Karlsruhe Institute of Technology

3rd Iberoamerican Congress
4th Latin American Congress
2nd International Symposium on Lignocellulosic Materials
Biorefineries
Science, Technology and Innovation for the Bioeconomy
November 23 to 25, 2015, Concepción-Chile

Upgrading of low-grade biogenic feedstock by innovative screw pyrolysis

Marco Tomasi Morgano, Hans Leibold, Frank Richter

INSTITUTE FOR TECHNICAL CHEMISTRY, DEPT. OF PYROLYSIS AND GAS CLEANING

Outline

- Motivation
- STYX – an innovative screw pyrolysis technology
- Research with wood
- Low-grade biogenic feedstocks at STYX
- Potential applications
- Conclusion

Low-grade biogenic feedstock

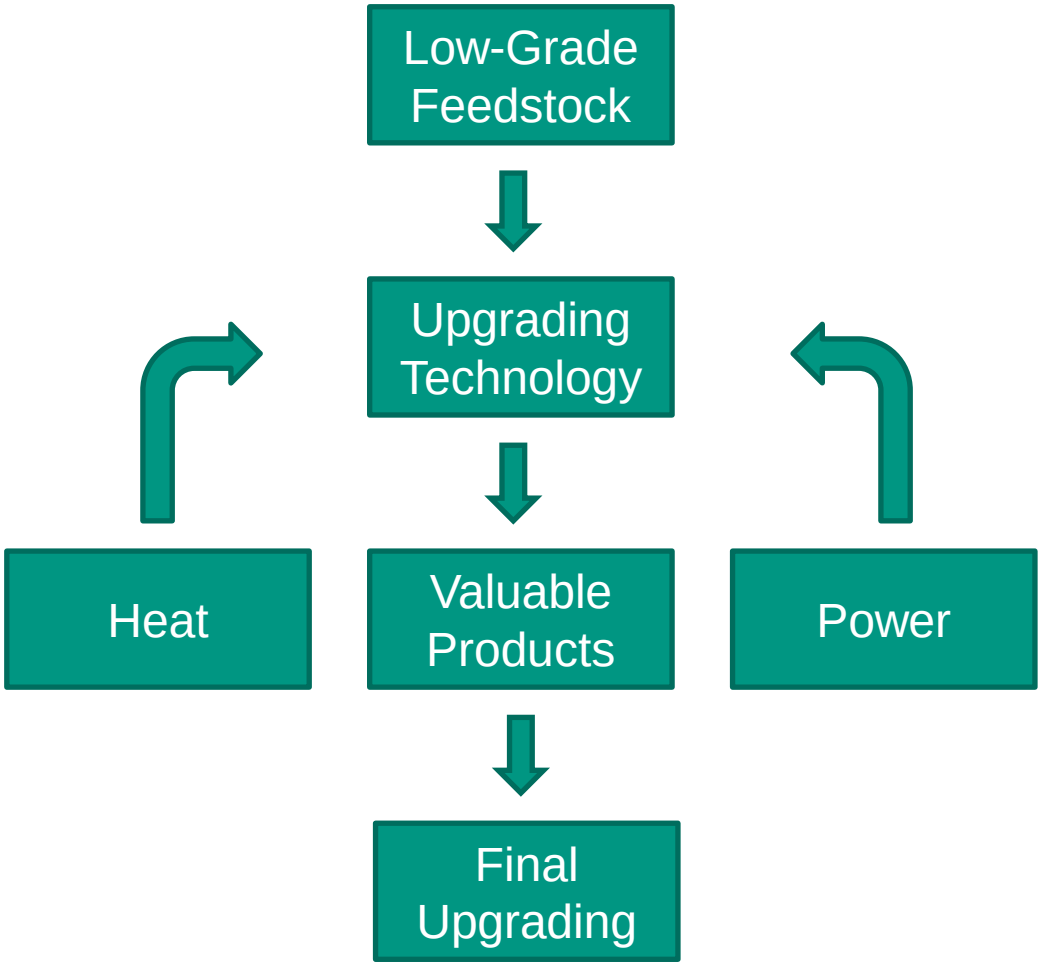
“Low-Grade biogenic feedstocks are an unexploited resource and are spread among the territory”

- High inorganic content
- High ash content
- Variable composition
- Low energy content
- High storage / logistic costs

