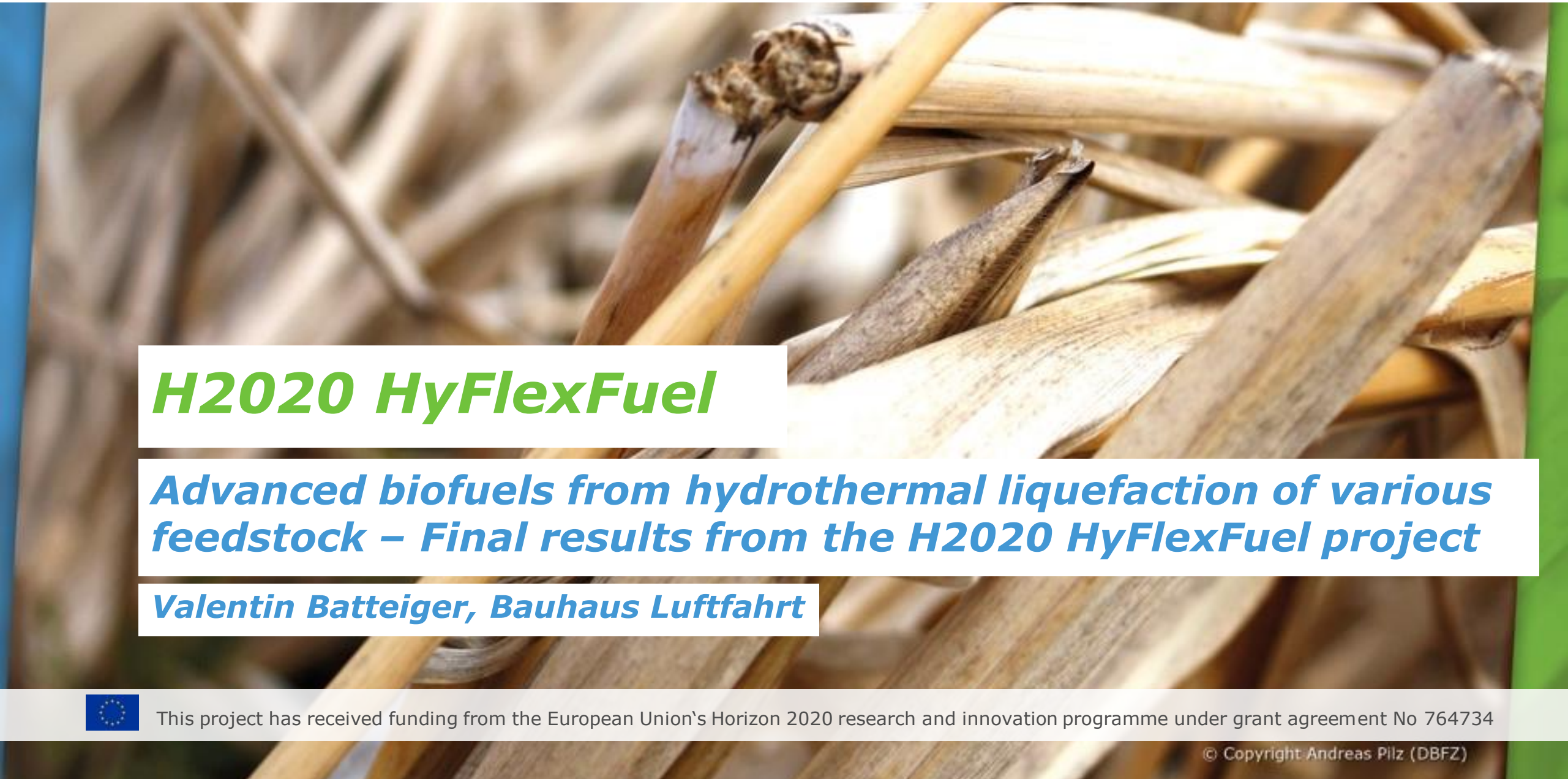


H2020 HyFlexFuel

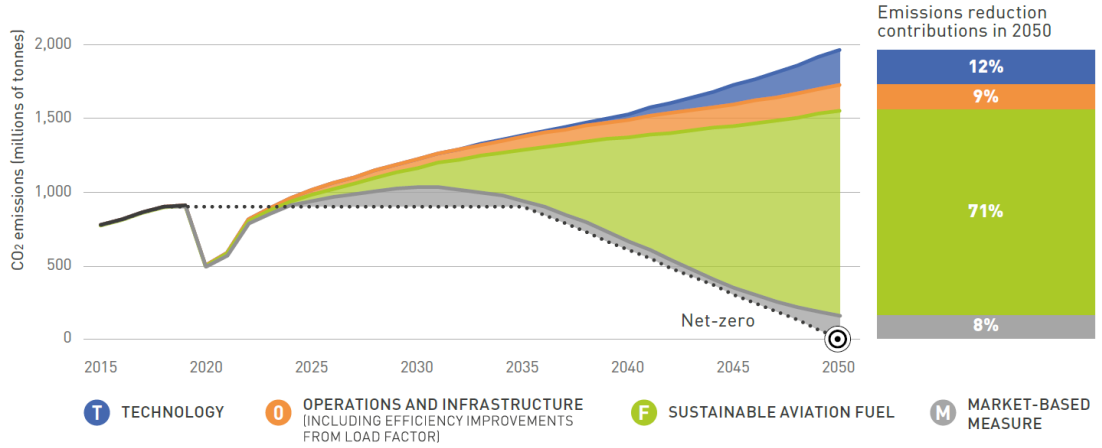
Advanced biofuels from hydrothermal liquefaction of various feedstock – Final results from the H2020 HyFlexFuel project

Valentin Batteiger, Bauhaus Luftfahrt

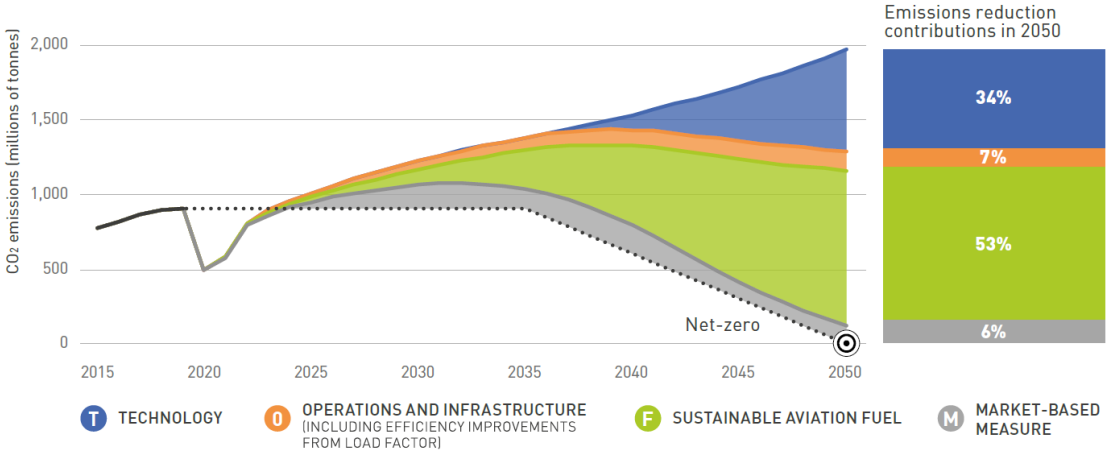
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764734

Motivation: Climate targets of the aviation industry

Aggressive sustainable fuel deployment (ATAG Scenario 2)



