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The Aviation Think Tank

Jet fuel production from residues and wastes via hydrothermal liquefaction

Results and perspectives from the EU projects HyFlexFuel and CIRCULAIR

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2nd CLARA Public Workshop
25.4.2023

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- Need for aviation fuels from advanced feedstock
- Project Results from H2020 HyFlexFuel

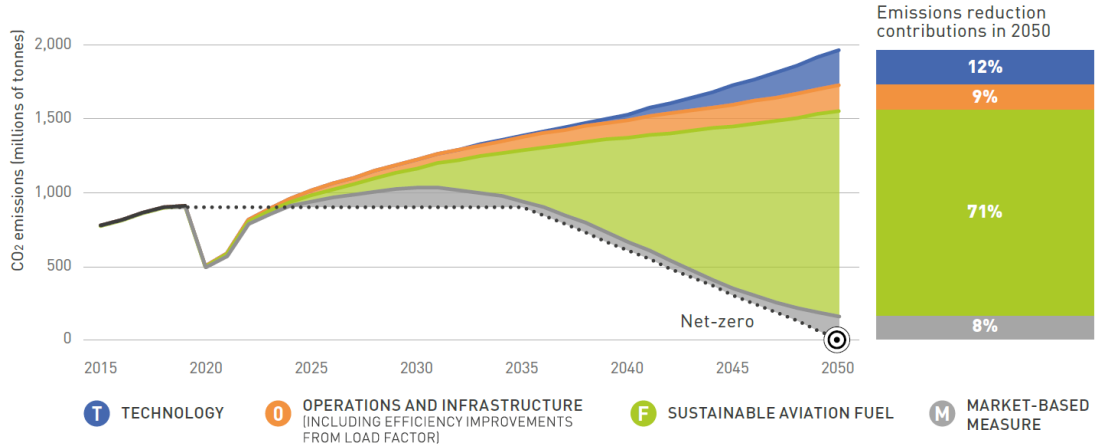
HyFlexFuel

- Outlook to Horizon Europe CIRCULAIR

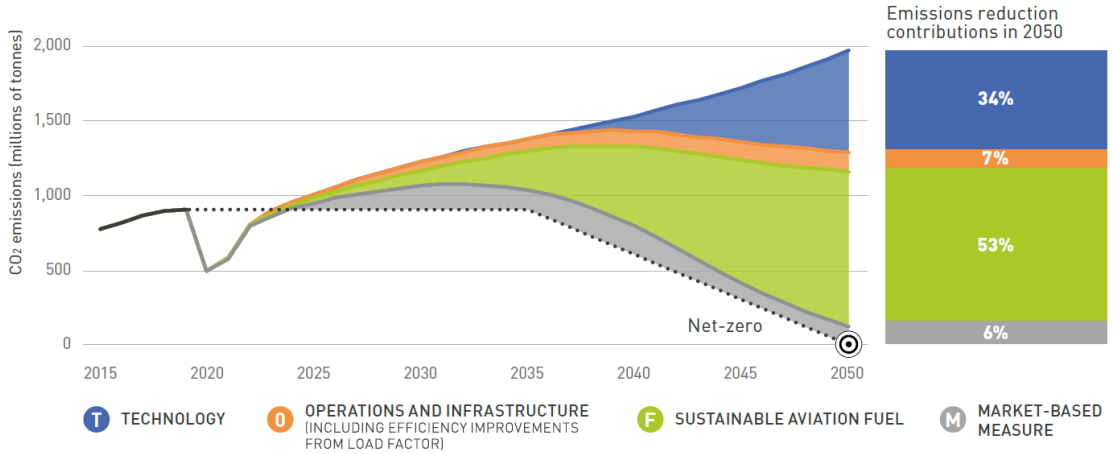
CIRCULAIR

Climate targets of the aviation industry: Net-zero by mid-century

Aggressive sustainable fuel deployment (ATAG Scenario 2)



Aspirational and aggressive technology perspective* (ATAG Scenario 3)



- **Efficiency increases: Important to limit future fuel demand**
- **Switch to sustainable aviation fuels is essential**
  - Most experts see ‘drop-in fuels’* as the baseline energy carrier for the transition in aviation

* Renewable kerosene-type fuels that can serve as substitute for conventional jet fuel

Source: ATAG – Air Transport Action Group, Waypoint 2050 https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/

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Liquid Fuels Needed for Bulk Part of Aviation's Energy Demand

Ce-Liner

Battery electric concept
Requires battery energy density > 1000 kWh/kg

Centreline:

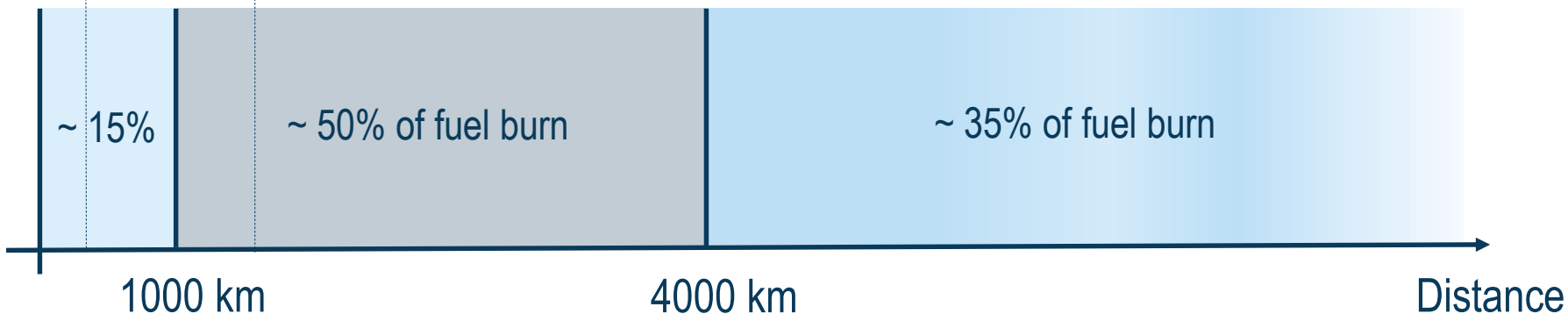
Turbo-electric concept
No change of energy carrier
Efficiency measure

