AD, HTL or both?

A techno-economic comparison of biomass valorisation

Christian Klüpfel[1], Hendrik Etzold[1], Mintu Monica Thomas[1], Ahmad Kordi[1], Benjamin Herklotz[1], Patrick Biller[2]

PYROLIQ III – 2025: Pyrolysis and Liquefaction of Biomass and Wastes, Cetraro, Italy

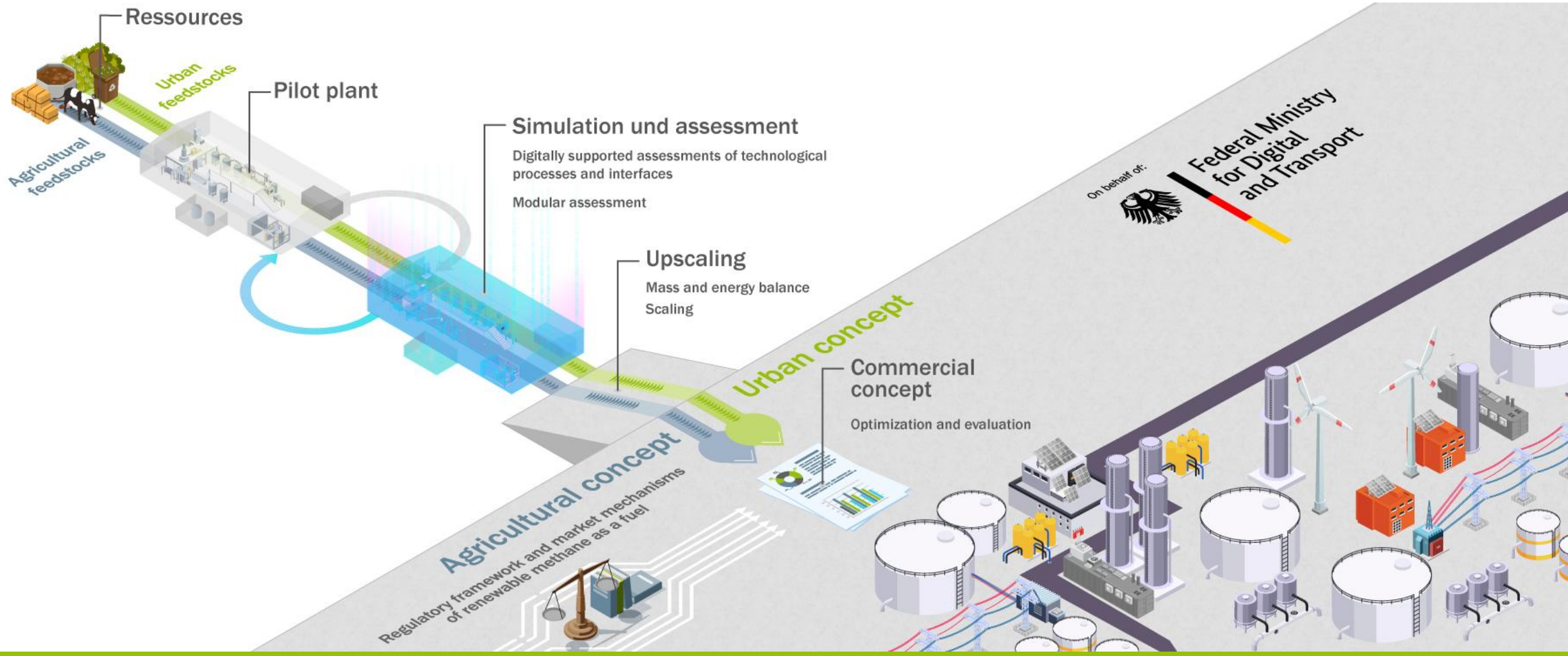
[1] Deutsches Biomasseforschungszentrum gGmbH, Leipzig, Germany

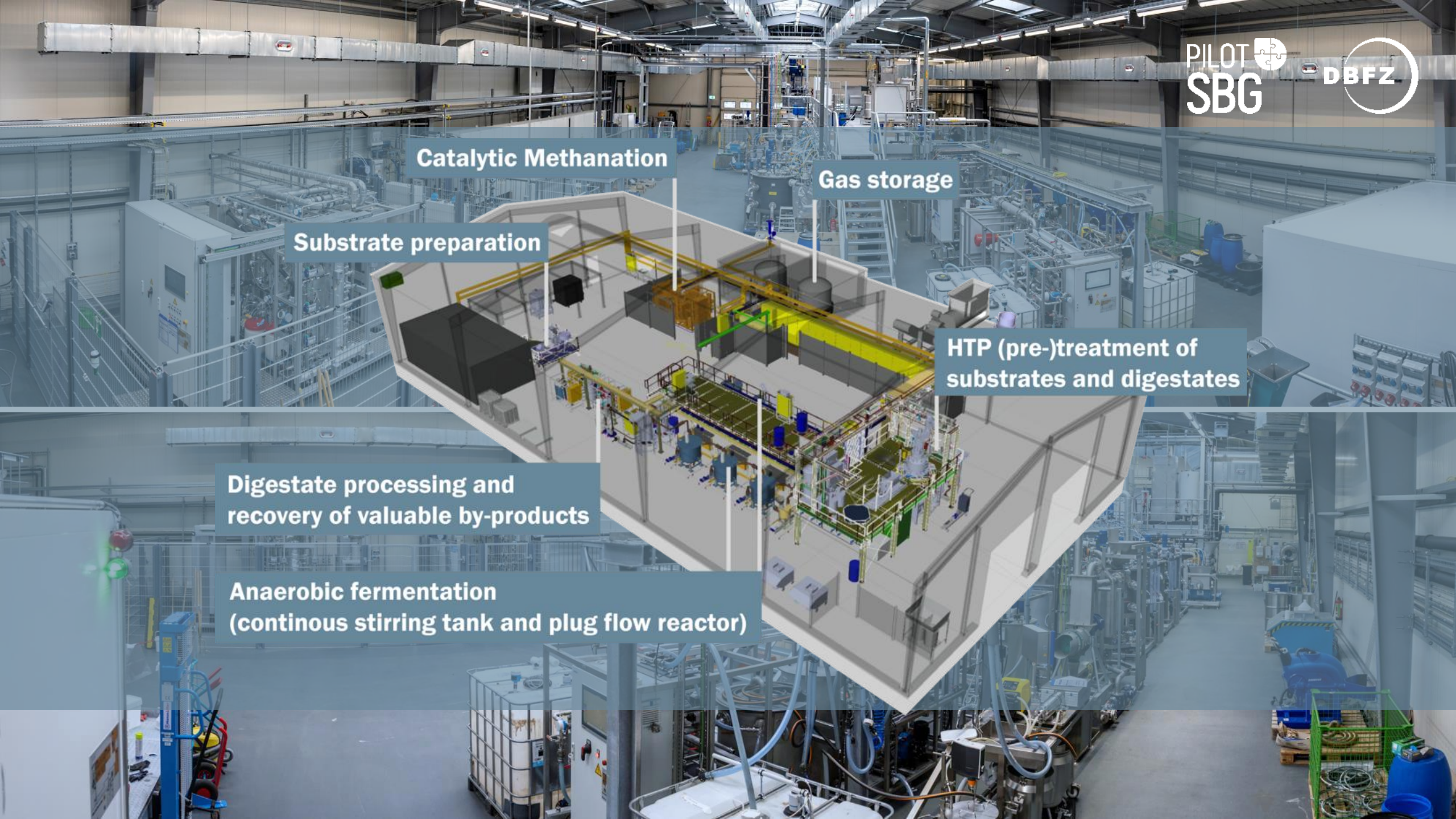
[2] Department of Biological and Chemical Engineering, Aarhus University, Aarhus, Denmark