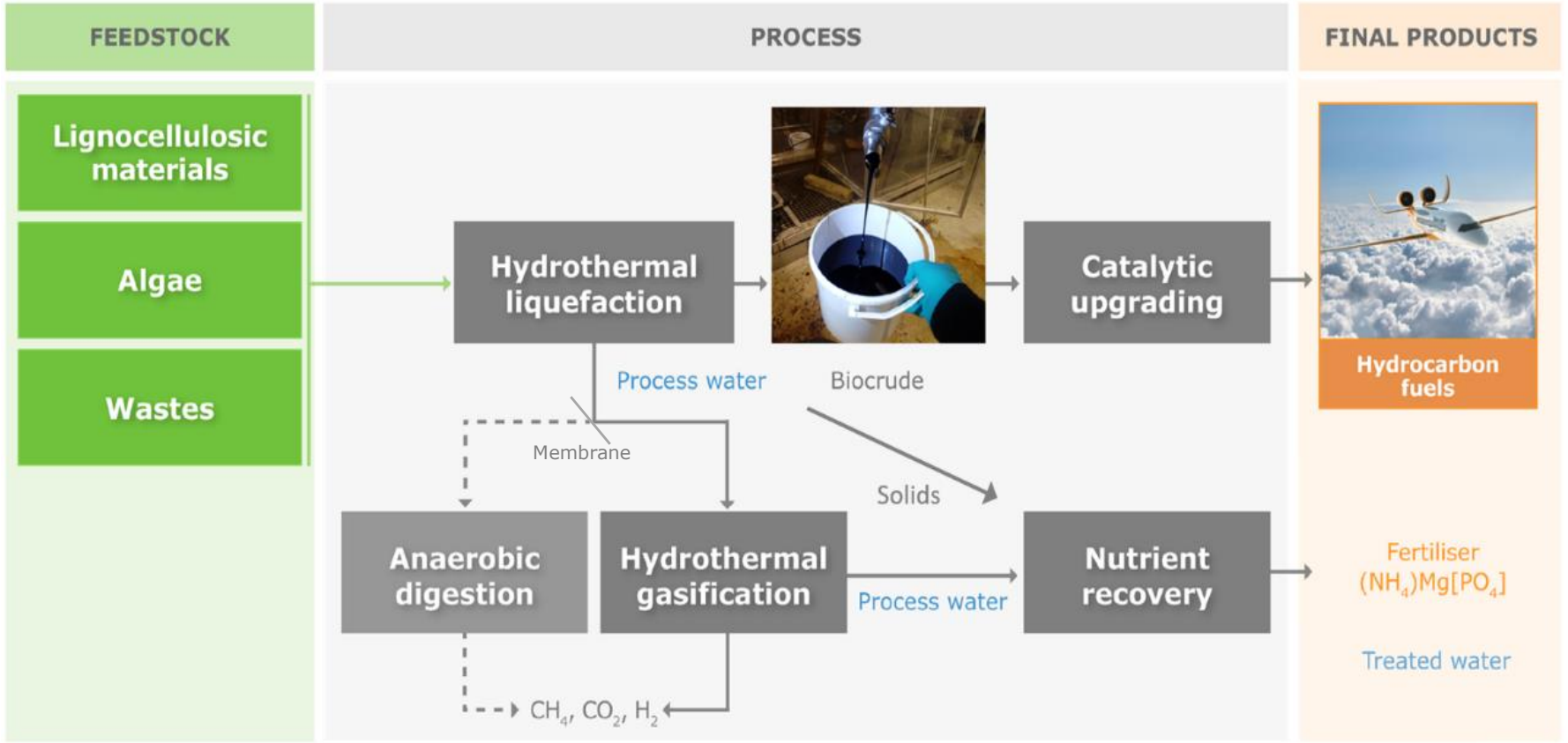
Aspirational and aggressive technology perspective* (ATAG Scenario 3)



- ***Switch to renewable energy carriers is essential to achieve climate targets***
- ***Efficiency increases (Technology/Operations) remain important to limit future energy demand***
- ***Renewable jet fuels (= kerosenes) are the baseline case for the energy transition in aviation***

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

HyFlexFuel Project overview slide



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H2020 HyFlexFuel: Main objectives

Develop process chain to sustainable liquid fuels via hydrothermal liquefaction of various biomass feedstock

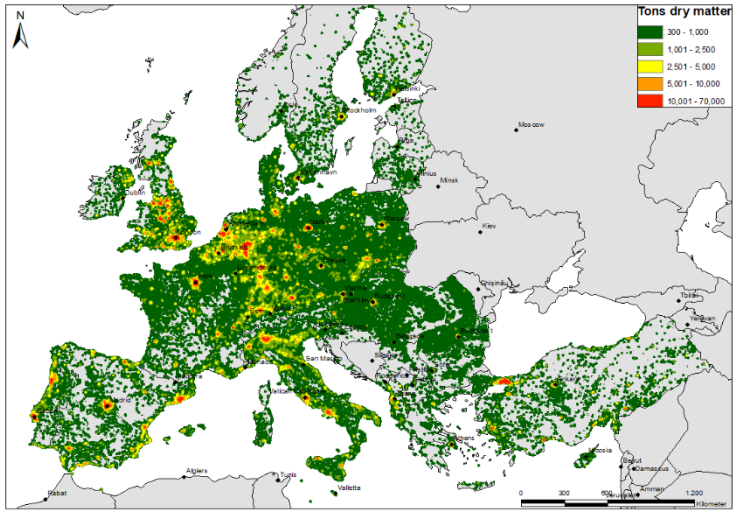
- *Feedstock potential assessment*
- *Hydrothermal liquefaction*
- *Catalytic upgrading*
- *Co-refining of biocrudes*
- *Valorization of HTL aqueous phase*
  - Catalytic hydrothermal gasification/anaerobic digestion
- *Recovery of inorganic nutrients*
- *System analyses*

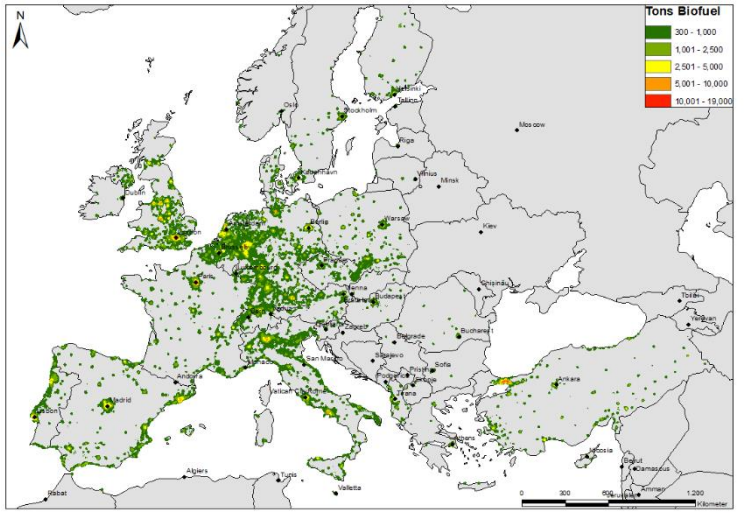
HTL feedstock potentials, wastes and residues in EU

- ***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 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