CoCoRe

Hybrid-electric commuter
High battery utilization

HyLiner

Liquid hydrogen powered long-haul aircraft



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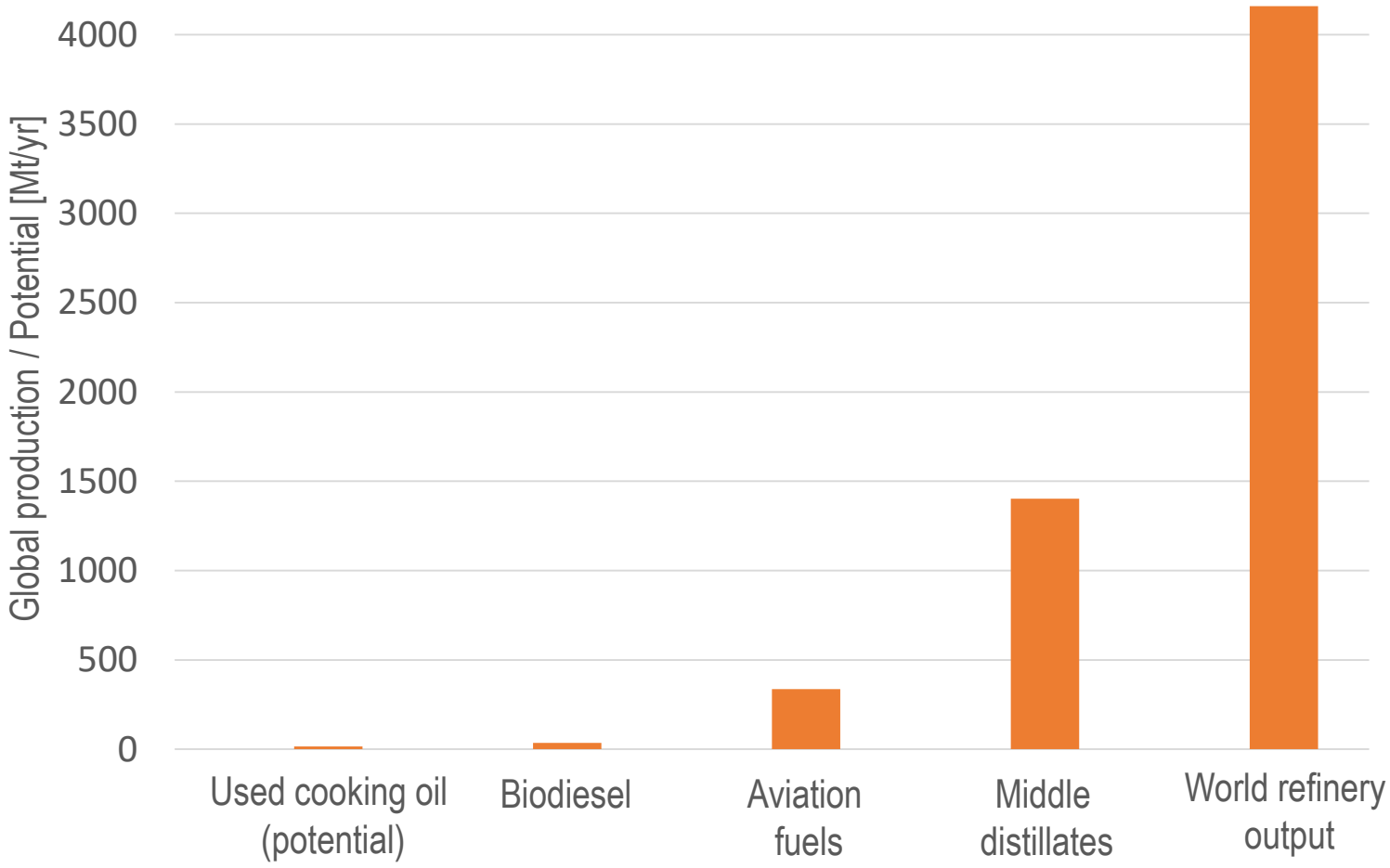
Global Aviation Fuel Consumption in Relation (2019 Data)



- **Aviation fuels: About 8% of global refinery output**
- **Feedstock competition in middle distillate markets (diesel, marine & jet fuels)**
  - Severe feedstock limitation for fuels from waste lipids (oils, fats and greases)
- **Need for additional pathways**
  - Biofuels from advanced feedstock
  - Synthetic fuels from H_2 and CO_2

Sources: IEA Key World Energy Statistics, Refining by product, 2019 data; Used cooking oil: EWABA; Biodiesel: UFOP