On behalf of: Federal Ministry of Transport

This publication was carried out on behalf of the Federal Ministry for Digital and Transport under file number 3552.1. The sole responsibility for the content lies with the author.

Pilot-SBG Phase 1b




PILOT SBG
DBFZ
Catalytic Methanation
Gas storage
Substrate preparation
HTP (pre-)treatment of substrates and digestates
Digestate processing and recovery of valuable by-products
Anaerobic fermentation (continous stirring tank and plug flow reactor)

Input materials

Hydrothermal (pre-)treatment

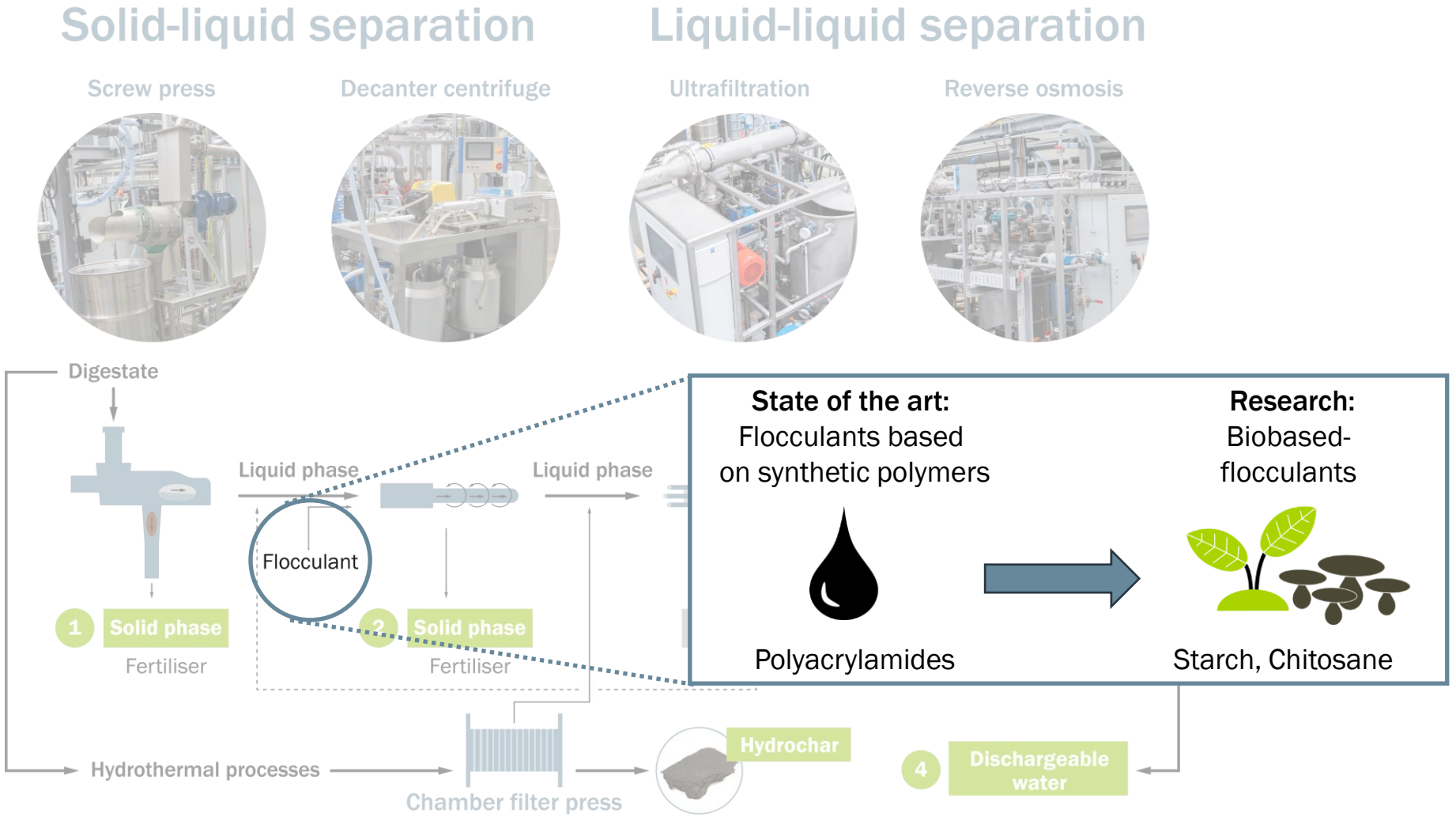
Anaerobic fermentation | Line 2

Anaerobic fermentation | Line 1


PILOT
SBG
DBFZ
Digestate treatment

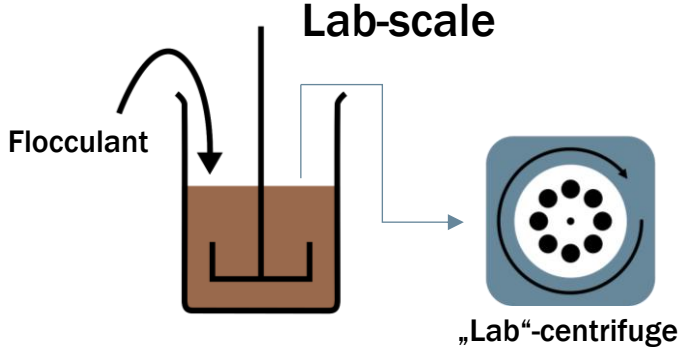

Digestate treatment

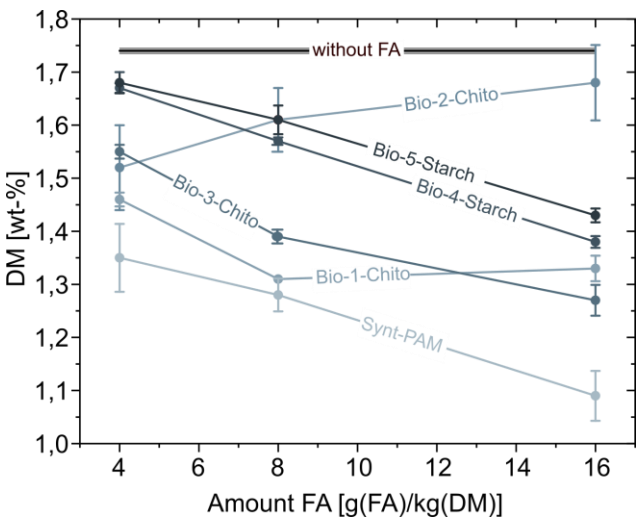
Overview

