HyFlexFuel

HTL-based liquid fuel production: First results from the European collaborative project HyFlexFuel

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Outline

- *The HyFlexFuel project*
- *First pilot-scale HTL campaign*
- *Catalytic upgrading of biocrude*
- *Anaerobic digestion of HTL process water*
- *Conclusions*

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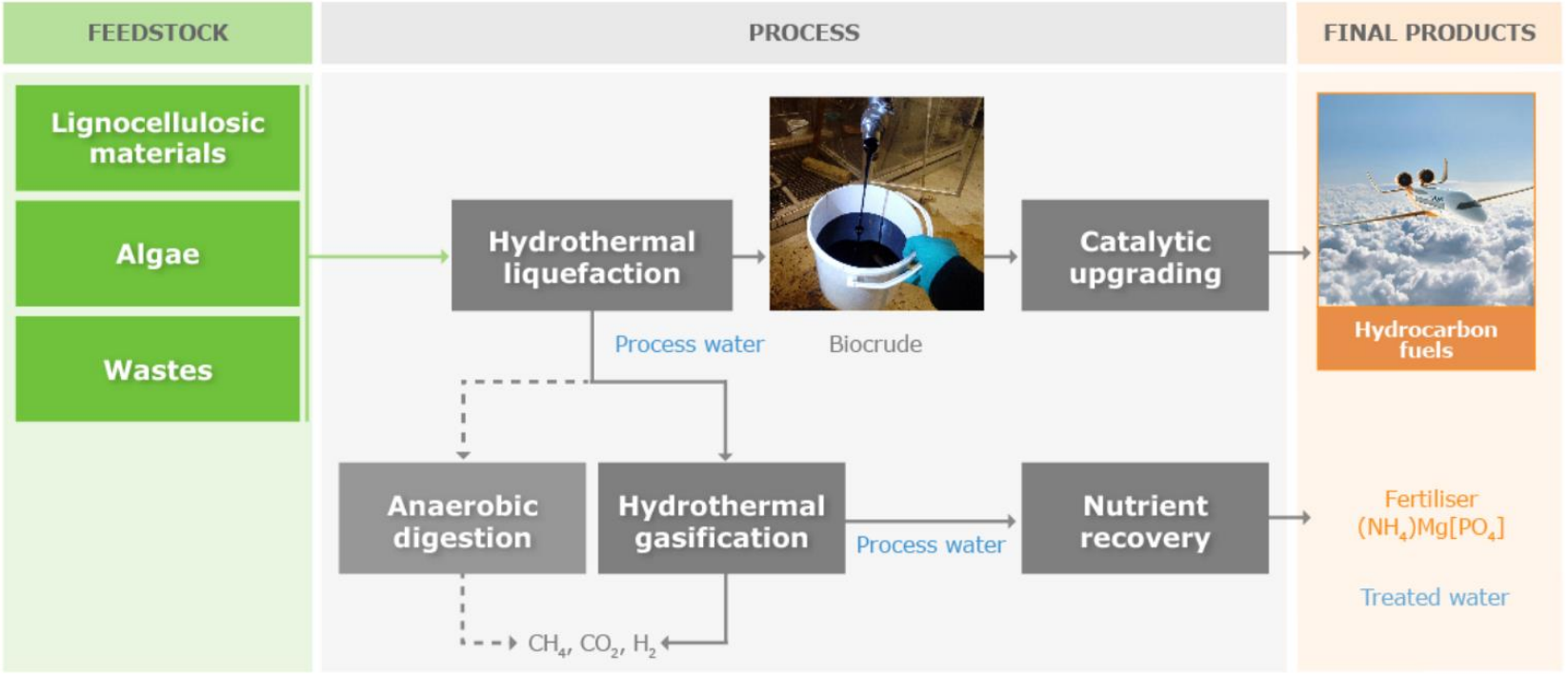
HyFlexFuel: Objectives

Development of a process chain to produce sustainable liquid fuels based on hydrothermal liquefaction of various biomass feedstocks

- ***Specific objectives***
  - **Demonstrate compatibility with diverse biomass feedstock portfolio (incl. algae and waste streams, such as sewage sludge)**
  - **Increase energy and carbon efficiency through improved heat integration and product recovery**
  - **Valorise organic and inorganic components in residual process streams**
  - **Upgrade biocrude by catalytic hydrotreatment into fuel products and demonstrate their drop-in capability**
  - **Assess technical, socio-economic and environmental performance potentials**

The HyFlexFuel process



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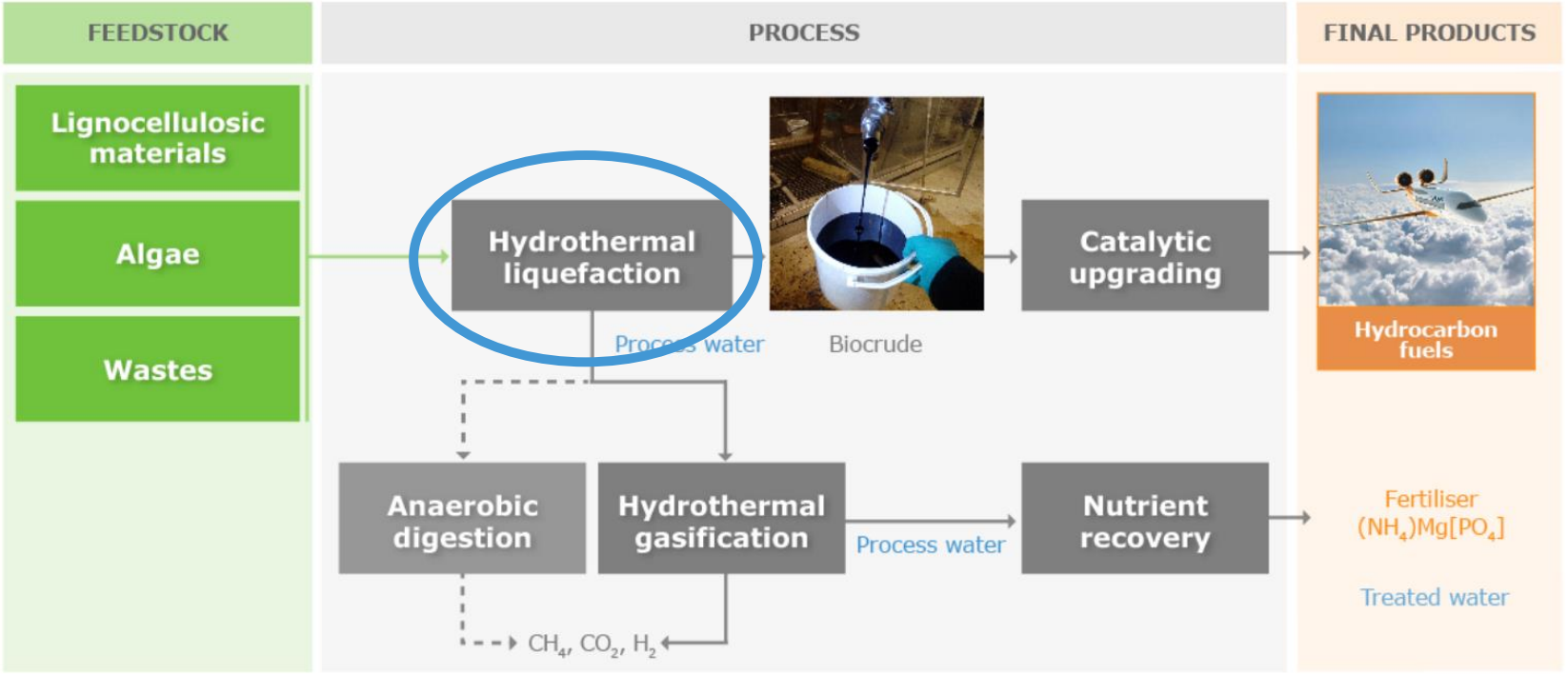

