HyFlexFuel

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Hydroprocessing of HTL biocrudes to liquid fuels: Lessons learned and milestones achieved

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Biofuels to decarbonize transportations

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- Long-haul transportations are important contributors to global warming issues
- Around 8.4% global CO_2 emissions come from freight road transport, aviation and shipping *(source: OurWorldinData.org)*
- Almost 40% of all CO_2 emissions in 2050 will be caused by shipping and aviation if left unregulated *(source: European Parliament study)*

- Electrification is less feasible for long-haul
- Potential use of hydrogen, though with some difficulties
- **Sustainable biofuels needed**

From biomass to drop-in fuels

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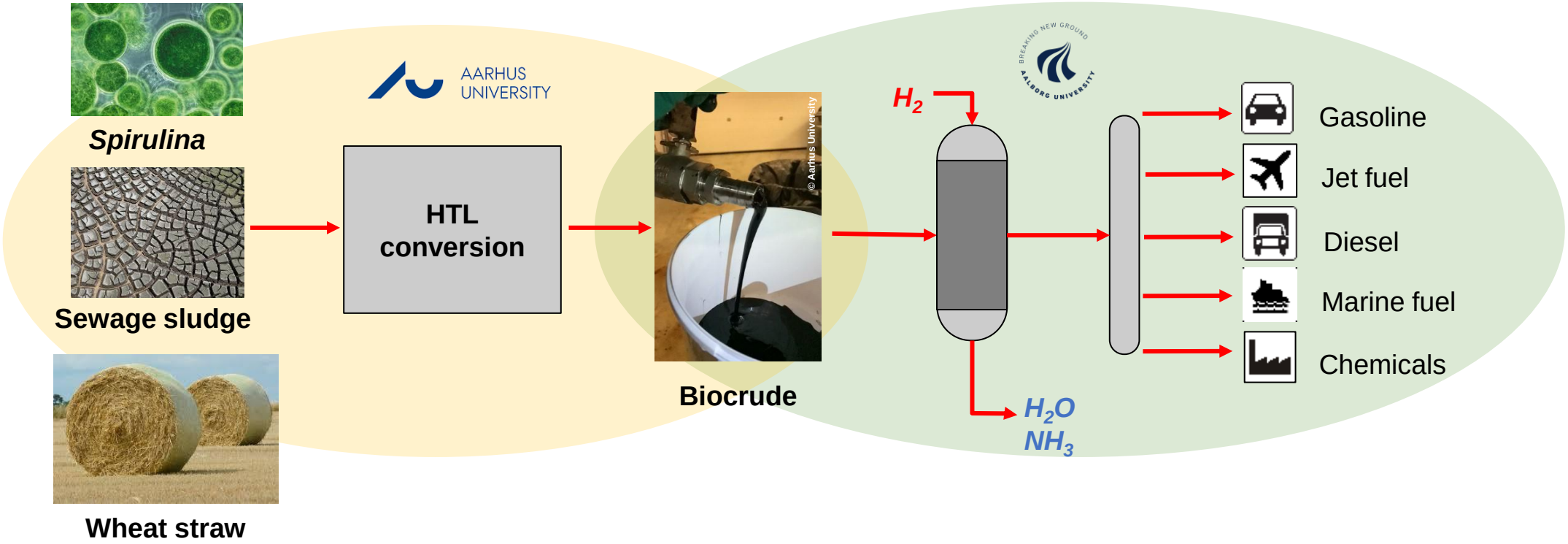
”Drop-in biofuels are defined as liquid hydro-carbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure”.