Agricultural residues

Animal residues

Decentral upgrading



- Limited volumes
- Handling issues

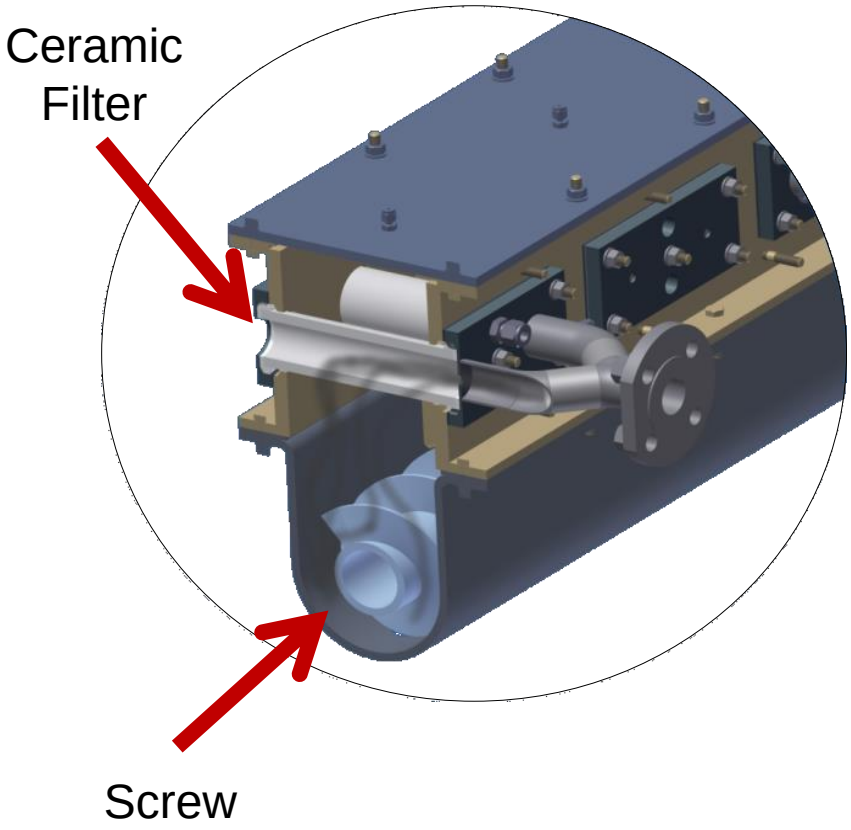
- Robust / Reliable / Flexible
- Not expensive
- Automatic / Low maintenance