Pilot-scale HTL

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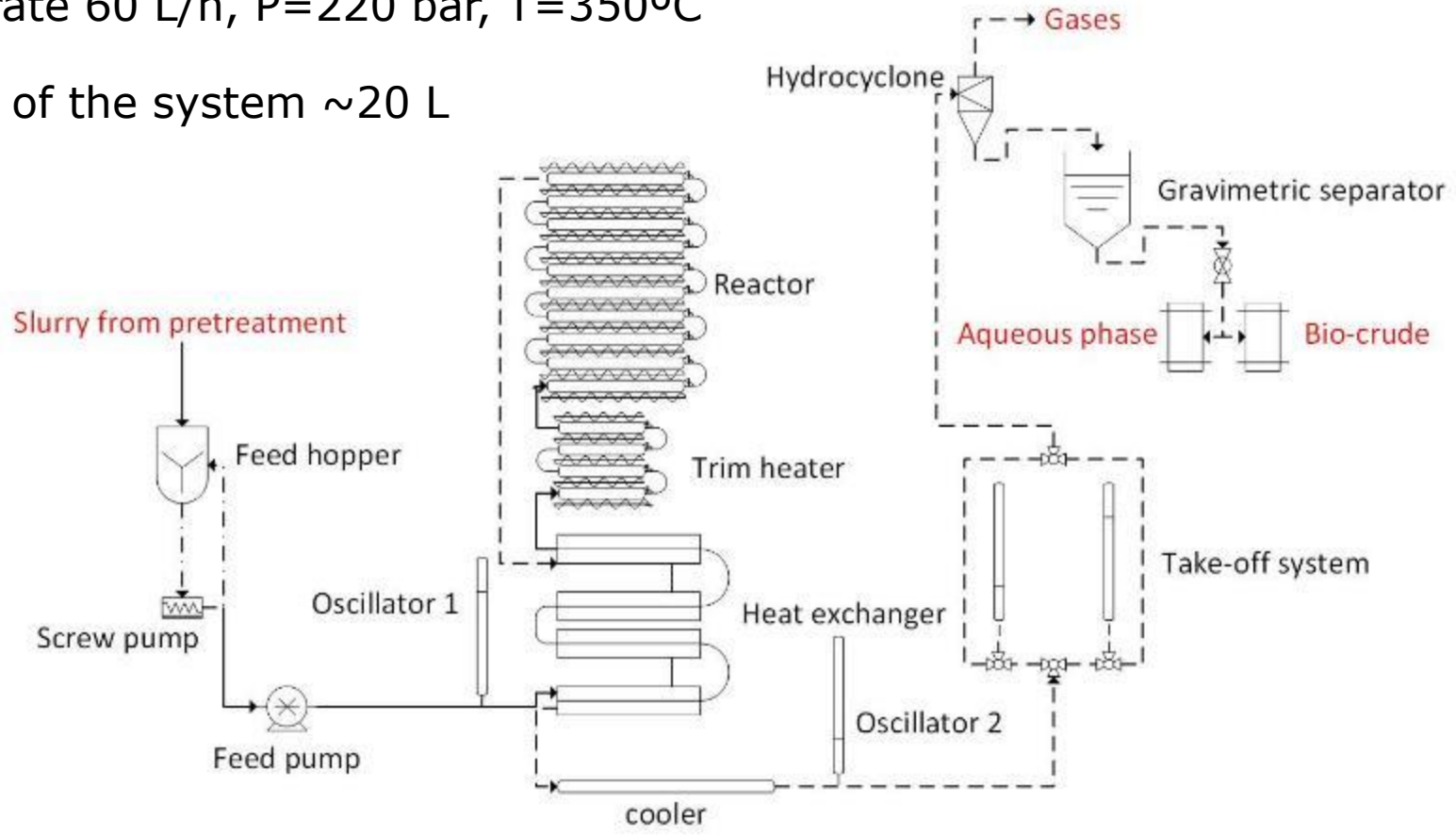
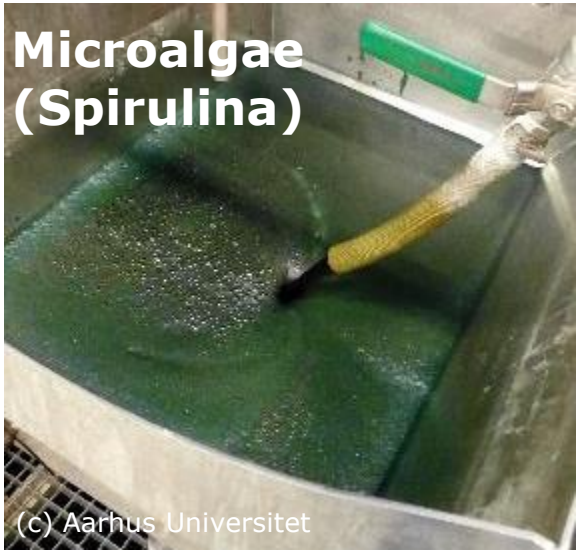
Typical flow rate 60 L/h, P=220 bar, T=350ºC

