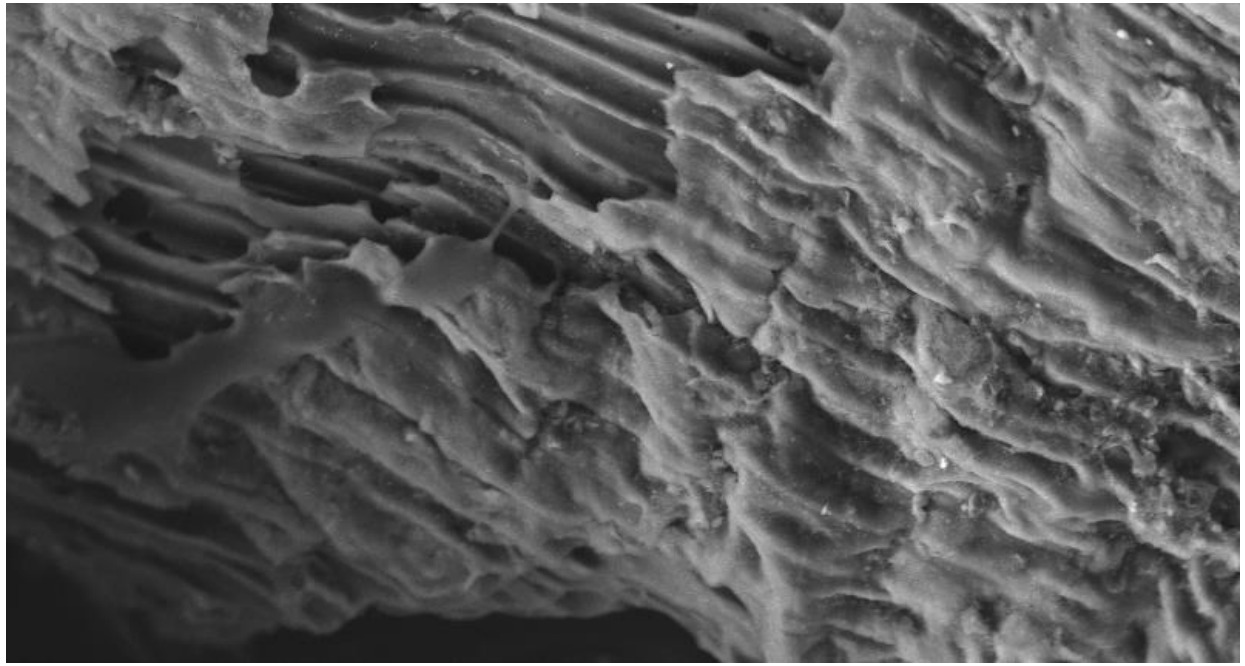
9-17-2019

Biochar - just a black matter is not enough!

Andreas Hornung

Fabian Stenzel

BIOCHAR –
JUST A BLACK MATTER IS NOT ENOUGH!



Prof. Dr. Andreas Hornung
Director of institute branch Fraunhofer UMSICHT
Sulzbach-Rosenberg, Germany

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General thoughts!

530 billion tonnes, 82 percent of all C in biomass (650 billion tonnes) on earth is stored in wood, the rain forest is storing as much as people burn in 10 years from various sources.

1/3 of world antropogenic CO_2 emissions are taken up every year by world wide forests.

But, CO_2 is also again released by natural processes

Carbon dioxide, naturaly captured in wood can be captured as carbon in char.

Feedstocks should show a wider range than wood only, residues from agriculture or sewage sludge and digestates as well as resdiues from modern processes producing ethanol from straw as well as macro algae

Capturing the carbon as a stabile bio-coal or charcoal as single product is just too expensive.

Side products are requried to close the bill.

Those products can be liquids, in best case fuels and green hydrogen.