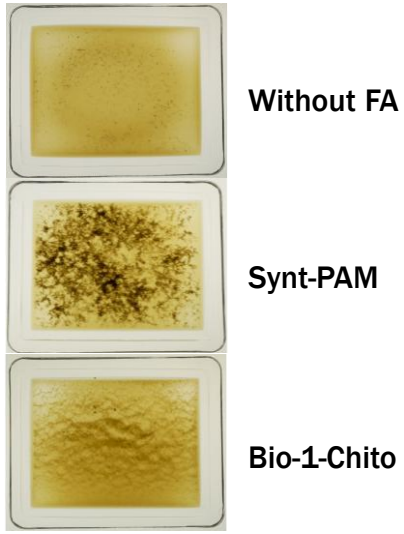

Solid-liquid separation
Liquid-liquid separation
Screw press
Decanter centrifuge
Ultrafiltration
Reverse osmosis
Digestate
Liquid phase
Liquid phase
Flocculant
1
Solid phase
Fertiliser
2
Solid phase
Fertiliser
State of the art:
Flocculants based on synthetic polymers
Research:
Biobased-flocculants
Polyacrylamides
Starch, Chitosane
Hydrothermal processes
Chamber filter press
Hydrochar
4
Dischargeable water

Bio-based flocculants for digestate treatment

Lab-scale







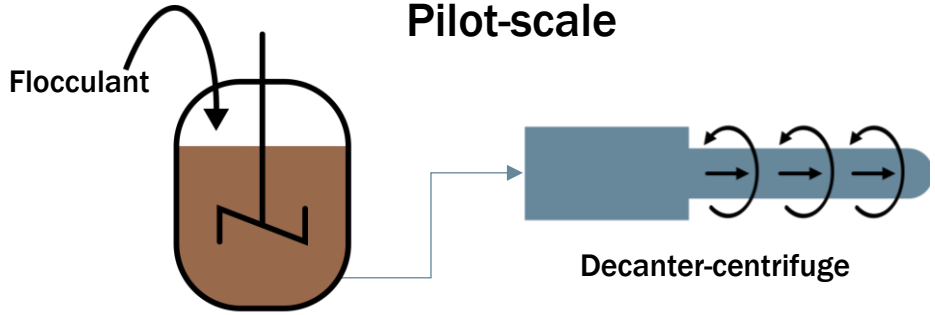
Without FA

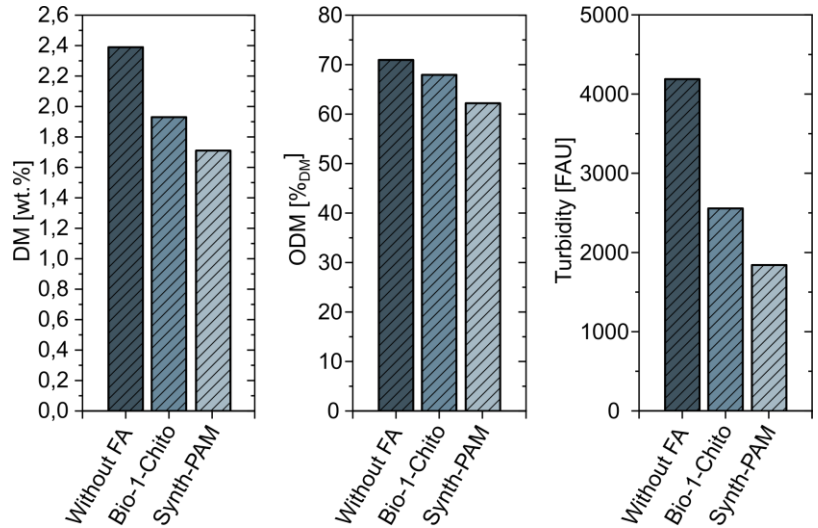
Synt-PAM

Bio-1-Chito

Left: Analysis of the supernatant after centrifugation: DM content of the supernatant for all flocculants and flocculant concentrations. Right: Pictures of the flocs formed with different flocculants