Total Volume of the system ~20 L



First HTL campaign

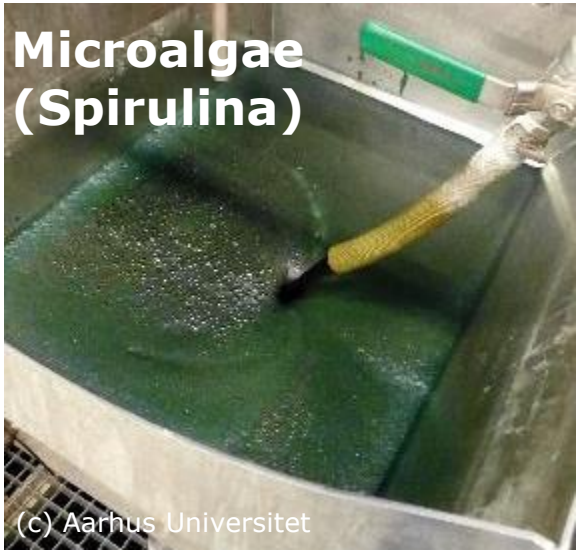
- *Three „model feedstocks"*



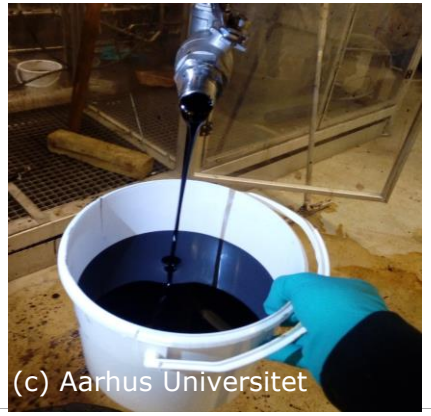
- *Input*
  - **Slurry: 250 kg (Miscanthus, Spirulina), 500 kg (sewage sludge)**

First HTL campaign

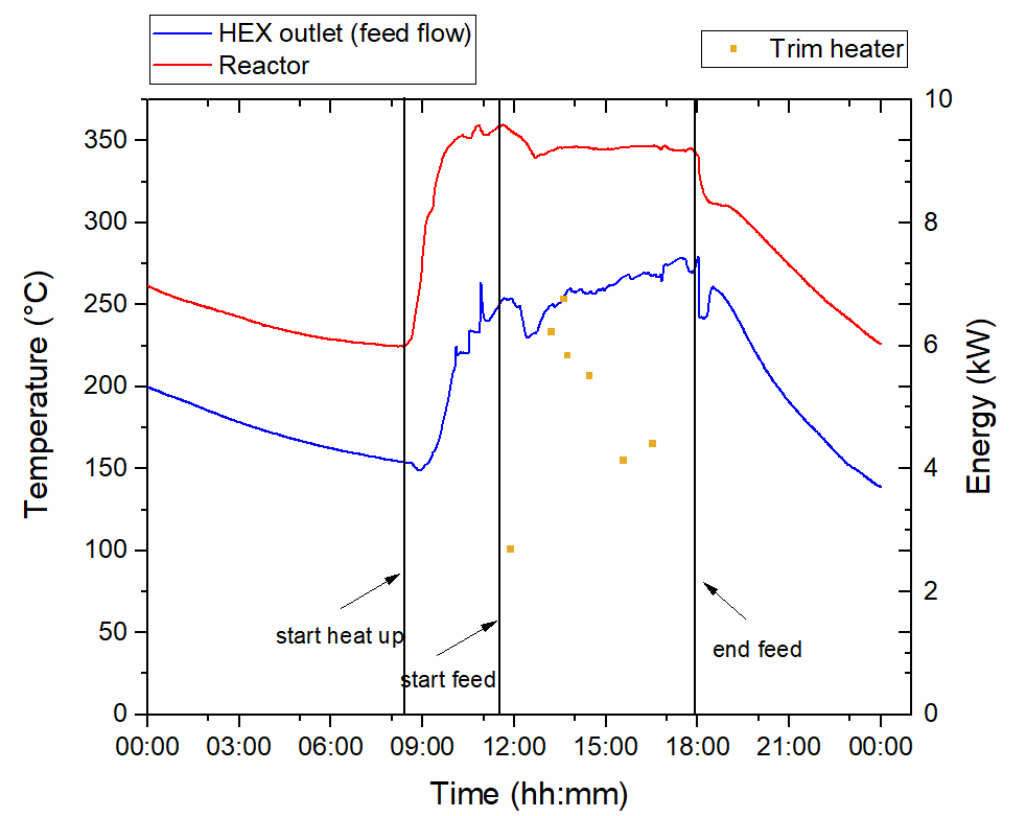
- *Three „model feedstocks"*



- *Output*
  - **>10 kg biocrude and >200 L aqueous phase per feedstock**



Heat recovery in heat exchanger



Time	HR (%)
12:00-13:00	69.1
13:00-14:00	73.3
14:00-15:00	74.8
15:00-16:00	76.7
16:00-17:00	77.6
17:00-18:00	79.9
Average	75.2

- **Heat recovery increases over duration of experiments**
- **Longer run times should further enhance heat recovery (> 80%)**

Anastasakis et al., Assessing Hydrothermal Liquefaction of Lignocellulosic Biomass, Microalgae and Sewage Sludge at Pilot Scale, 26th European Biomass Conference & Exhibition, Copenhagen, 2018.

Process performance

Anastasakis et al., Assessing Hydrothermal Liquefaction of Lignocellulosic Biomass, Microalgae and Sewage Sludge at Pilot Scale, 26th European Biomass Conference & Exhibition, Copenhagen, 2018.

	Miscanthus	Spirulina	Sewage sludge
Flow rate (L/h)	60	60	60
DM content (%)	0.15	0.16	0.04
Time (h)	1	1	1
Feedstock consumed (kg, dry)	9	9.8	2.4
Energy in feedstock (kW, dry)	42.7 (HHV=17.1MJ/kg)	63.1 (HHV=23.1MJ/kg)	13.2 (HHV=19.8MJ/kg)
Bio-crude yield (wt.%)	**26.2**	**32.9**	**24.5**
Energy in bio-crude (kW, dry)	19.9 (HHV=30.6 MJ/kg)	32 (HHV=35.6 MJ/kg)	4.4 (HHV=26.8 MJ/kg)
η_{th} (%)	**46.5**	**50.7**	**33.2**
Trim heater energy req. (kW)	4.4	5.5	5.4
Reactor energy req. (kW)	2	2.8	2.5
Main pump energy req. (kW)	0.7	0.7	0.7
η_{tot} (%)	**39.9**	**44.4**	**20.1**

HTL campaign: Summary & outlook

- ***Successful liquefaction of three different feedstocks***
  - **Samples (biocrude, aq. phase, solids) could be supplied to partners**
  - **Heat recovery of up to 80%**
  - **Average biocrude yields 26.2% (Miscanthus), 32.9% (Spirulina) and 24.5% (sewage sludge)**