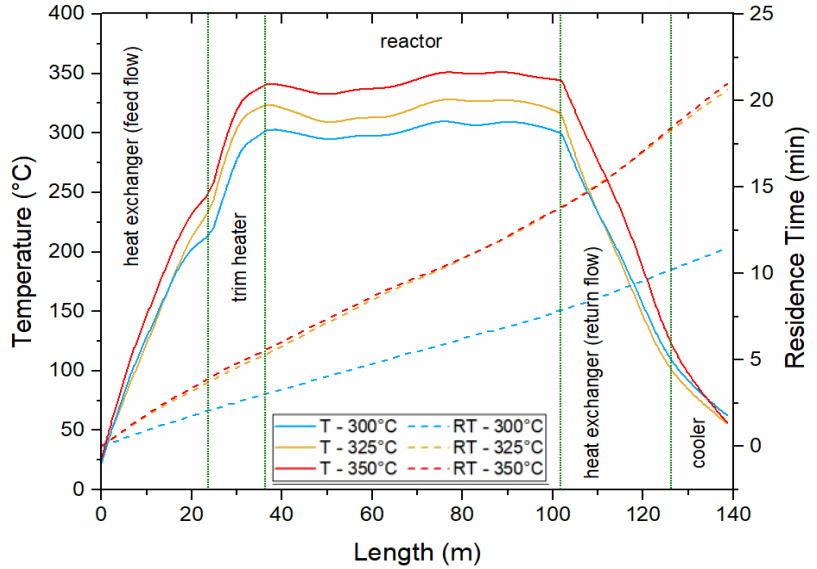


Sewage sludge: Biofuel potential

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

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***

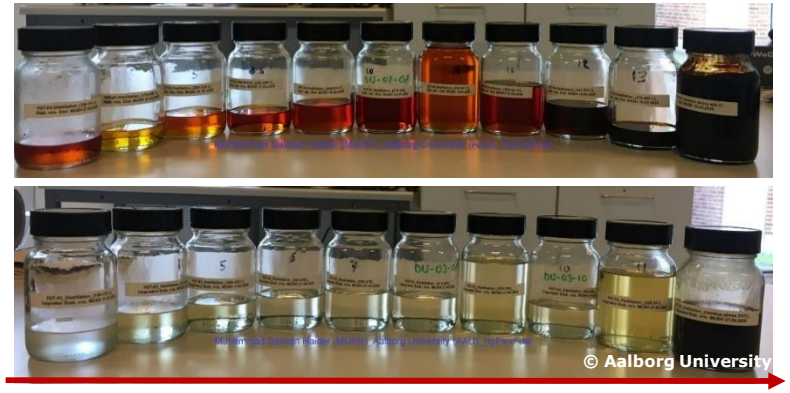


Source: Anastasakis et al., *Continuous Hydrothermal Liquefaction of Biomass in a Novel Pilot Plant with Heat Recovery and Hydraulic Oscillation*, Energies 2018, *11*(10), 2695
Thomsen et al., *Hydrothermal liquefaction of sewage sludge; energy considerations and fate of micropollutants during pilot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

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

Biocrude upgrading

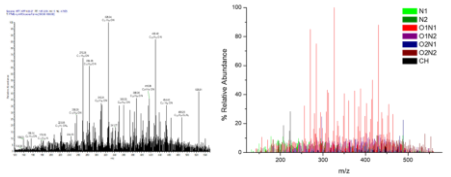
- **Continuous catalytic hydrotreatment**
  (Spirulina 335 h, sewage sludge 165 h, wheat straw 215 h)



Boiling point

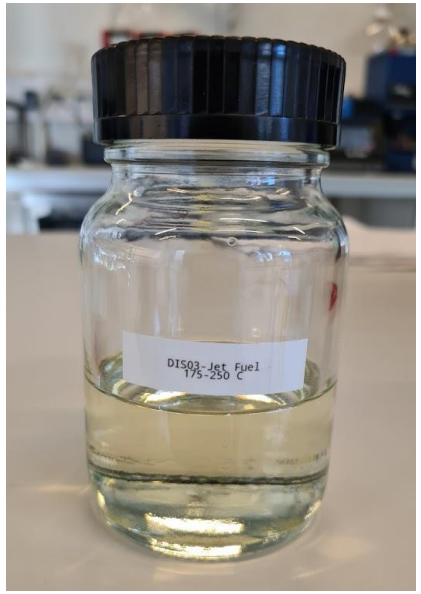
- **Co-processing of HTL biocrudes**

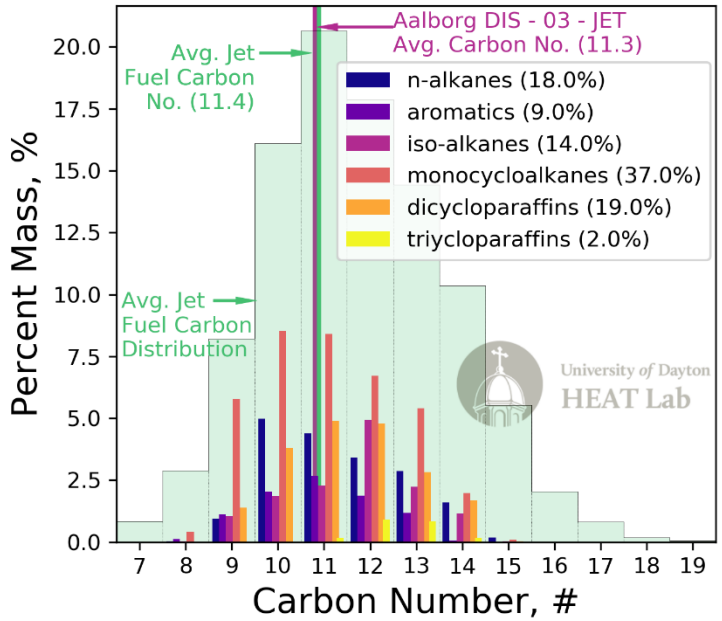
Petroleomic Characterization of Bio-Crudes

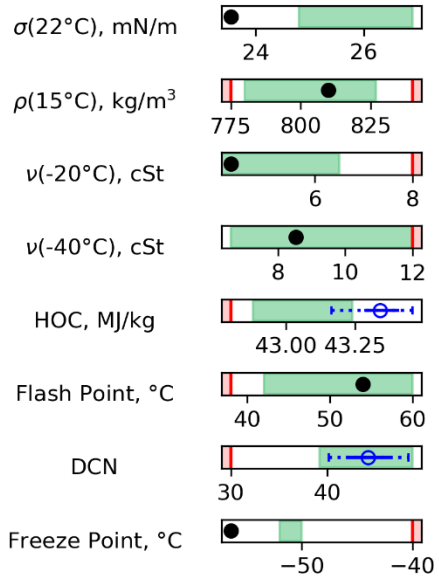


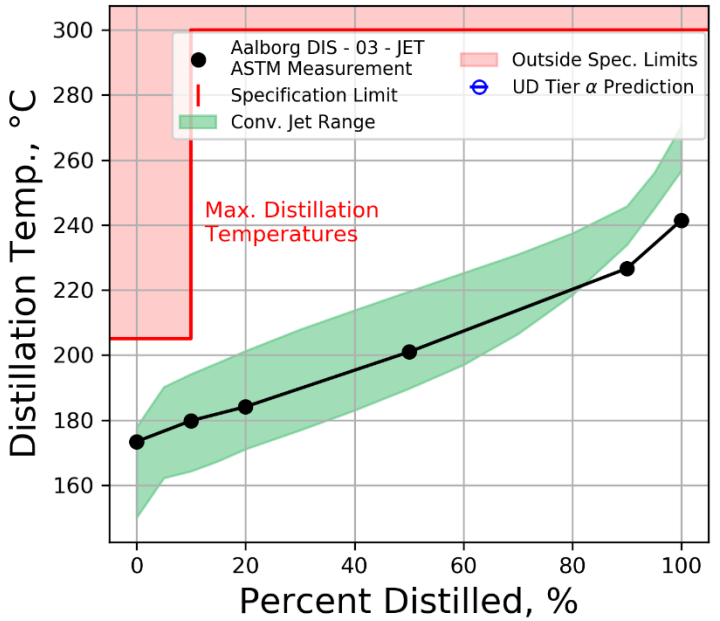
Co-Distillation - Refining Tests: Ratio between Biocrude:Fossil Feed determined according to BioCrude quality

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**

Valorisation of aqueous phase and solids

- ***Energetic valorization of aqueous phase***
  - **Catalytic hydrothermal gasification (cHTG)**
  - **Anaerobic digestion**

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- ***Nutrient recovery (phosphates)***
  - **Precipitation of struvite from solids, cHTG brine and HTL process water**

