Karlsruhe Institute of Technology

Thermochemical Processes for Feedstock Recycling of Waste

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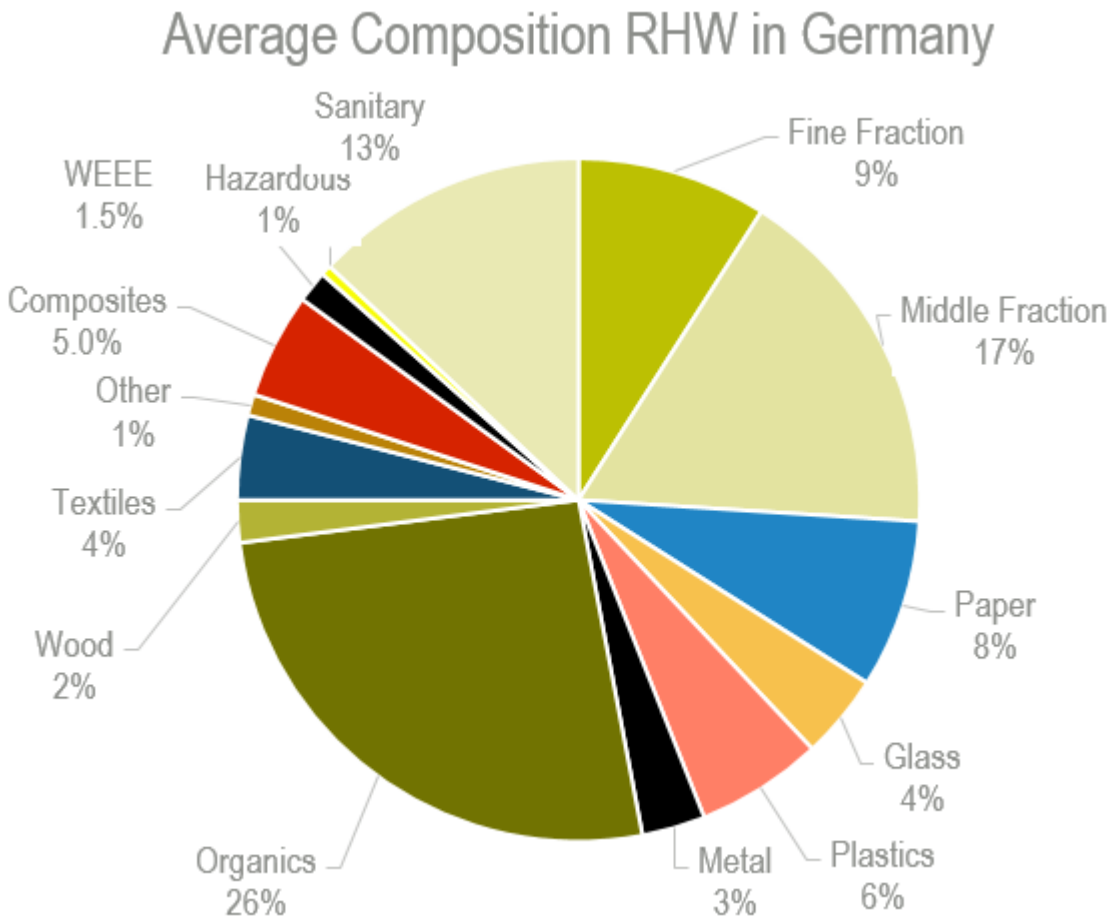
Certificated Solid Recovered Fuel (SRF) produced from biomass and household waste in the frame of the EU funded RECOMBIO project [1]

Residual Household Waste Composition in Developed Countries



Conversio, 2018, in: Survey on feedstock recycling of plastic waste (Publisher: BKV & plastics Europe, in prep.)