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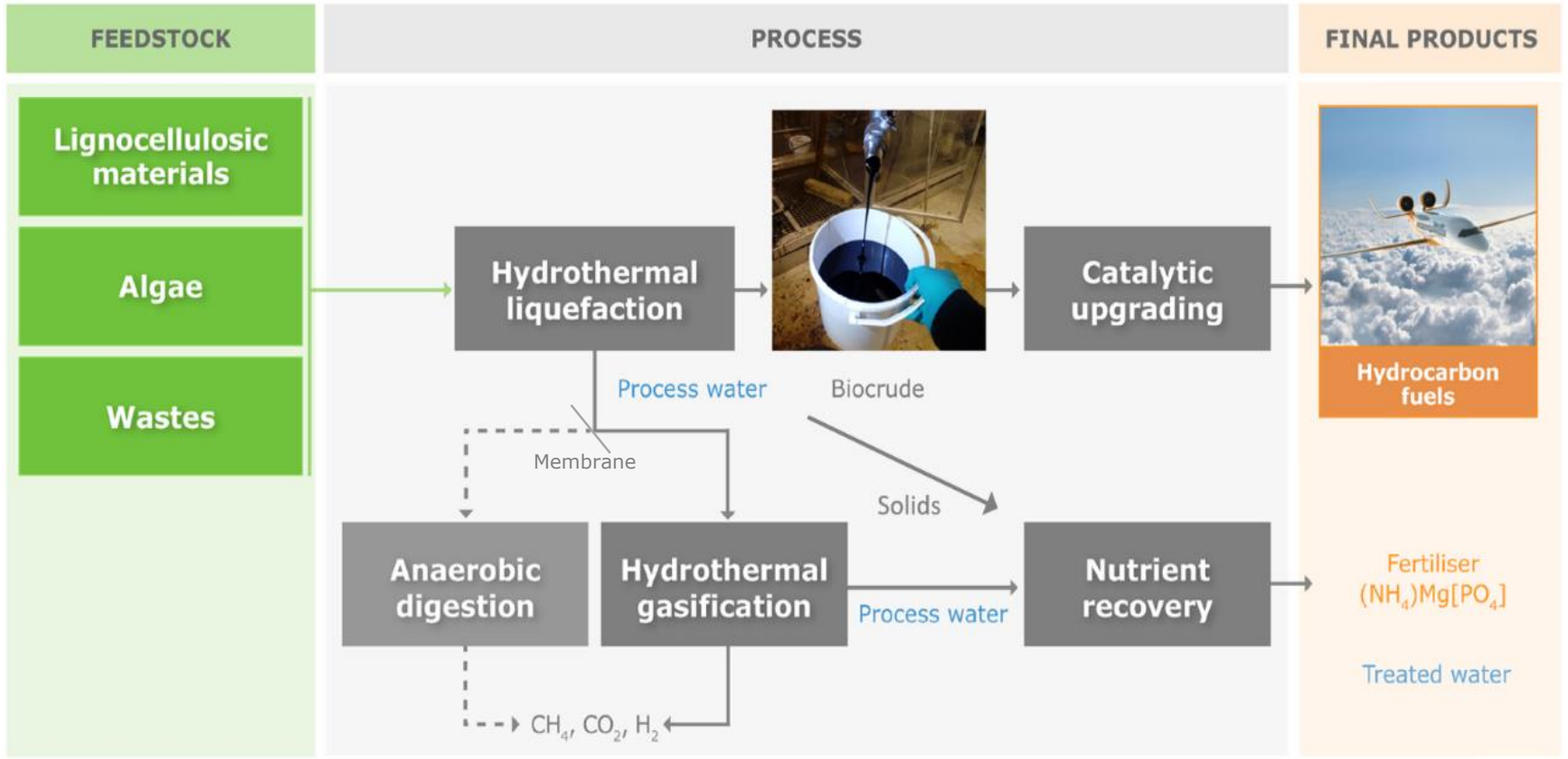
H2020 HyFlexFuel (2017-2021): Project overview



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ARTTIC

www.hyflexfuel.eu
project video:
www.youtube.com/watch?v=yDBIxPf06go

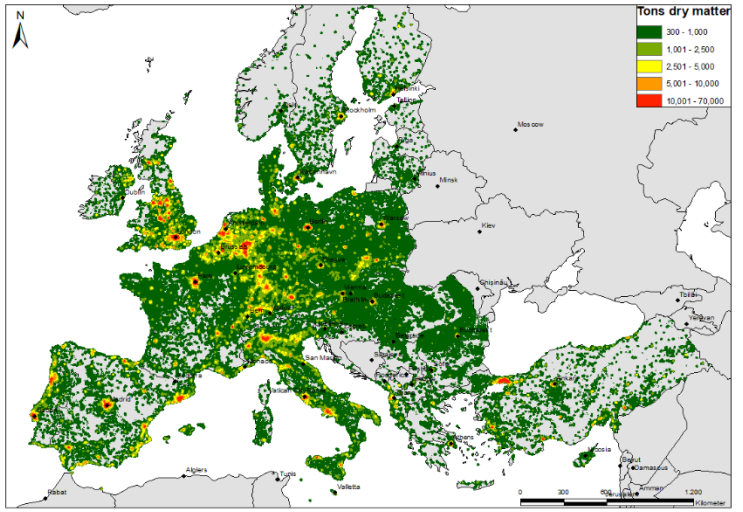
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764734