IEA Task 39



AAU's continuous hydrotreater

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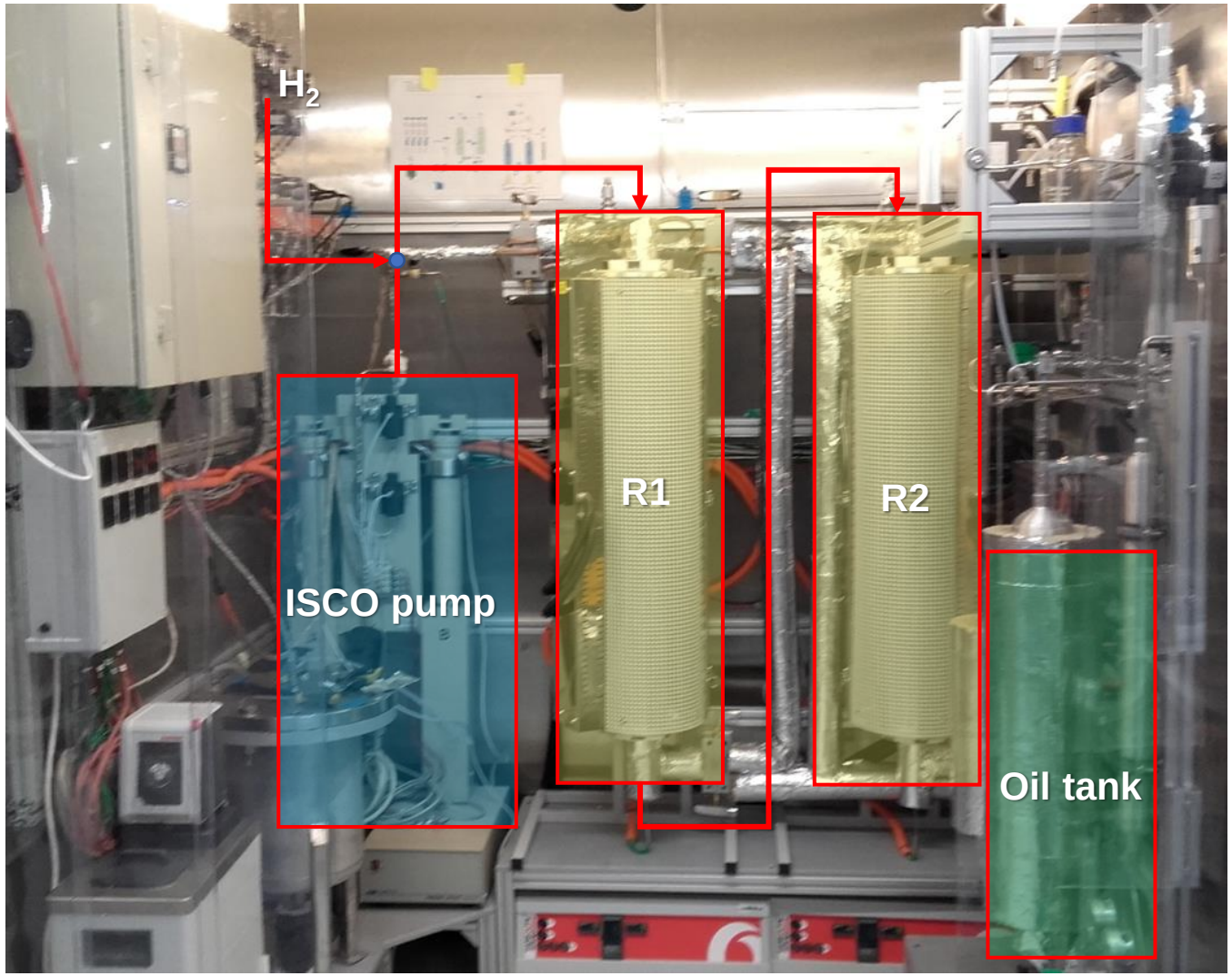
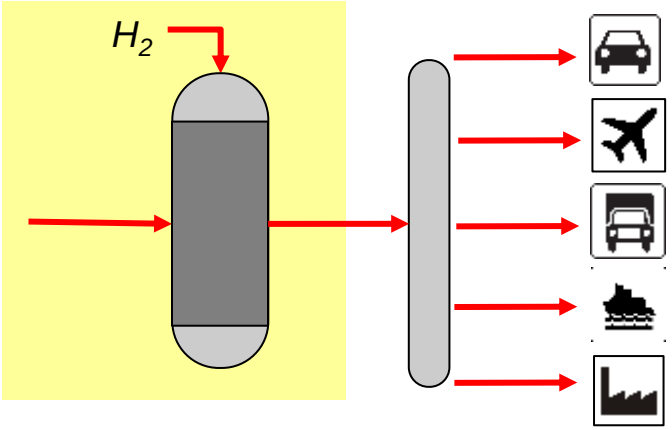
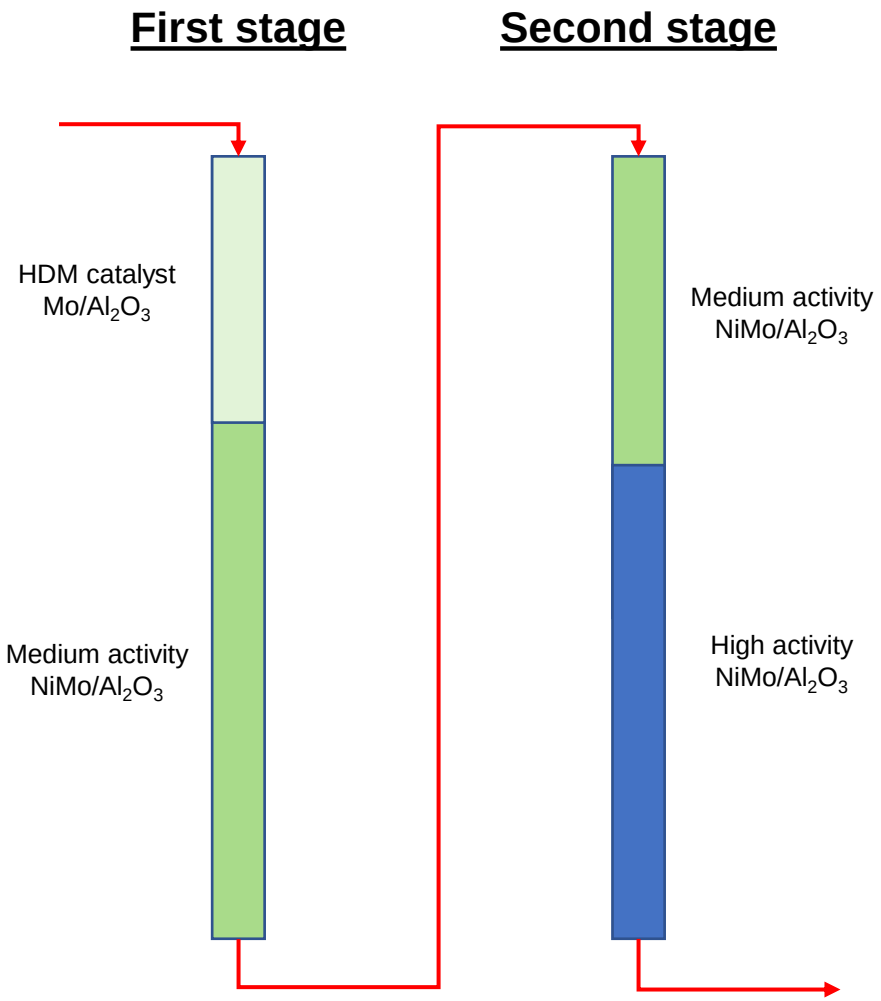