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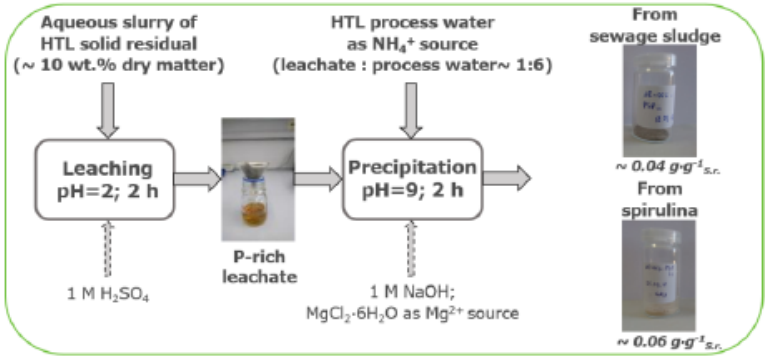
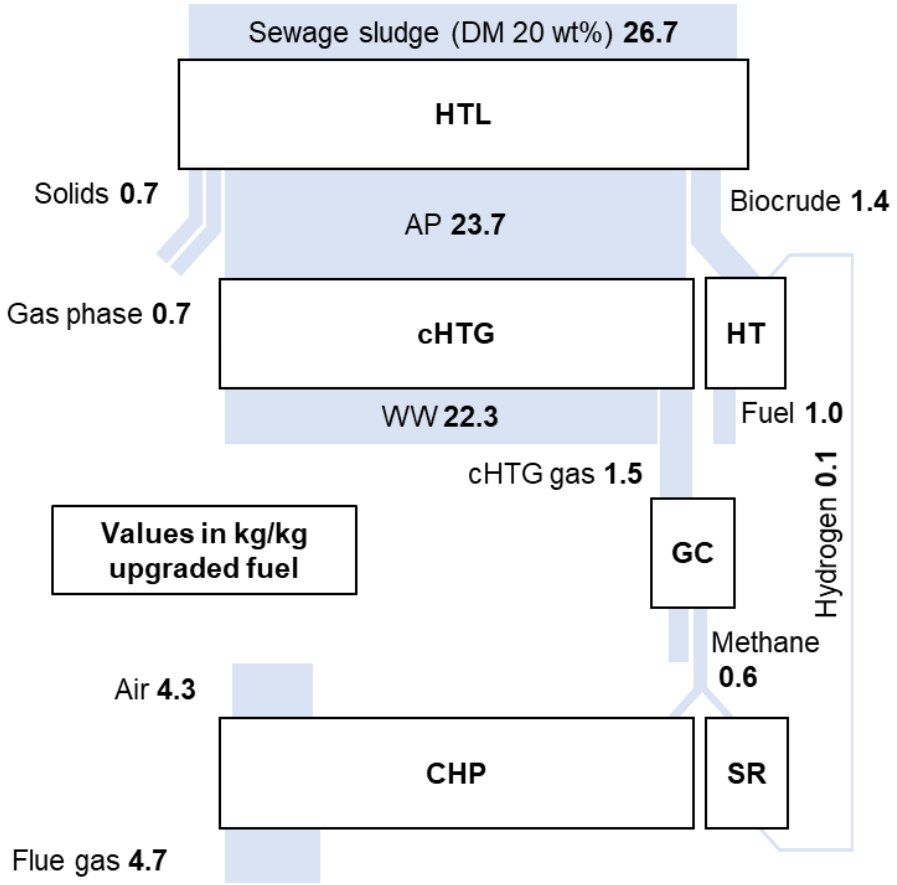


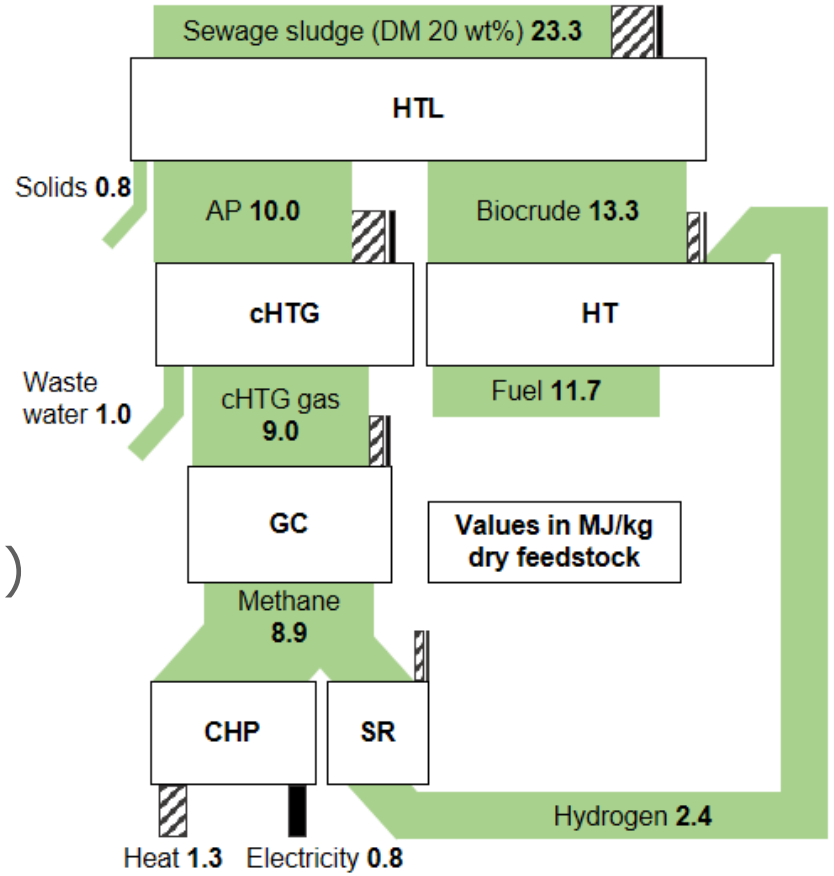
Source: E. Ovsyannikova et al., Feedstock-Dependent Phosphate Recovery in a Pilot-Scale Hydrothermal Liquefaction Bio-Crude Production, *Energies* **2020**, *13*, 379

Typical mass balance and energy balance

- ***Key considerations from mass (left) and energy balance (right)***



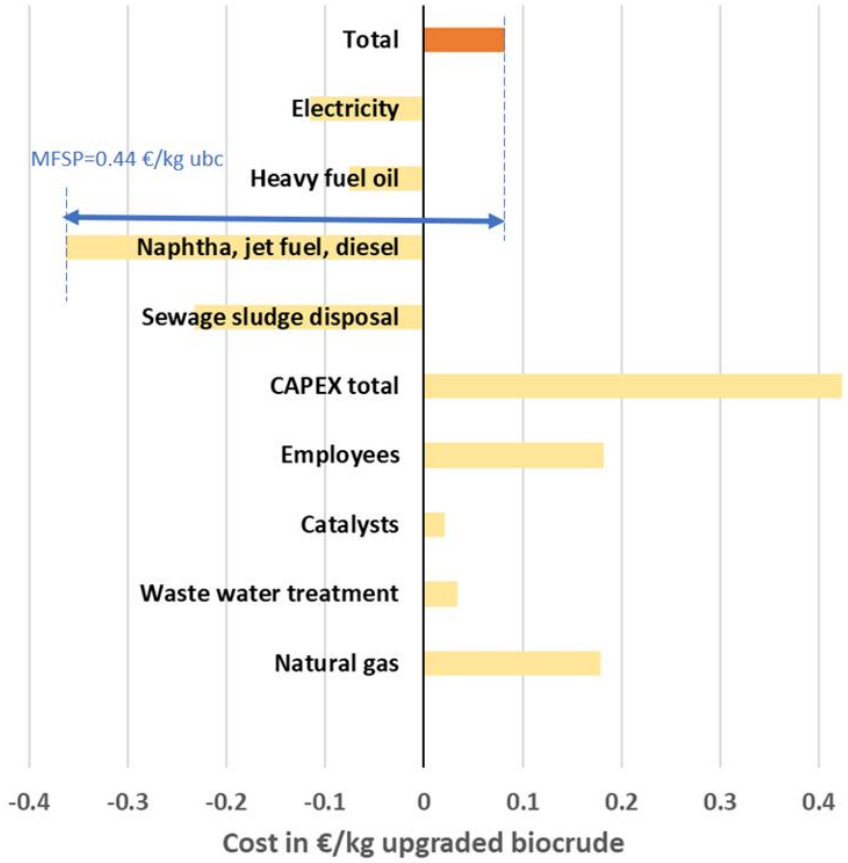
- **Heat exchange for HTL is key** (large "thermal mass" of process water)
- **Energetic utilization of aqueous phase** (soluble carbon-containing species)
- **Hydrogen supply for biocrude upgrading**



Source: C. Penke, L. Moser, VB: *Modeling of cost optimized process integration of HTL fuel production*, submitted to Biomass & Bioenergy.