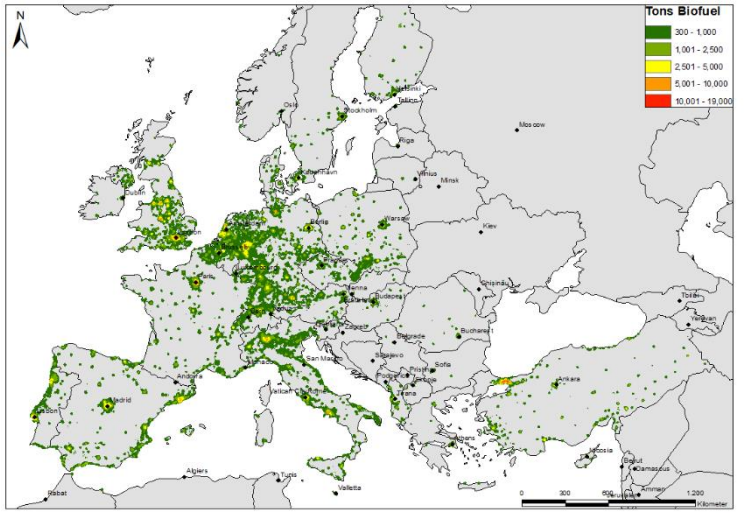
HTL feedstock potentials, wastes and residues in EU

- ***Spatial analysis of residue and waste availability in Europe***
- ***Feedstock density maps available for:***
  - **Animal excretions (cattle, pigs, poultry), agricultural by-products (straws, sugar beet leaves, corn stover), sewage sludge, biowastes**
- ***Conversion to biofuels potentials (yield model)***
- ***Theoretical annual fuel production potentials***
  - **Agricultural by-products: 26-29 Mt**
  - **Animal excretions: 10-26 Mt**
  - **Sewage sludge: 3 Mt**
  - **Biowastes: 1.5 Mt**

Potentials refer to mixture of liquid hydrocarbons!

Sewage sludge: Theoretical feedstock potential



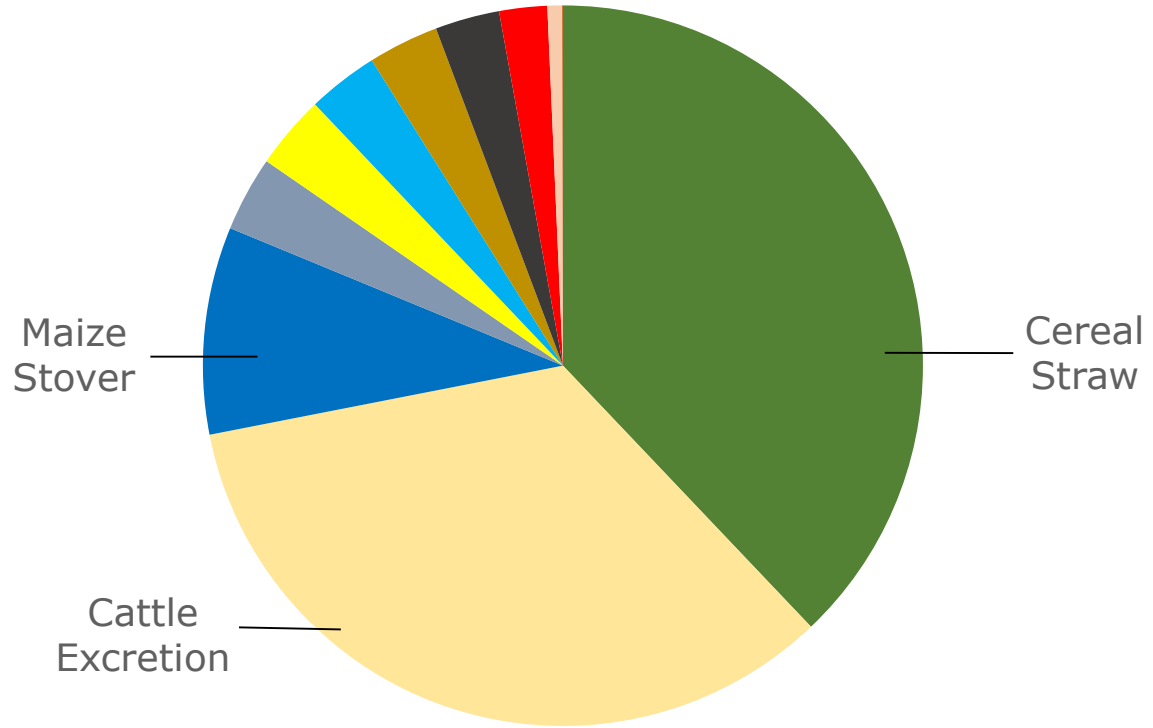


Sewage sludge: Biofuel potential

Source: T. Horschig et al. *Regional feedstock potentials and preference regions for HTL projects*, HyFlexFuel Public Deliverable 2019.

Quantification of feedstock potentials in EU-27 and UK

- **Cereal straw, cattle excretions and maize stover more than 80% of selected biogenic residues (forestry excluded here)**



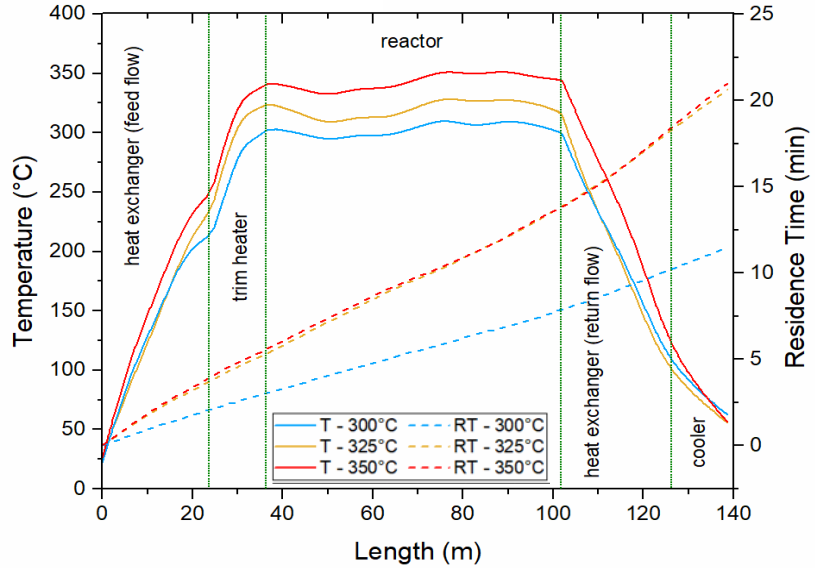
Residue	t/dm	%
Cereal Straw	111,218,767	37.90
Cattle Excretions	99,833,871	34.02
Maize Stover	27,303,796	9.31
Pigs Excretions	9,894,913	3.37
Biogenic Municipal Waste	9,701,468	3.31
Sewage Sludge	9,331,943	3.18
Oilseed Rape Straw	9,315,992	3.17
Sunflower Straw	8,495,328	2.90
Sugarbeet Leaves	6,294,350	2.15
Rice Straw	1,948,126	0.66
Poultry Excretions	86,004	0.03
Total	**293,424,558**	**100.00**