Case: Residual Household Waste RHW to Methanol Syngas

Feedstock Recycling of Waste

Pretreatment	Conversion	Product upgrading
Mechanical pretreatment	Fluidized bed gasification	Multi step syngas treatment

RHW	Gasifier Feed	Raw syngas	On-spec-feed to methanol synthesis
		CO_2, CO, H_2, CH_4, tars, H_2S, HCl, Hg, …	H_2:CO = 2:1, tar free, gas contaminants below 0.1ppmv

CFB Gasification

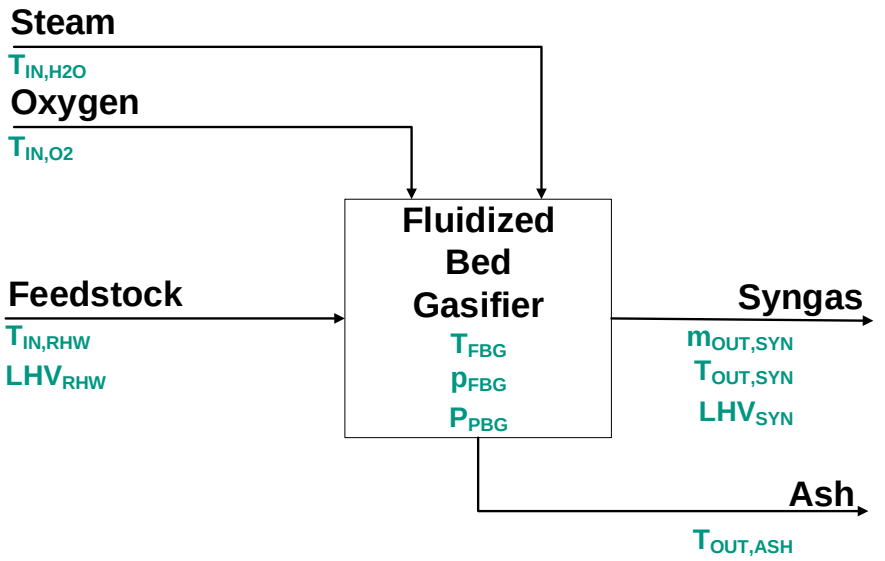
Gasification of RHW in a CFB-Gasifier

Calculated Balance

- $T_{IN,RHW}$ = 25°C
- $T_{IN,O2}$ = 23°C
- $T_{IN,H20}$ = 500°C

- p_{CFB} = 1 bar
- $T_{OUT,SYN}$ = 950°C

→ Input of O_2



Syngas composition		
CO	mole-%	25.0
H_2	mole-%	37.2
CO_2	mole-%	15.3
H_2O	mole-%	21.0
CH_4	mole-%	0.08
O_2	mole-%	0.00
N_2	mole-%	1.1
H_2 : CO	/	1.488

Syngas composition		
LHV	MJ/m_N^3	7.2
Particles (Alkaline)	mg/m_N^3	
Tar	mg/m_N^3	10,000*
NH_3 / HCN	mg/m_N^3	16.5 / 0.0
H_2S / COS	mg/m_N^3	992 / 2624
Halogenes (Cl, Br)	mg/m_N^3	
Heavy Metals	$\mu g/m_N^3$	

*according to Han (2008)