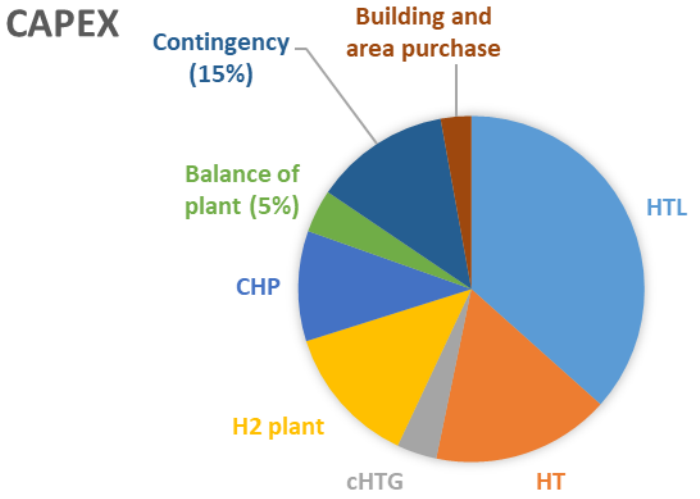
Techno-economic assessment

Feedstock sewage sludge



Minimum fuel selling price

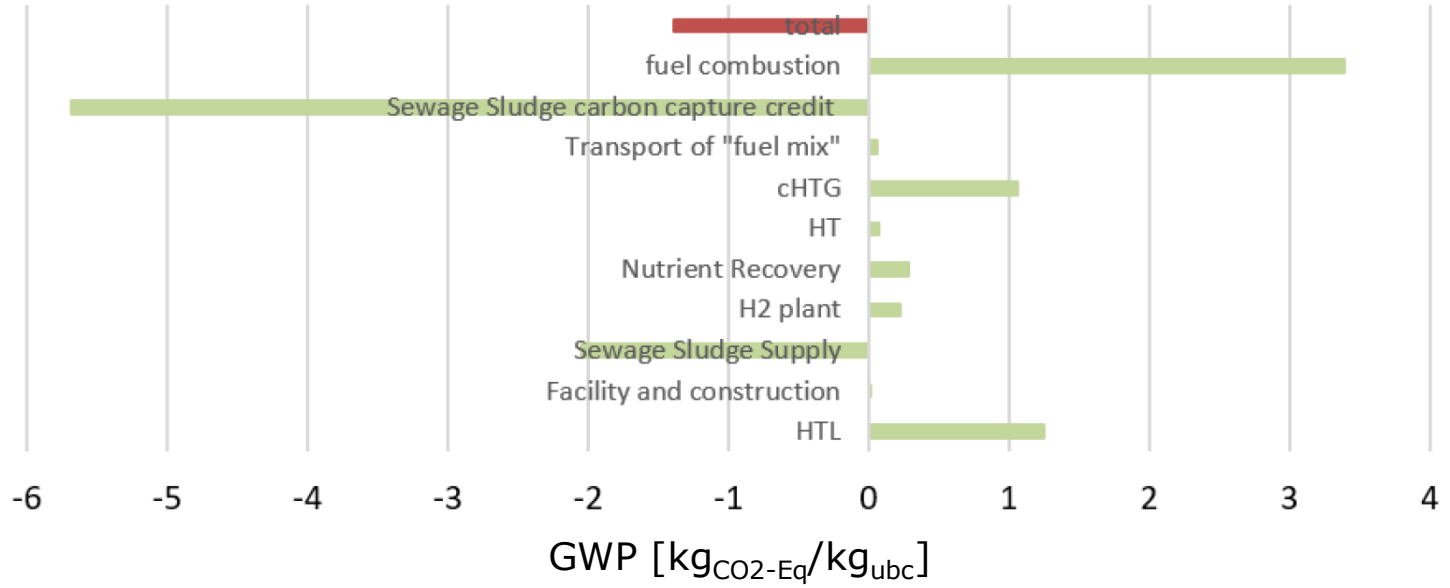
- Sewage sludge
  0.44 €/kg upgraded biocrude
  (= mixture of hydrocarbon fuels)



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

Life cycle assessment

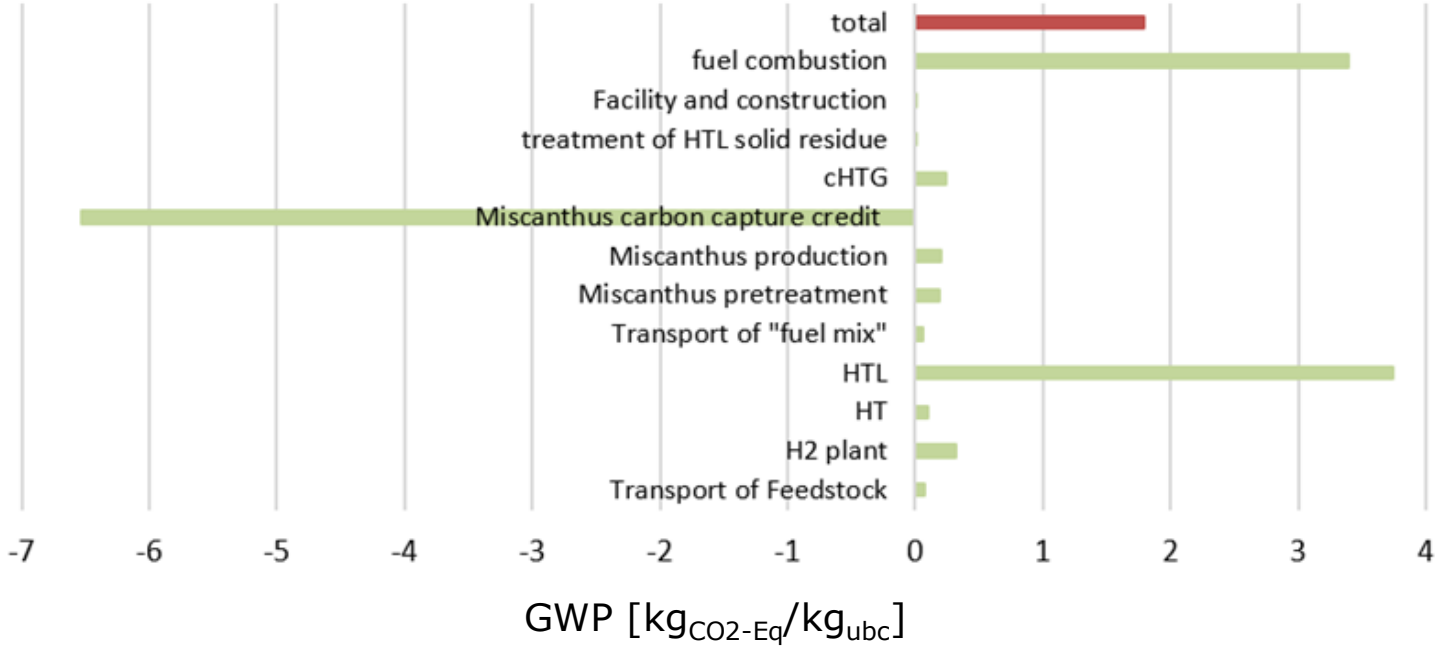
- **For sewage sludge HTL: Negative GHG balance is possible when accounting for avoided burden as a credit (displacement of sewage sludge drying and incineration)**