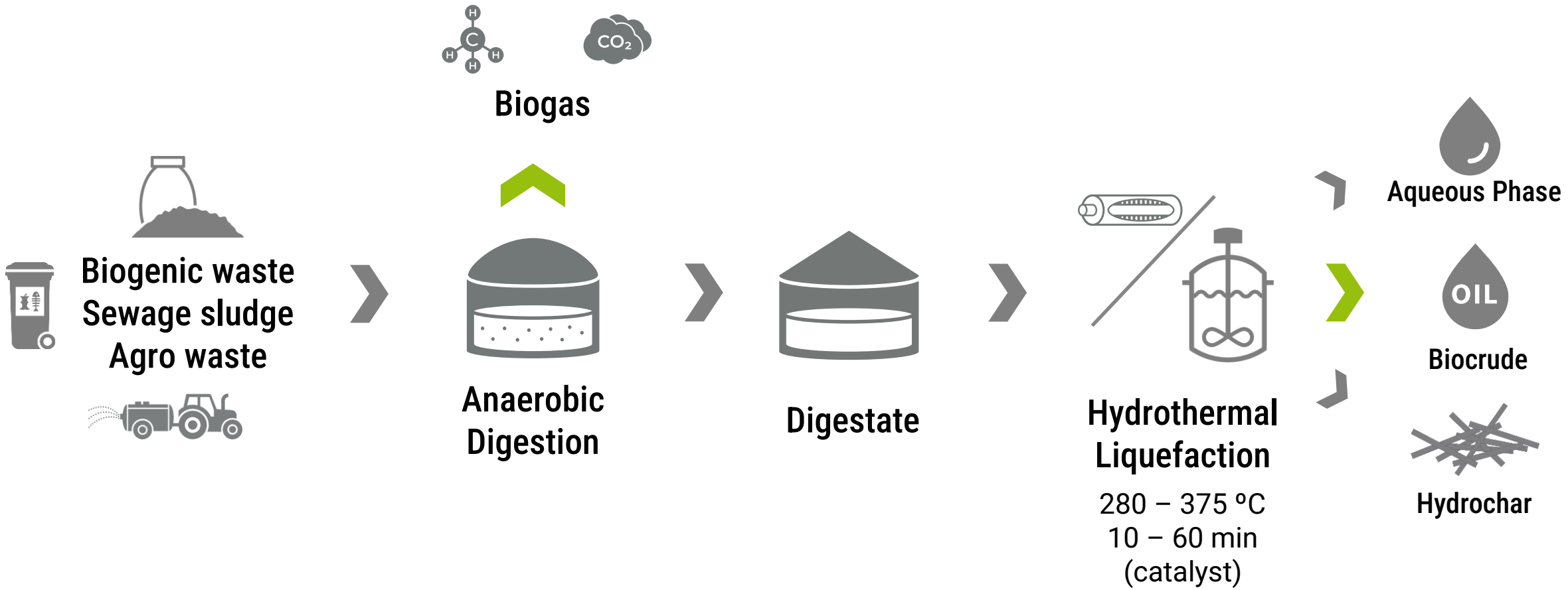
Pilot-scale





Analysis of the centrifugate without, for one synthetic and one biobased flocculant. Shown are the dry mass content, the organic dry mass content and the turbidity of the centrifugate.

Anaerobic Digestion + Hydrothermal Liquefaction



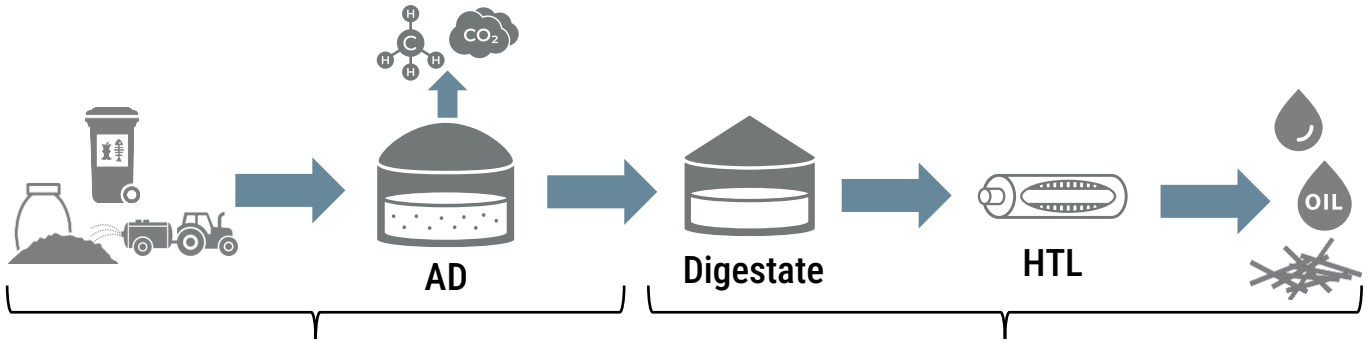
Lab experiments

- **Materials**: Sewage sludge (SS), Biogenic waste (BW), Straw/manure (SM) and their respective digestates (D)

  → **six biomass in total**
- **Biogas data** collected from plant operators
- **Experimental method:** HTL at 300, 325, 350 °C for 20 min in 20 mL batch autoclaves; separation by centrifugation, followed by DCM extraction
- **Analytics:** Proximate analysis and ICP of biomass; ultimate analysis of biomass, biocrude and hydrochar; COD, TOC, TN of HTL aqueous phase

Modeling and cost estimation approach

- **Simulation of HTL** with Aspen Plus v14
- **Equipment price estimation and comparison** with APEA, DACE[2], Peters[3], Matches[4] and KTBL[5]
- Calculation of **production cost** according to VDI Guideline 6025
- Biomethane sales price from DENA



KTBL Biogas calculator
CAPEX, OPEX

Aspen Plus
CAPEX, OPEX, Equipment Design, Energy consumption

DACE, Matches, Peters
Comparative equipment cost estimation

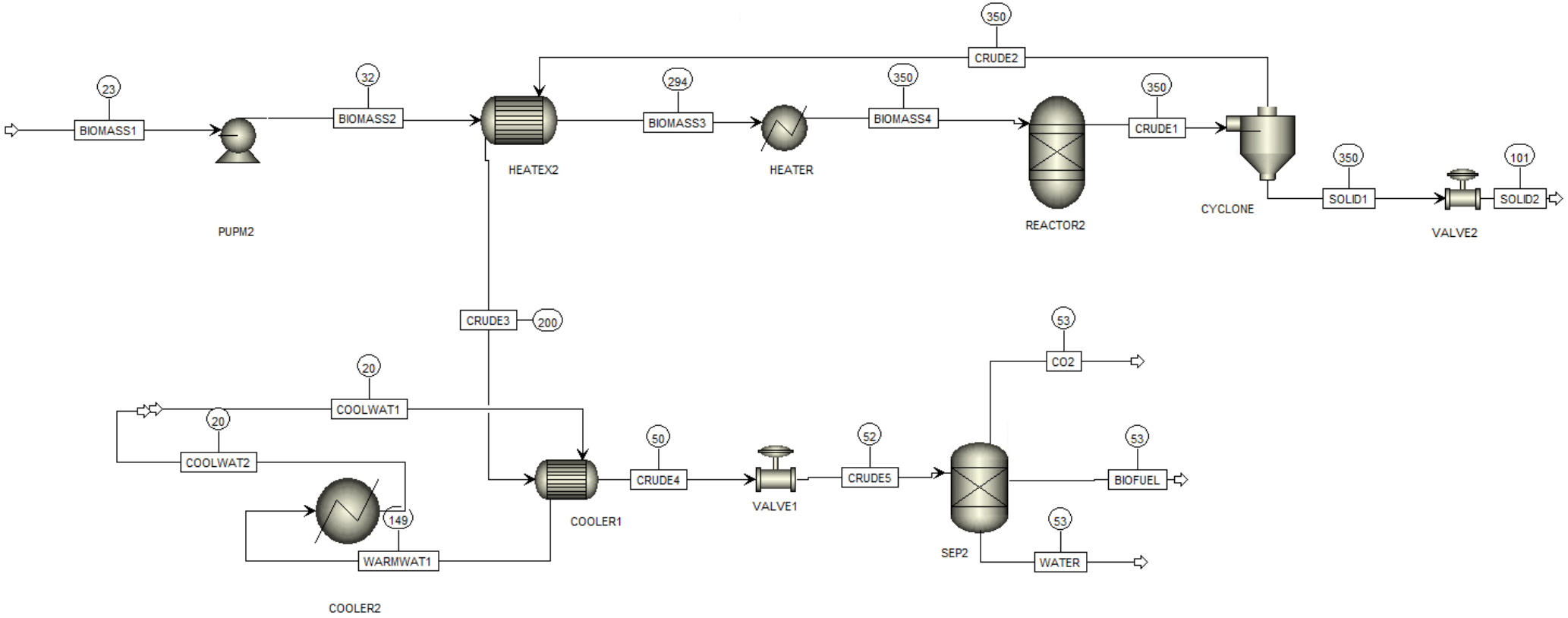
[2]DACE price booklet (2024), available online: https://www.dacepricebooklet.com/
[3]Peters et al. (2004) Plant design and economics for chemical engineers, 5th ed. McGraw-Hill, Boston, 988 pp.
[4]Matches (2024), available online: https://www.matche.com/
[5]KTBL (2024) KTBL Biogasrechner, available online: https://daten.ktbl.de/biogas/startseite.do

