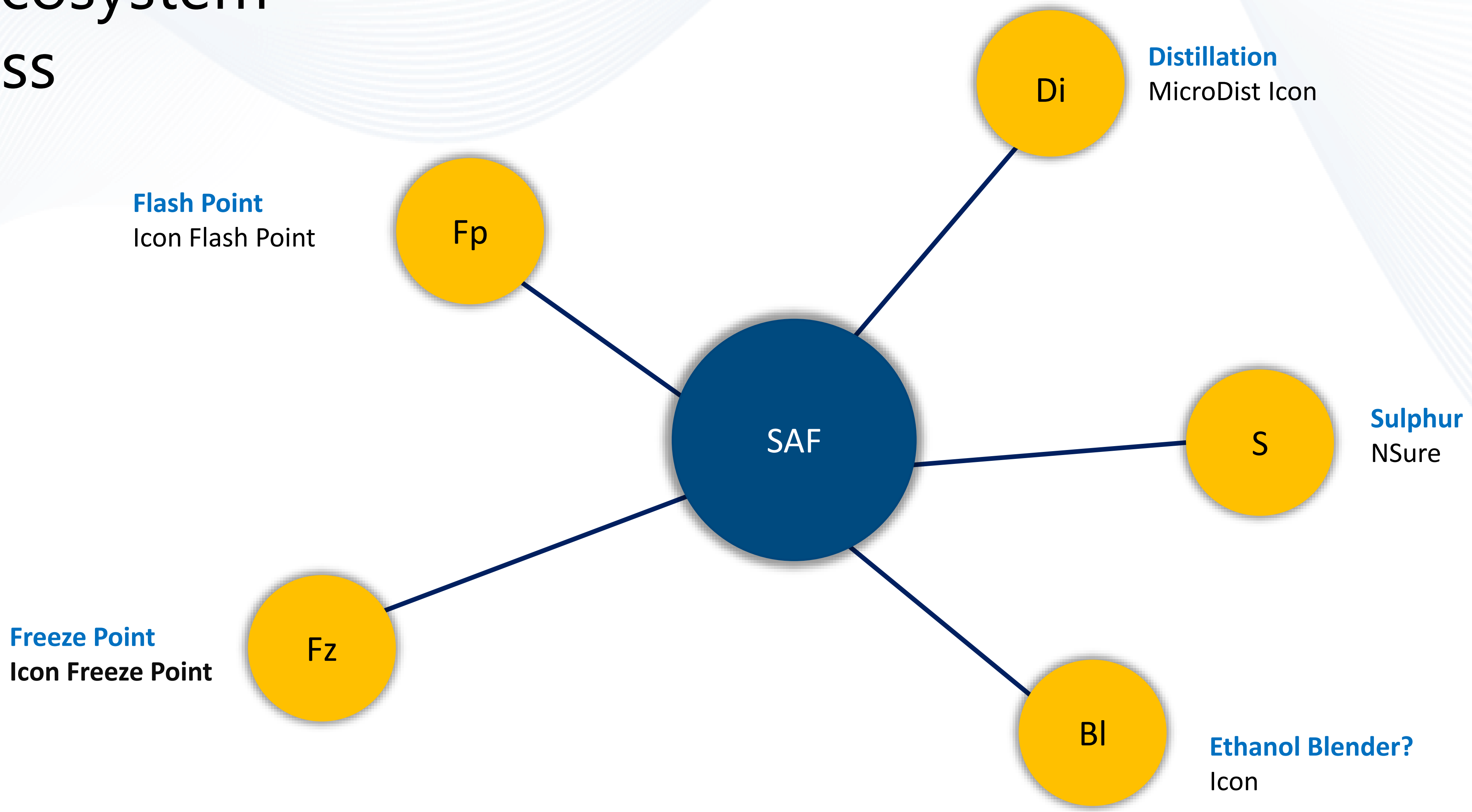
Viscosity
JFA 70Xi

Hydrocarbon Composition
Custom GCxGC

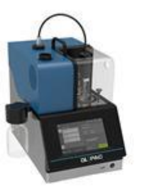
Aromatics
MDA/Custom GC

Fame
FAME in Avtur Analyzer

SAF Ecosystem Process






TAG Closed Cup Flash Point	Small Scale Flash Point	Jet Fuel & Diesel	Atmospheric Pressure Distillation	Atmospheric Micro-Distillation	Total Sulfur
OptiFlash TAG	OptiFlash Small Scale	Phase Technology JFA & DFA-70Xi	Herzog OptiDist	ISL OptiPMD	ElemeNtS (Vertical) Ultra-Violet Fluorescence






Jet Fuel Thermal Oxidation	Ellipsometric Heater Tube Scanner	Automatic Freezing Point	Gasoline, Diesel & Jet Fuel FTIR	Aromatics	Fame
Alcor JFTOT IV	OptiReader	ISL OptiFZP	OptiFuel	Mid Distillates Analyze/Custom GC	FAME in Avtur Analyzer


Total Nitrogen & Sulfur	Flash Point	Atmospheric Micro-Distillation	Atmospheric Pressure Distillation	Freeze Point
NSure	Icon Flash Point Analyser	MicroDist	Icon Distillation Analyser	Icon Freeze Point Analyser

Thank you!

Visit paclp.com or contact your local PAC representative to learn more about SAF solutions.