Based on maximum technical biomass potential

Source: F. Bellot, DBFZ, HyFlexFuel Final Workshop 2021, https://www.hyflexfuel.eu/wp-content/uploads/11_2021-09-24_HFF_Final_Workshop_DBFZ_v1_Bellot_FINAL.pdf

Pilot-scale HTL campaigns

- ***Typical conditions: 160-220 bar, 300-350ºC, 10-20 min, 60 L/h***
- ***Tubular system: 140 m, 14.7 mm diameter***
- ***Counter current heat exchanger***
  - **Heat recovery 75-85% (EROI* 3-7)**
- ***Feedstocks: Spirulina, sewage sludge, wheat straw,*** *miscanthus, manure, food waste, digestate fibres…*
- ***Total biocrude production: > 300 kg***
- ***48 h operation demonstrated***



Source: Anastasakis et al., *Continuous Hydrothermal Liquefaction of Biomass in a Novel Pilot Plant with Heat Recovery and Hydraulic Oscillation*, Energies 2018, *11*(10), 2695
Thomsen et al., *Hydrothermal liquefaction of sewage sludge; energy considerations and fate of micropollutants during pilot scale processing*, Water Reseach 183, 2020, 116101

***EROI reactor**: heating value of the bio-crude/ energy input in the system (heating, pumps).

Summary of HyFlexFuel hydrotreatment campaigns

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

Source: Castello, *Hydroprocessing of HTL biocrudes to liquid fuels: Lessons learned and milestones achieved*, HyFlexFuel Final Project Workshop, 2021 https://www.hyflexfuel.eu/final-project-workshop/

Summary of HyFlexFuel hydrotreatment campaigns

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

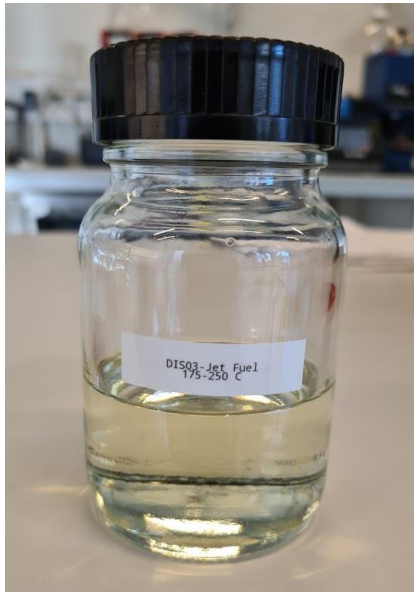
Wheat straw

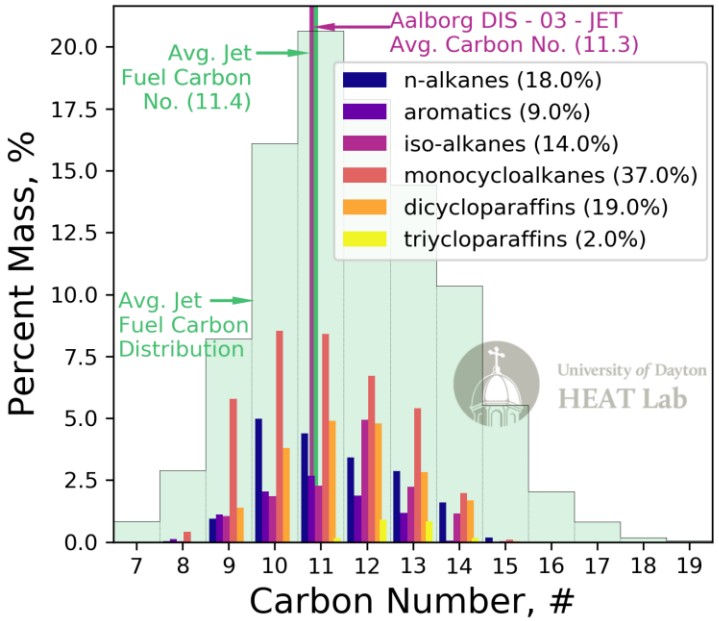
Stabilization (260-340 °C) → Upgrading (300-380 °C)