Aspen Model

- **Aspen plus v.14**
- **Equation of state:** Soave-Redlich-Kwong
- **Scale:** 10 kt/a and 250 kt/a
- Biomass, digestates and hydrochar as **non conventional solid** based on analytics.
- Biocrude and AP as **mixture of organic compounds** found in GC-MS to fit elemental composition

Analysis	Straw/manure	Straw/manure digestate	Hydrochar
Proximate			
Ash [%]	11.1	18.25	34.6
Ultimate			
C [%]	47.95	43.8	48.12
H [%]	5.38	5.44	3.82
N [%]	1.28	1.71	2.12
S [%]	0.27	0.37	0.46
O [%]	34.02	30.43	13.00
Sulfanate			
Organic [%]	88.9	81.75	65.37

Aspen flow sheet



Mass and energy balance

Feedstock	Process	T_{HTL} [°C]	$Y_{Methane}$ [Ma.%]	$ER_{Methane}$ [%]	$Y_{Biocrude}$ [Ma.%]	$ER_{Biocrude}$ [%]	ER_{total} [%]	
Sewage sludge	AD + HTL	300	14.45	47.86	13.02	28.64	62.87	x 1.6-2
		325			12.81	30.27	63.72	
		350			12.58	30.43	63.80	
	HTL	300	-	-	15.60	31.83	-	
		325			17.09	32.31	-	
		350			19.19	39.28	-	
Straw/ manure	AD + HTL	300	17.16	49.27	20.50	32.36	68.89	x 2
		325			19.68	33.23	69.41	
		350			19.08	34.71	70.31	
	HTL	300	-	-	21.07	32.35	-	
		325			23.53	37.15	-	
		350			22.59	36.40	-	
Biogenic waste	AD + HTL	300	3.05	10.38	9.75	21.33	27.79	
		325			9.30	20.90	27.43	
		350			10.52	20.87	27.41	
	HTL	300	-	-	14.66	27.26	-	
		325			15.04	29.81	-	
		350			15.96	31.91	-	

Preliminary economic assessment – minimum fuel selling price (MFSP)

Feedstock	Process	T_{HTL} [°C]	Biomethane sales €/y	CAPEX €	Annuity €/y	OPEX €/y	Total deficit €/y	MFSP €/kg	MFSP €/GJ
Sewage sludge	AD + HTL	300	514,739	5,836,469	755,849	2,056,261	2,297,372	13.17	435.09
		325		6,055,397	784,202	2,067,976	2,337,439	13.63	418.79
		350		6,300,806	815,983	2,117,378	2,418,622	14.35	431.09
	HTL	300	-	2,986,283	386,737	1,989,506	2,376,244	7.26	212.10
		325		3,202,527	414,742	2,001,267	2,416,009	6.73	212.48
		350		3,378,630	437,548	2,037,811	2,475,359	6.14	179.06
Straw/ manure	AD + HTL	300	1,011,051	5,845,669	757,041	1,632,898	1,378,888	5.31	184.89
		325		6,058,755	784,636	1,644,604	1,418,189	5.68	185.21
		350		6,143,630	795,628	1,677,207	1,461,784	6.04	182.77
	HTL	300	-	3,013,356	390,243	1,569,034	1,959,278	4.73	138.25
		325		3,211,599	415,917	1,581,232	1,997,148	4.32	136.27
		350		3,285,136	425,440	1,614,208	2,039,648	4.59	133.86
Biogenic waste	AD + HTL	300	559,483	5,732,567	742,394	1,610,367	1,793,277	10.31	316.00
		325		5,895,584	763,505	1,621,991	1,826,013	11.00	328.44
		350		6,091,225	788,841	1,658,134	1,887,492	10.06	339.95
	HTL	300	-	2,962,696	383,683	1,559,259	1,942,942	6.63	218.63
		325		3,162,314	409,534	1,573,668	1,983,202	6.59	204.05
		350		3,453,896	447,295	1,604,024	2,051,319	6.43	197.19

Preliminary economic assessment – minimum fuel selling price (MFSP)

Feedstock	Process	T_{HTL} [°C]	Biomethane sales €/y	CAPEX €	Annuity €/y	OPEX €/y	Total deficit €/y	MFSP €/kg	MFSP €/GJ
Sewage sludge	AD + HTL	300	514,739	5,836,469	755,849	2,056,261	2,297,372	13.17	435.09
		325		6,055,397	784,202	2,067,976	2,337,439	13.63	418.79
		350		6,300,806	815,983	2,117,378	2,418,622	14.35	431.09
	HTL	300	-	2,986,283	386,737	1,989,506	2,376,244	7.26	212.10
		325		3,202,527	414,742	2,001,267	2,416,009	6.73	212.48
		350		3,378,630	437,548	2,037,811	2,475,359	6.14	179.06
Straw/ manure	AD + HTL	300	1,011,051	5,845,669	757,041	1,632,898	1,378,888	5.31	184.89
		325		6,058,755	784,636	1,644,604	1,418,189	5.68	185.21
		350		6,143,630	795,628	1,677,207	1,461,784	6.04	182.77
	HTL	300	-	3,013,356	390,243	1,569,034	1,959,278	4.73	138.25
		325		3,211,599	415,917	1,581,232	1,997,148	4.32	136.27
		350		3,285,136	425,440	1,614,208	2,039,648	4.59	133.86
Biogenic waste	AD + HTL	300	559,483	5,732,567	742,394	1,610,367	1,793,277	10.31	316.00
		325		5,895,584	763,505	1,621,991	1,826,013	11.00	328.44
		350		6,091,225	788,841	1,658,134	1,887,492	10.06	339.95
	HTL	300	-	2,962,696	383,683	1,559,259	1,942,942	6.63	218.63
		325		3,162,314	409,534	1,573,668	1,983,202	6.59	204.05
		350		3,453,896	447,295	1,604,024	2,051,319	6.43	197.19