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

Specific GHG emissions of HTL fuel

Sources and sinks of GHG emissons (miscanthus)



- **Sewage sludge (without avoided burden)**

0.65 kg CO_2-Eq / kg ubc

- **Miscanthus**

1.80 kg CO_2-Eq / kg ubc

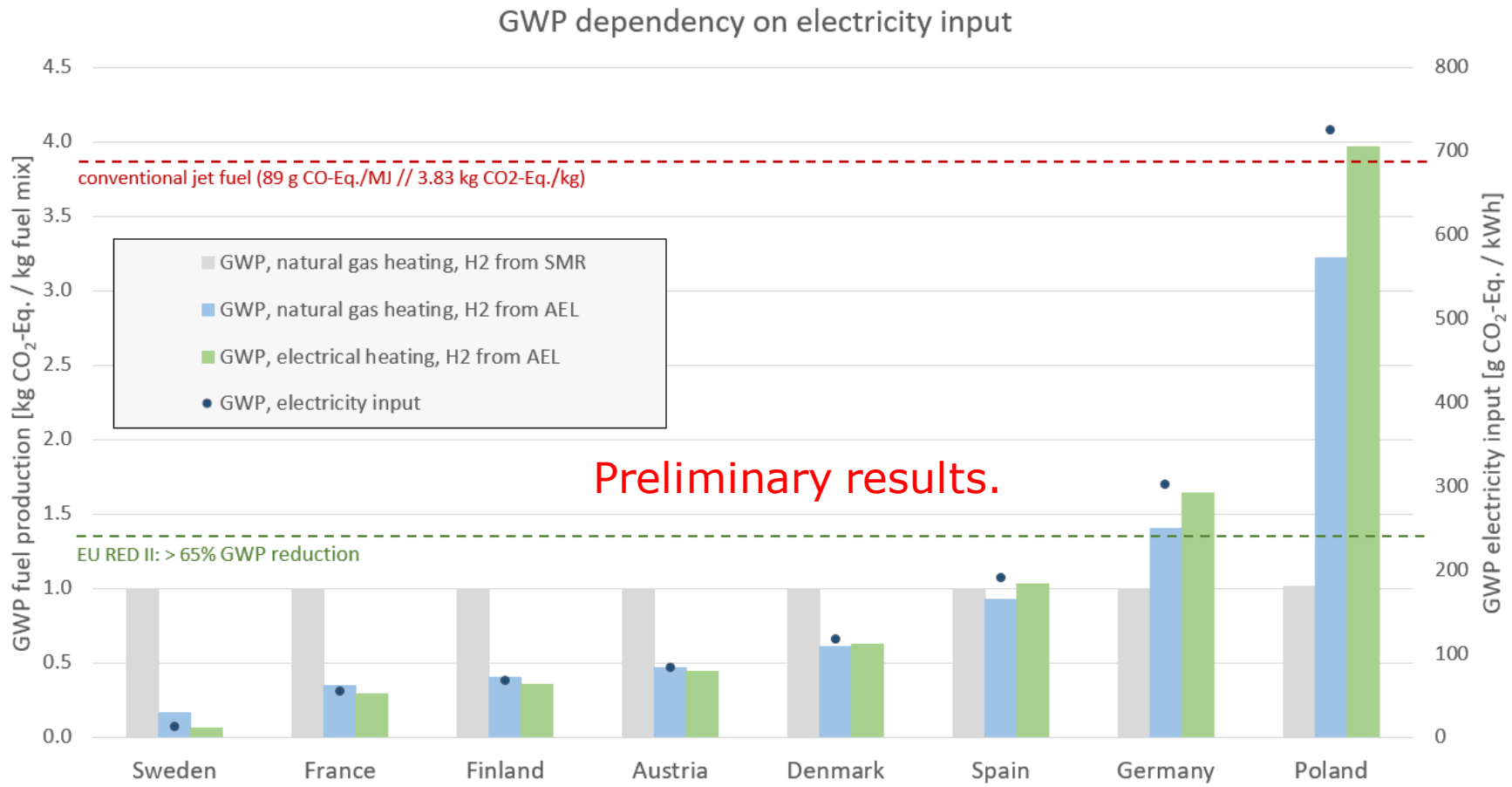
- **Cereal straw**

1.86 kg CO_2-Eq / kg ubc

- ***Main contributors to GHG emissions: heat and hydrogen supply, as well as CO_2-containing off-gas evolving during conversion process***
- ***High potential for improvement by using green hydrogen, renewable heat and carbon capturing processes (e. g. CCS) -> negative carbon emissions possible***

Coupling with renewable electricity / green hydrogen

- **Potential GWP reduction depends on GWP of electricity feed**



L. Moser, et al., EUBCE 2022 preliminary result.

Conclusions

- ***Advanced biofuel production from residues & wastes is highly relevant (e.g. fit-for-55)***
  - **HTL conversion is increasingly perceived as a prime option for the conversion of wet waste streams**
- ***HyFlexFuel demonstrated feedstock flexible HTL at pilot-scale in academic environment***
- ***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***

Thank you!

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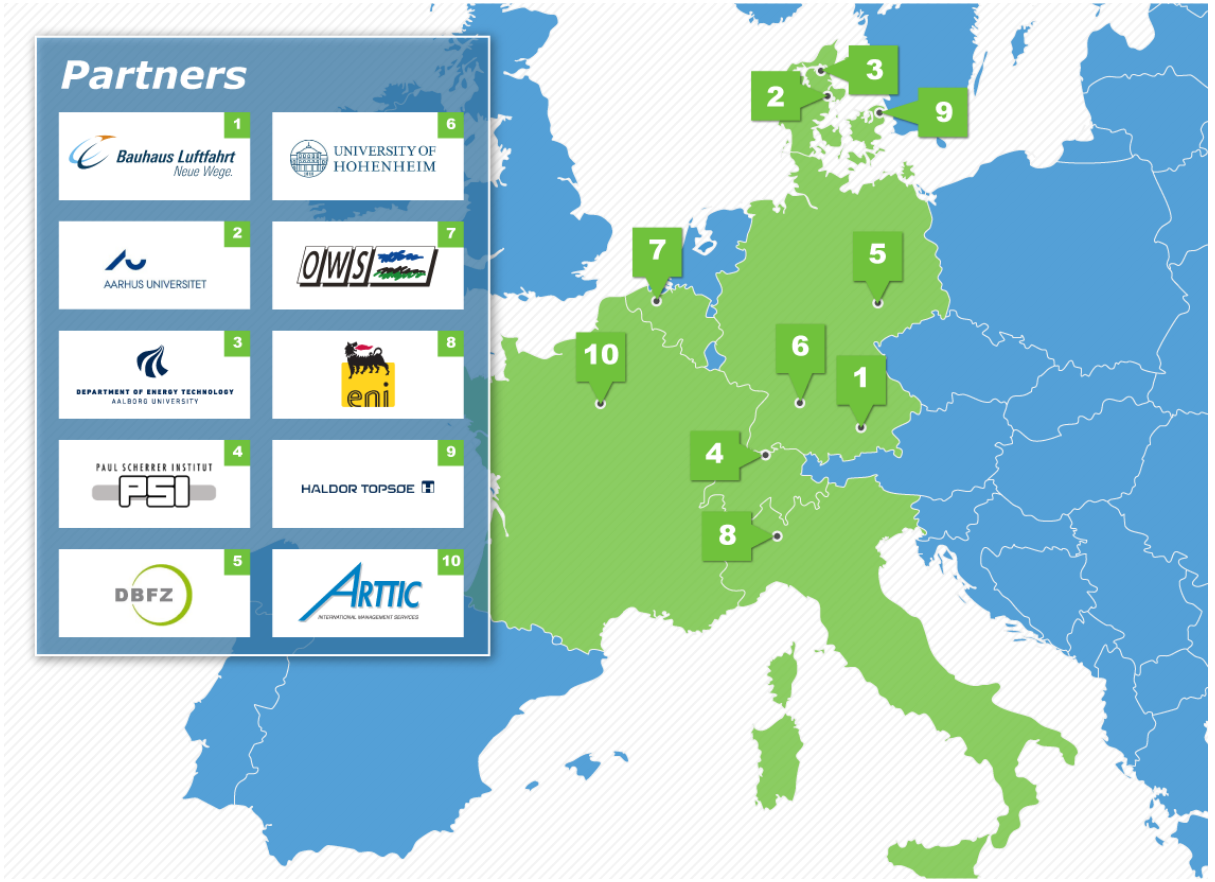