Gasification of RHW in a CFB-Gasifier

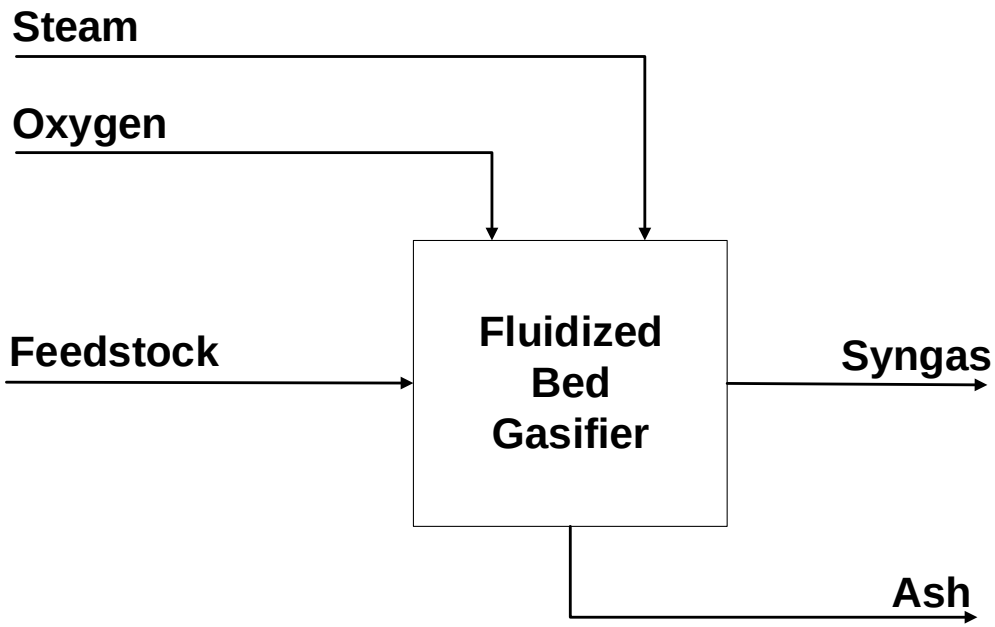
Cost Calculation – Boundary Conditions

Thermal Capacity	[MW]	100
$LHV_{Pretr.RHW}$	[MJ/kg]	15.0
→ Mass Flow Pretreated RHW	[t/h]	24.0

Temperature	[°C]	950
→ Mass Flow O_2	[t/h]	10.2

Cold gas efficiency	[-]	> 0.8
→ Mass Flow H_2O	[t/h]	3.6

Mass Flow Raw Gas	[t/h]	34.4
→ Volume Flow	[m_N^3/h]	41.208



- Further Assumtions
  - O_2 has to be purchased
  - Process heat is used to supply process steam (purchase of demin water)
  - Combustion of Tars

Gasification of RHW in a CFB-Gasifier

Cost Calculation – CapEx & OpEx

Invest in 1995	[Mio. DM]	38.7	Scur (2001)
→ Invest in 2017	[Mio. €]	28.3	VCI (div.)

- Plant factor: 3
- Annual costs of Gasifier:
  - Depreciation Period: 10 years
  - Depreciation: 10 % of Invest per year
  - Capital costs: 10 % of Invest per year
  - Operating costs: 5 % of Invest per year