Scale-up and cost comparison

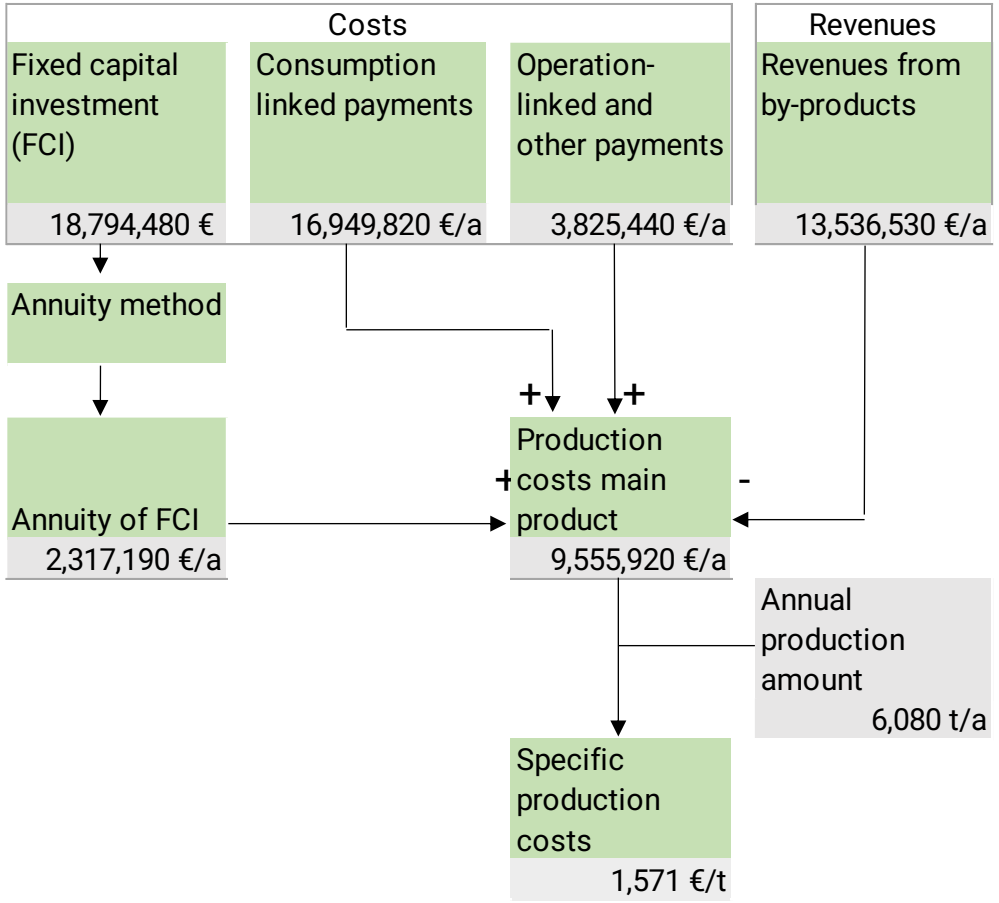
- **Scale-up to 250 kt/a** of biomass performed for economically most viable cases (by tonnage):
  - **AD + HTL** >> Straw/manure digestate 300 ºC

    → **5.31 €/kg**
  - **HTL** >> Straw/manure 325 ºC

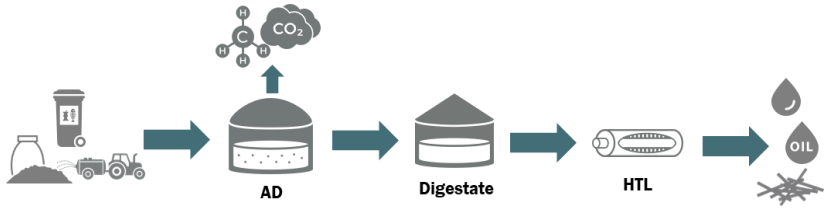
    → **4.32 €/kg**
- Comparative equipment cost estimation for **heat exchanger, pump and reactor** using DACE, Peters and Matches
- Prices were adapted with CEPCI factor if necessary

Properties & assumptions

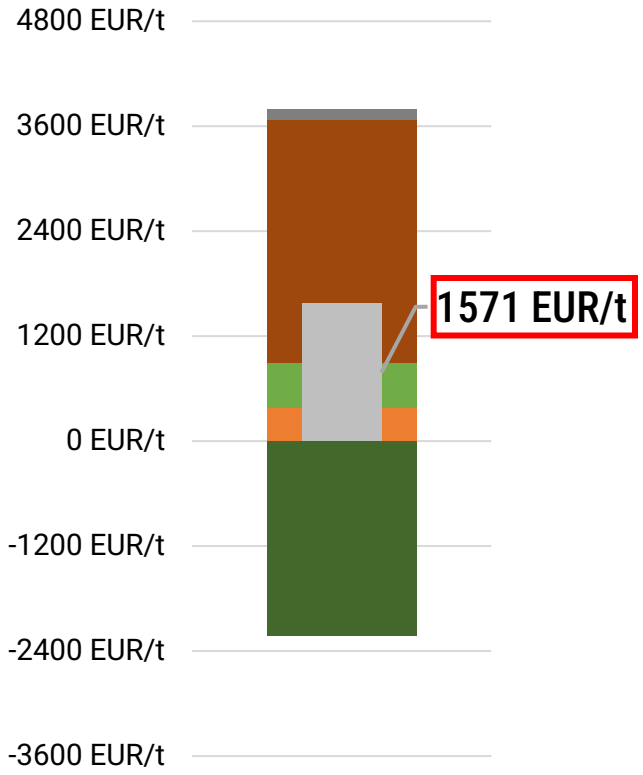
- **Aspen Plus Economic Analyzer** provides relatively high cost estimation compared to other methods
- Mean of DACE, Peters and Matches was usually lower
- Aspen cost estimation was selected as a *worst-case scenario* for **equipment cost**
- **Operating cost** was calculated using Peters plant capacity estimation
- **Process water treatment** cost is based on the Leipziger Wasserwerke price list for TOC and TNB

