<u>14:00-15:00</u> Presentation:

How can today's refineries prepare for tomorrow? A Topsoe perspective





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HOW CAN TODAY'S REFINERIES PREPARE FOR **TOMORROW: A** TOPSOE PERSPECTING-SCHMIDTO

TOPSOE

Copenhagen Contrails Conference March 25-26, 2025

Rasmus Egeberg March 26, 2025

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PRESENTATION AGENDA

1	A FEW WORDS ABOUT TOPSOE
2	JET FUEL PRODUCTION
3	WHAT IS HYDROPROCESSING?
4	WHAT CAN BE DONE IN REFINERIES?
5	TAKE-HOME MESSAGES

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TOPSOE AT A GLANCE: OVER 80 YEARS OF INNOVATION AND LEADERSHIP

We are a leading global provider of technology and solutions for the energy transition. We combat climate change by helping our customers and partners achieve their decarbonization and emission reduction goals.

Based on decades of scientific research and innovation, we offer world-leading solutions for transforming renewable resources into fuels and chemicals for a sustainable world, and for efficient and low carbon fuel production and clean air.

We were founded in 1940 and are headquartered in Denmark.



OUR AREAS OF EXPERTISE ARE THE ELEMENTS OF OUR OFFERING





*Not approved ASTM pathways yet

Source: CORSIA, ICCT paper 2021-11, WEF+ McKinsey 2020-11

TOPSOE HAS HIGHEST NUMBER OF OPERATING UNITS PRODUCING HVO AND SAF



TOPSOE

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OUR CLIENTS RANGE FROM ESTABLISHED FUEL PRODUCERS TO PROJECT DEVELOPERS OR FEEDSTOCK OWNERS (SELECTED REFERENCES)





TOPSOE

BY THE WAY, WHERE ARE WE IN THE SAF JOURNEY?



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A FEW THOUGHTS ABOUT REFINERIES



The purpose of a refinery is to produce on-spec fuels (gasoline, jet fuel, diesel, bunker fuel) and other products (feed for petrochemicals, lubricants, asphalt, coke, etc.) Crude oil properties Several options exist to upgrade crude oil to products: adding H2, removing carbon or cracking

Crude oil properties vary significantly depending on origin (sulfur content, aromatics, distillation curve, etc.). Many refineries operate with different crudes. As fuel specifications are fixed, refinery flexibility is key. Refinery products are interdependent.

HOW DOES A "TYPICAL REFINERY" LOOK LIKE AND WHICH UNITS CAN PRODUCE JET FUEL?



A FEW NUMBERS ABOUT JET FUEL



JET FUEL STANDARDS AND PROPERTIES

- A number of **regional specifications** and fuel types are in use globally for fossil jet fuel:
 - Jet A-1 (Europe) (DS 91-091 and ASTM D1655)
 - Jet A (North America) (ASTM D1655)
 - Jet B (Canada) (CAN/CGSB 3.23)
 - No.3 Jet Fuel (China)
 - TS-1 (Russia and CIS states)
- Some key jet fuel properties are:
 - Freezing point, smoke point, density, boiling curve, aromatics, flash point, viscosity, LHV, thermal stability, sulfur
- These properties are affected by the chemical composition of the fuel



WHAT FUEL PROPERTIES ARE IMPORTANT FOR CONTRAIL FORMATION



TOPSOE Märkl, R. S et al: Powering aircraft with 100% sustainable aviation fuel reduces ice crystals in contrails, Atmos. Chem. Phys., 24, 3813–3837, https://doi.org/10.5194/acp-24-3813-2024, 2024.

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CRUDE OILS IS COMPOSED OF MANY CLASSES OF MOLECULES



ADJUSTING CHEMICAL COMPOSITION TO MEET JET FUEL PROPERTIES IS AN INTERESTING PUZZLE



A FEW POINTS TO REMEMBER



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HYDROPROCESSING BY CATALYSIS HYDROPROCESSING = EITHER HYDROTREATMENT OR HYDROCRACKING

Hydrotreating	Remove sulfur Remove nitrogen Saturate aromatics Improve fuel quality	Requires a catalyst and hydrogen
Hydrocracking	Induce carbon-carbon bond breakage in order to convert higher boiling crude oil fractions into lower boiling transportation fuels	Requires a catalyst and high-pressure hydrogen

WHAT ARE THE TYPICAL REACTIONS TAKING PLACE IN HDP REACTORS?