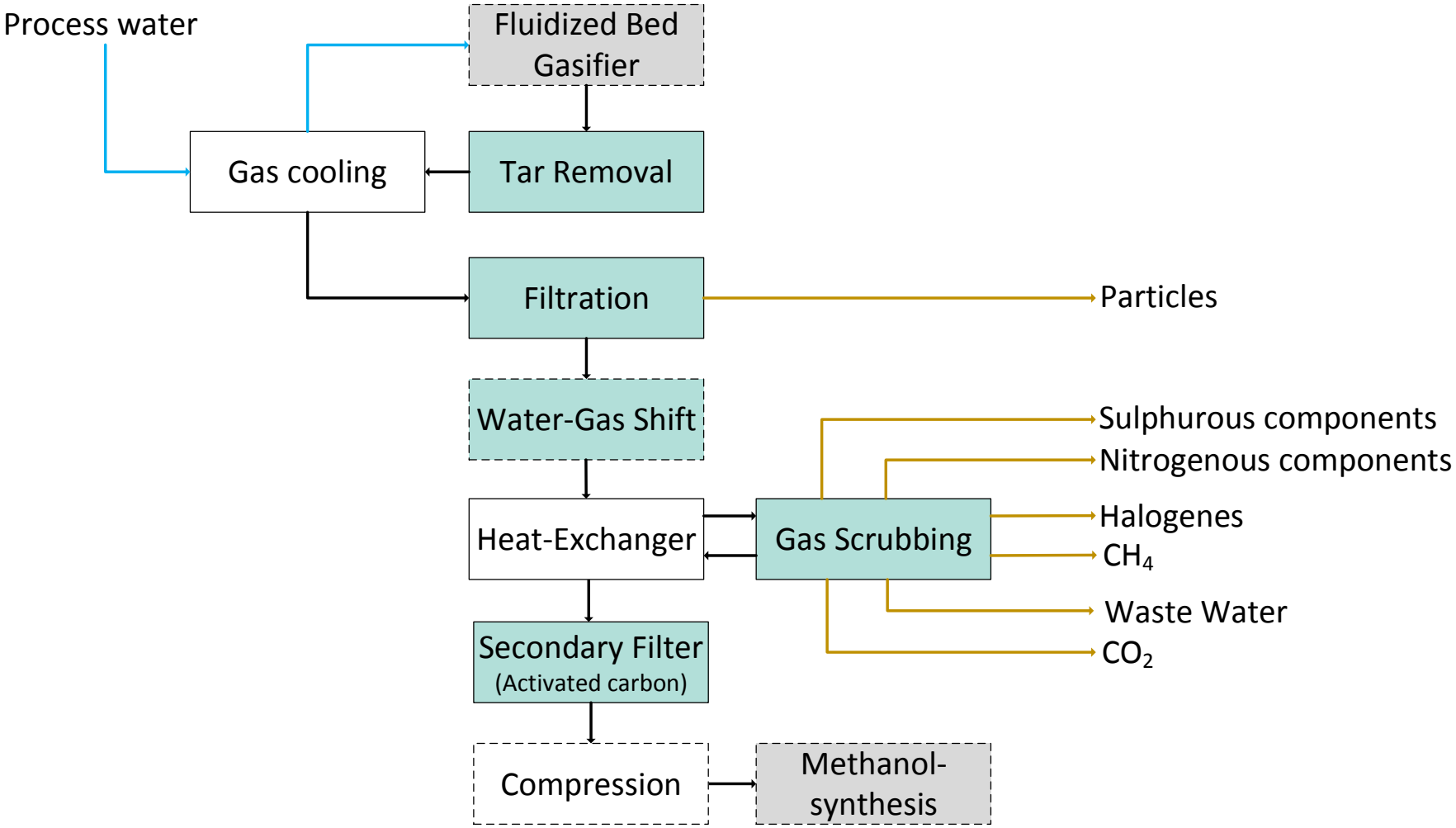
CapEx
76 €/t_{RHW}

Operation hours	[h/yr]	8,000	
Electricity	[MWh/h]	2.0	
	[€/kWh]	0.08	
Process Water	[€/t_{H2O}]	1.00	Doymaz (2015)
Oxygen	[€/t_{O2}]	19.00	Doymaz (2015)

OpEx
10 €/t_{RHW}

Gasification of RHW in a CFB-Gasifier

Gas conditioning – Flow scheme



Gasification of RHW in a CFB-Gasifier

Gas conditioning – Cost Calculation – CapEx & OpEx

- Costs of main plant components [k€] (2017)

Tar Removal	6,562	Boerrigter (2015)
Heat Exchanger	249	Peters (2003)
Electrostatic Precipitator	683	Peters (2003) Scur (2001) CCA (2018)
Water-gas Shift	372	Trippe (2013)
Gas Scrubber (Rectisol)	10,618	Trippe (2013)
Activated Carbon Filter	20	gutmbh.de
Compressor	15.176	Peters (2003)

- Plant factor: 3
- Annual costs of Gas Cleaning Plant:
  - Depreciation Period: 10 years
  - Depreciation: 10 % of Invest/yr
  - Capital costs 10 % of Invest/yr
  - Operating costs: 5 % of Invest/yr

CapEx

92 €/t_{RHW}

- Operating Parameters

Operation hours	[h/yr]	8,000	
Electricity	[€/kWh]	0.08	
Waste Water	[€/t_{H2O}]	35.00	Messmer (2015)
Methanol	[€/t_{MeOH}]	367.50	Spitzbarth (2005)
CO_2 Emission	[€/t_{CO2}]	8	Doymaz (2015)
Activated Carbon	[€/t_{AC}]	2,000	gutmbh.de