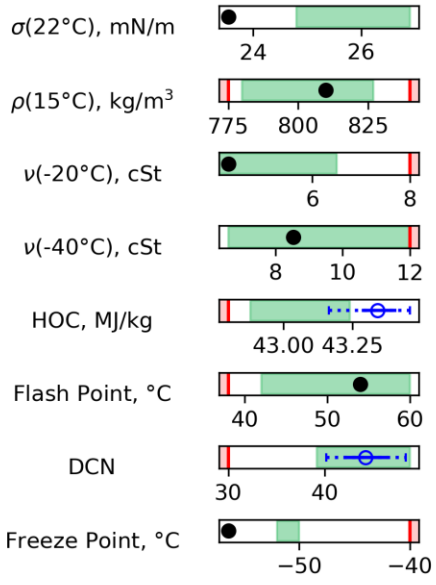
	C	H	N	O	H/C
Biocrude	72.3	7.2	1.2	19.3	1.19
Upgraded	87.7	12.1	0.9	0	1.66

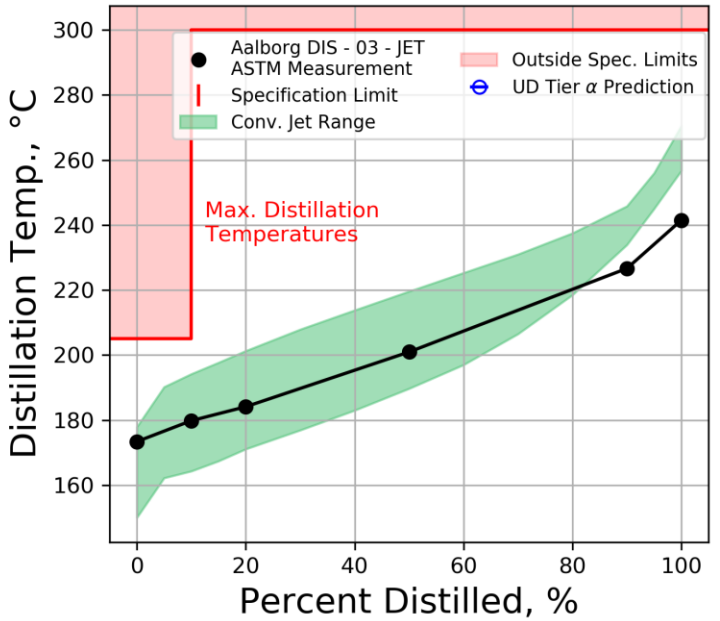
Source: Castello, *Hydroprocessing of HTL biocrudes to liquid fuels: Lessons learned and milestones achieved*, HyFlexFuel Final Project Workshop, 2021 https://www.hyflexfuel.eu/final-project-workshop/

Jet-fuel properties, sewage sludge







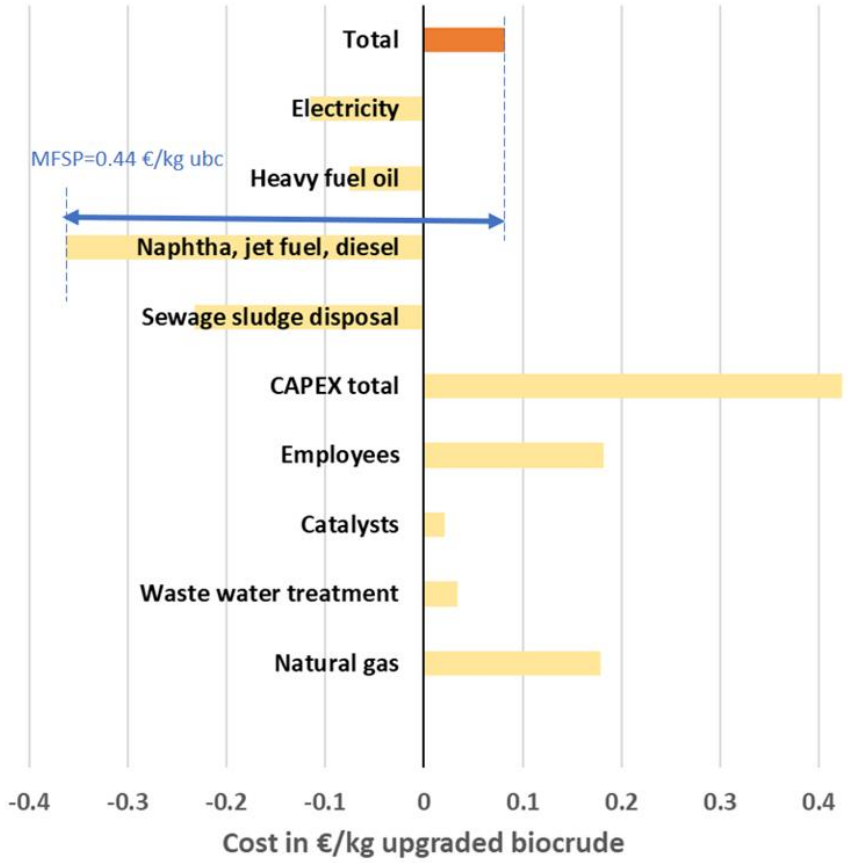


- Boiling point distribution and carbon numbers are in line with standard Jet A-1.
- Physico-chemical properties are compliant with positive ASTM D4054 Tier 1 testing.
- Aromatic content is on target: **9%** (acceptable range: 8-25%, ASTM D7566)
- Residual nitrogen content: ~**30 ppm**

Source: Castello, *Hydroprocessing of HTL biocrudes to liquid fuels: Lessons learned and milestones achieved*, HyFlexFuel Final Project Workshop, 2021