No. reactors	2
Reactor volume	150 cm^3 (each)
Operating mode	Independent / serial
Reactor type	Tubular, packed bed
Flow mode	Downflow
Usual throughput	~ 50 mL/h
Heating	Tubular furnace, 3 zones Trace heating on pipes
Max. operating P	150 bar

Choosing the right catalysts



- Sulfided hydroprocessing catalysts are used
- Biocrude has typically high inorganic content (often from 500 to 4000 ppm)
- Proper catalyst selection is crucial
- Temperature profile and grading are specific to each biocrude → know-how is needed!

HALDOR TOPSØE

Summary of the hydrotreating campaigns

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Spirulina

Stabilization (330-350 °C) → **Upgrading** (330-400 °C)

335 hours

Sewage sludge

Pre-stabilization (260 °C) → **Stabilization** (330-350 °C) → **Upgrading** (330-400 °C) → **Deep upgrading** (400 °C)

165 hours

Wheat straw

Stabilization (260-340 °C) → **Upgrading** (300-380 °C)

215 hours

Summary of the hydrotreating campaigns

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Spirulina

Stabilization (330-350 °C) → **Upgrading** (330-400 °C)

	C	H	N	O	H/C
Biocrude	75.1	10.8	7.6	6.5	1.73
Upgraded	83.8	15.5	0.6	0	2.21

Sewage sludge

Pre-stabilization (260 °C) → **Stabilization** (330-350 °C) → **Upgrading** (330-400 °C) → **Deep upgrading** (400 °C)

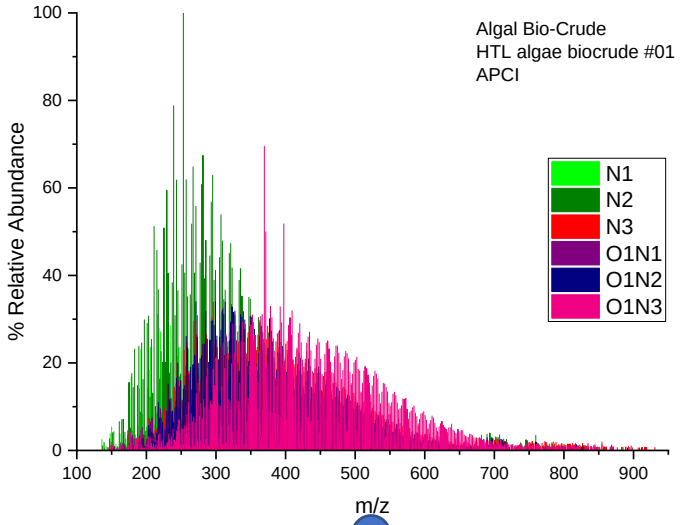
	C	H	N	O	H/C
Biocrude	75.6	95	3.0	11.8	1.51
Upgraded	84.5	14.7	0.8	0	2.09