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764734

Further information

- **HyFlexFuel publications and media material:** www.hyflexfuel.eu/media-centre
- **HyFlexFuel final project workshop, presentations:** www.hyflexfuel.eu/final-project-workshop
- **HyFlexFuel project video:** www.youtube.com/watch?v=yDBlxPf06go
- **JETSCREEN project video:** www.youtube.com/watch?v=VQinw9QCECs
- **HyFlexFuel press release:** www.hyflexfuel.eu/wp-content/uploads/HyFlexFuel_press-release_Website.pdf

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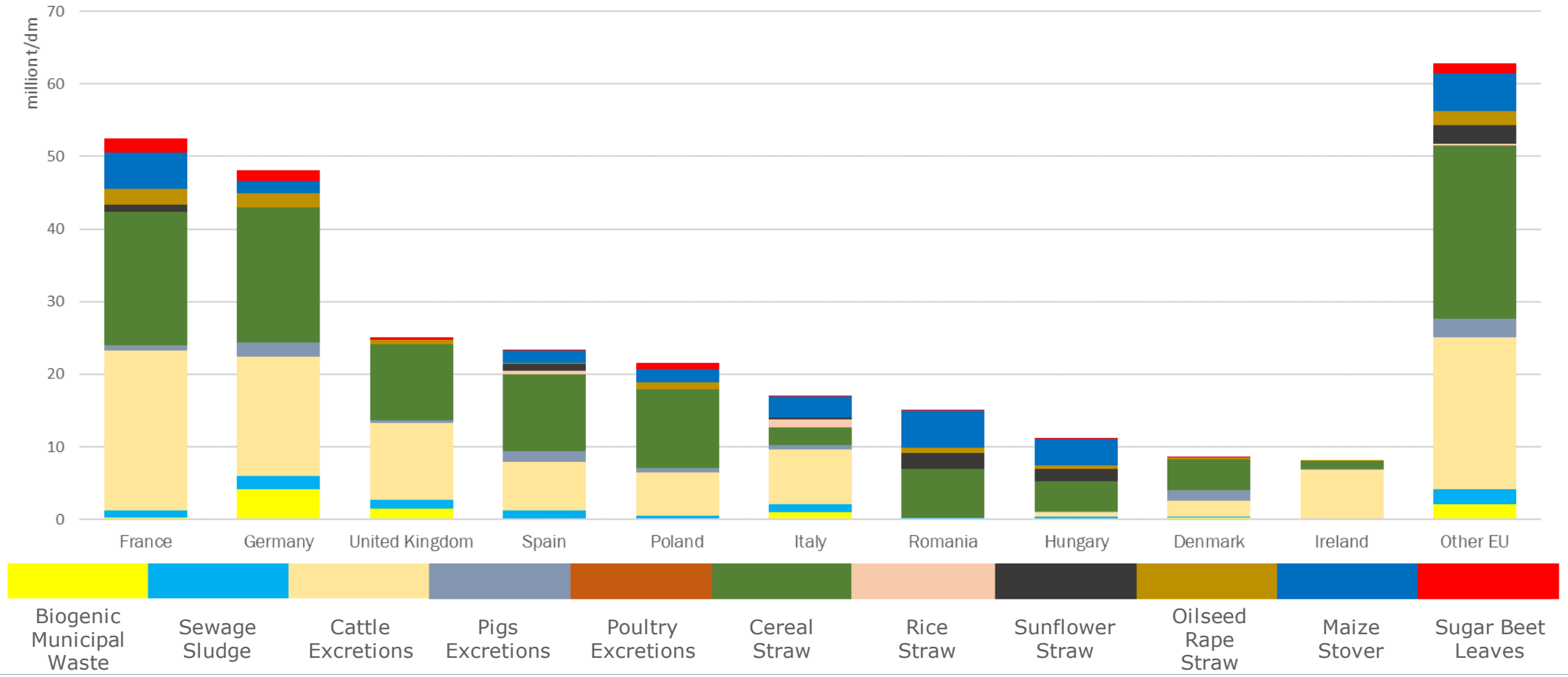
Quantification of feedstock potentials in EU-27 and UK

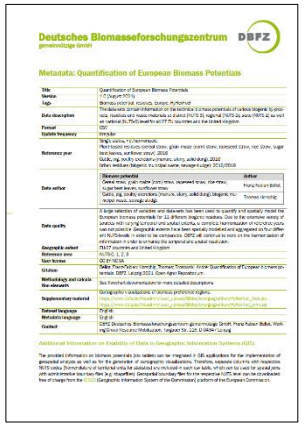
- **Top 10 European countries – Max. tech. potential (t/dm)**