- ***Further work will focus on improvement of process conditions (e.g. heat recovery, in-line filtration) and other feedstocks***

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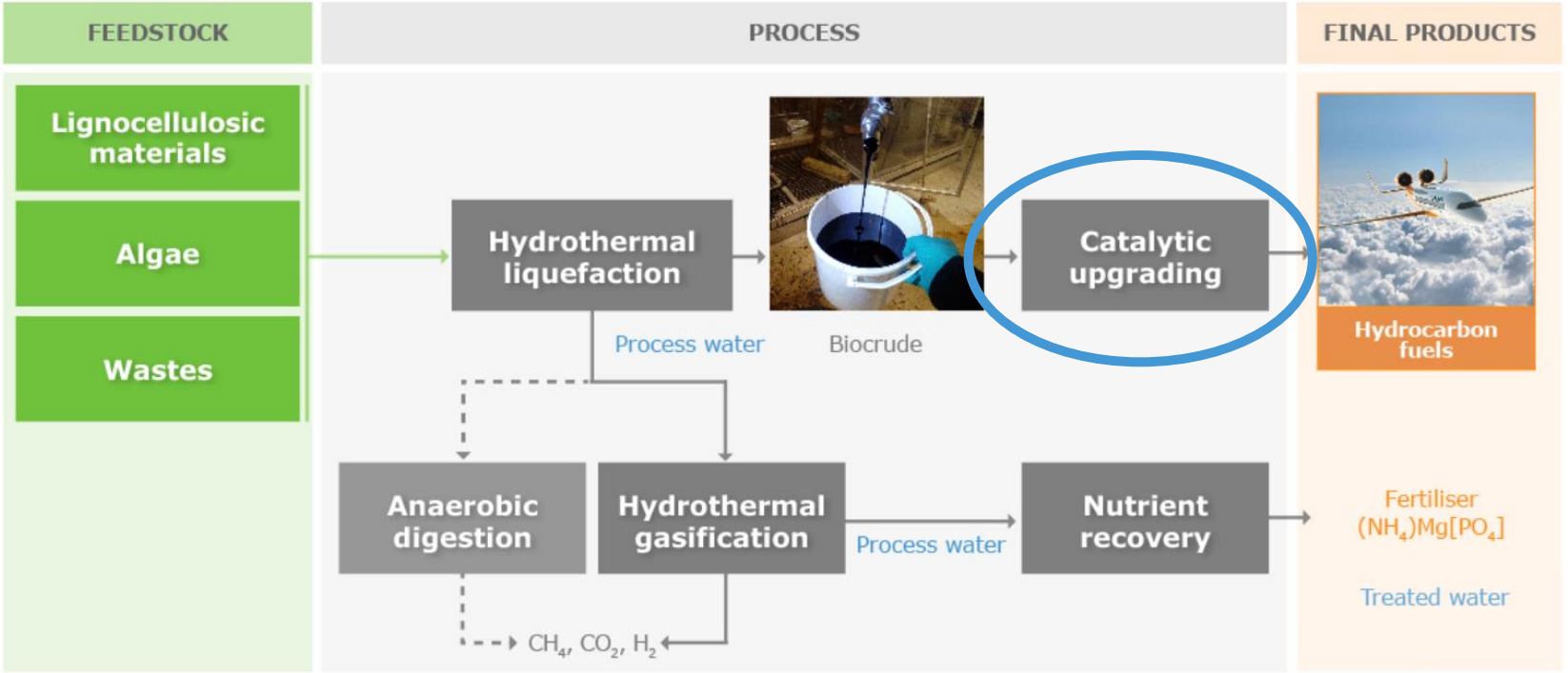
The HyFlexFuel process



First catalytic upgrading experiments

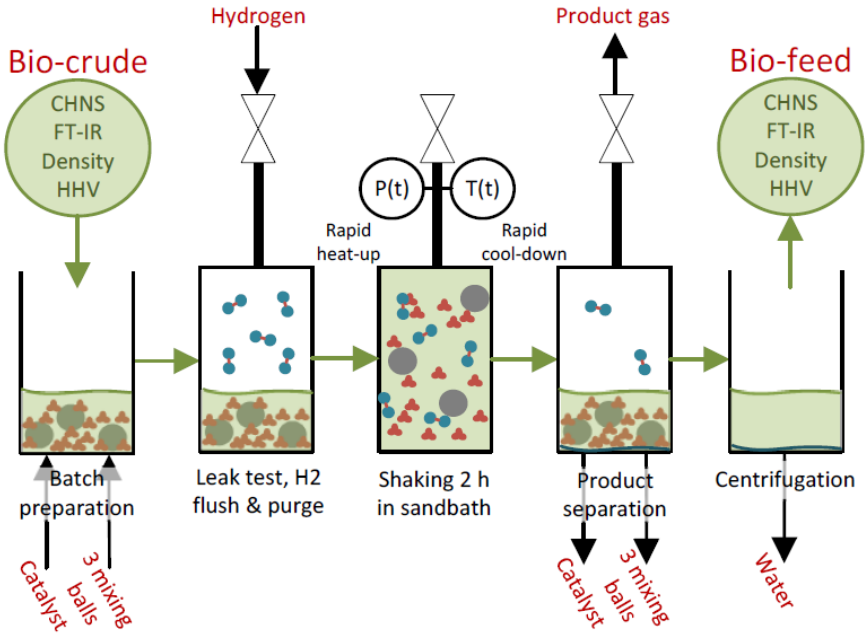
- ***Catalytic hydrotreatment of biocrudes from first HTL campaign***
  - **Spirulina, sewage sludge, miscanthus**
  - **Batch mode**
  - **Screening of reaction conditions and pre-treatment procedures**