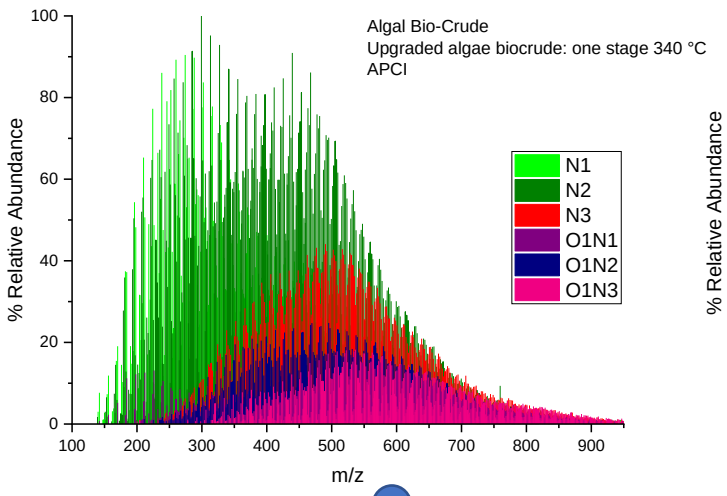
Wheat straw

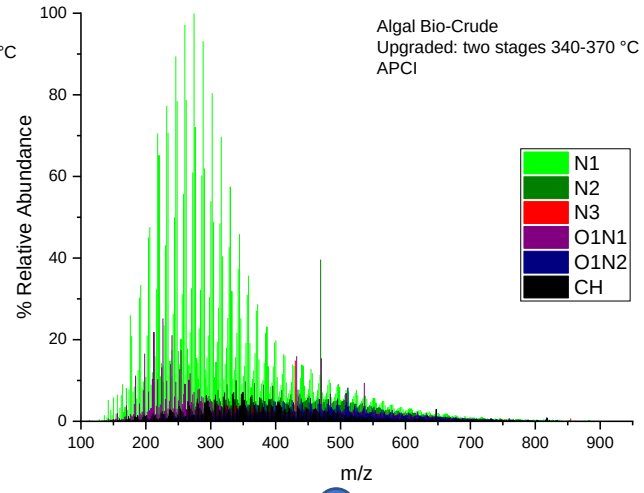
Stabilization (260-340 °C) → **Upgrading** (300-380 °C)

	C	H	N	O	H/C
Biocrude	72.3	7.2	1.2	19.3	1.19
Upgraded	87.7	12.1	0.9	0	1.66

Advanced characterization of the biocrude







***Spirulina* biocrude**

After 1st stage (340 °C)

After 2nd stage (340+370 °C)

- FTICR-MS analysis helps understanding the fate of N-containing compounds
- Information on the whole spectrum of biocrude
- N removal requires high temperatures!
- N_1 compounds are the most refractory to treatment

Fractional distillation

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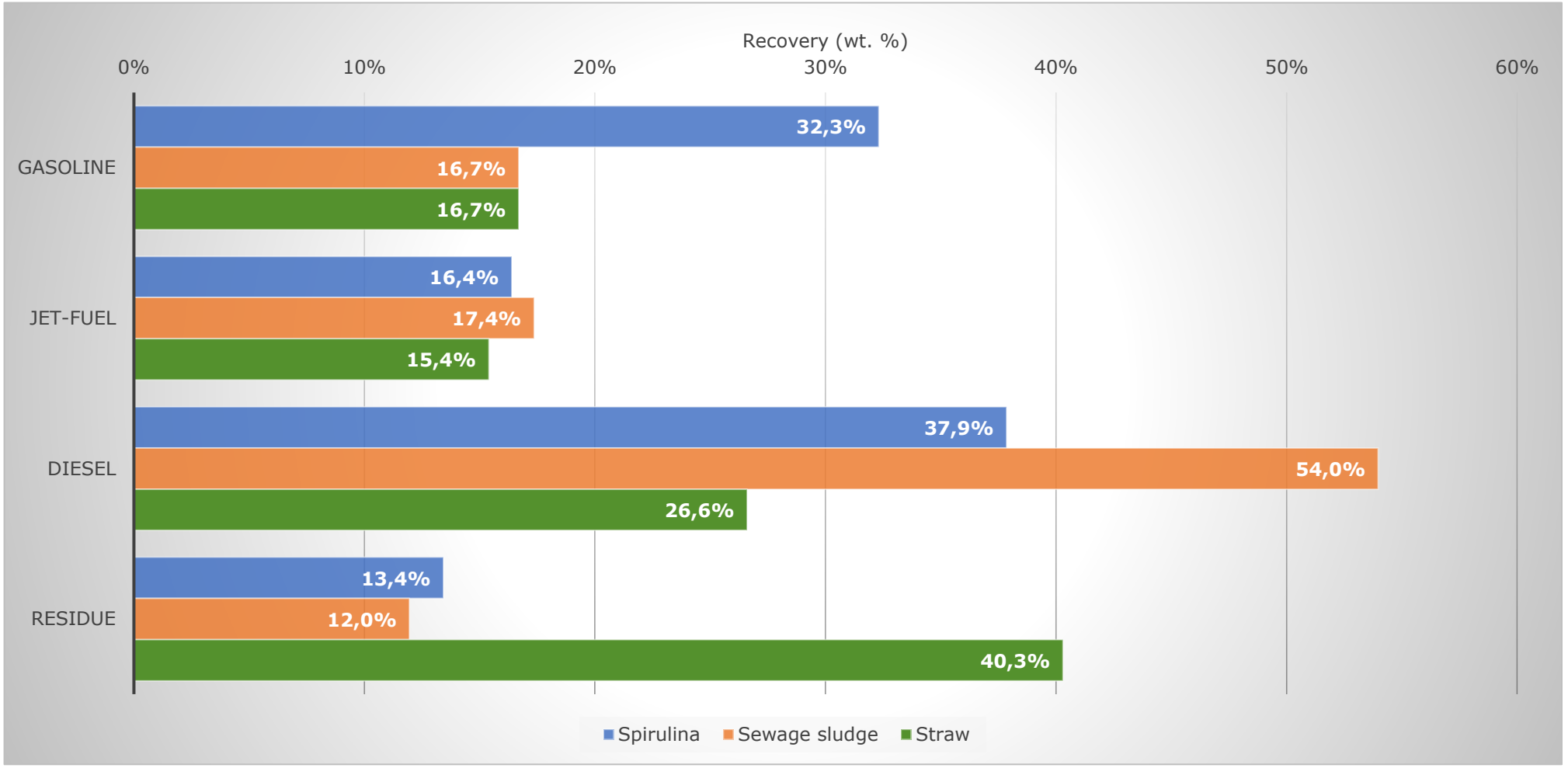
Distillation in a 15 theoretical plates column
(ASTM D2892)