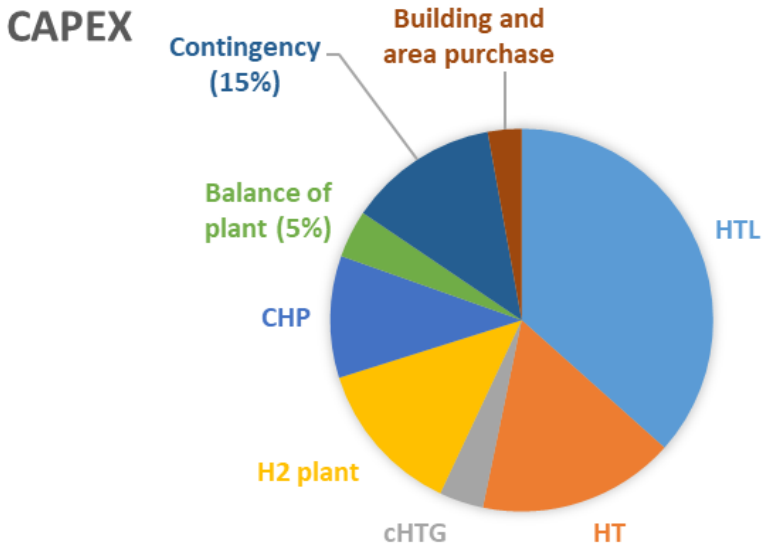
Techno-economic assessment, sewage sludge

Feedstock sewage sludge



Minimum fuel selling price (2020 assumptions)

- Sewage sludge: 0.44 €/kg upgraded biocrude (= mixture of hydrocarbon fuels)



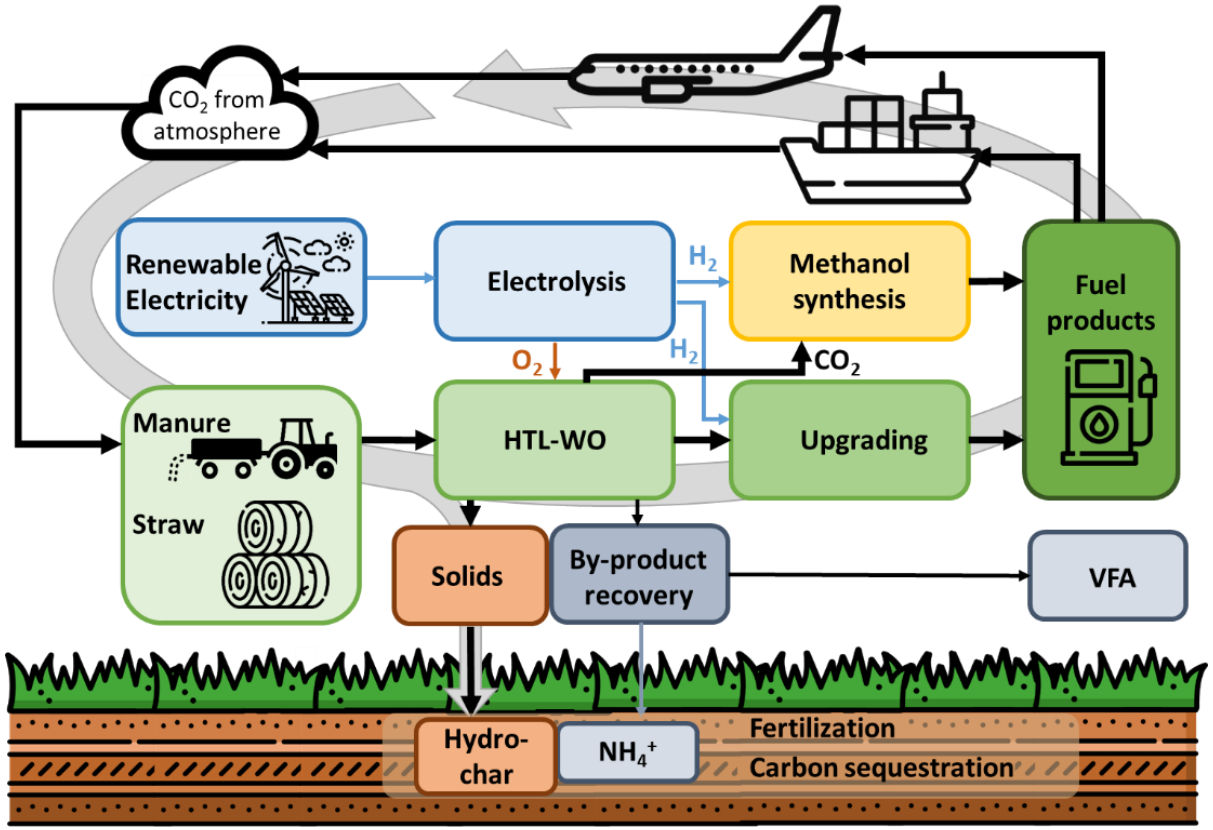
Source: C. Penke, L. Moser, G. Özal, A. Habersetzer, V. Batteiger, HyFlexFuel Public Report - Report on techno-economic and environmental assessment, 2021.