Spirulina biocrude

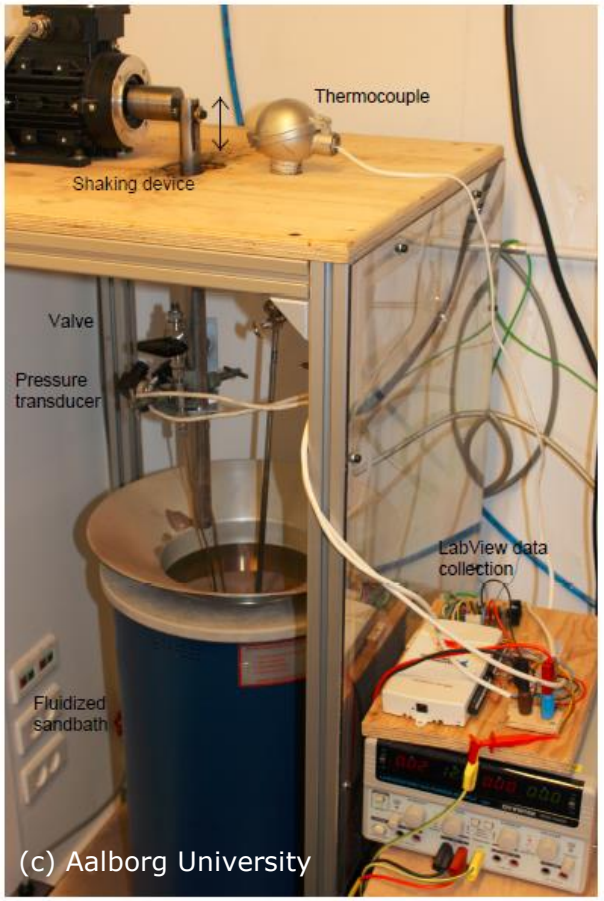
- ***Objectives***
  - **To identify sample-specific challenges**
  - **To find suitable reaction conditions for upgrading campaigns in continuous mode**
  - **To collect data enabling specific catalyst design**

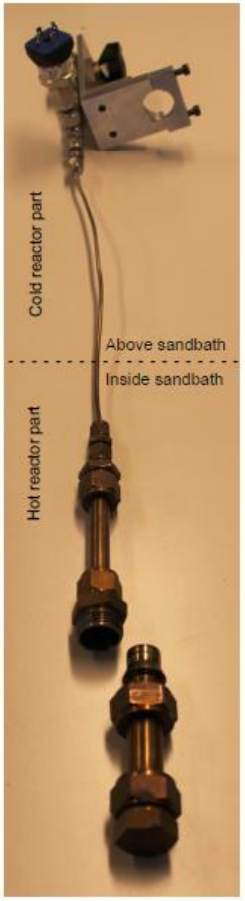
First catalytic upgrading experiments

- ***Experimental setup***



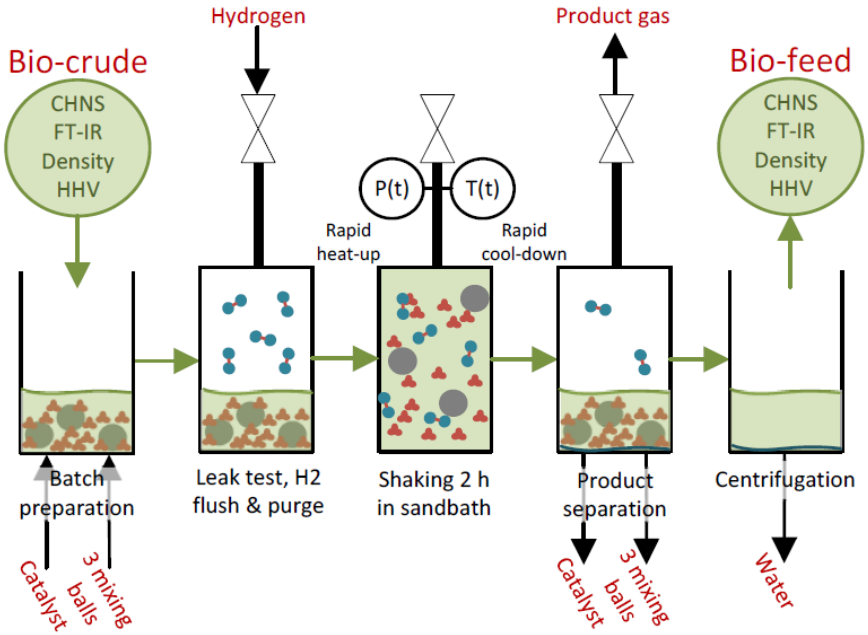
Jensen et al., Fuel **2016**, *165*, 536-543.





First catalytic upgrading experiments

- ***Experimental setup***



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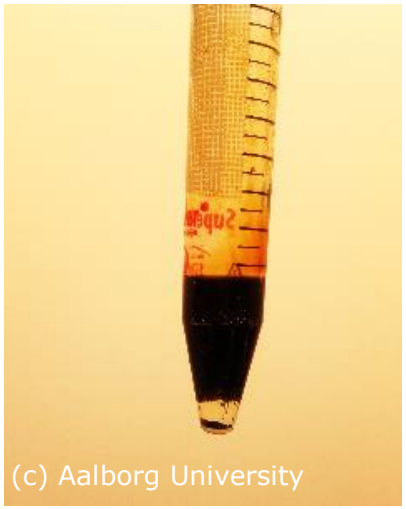
Reaction condition	T *(°C)*	P_0 *(bar)*	t *(h)*
Mild	250	40	2
Medium	300	60	3
Severe	300	80	4