- Around **1.2 L** feed
- Four steps distillation
  - 760 torr (atmospheric)
  - 100, 20, 1 torr (vacuum)
- Cuts collected every 25 °C

Gasoline	< 175 °C
Jet-fuel	175-250 °C
Diesel	250-350 °C
Residue	> 350 °C

Distillation and yields



Produced biofuels

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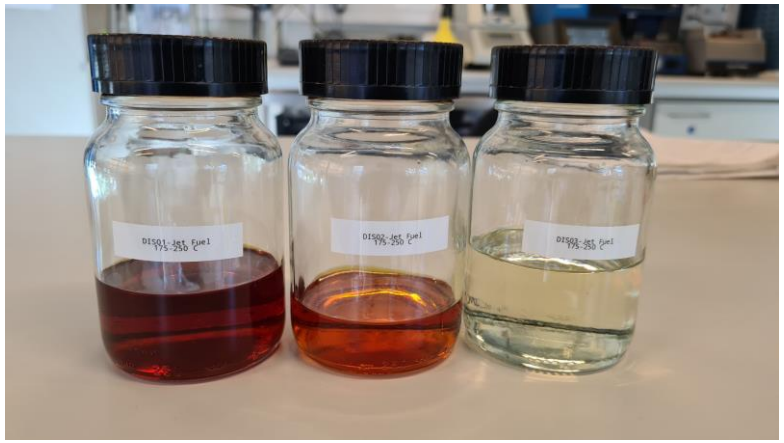


Jet-fuel
175-250 °C

Diesel
250-350 °C

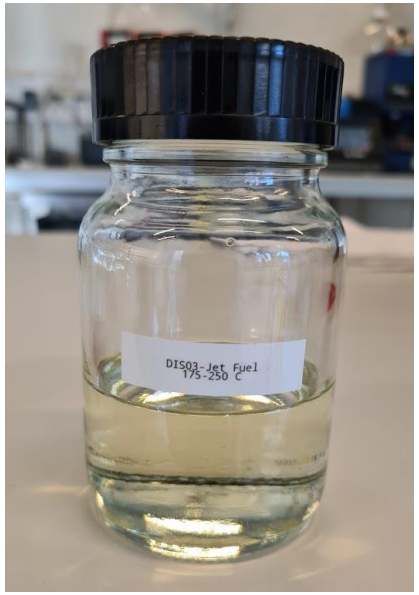
- Representative fuels were obtained
- Jet-fuel was characterized against ASTM D7566
- Diesel was characterized against EN 590
- **<u>Most specifications were achieved</u>**