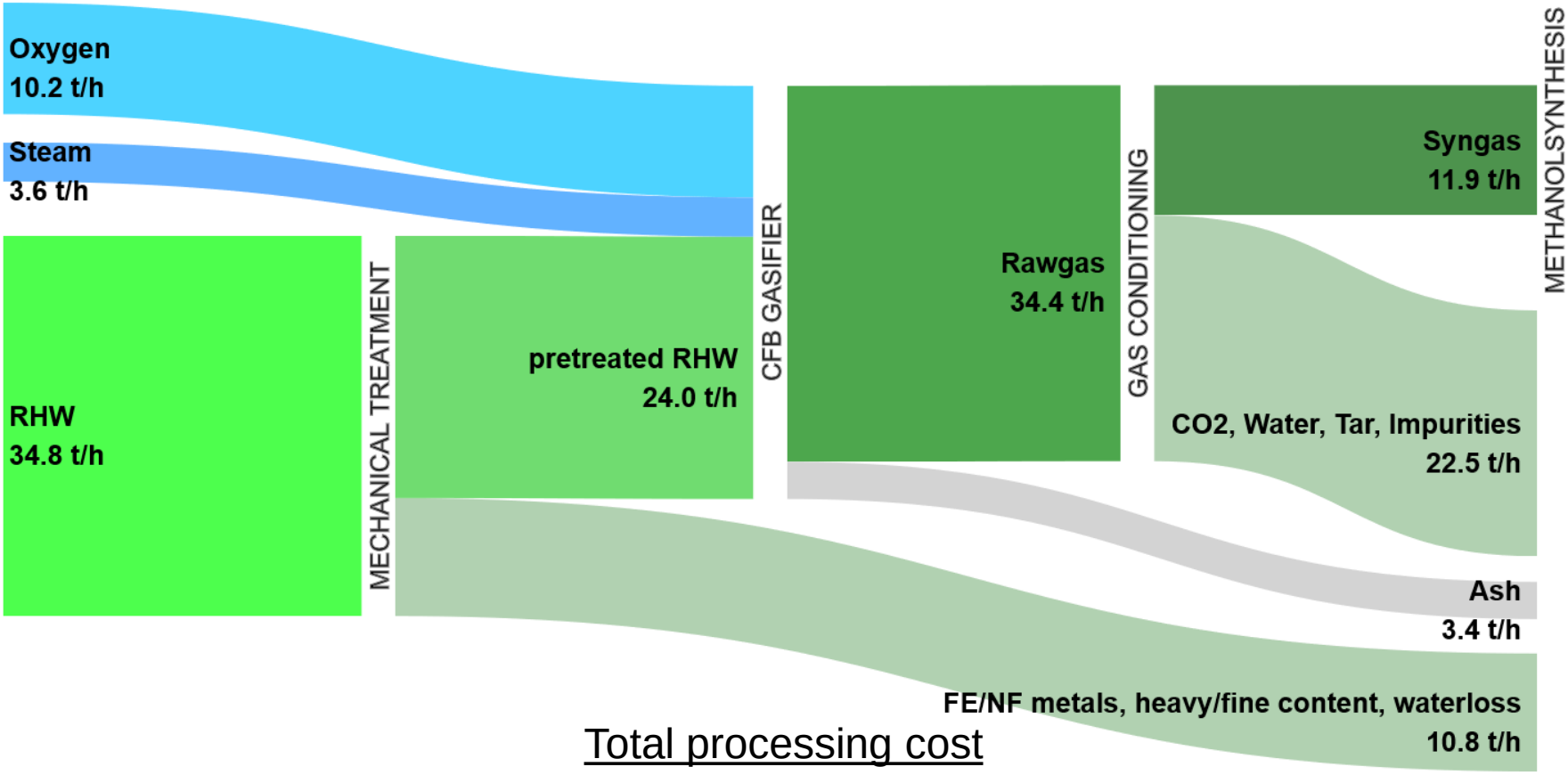
- Ash is used as Feedstock in Cement Plant
- Tars are incinerated