- Internal reuse of products
- Remote / Off-Grid

- From decentral to central
- Favorable logistic costs
- High valuable products

Innovative screw pyrolysis technology

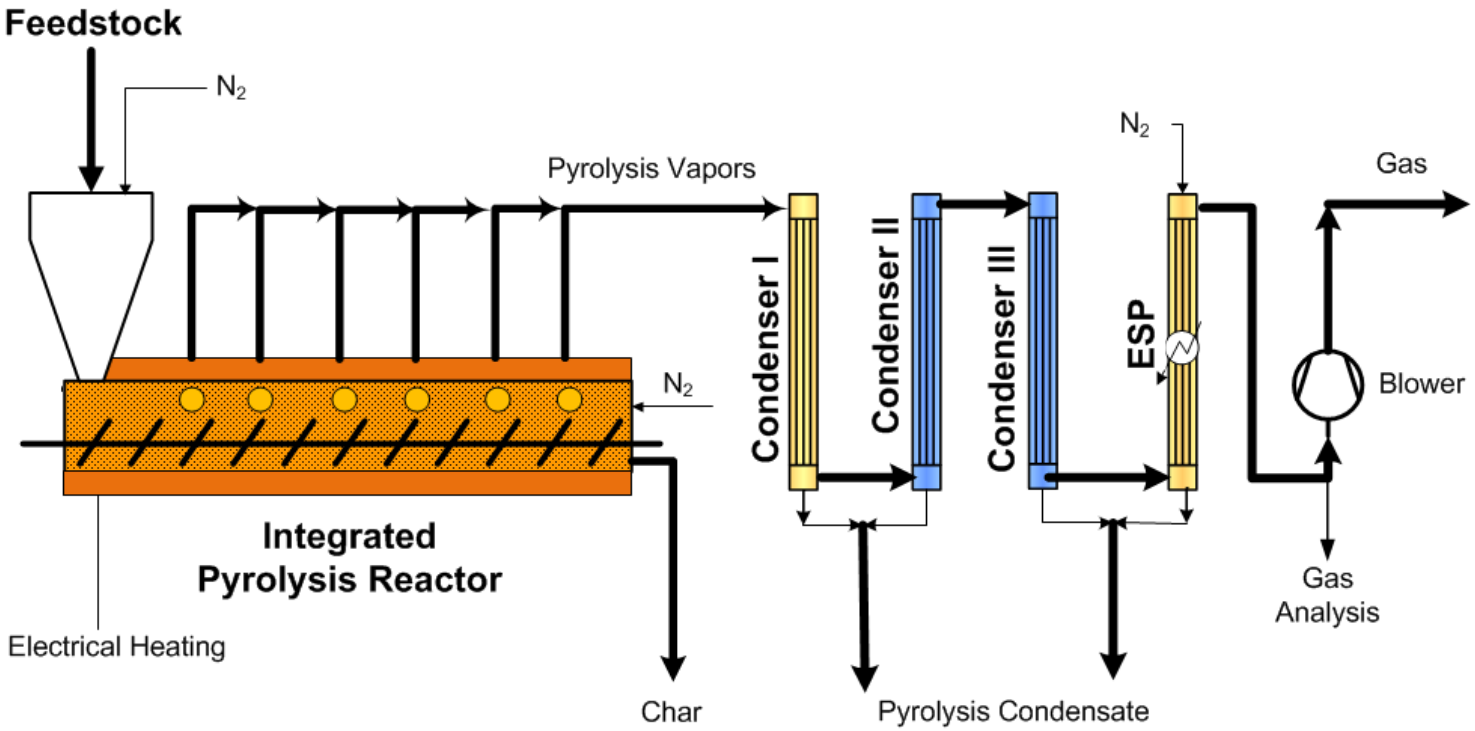
STYX Reactor



- Trough screw reactor with integrated hot gas filters
- Heating rate 100 – 200 K/min
- Contact residence time vapors - solids < 2 s
- Narrow temperature and residence time distributions in the reactor
- Heat exchange by trough / screw
- Sequential separation of vapors along the reactor (optional)
- Particle-free vapors and gases

STYX Reactor

Plant schema & data



Reactor Data

Flow Rate	< 10	Kg/h
Temperature	< 600	°C
Residence time	5 - 25	Min
Heated length	2000	mm
Screw Diameter	150	mm

Filtration Data

N° Elements	2 – 14	
Length	200	mm
Diameter	60	mm
Material	SiC	
Online recleaning		

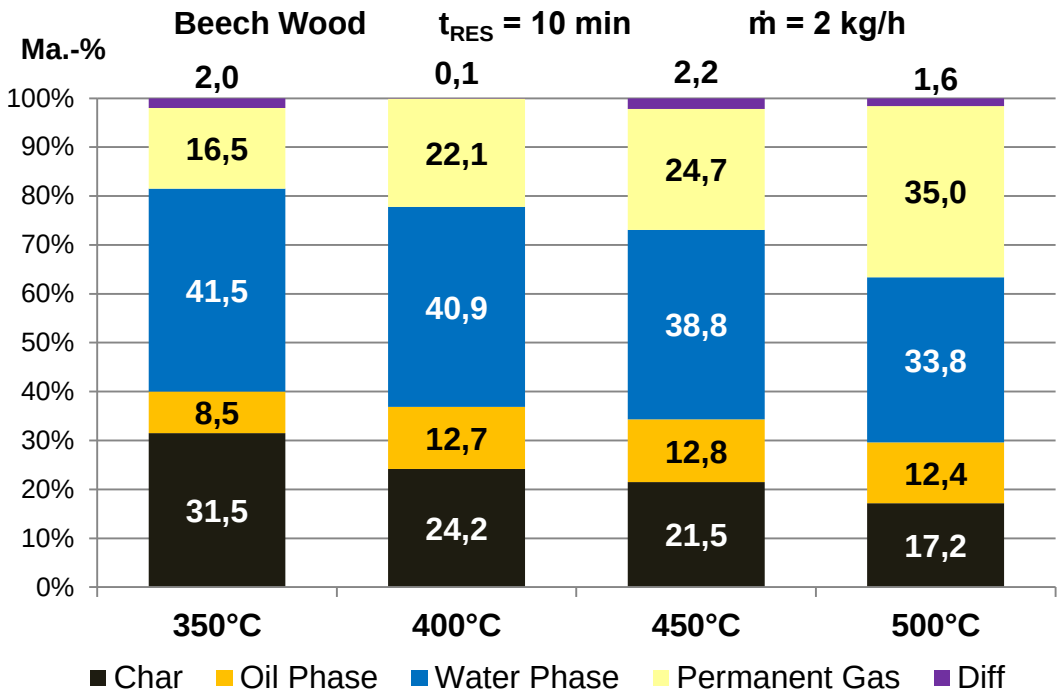
Operation Data

Time (2012-2015)	3000	h
Material (2012-2014)	7,5	tons
Main Feedstocks:		

Wood chips, wheat straw, chicken manure, sewage sludge, oil sand, etc.