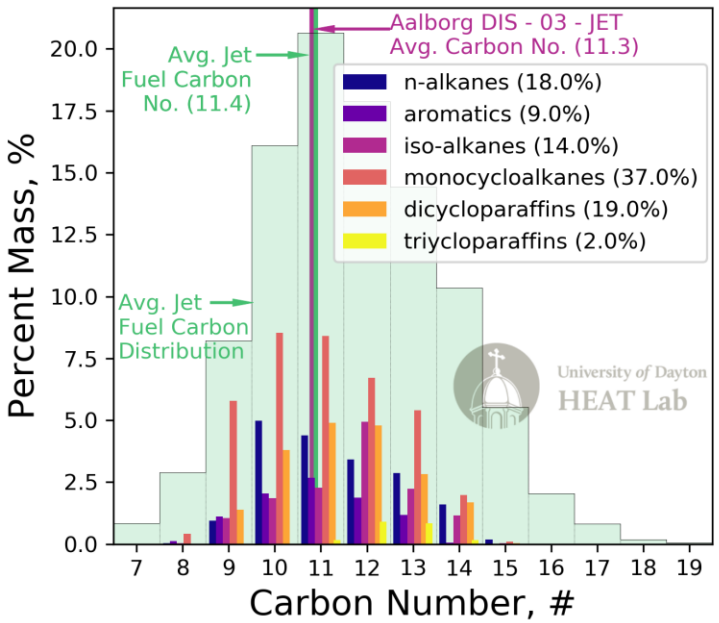
Diesel products

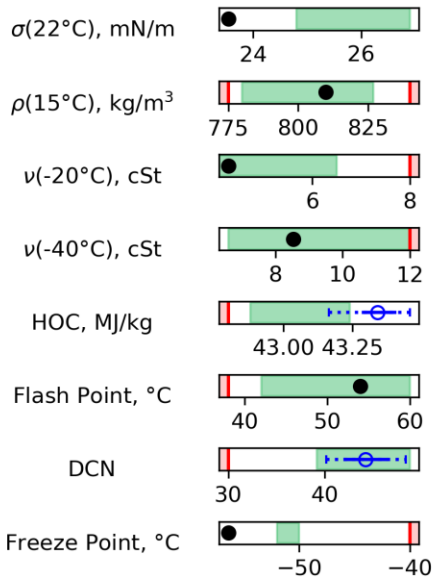
- Diesel compliant with most specification of EN 590 was produced, **even with no blending**
- High paraffinic nature
- Very good parameters, especially on cetane index
- Cold-flow properties can improve upon blending
- Fully on-spec up to 10% blending

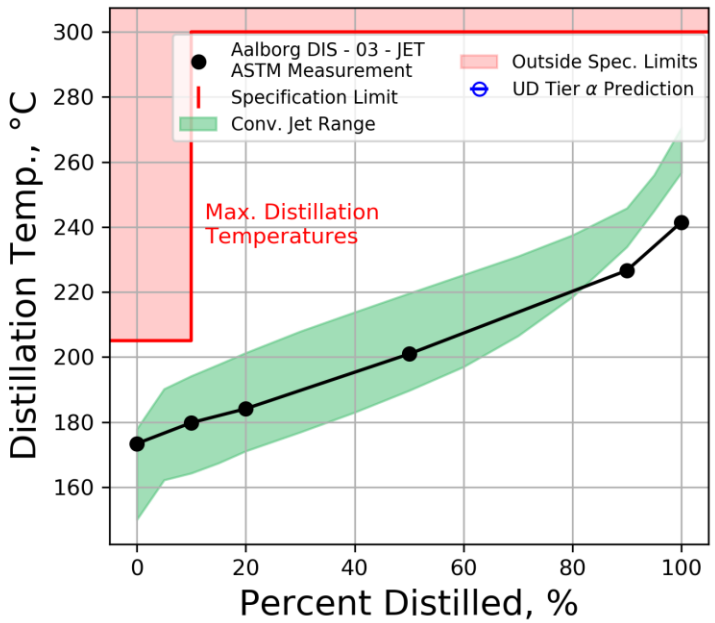
	EN590	*Spirulina* diesel	Sludge diesel
Density (kg m^{-3})	820-845	816.3	813.2
Viscosity (mm^2 s^{-1})	2 – 4	3.650	3.664
Cloud point (°C)	< -6	7	14
Pour point (°C)		6	12
TAN (g_{KOH} kg^{-1})		0.31	0.05
Cetane Index (-)	> 46	79	79
Sulfur (ppm)	< 10	43.2	4.7
E250 (%)	< 65	7	8
E350 (%)	> 85	100	94
T_{95} (°C)	< 360	323	333

Sewage sludge jet-fuel properties









- Boiling point distribution and carbon numbers are in line with standard Jet A-1.
- Physico-chemical properties are compliant with positive ASTM D4054 Tier 1 testing.
- Aromatic content is on target: **9%** (acceptable range: 8-25%, ASTM D7566)
- Residual nitrogen content: ~**30 ppm**