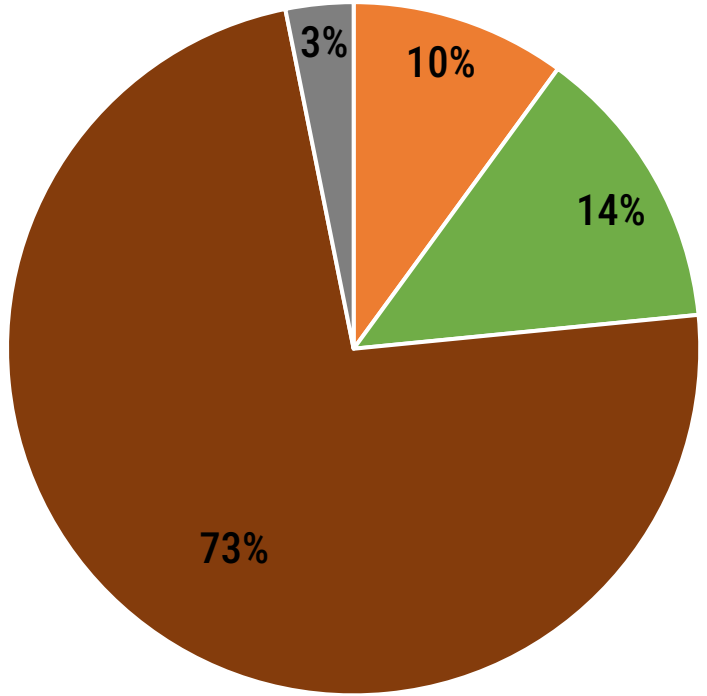


AD + HTL

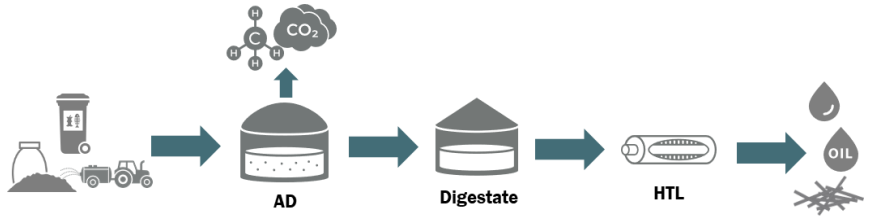


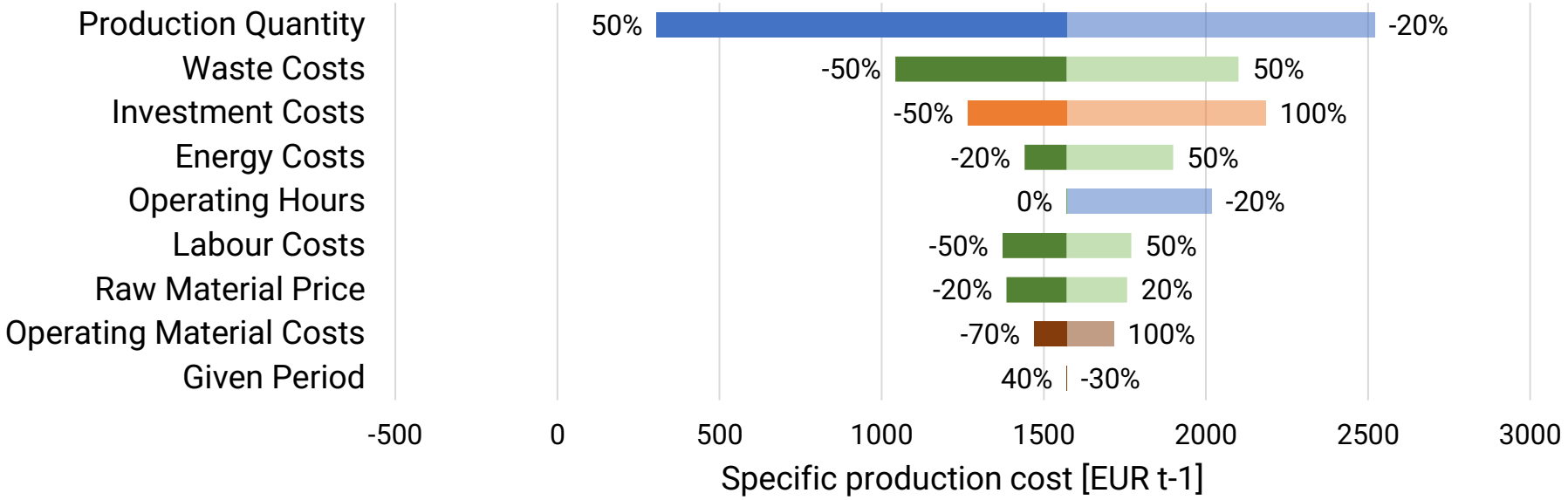
- Revenues: 2226 [EUR/t]
- Other cost: 120 [EUR/t]
- Consumption-related cost: 2787 [EUR/t]
- Operating cost: 509 [EUR/t]
- Annual capital cost: 381 [EUR/t]
- MFSP [EUR/t]