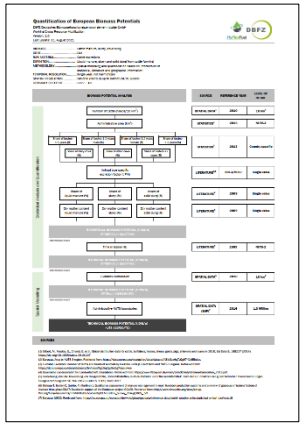


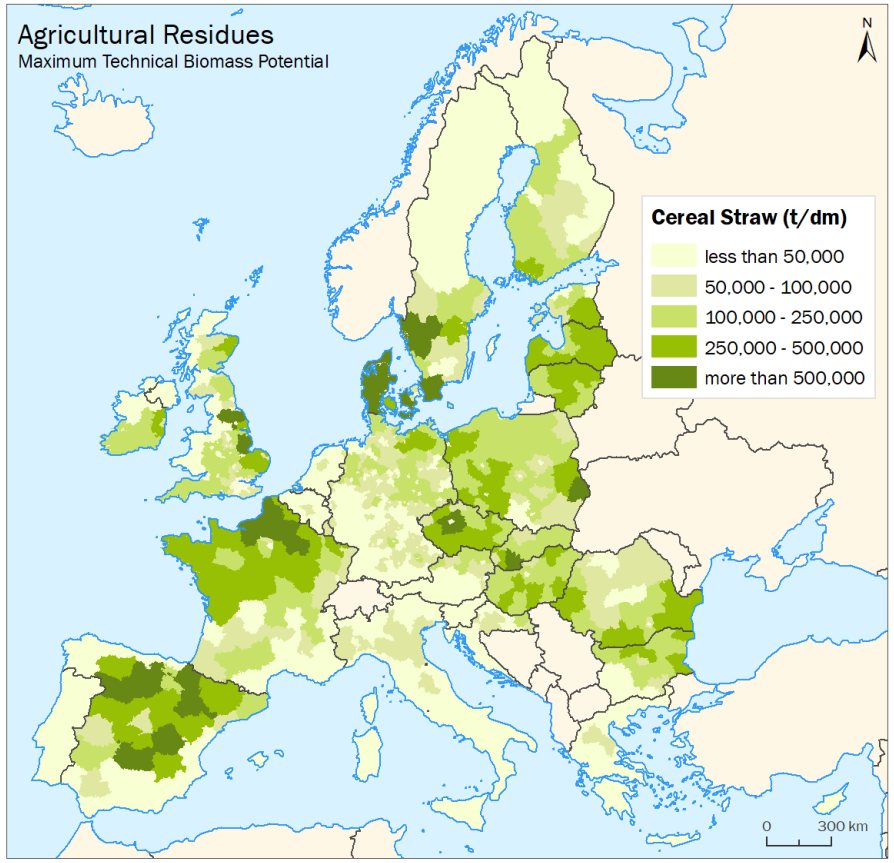
Results and data availability

- **Data publication available online:**

  https://www.openagrar.de/receive/openagrar_mods_00073600







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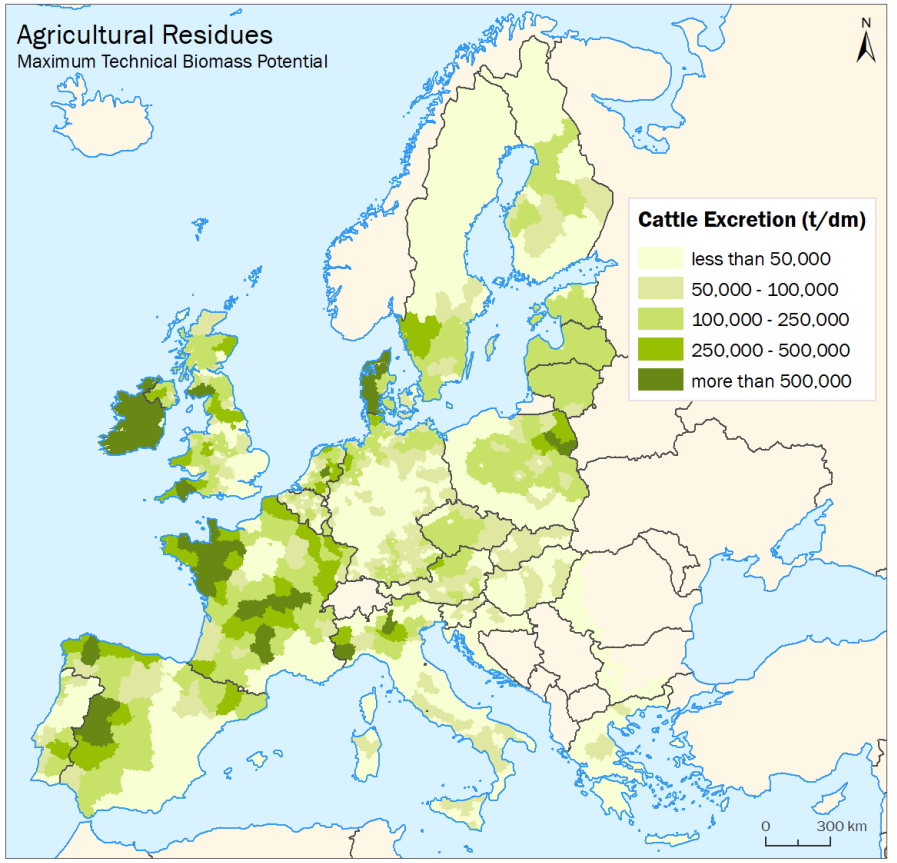

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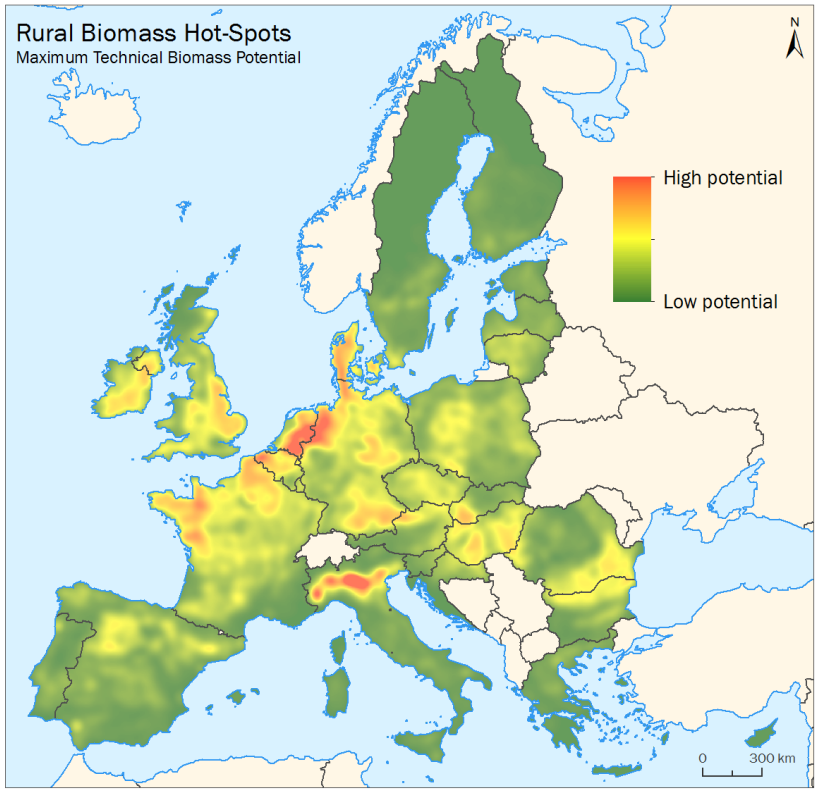
Results and data availability

- ***Cartographic visualizations available online:***

  https://www.dbfz.de/fileadmin/user_upload/Bilder/energiegrafiken/Hyflexfuel_Web.zip

  https://www.dbfz.de/fileadmin/user_upload/Bilder/energiegrafiken/Hyflexfuel_print.zip



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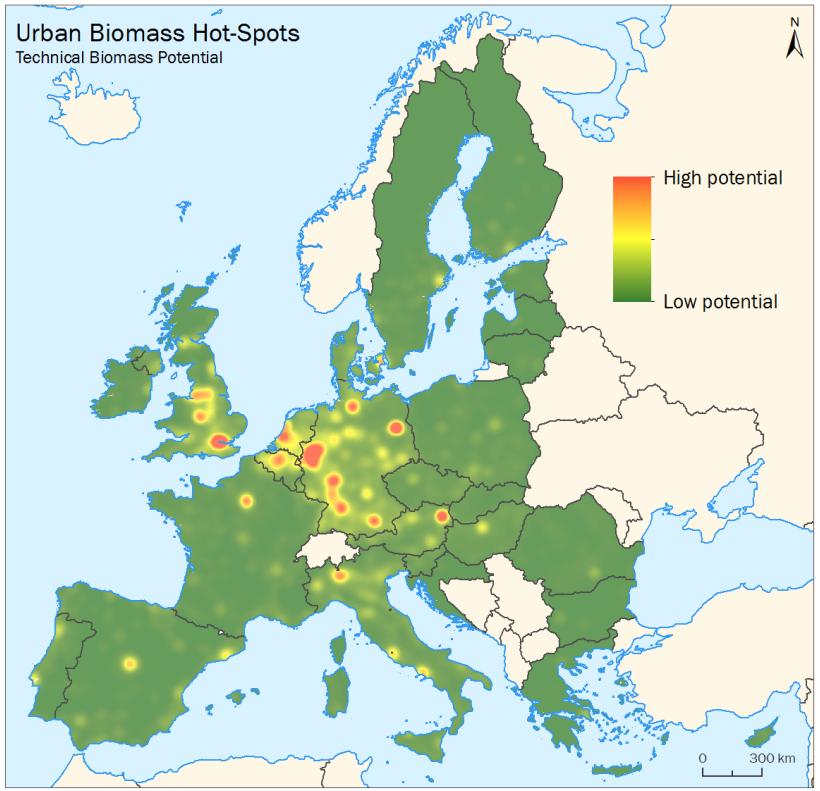

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