Test in an aviation turbine

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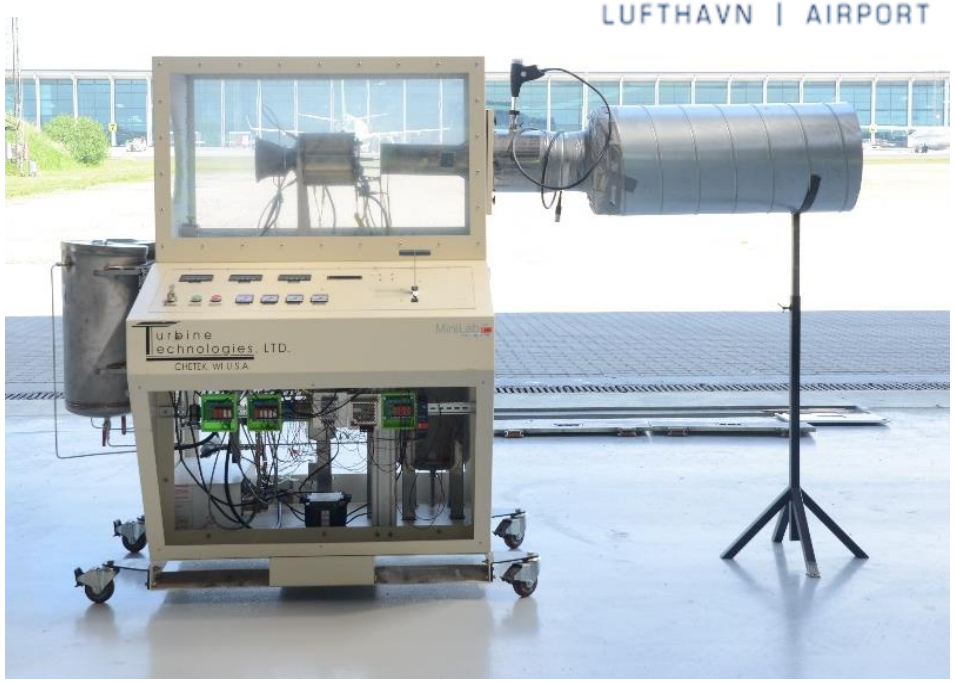
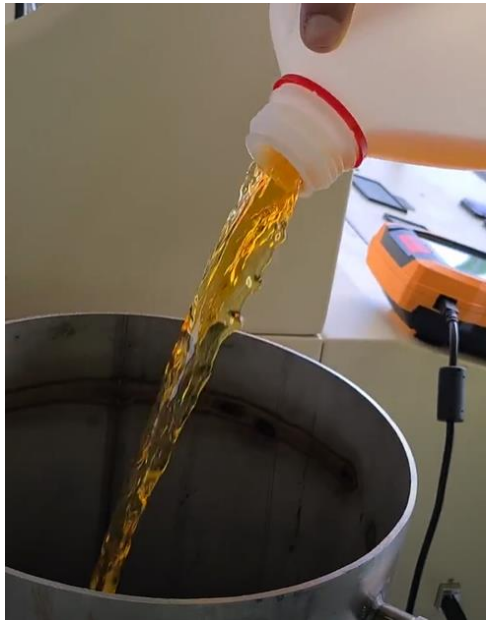


- How does HTL-derived SAF (sustainable aviation fuel) affect combustion?
- Tests at 50k, 60k, 70k rpm



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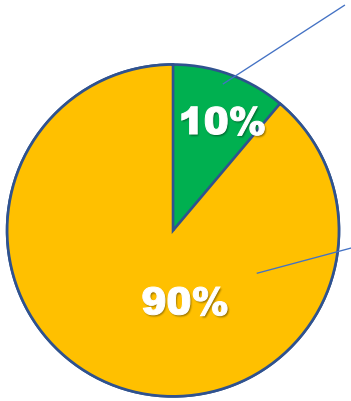
Mix of Spirulina, sewage sludge, straw jet-fuel component