- Biocrude 4 g, Catalyst 2 g
- Commercial $NiMo/Al_2O_3$ catalyst
- Pre-sulfided

Catalytic upgrading of Spirulina biocrude

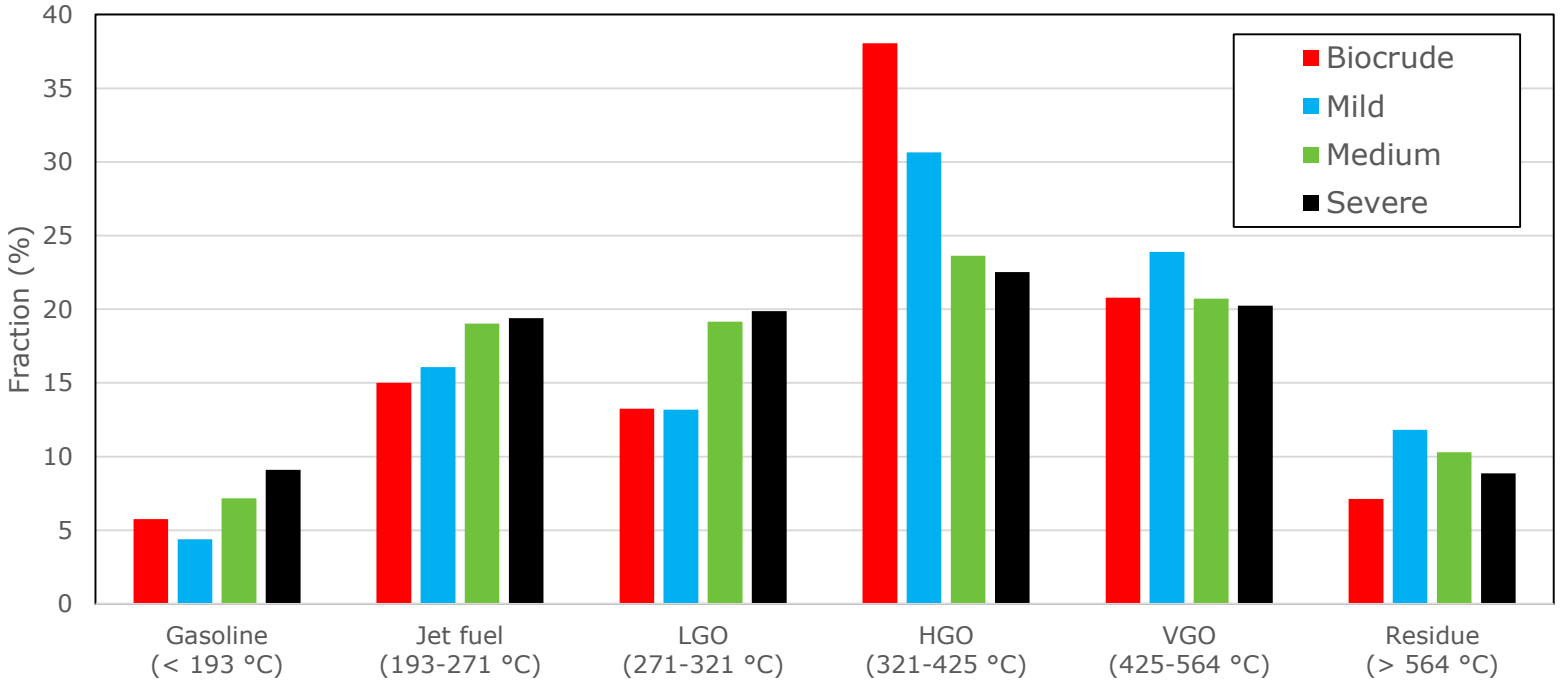
	Dry ash free *(wt. %)*				H/C *(-)*	de-O *(wt. %)*	de-N *(wt. %)*
	C	H	N	O			
Spirulina	53.5	7.2	12.6	26.6	1.62	-	-
Biocrude	78.1	10.4	8.0	3.5	1.60	86.8	36.7
Mild	79.2	10.8	7.4	2.6	1.63	90.2	41.2
Medium	79.7	11.7	6.3	2.3	1.76	91.4	50.1
Severe	81.0	12.1	6.0	1.0	1.79	96.4	52.7


(c) Aalborg University

- More severe conditions result in more effective removal of heteroatoms
- Increasing H/C ratio
- Relatively high deoxygenation
- Denitrogenation is around or below 50%

Catalytic upgrading of Spirulina biocrude

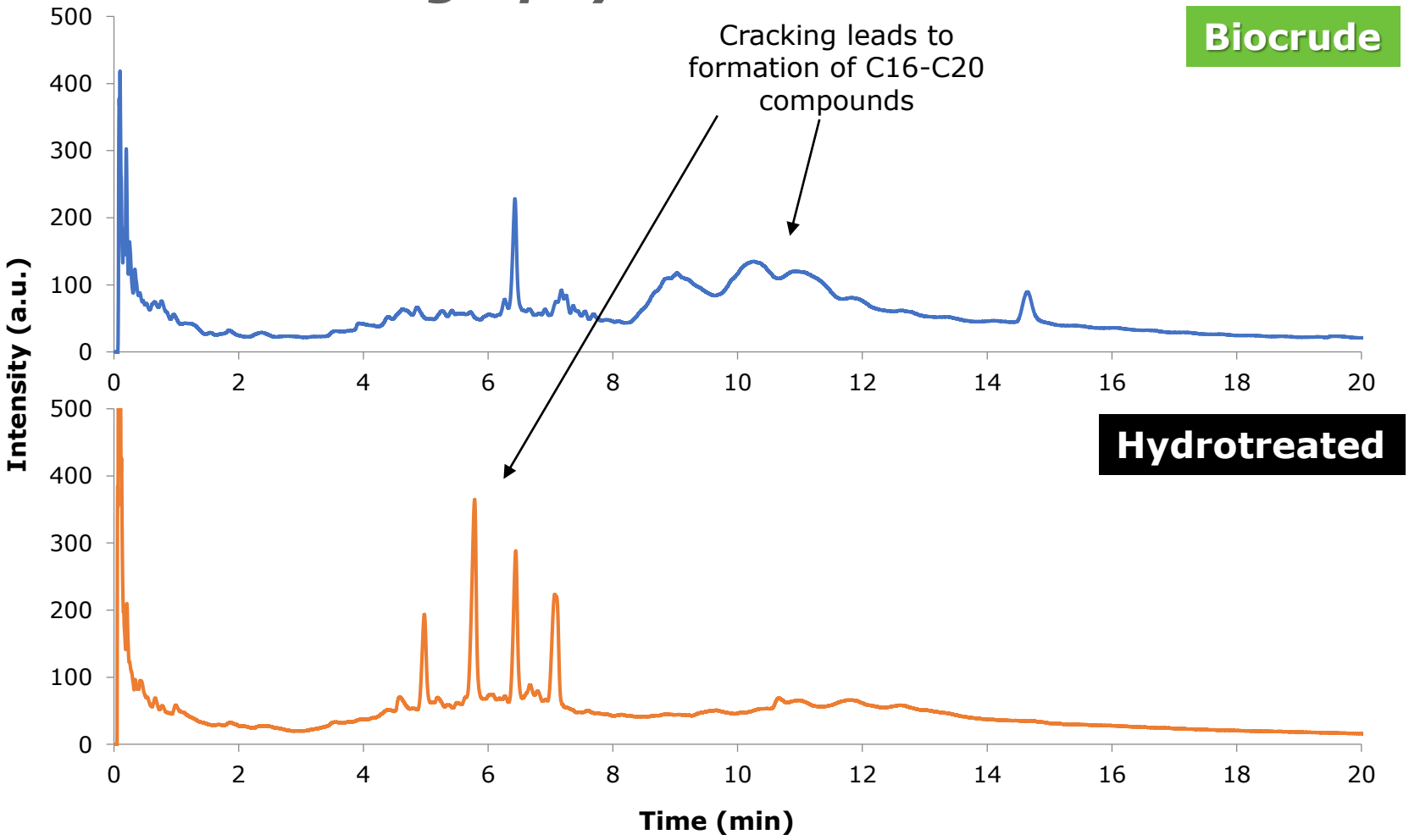
- ***Simulated distillation***



- **Simulated distillation according to ASTM D7169**
- **Increase in the lighter fractions, reduction of HGO**