Process & feedstock flexibility

- Mass / Energy balance
- Design and control of products yields and properties
- Optimization
- Kinetics investigations on bench scale
- Process simulation and system analysis

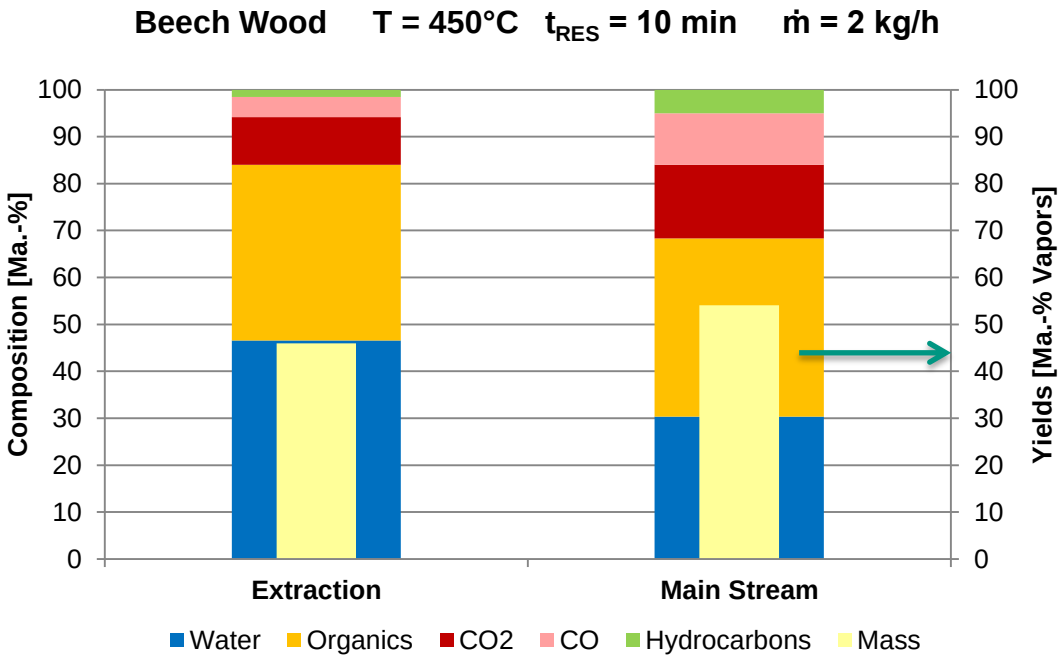


Temperature [°C]	Char [MJ/kg]	Oil Phase [MJ/kg]	Water Phase [MJ/kg]	Gas [MJ/kg]	Viscosity Oil [mPa s]
350	26.5	19.0	5.0	3.4	75
400	28.9	20.6	6.3	6.5	106
450	29.5	21.0	3.2	8.5	163
500	31.0	22.4	1.5	12.6	132