What is biochar?
Definition

- Carbonaceous material
- Consists almost of carbon and ash (depends on feedstock
- oxygen an hydrogen were depleted
- Porous surface structure was formed
- Produced by thermochemical conversion with the absence of oxygen
- Derived from biomass
- Intent to be applied in soil
- Further application options are investigated too

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Feedstock
Any kind of biogenic material

Biowaste

Garden- and greenwaste

Digestate

Manure

Straw

Hay

(Residual) wood

Skins of citrus fruits

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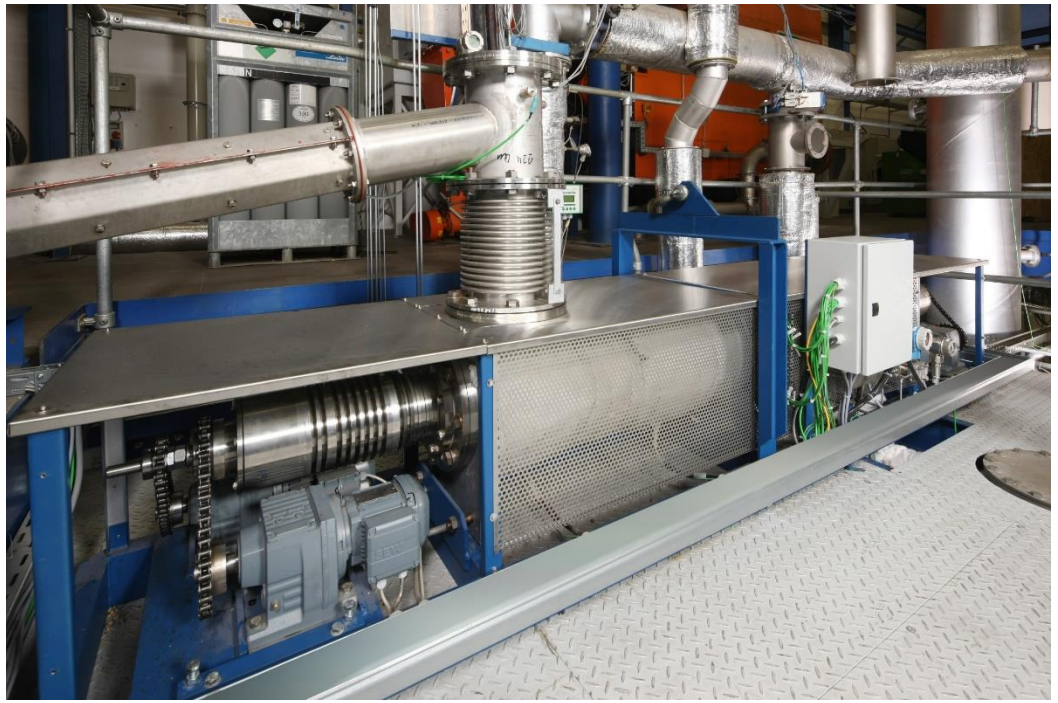
From charcoal to biochar
From history to modernity



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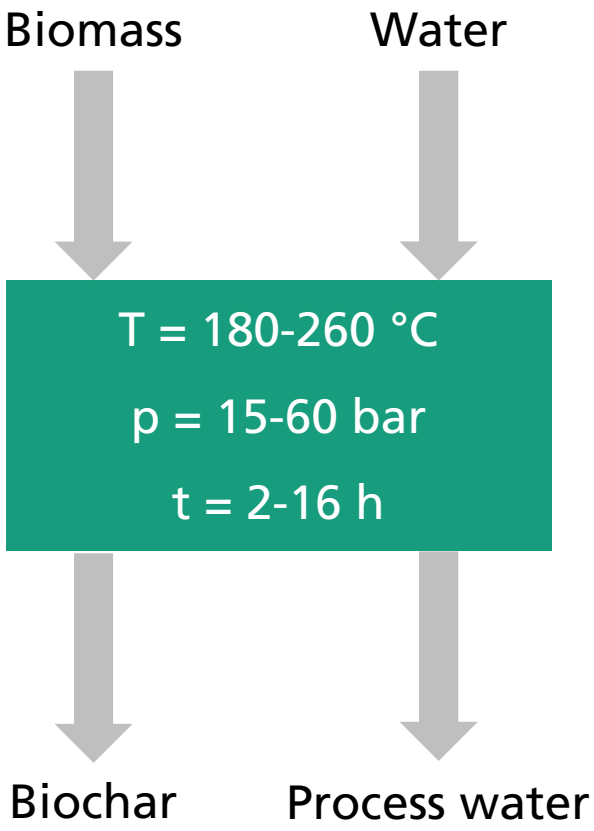
Processes
Hydrothermal Carbonisation (HTC)