Catalytic upgrading of Spirulina biocrude

- **Gas chromatography**



Catalytic upgrading: Summary & outlook

- ***First batch experiments on catalytic upgrading of HTL biocrudes conducted***
- ***Fuel quality (H/C, de-O, de-N) substantially enhanced; de-N not yet sufficient***
- ***Gasoline and middle distillate fraction increased***

- ***Next steps***
  - **More screening experiments**
  - **Improvement of pre-treatment techniques**
  - **Taylored catalysts**
  - **First experiments in continuous mode**

HALDOR TOPSØE

Catalytic upgrading: Summary & outlook

- ***First batch experiments on catalytic upgrading of HTL biocrudes conducted***
- ***Fu***
  en
- ***Ga***
  in

More details and data from catalytic upgrading experiments in HyFlexFuel soon to be presented by D. Castello *et al.* on the ***7th International Symposium on Energy from Biomass and Wastes***, Oct. 15-18, 2018, Venice

- ***Next steps***
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  - **Taylored catalysts**
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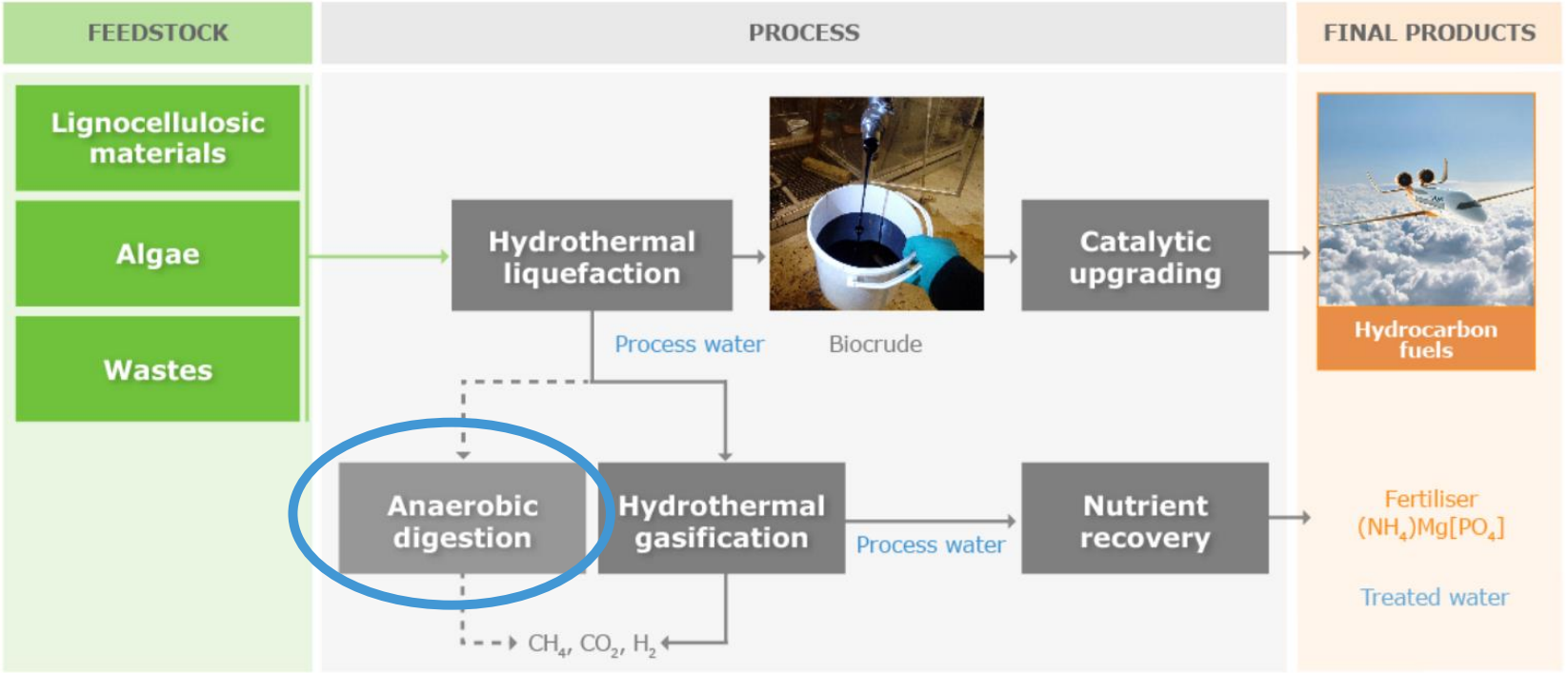


Anaerobic digestion of HTL process water

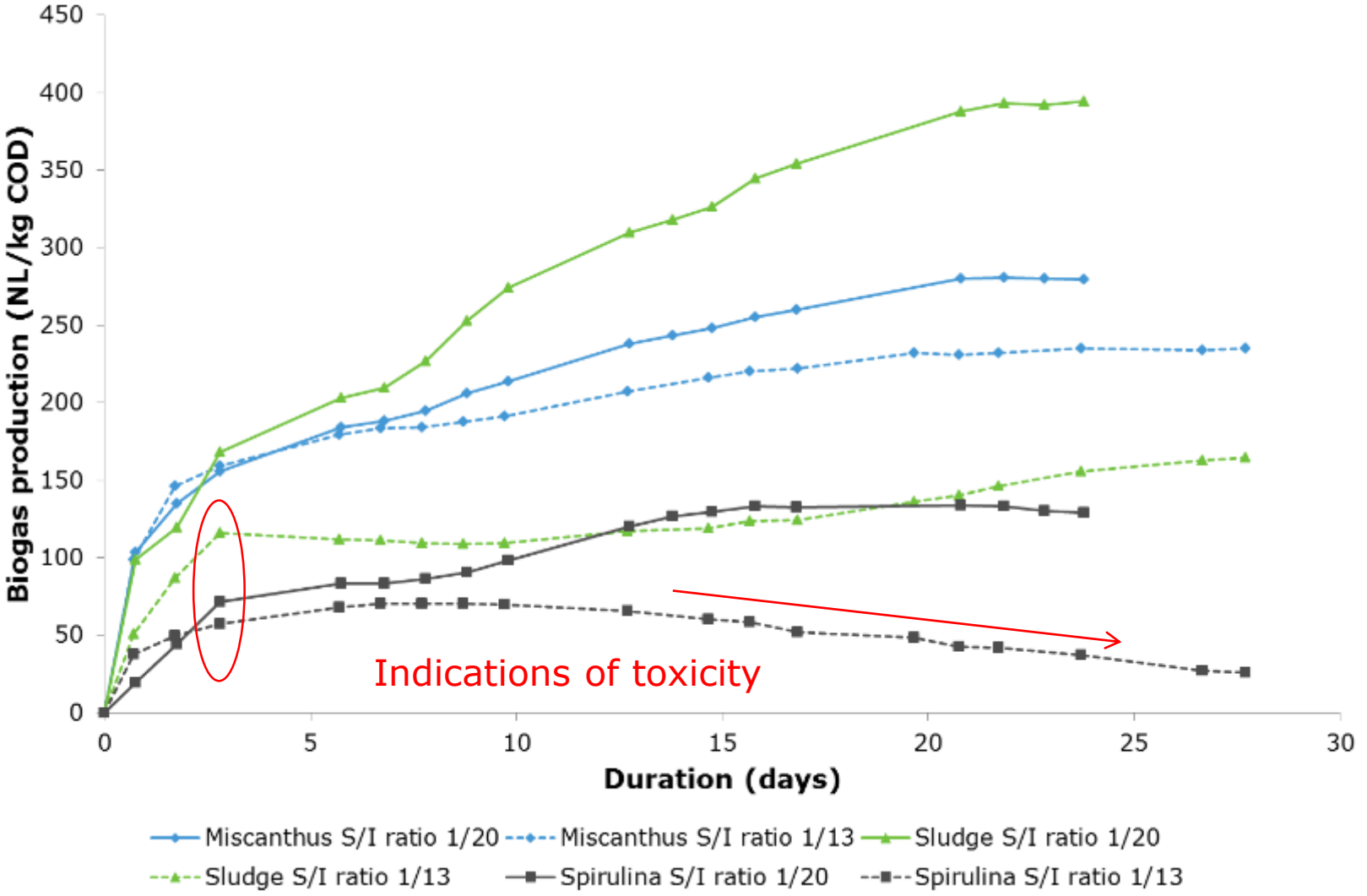
- ***Biogas production potential test***