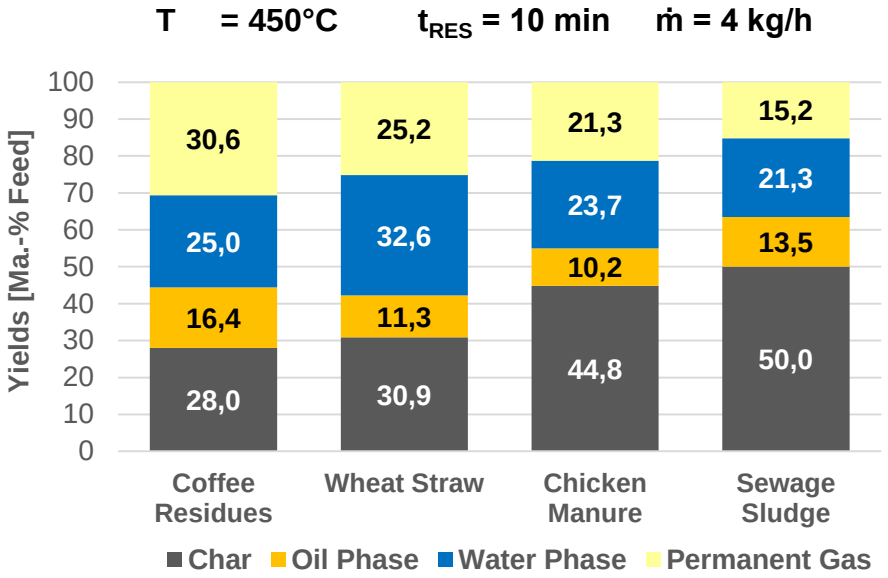
Sequential extraction and filtration

- Local balance → displacement of the filters along the screw reactor
- Multi-Step to One-Step → reduction of the drying process requirements

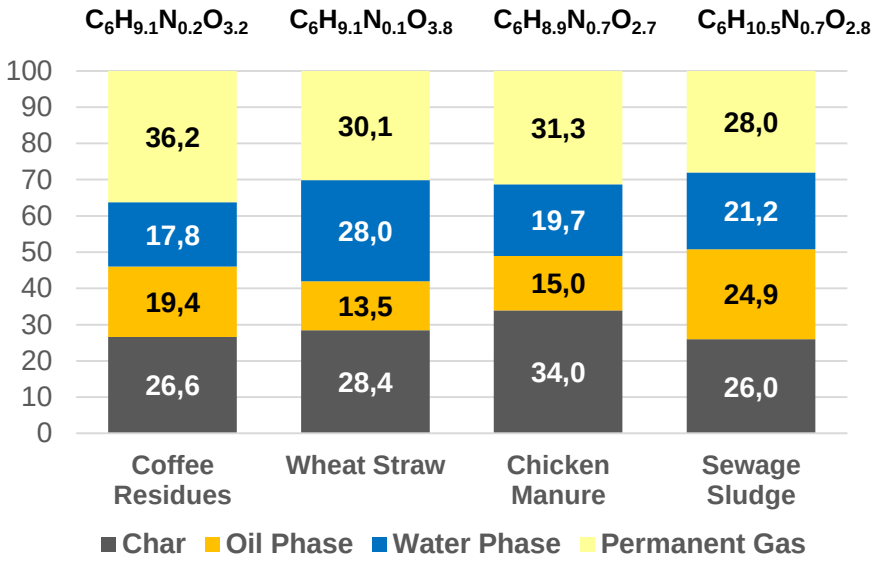
- Release of moisture water and CO_2 in the early stage
- Targeted extraction of low calorific species
- Concentration of acids and aldehydes in the extracted stream
- Increase of the heating value of the main stream



Low-grade biomass conversion
Balance and properties



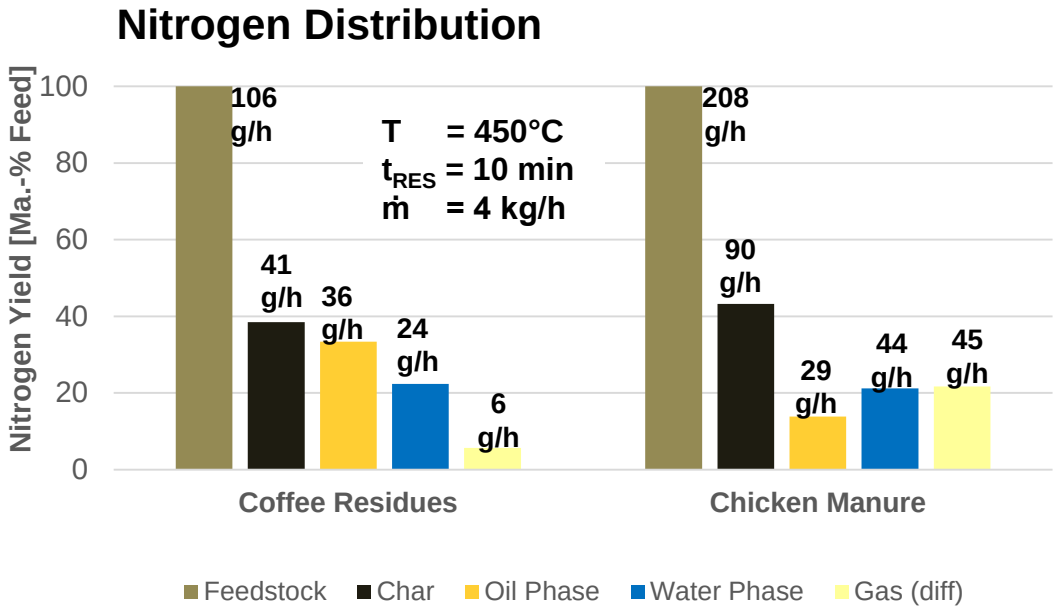
Mass Balance "as received"