HDP = HYDROPROCESSING



- Hydrogenation of olefins
- Hydrogenation of aromatics
- Hydrodemetallization
- Sulfur and nitrogen removal
- Hydrocracking
- Isomerization

WHAT DOES A HYDROPROCESSING CATALYST LOOK LIKE ?



AROMATIC SATURATION IS REVERSIBLE REACTION AND IS A BALANCE BETWEEN TWO OPPOSITE FORCES (THERMODYNAMICS VS. KINETICS)

- Hydrogenation (forward reaction) typically dominates in hydroprocessing units at lower temperatures and high pressures
- Dehydrogenation dominates at higher temperatures as reactions become thermodynamically controlled



- Many parameters have an impact on hydrogenation reaction
 - Operating conditions such as temperature, pressure and LHSV
 - Feedstock reactivity



HYDROGENATION REACTIONS IN A KEROSENE HYDROTREATER REMOVE SULFUR AND SATURATE AROMATICS



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FOUR SOLUTIONS ARE POSSIBLE TO CHANGE THE CHEMISTRY OF JET FUEL

1 – Hydrotreating of fossil kerosene in a kerosene or diesel hydrotreater (aromatic saturation)	2 – Hydrocracking of a Vacuum Gas Oil (VGO) in a hydrocracker (more paraffinic jet fuel)
3 – Co-processing renewable feedstock in a hydroprocessing unit (more paraffinic jet fuel)	4 – Producing Synthetic Paraffinic Kerosine with low aromatic content (HEFA-SPK or FT-SPK)

HYDROTREATING IN A KEROSENE OR DIESEL HYDROTREATER ALLOWS CATALYTIC AROMATIC SATURATION THAT IS DICTATED BY THERMODYNAMIC EQUILIBRIUM



AROMATIC (AND ESPECIALLY NAPHTHALENES) CAN EASILY BE HYDROTREATED D8267 GC-VUV OF PRODUCTS WITH VARYING AROMATIC CONTENT



GC-GC-FID ANALYSIS CONFIRMS THAT NAPHTHENE (CYCLOPARAFFIN) CONTENT INCREASES WHEN AROMATICS ARE SATURATED



AS AROMATIC CONTENT DECREASES, H₂ CONSUMPTION INCREASES THOUGH IT CAN BE EXPENSIVE; HOWEVER, QUALITY OF JET FUEL ALSO INCREASES,



H₂ CONSUMPTION WILL AFFECT THE CARBON INTENSITY OF THE JET FUEL BUT IT DEPENDS ON THE EMISSION FACTOR OF THE HYDROGEN USED



HYDROCRACKING OF A VACUUM GAS OIL (VGO) IN A HYDROCRACKER ALLOWS PRODUCTION OF A HIGH QUALITY AND PARAFFINIC JET FUEL

- VGO can be hydrocracked to obtain high quality jet fuel and diesel.
- The higher the cracking conversion, the higher the selectivity to jet fuel.
- For example: a high-quality jet fuel obtained at ≥ 70 wt% conversion at the following conditions:
 - Catalysts: Topsoe hydrocracking TK-931, TK-951
 - Conditions: 80-100 barg, 370-400°C, LHSV=1 h-1



CO-HYDROPROCESSING IN KEROSENE HYDROTREATER INCREASES THE PARAFFINIC CONTENT OF JET FUEL



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JET FUEL PRODUCTION SQUEEZED FROM ALL SIDES



TAKE-HOME MESSAGES

- Lowering aromatics and sulfur in fossil kerosene can be done with existing catalysts and hydroprocessing technology.
- Additional hydrogen consumption is unavoidable and grey hydrogen carries CO2-emissions
- Only lowering di-aromatic content is simpler, less costly and with minimal hydrogen consumption
- Requiring substantially lower total aromatic content in jet fuel will increase jet fuel price and require investments from refineries
- SAF in the form of HEFA-SPK or FT-SPK delivers on both low aromatics and sustainability
- Co-processing brings some of these benefits with low investments



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