- Feedstock biomass with high water content possible (no drying required)
- Biochar with high content of oxygen and hydrogen, but less PAH content
- Biochar has to be dried
- Large quantities of process water containing COD

SUNCOAL TerraNova energy

AVALON Industries ingelia

Avello Bioenergy

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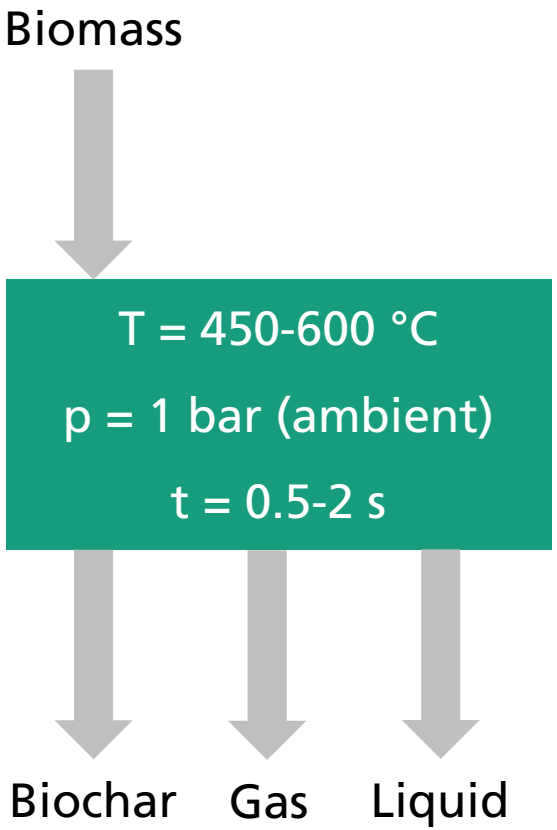
Processes
Fast pyrolysis



- Absolute dry and finely grounded feedstock is required
- Biochar with high content of oxygen and hydrogen
- High acidity of the oil as well as high water and oxygen content
- Lowest biochar yield compared to slow and intermediate pyloysis