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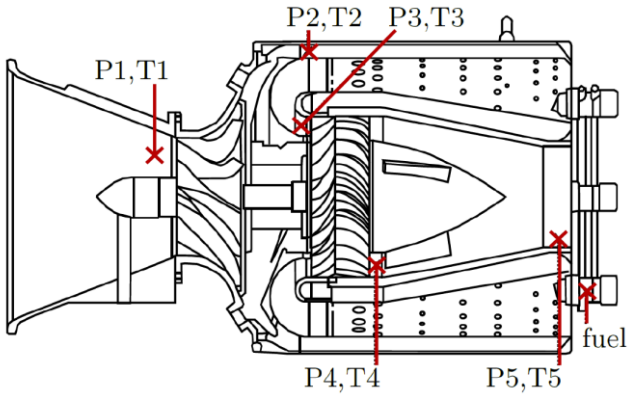
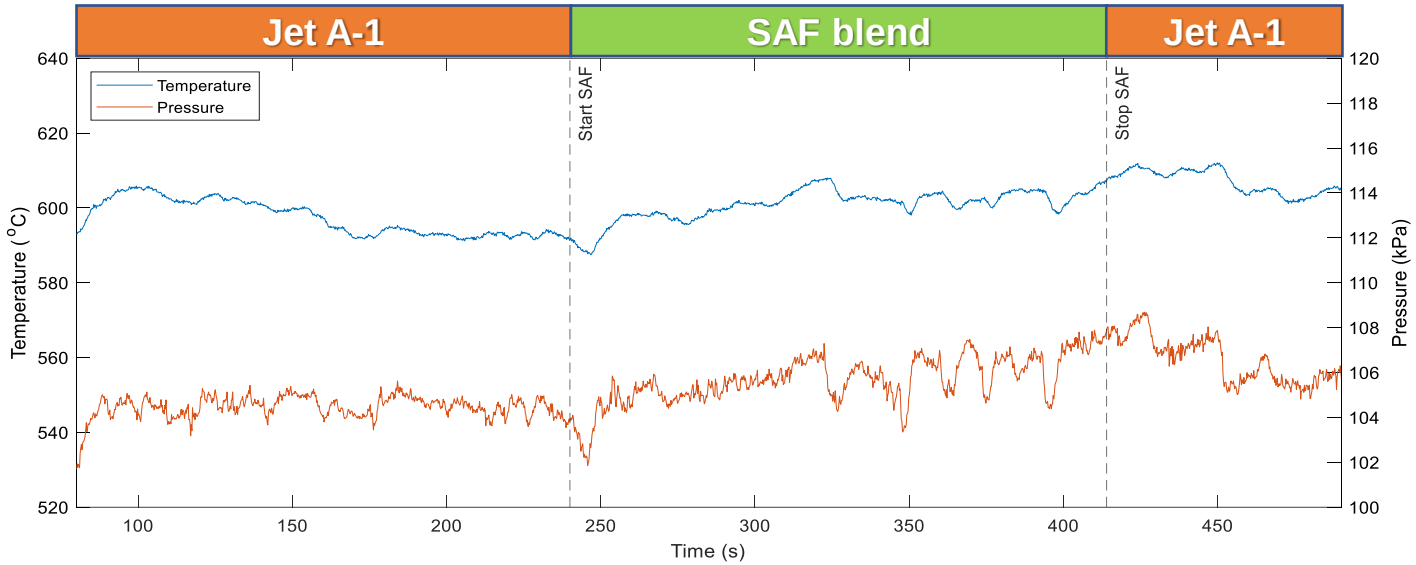
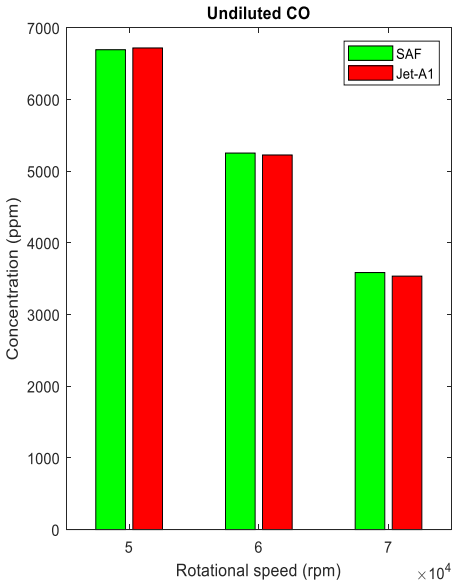
Commercial Jet-A1

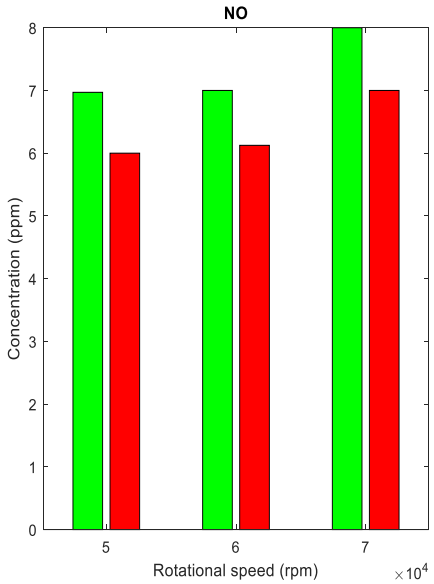
	ASTM D7566	SAF blend at 10%
Density (kg m^{-3})	**775-840**	798.2
Pour point (°C)*	**< -47**	-63.3
Cloud point (°C)		-61.2
T_{10} (°C)	**< 205**	165
T_{50} (°C)	**report**	179
T_{90} (°C)	**report**	204
FBP (°C)	**< 300**	237

Test in an aviation turbine









- Switching from Jet A-1 to SAF did not cause visible changes
- Similar flue gas emissions were found
- Only a slight increase in NO concentrations

Conclusions

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- HTL is able to produce promising drop-in fuels, with the highest flexibility for feedstock...
- ... but know-how is important: there is no one-size-fits-all!
- Great potential to produce on-spec diesel and jet-fuel (SAF)
- Succesful jet engine test with a 10% blend
- The potential towards an HTL-derived SAF is concrete: tests with higher volumes are required in view of a formal approval

HyFlexFuel

Thank you!

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