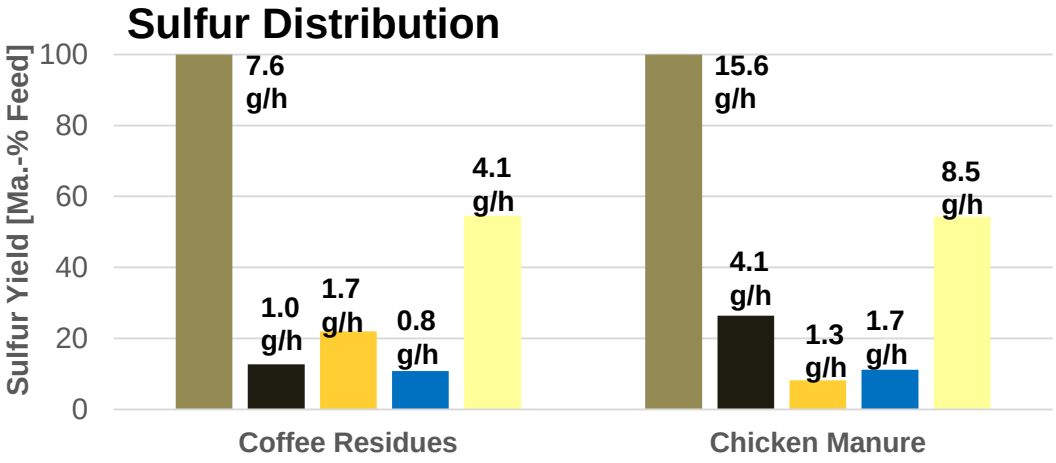


Mass Balance "dry ash free"

Material	Pyrolysis Oil				Pyrolysis Char				
	Average Formula	LHV [MJ/kg]	Water [Ma.-%]	pH Value	Average Formula	LHV [MJ/kg]	Ash [Ma.-%]	Sulfur [mg/kg]	Chlorine [mg/kg]
Coffee Residues	$C_6H_{8.2}N_{0.3}O_{0.4}$	27.9	9.8	9.5	$C_6H_{4.1}N_{0.2}O_{0.3}$	24.8	22.6	700	1400
Wheat Straw	$C_6H_{8.4}N_{0.1}O_{0.5}$	22.1	17.5	2.5	$C_6H_{3.5}N_{0.1}O_{0.6}$	24.1	21.3	1600	4100
Chicken Manure	$C_6H_9N_{0.6}O$	25.0	10.0	9.8	$C_6H_{3.7}N_{0.7}O_{0.4}$	14.0	49.8	2300	5800
Sewage Sludge	$C_6H_{11.4}N_{0.7}O_{1.4}$	26.9	22.6	9.6	$C_6H_{7.1}N_{0.7}O_1$	11.2	59.0	8500	253

Low-grade biomass conversion
Nitrogen / Sulfur distribution





- Ammonia and amines in the water phase
- Aromatic nitrogen species in the oil phase (pyrrole, indole)
- Water phase pH ≈ 9,5
- Nitrogen in char < 50 Ma.-%

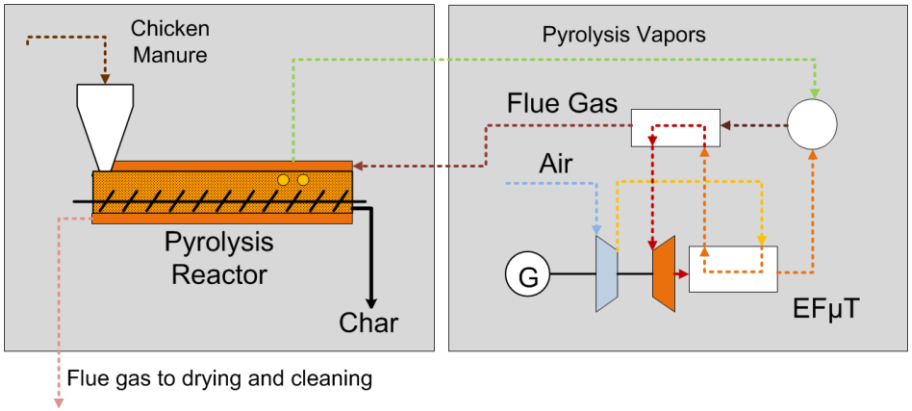
- Sulfur in permanent gas
  - H_2S
  - COS
  - SO_2
  - Mercaptans