OpEx

13 €/t_{RHW}

Gasification of RHW in a CFB-Gasifier

Quantitative Evaluation of the Full Process Chain



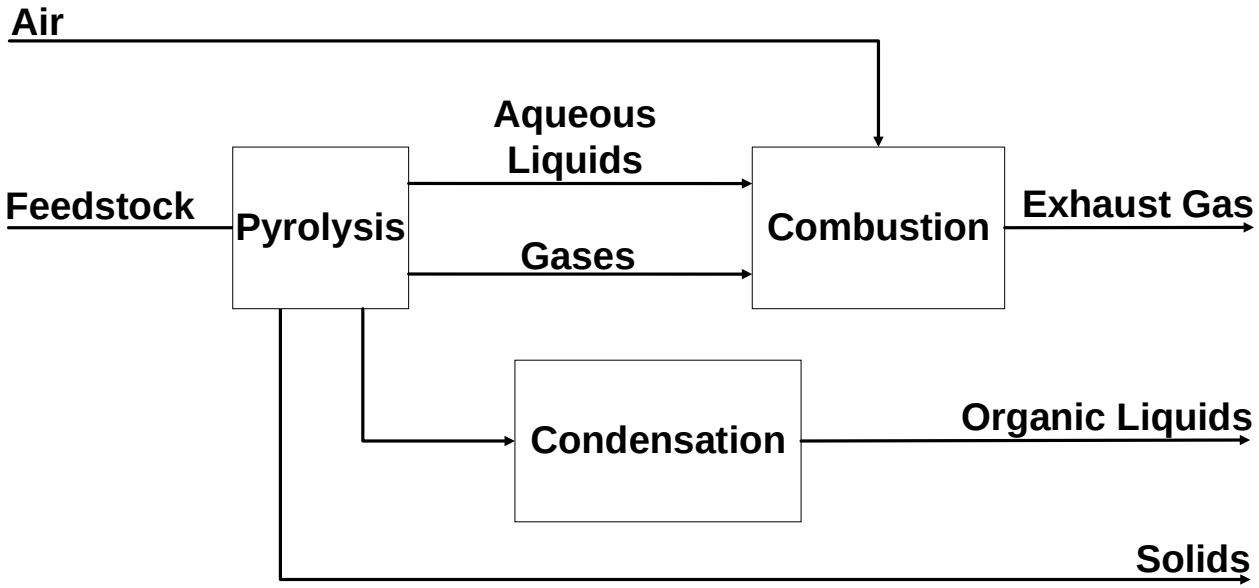
Total processing cost

212 €/t_{RHW}

Pyrolysis

Rotary Kiln Pyrolysis of RHW

Cost Calculation – Boundary Conditions



Capacity Pyrolysis	[t/h]	22.4

Temperature Exhaust Gas	[°C]	800
→ Mass Flow Air	[t/h]	90.3

Mass Flow Gases	[t/h]	4.1
Mass Flow Aqueous Liqiuds	[t/h]	7.2
Mass Flow Organic Liquids	[t/h]	5.6
Mass Flow Solids	[t/h]	5.5

Rotary Kiln Pyrolysis of RHW

Cost Calculation – CapEx & OpEx

- Costs of main plant components [Mio.€] (2017)

Total Rotary Kiln Pyrolysis plant	146.5	Based on Hartenstein 2004

- Annual costs of Pyrolysis Plant:
  - Depreciation Period: 10 years
  - Depreciation: 10 % of Invest/yr
  - Capital costs 10 % of Invest/yr
  - Operating costs: 5 % of Invest/yr

- Operating Parameters

Process Heat		self-generated	
Combustion Air	[€/t]	4.17	Spitzbarth (2004)
Landfill Fees: solids	[€/t_{Solids}]	100	CCA (2018)
Revenue: District Heating	[€/kWh]	0.03	boerse.de