- ***Goal:***
  - **Determine max potential**
  - **Detect acute toxicity/deficiency**

- ***Experimental setup***
  - **10-100 g of substrate to 1 kg active inoculum**
  - **Typical duration: 14 days or until daily gas production < 1% of cumulative production**

- ***Basis for continuous test set-up***

Anaerobic digestion of HTL process water



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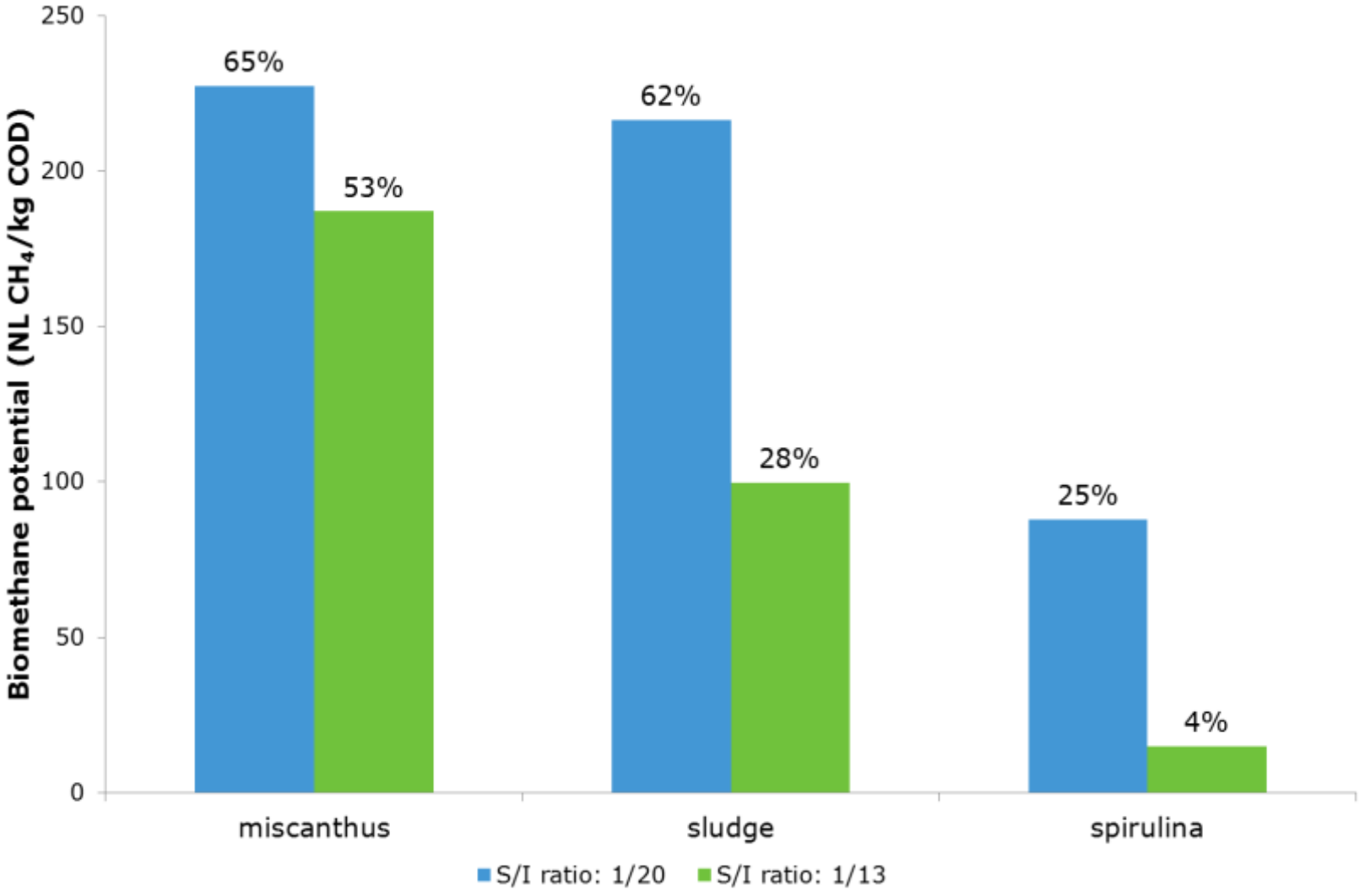

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Conclusions

- ***HyFlexFuel develops a process chain for production of liquid fuels based on hydrothermal liquefaction***
- ***First HTL campaign conducted***
  - **Successful liquefaction of Spirulina, sewage sludge, Miscanthus**
  - **Pilot-scale, relevant process conditions**
- ***First batch experiments on catalytic upgrading of HTL biocrudes conducted***
  - **Deoxygenation successful; denitrogenation challenging**
- ***Anaerobic digestion of HTL process water***
  - **Substantial methane formation, but also indication of toxicity observed**

Thank you!

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