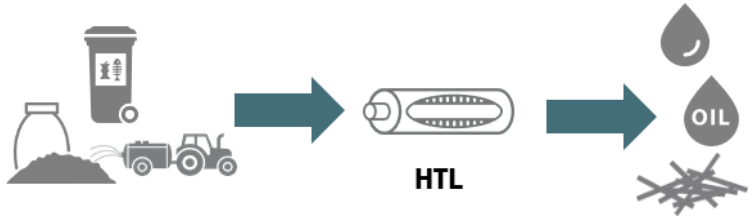
AD + HTL



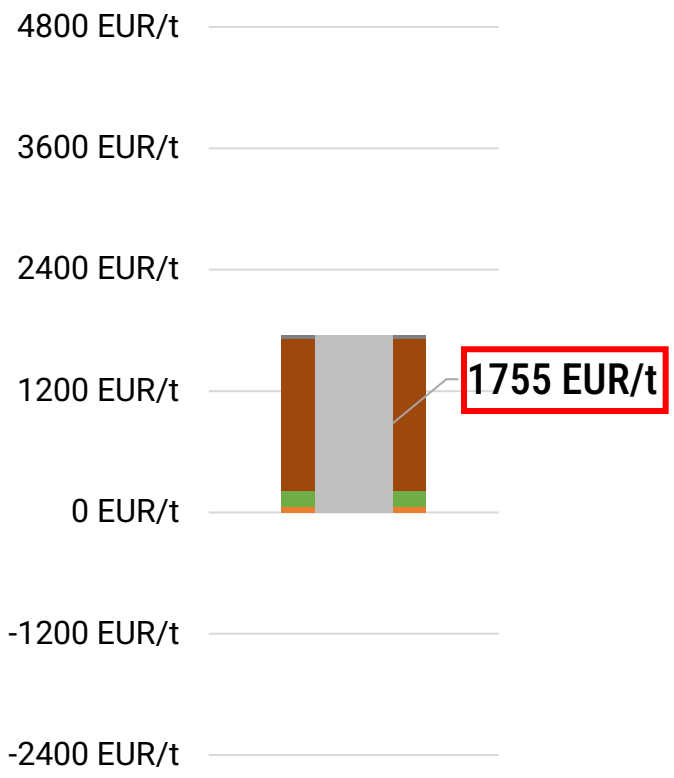


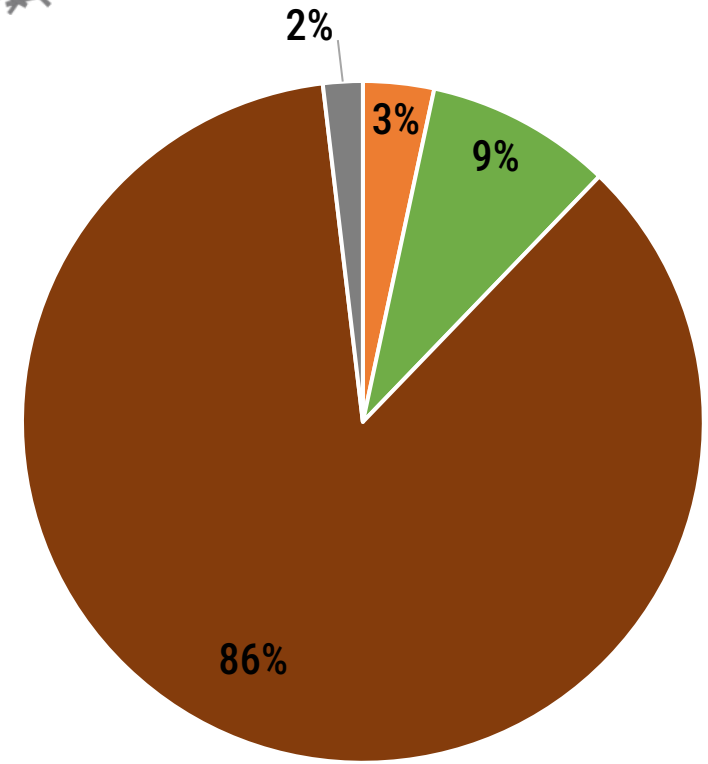
- **Production quantity**, **waste** and **investment cost** as main price drivers
- **Labor cost, raw material price** have a lower influence

HTL

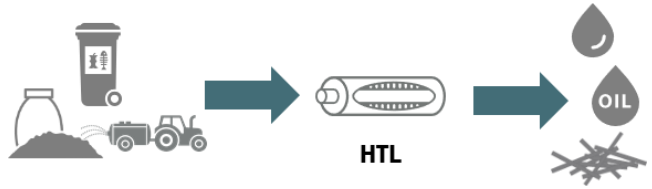


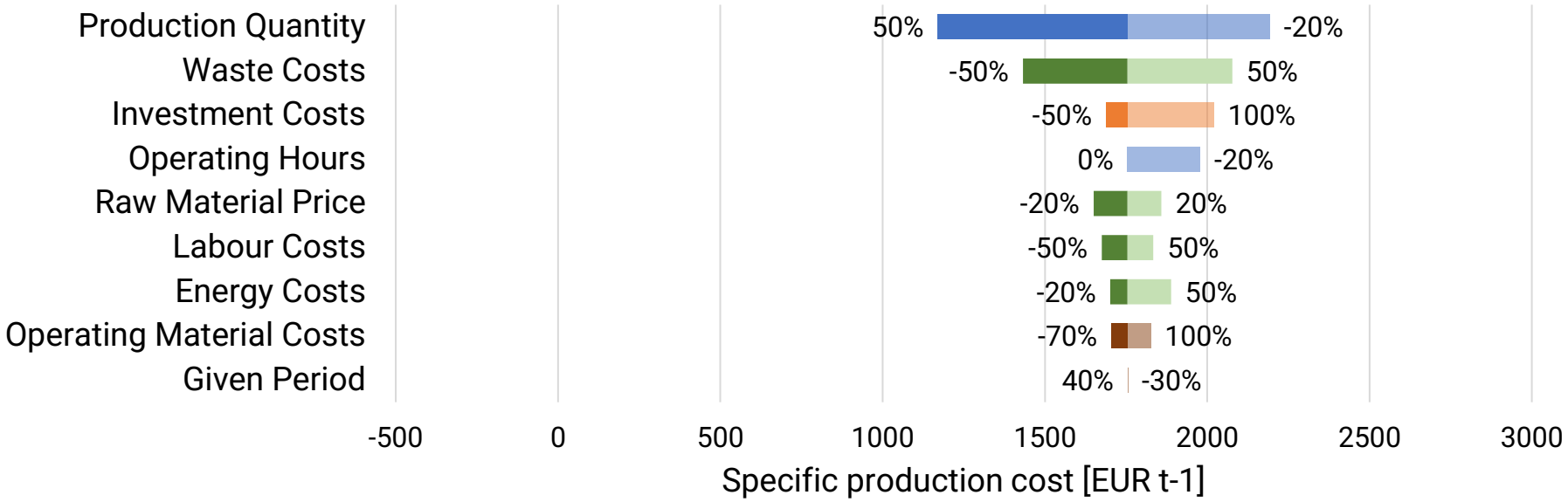
- Revenues: 0 [EUR/t]
- Other cost: 33 [EUR/t]
- Consumption-related cost: 1507 [EUR/t]
- Operating cost: 155 [EUR/t]
- Annual capital cost: 59 [EUR/t]
- MFSP [EUR/t]





AD + HTL





➢ **Production quantity**, **waste** and **investment cost** as main price drivers similar to AD + HTL

Conclusion

- Combination of AD + HTL can make sense **energetically** depending on the scenario.
- Aspen Plus Economic Analyzer **gives high estimations** compared to other established estimation methods.
- Sensitivity analysis reveals **similar cost structure** and price drivers when comparing AD + HTL and HTL.
- **Process water treatment / waste cost** found to be the crucial economic barrier.
- Combination of AD and HTL can allow for a **lower MFSP** of biocrude while significantly **increasing the energetic exploitation** of the biomass.

Interested? Contact us!

Christian Klüpfel
Biorefineries Department
Research fellow

Deutsches Biomasseforschungszentrum gGmbH
Torgauer Straße 116
D-04347
Leipzig

christian.kluepfel@dbfz.de
+49 (0)341 2434-436

www.dbfz.de/pilot-sbg