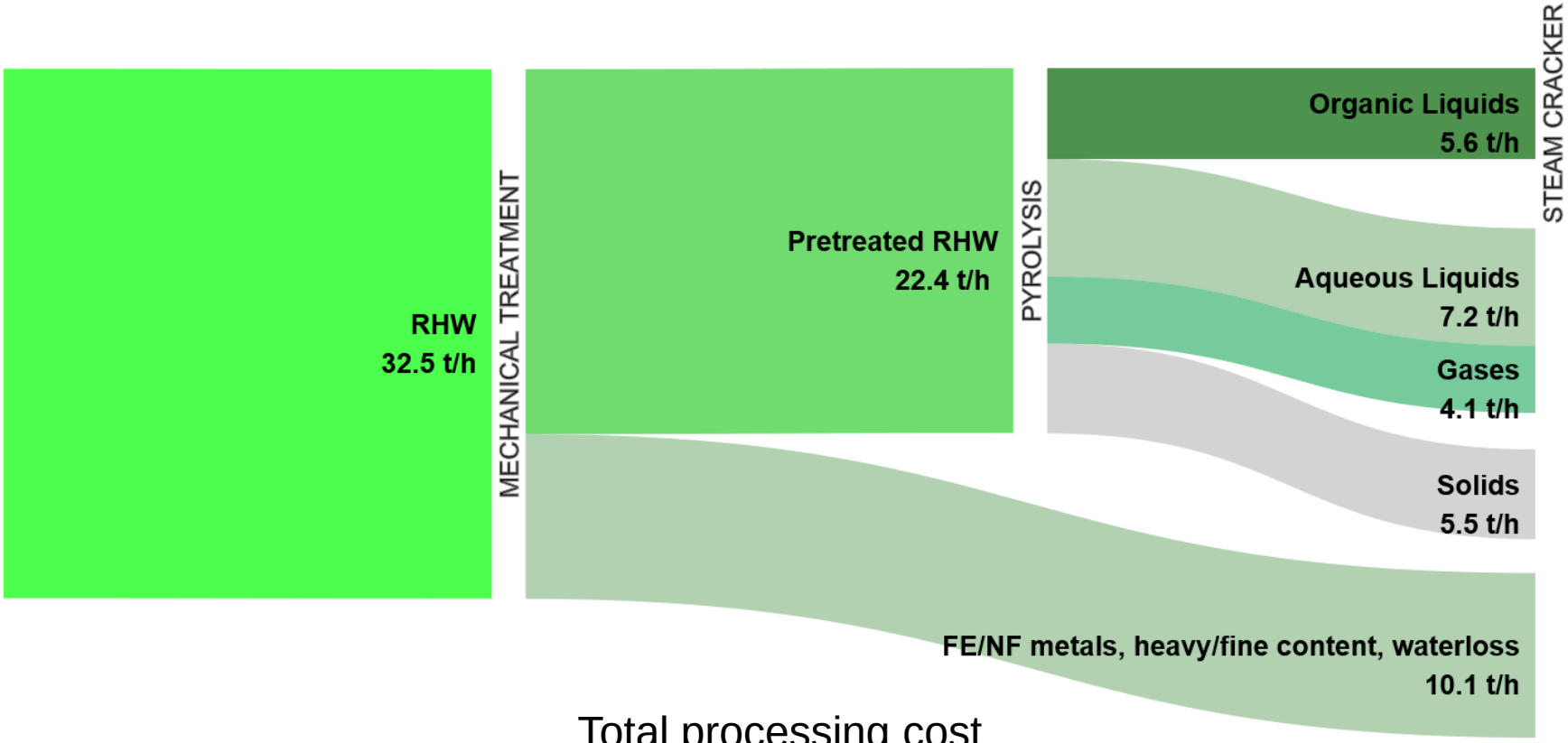
- Solids go to Landfill, class I
- Process heat is generated on side
- Excess Heat is sold as methane substitute (district heating grid)