  } ?
- Sulfur in char < 25 Ma.-%
- Aromatic sulfur species (Thiopenes) in the condensate

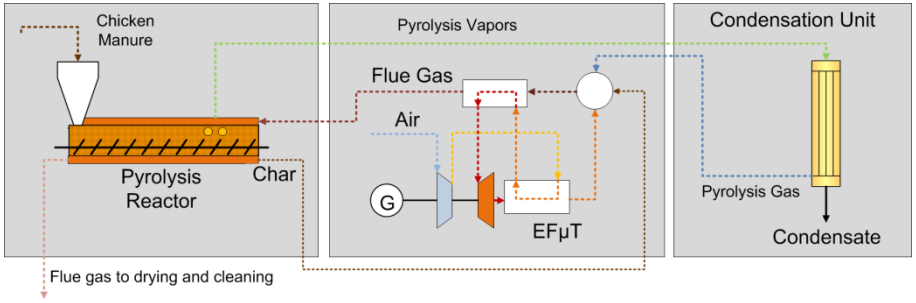
Potential of low-grade biomass
Decentral CHP and valuable products

- Decentral pyrolysis plant
  Capacity < 5 MW_{TH}
- Self-sustainability
  - No external heat / power
  - Internal use of pyrolysis products
  - Waste heat for drying process
- Fuel / Load flexibility
  - Seasonal / Blended feedstocks
  - Polygeneration
- Alternative: in-situ at the Biorefinery
  - Heat / power from the plant
  - Condensation
  - Direct post-processing of vapors

Option 1: Vapors Combustion



Option 2: Gas & Condensation



Potential of low-grade biomass
Decentral CHP and char

- Remediated solid
- High phosphorus content
- High potassium content
- Building-block for fertilizers
- Suitable for very acid soils

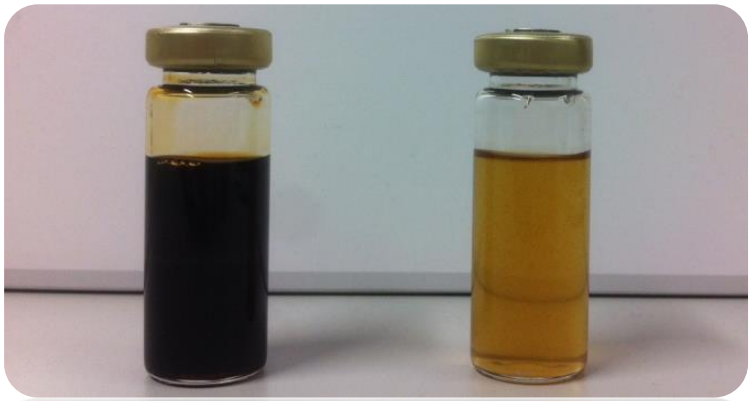
Feed Char 450°C

Plant Nutrients	Char 450°C	Availability [%]
pH	13	-
Potassium	58019 mg/kg	50,7
Phosphorus	29248 mg/kg	18,0

	Unit	Feed	Char
C	[%]	40,4	42,1
H	"	5,0	2,3
N	"	5,79	4,71
S	"	0,435	0,830
Cl	[mg/kg]	3420	3365
Ash (550°C)	[%]	24,20	47,87
Na_2O	[%-Ash]	1,50	1,49
MgO	"	5,0	5,2
Al_2O_3	"	1,5	1,4
SiO_2	"	6,6	6,9
P_2O_5	"	13,3	14,0
SO_3	"	3,7	2,6
Cl	"	-	1,19
K_2O	"	12,0	14,6
CaO	"	36,6	35,9
MnO	"	0,28	0,27
Fe_2O_3	"	-	0,90
ZnO	"	-	0,17