Conclusions from HyFlexFuel (2017-2021)

- ***HTL is increasingly perceived as a prime option for the conversion of wet waste streams***
- ***HyFlexFuel demonstrated feedstock flexible HTL at pilot-scale***
- ***Attempts to commercialize HTL are underway, academic research should broaden the knowledge base & support industrialization***
- ***HyFlexFuel contributed important achievements towards jet fuel approval, continued effort is needed***
- ***Appropriate options need to be developed for aqueous phase treatment (context specific)***
- ***Potentially cost-competitive, potentially attractive GHG balance***

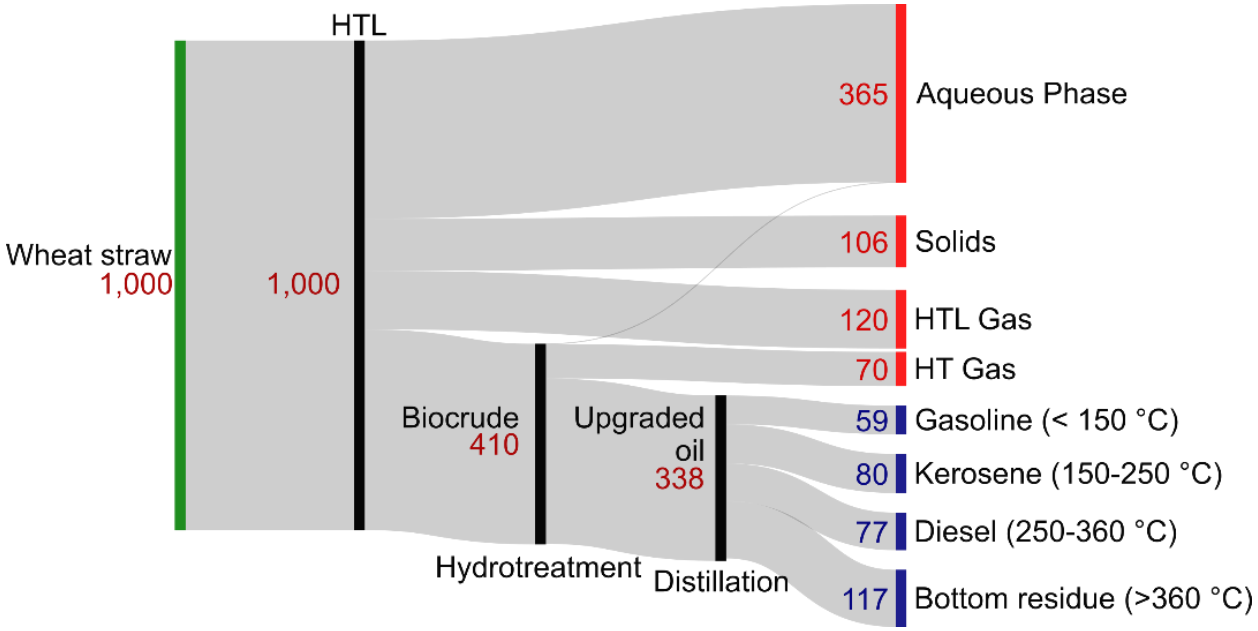
Horizon Europe CIRCULAIR (1/2023-12/2026)

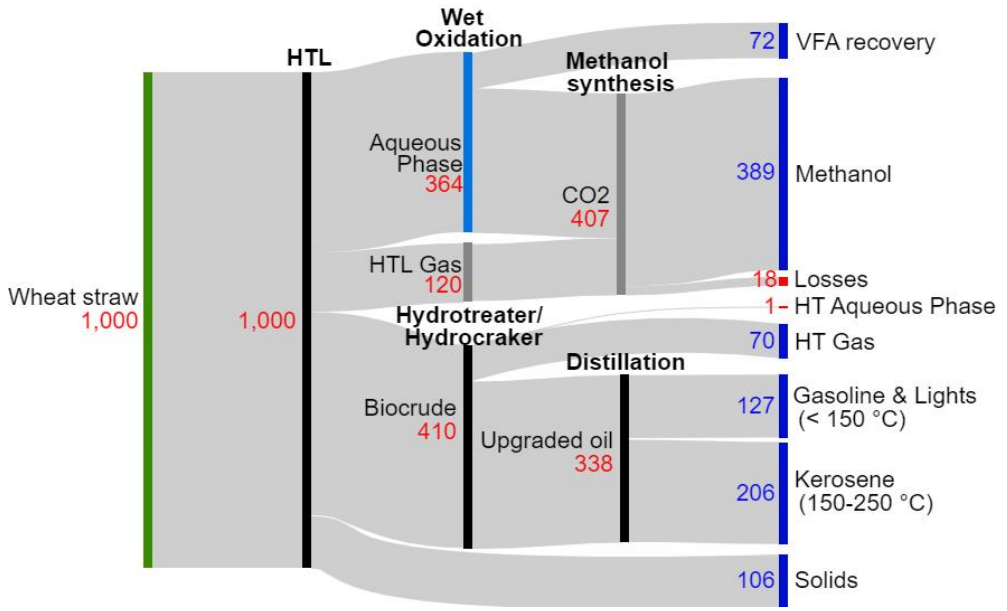
- CIRCULAIR demonstrates the production of jet fuel, methanol and further products from manure and straw via hydrothermal liquefaction



CIRCULAIR: Ambition beyond state-of-art

- Integration of HTL with wet oxidation of HTL aqueous phase
- Biocrude upgrading: Large kerosene fraction, fulfill jet fuel specifications
- Ensure near complete biomass utilization:
  - Recovery of suitable products from all major by-product streams





Note: Numbers within the shown carbon balances are indicative to explain the concept. Please do not cite or quote.

Summary and Conclusion

- Liquid fuels are needed to achieve climate targets in aviation
  - Specific need for fuels from advanced biomass feedstock, solar & wind
- HyFlexFuel demonstrated HTL conversion & upgrading (various feedstock)
  - Commercialization is underway for selected cases (e.g. sewage sludge)
- Horizon Europe CIRCULAIR, perspective:
  - Develop HTL conversion of abundant residues (manure, straw)
  - Address process water challenge by wet oxidation of aqueous phase
  - Maximize jet fuel yield & quality by appropriate upgrading schemes
  - Almost complete feedstock utilization by coupling with green H_2 and further product recovery incl. use of solids for carbon sequestration

Thank you!

For questions,
please contact:

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