CapEx
141 €/t_{RHW}

OpEx
21 €/t_{RHW}

Rotary Kiln Pyrolysis of RHW

Quantitative Evaluation of the Full Process Chain



Total processing cost

162 €/t_{RHW}

Summary

Pyrolysis & Gasification Technology Readiness

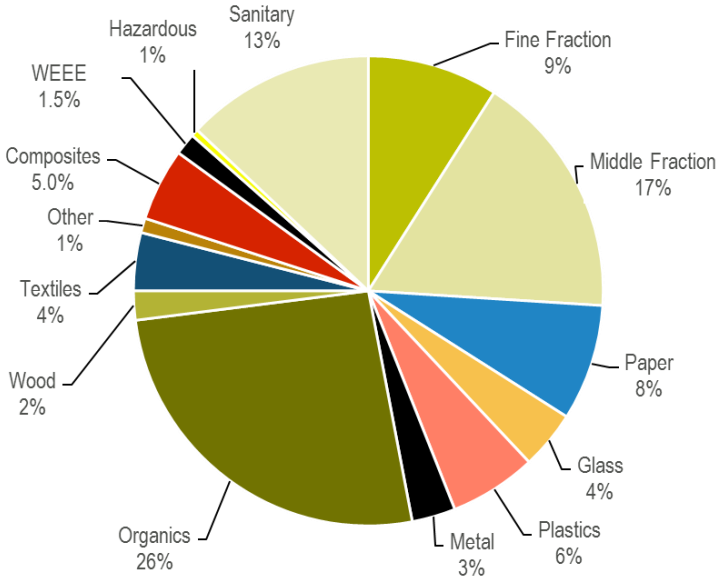
Feedstock recycling of pretreated residual household waste

- CFB gasifier TRL: 8 - 9
  - Key technical issue:
    - Optimization and reliable operation of syngas postprocessing unit (Tar removal, plugging, etc.)
- Rotary kiln pyrolysis unit TRL: 5 - 6
  - Product composition and quality not validated
  - Key technical issues:
    - Design, optimization and reliable operation of a product condensing system (Plugging, polymerization, etc.)
    - Cost of pyrolysis product posttreatment systems
    - Optimization of a pyrolysis unit that assures multiproduct quality (organic condensate as cracker feedstock, solids quality) inline with required feedstock flexibility

Process Overview: Economics**

Residual Household Waste (RHW)

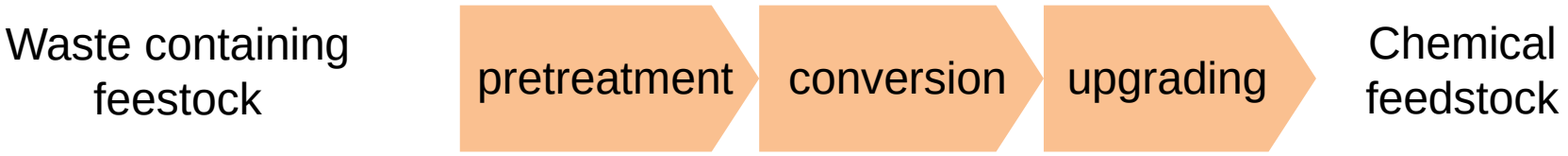
Process	Pretreatment [€/t_{RHW}]	Conversion [€/t_{RHW}]	Upgrading [€/t_{RHW}]	Total processing cost [€/t_{RHW}]	Revenues* [€/t_{RHW}]
Gasification	21	86	105	212	- 68
Pyrolysis	21	162	0	183	- 86



*) Syngas @ 200 €/t
Naphtha @ 500 €/t

**) unit size ca. 100 MW / ca. 25 t/h of pretreated household waste (RDF)
Capital investment cost estimate accuracy: ± 30%

Feedstock Recycling of Waste



- Total cost for gasification as well as pyrolysis process chains range between 100 and 180 €/t for residual household waste
  - Products: Syngas (gasification) or Syncrude (pyrolysis)
  - Processing cost are most sensitive to capital investment
- Scalable processes competitive to incineration
  - Additional value by feedstock recycling
  - Waste / biomass co-processing
  - Contribution to circular economy

Economical attractiveness versus technology readiness

Acknowledgements

Material and Energy Valorisation of Waste in a Circular Economy

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