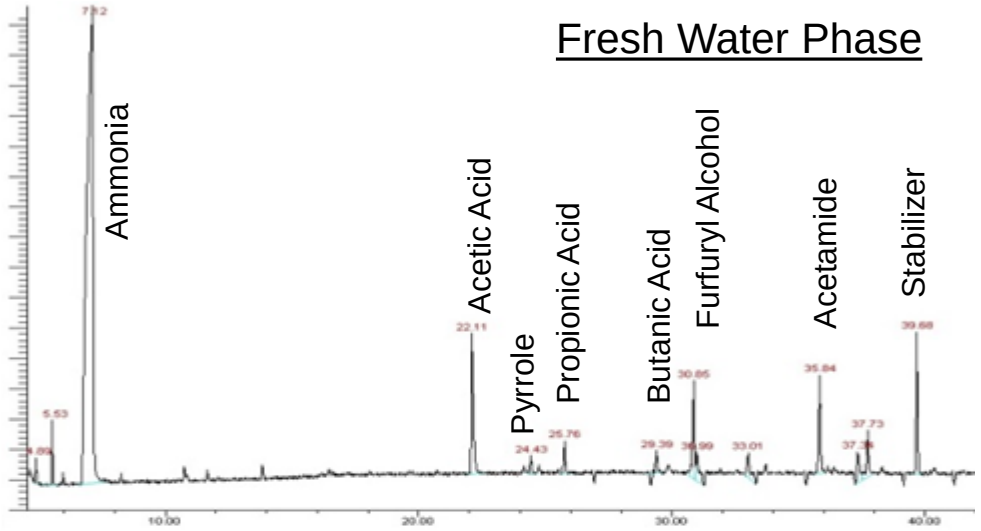
Potential of low-grade biomass
Distillation of chicken manure condensate

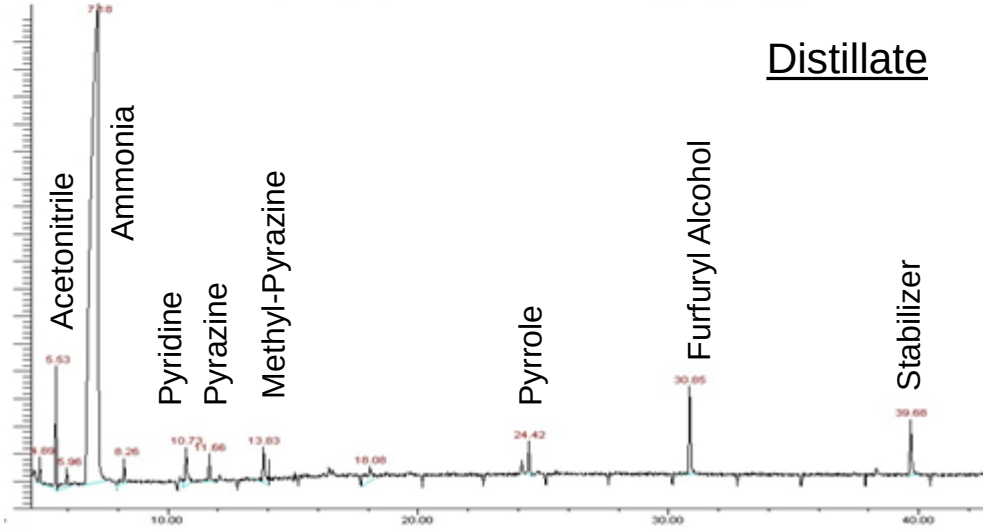
- Distillation of the water phase
  T = 130°C
  Distillate = 75 Ma.-%
- Concentration of the nitrogen species in the distillate
- Acids in the retentate



Fresh Water Phase

Distillate





Conclusion

- Low-grade biogenic feedstocks are difficult resources
- Pyrolysis is a suitable upgrading process
- STYX couples the advantages of screw reactors and hot gas filtration
- Background studies on pyrolysis at bench scale
- Production in technical relevant scale for reliable products characterizations
- Potential to reduce the costs of separated drying process
- Condensate products suitable for further upgrading in biorefineries
- Solid products suitable for co-firing / fertilizer building-block / activated carbon

Thank You for the kind attention

Contact:
Marco Tomasi Morgano

Phone: +49 721 608 22869
Email: marco.tomasimorgano@kit.edu

Karlsruhe Institute of Technology (KIT)
Institute for Technical Chemistry
Dept. Pretreatment and Gas Cleaning

Hermann-von-Helmholtz-Platz-1
76344 Eggenstein-Leopoldshafen (D)