btg biomass technology group

ENSYN

EMERGENT WASTE SOLUTIONS

KIT Karlsruher Institut für Technologie

Avello Bioenergy™

bioliq®

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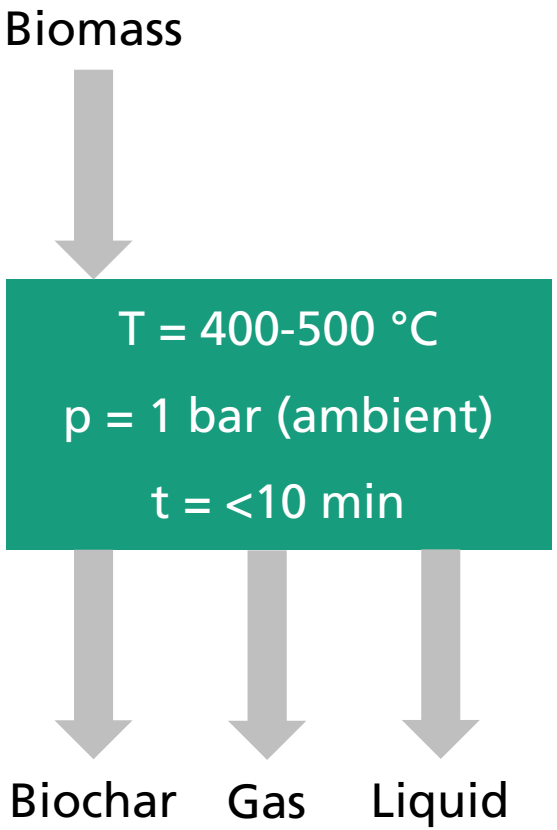
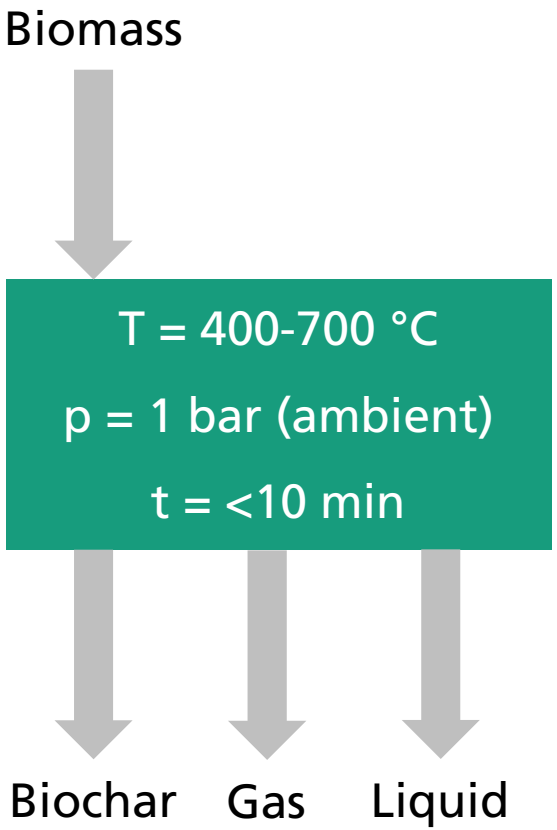
Processes
Intermediate pyrolysis



- Feedstock with a certain percentage of moisture is possible (up to 40%)
- Coarse, shredded, chopped or briquetted material
- Biochar with low content of oxygen and hydrogen
- Biochar yield is between slow and fast pyrolysis

Processes

Intermediate pyrolysis combined with post reforming (Thermo-Catalytic Reforming TCR®)



- Feedstock with a certain percentage of moisture is possible (up to 40%)
- Coarse, shredded, chopped or briquetted material
- Biochar with very low content of oxygen and hydrogen
- Almost free of PAHs
- Oil has very low acidity as well as in water and oxygen content
- Biochar yield is between slow and fast pyloysis

susteen
sustainable resources from waste

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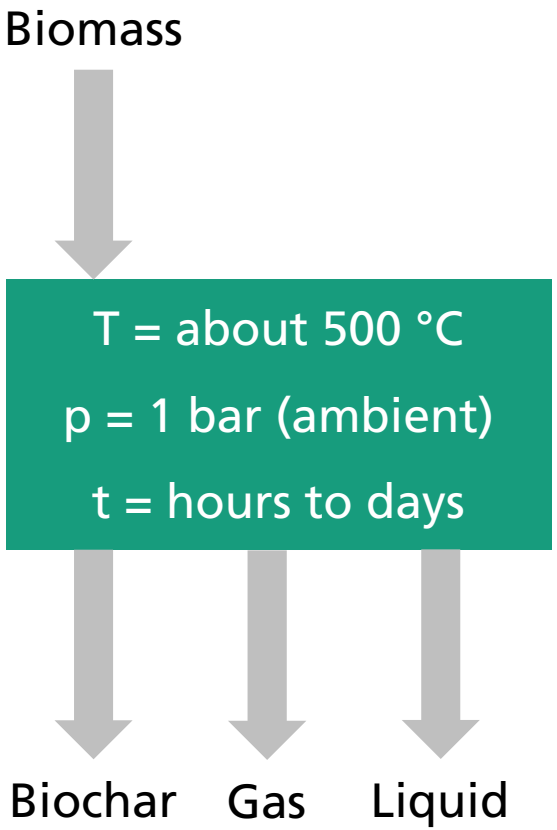
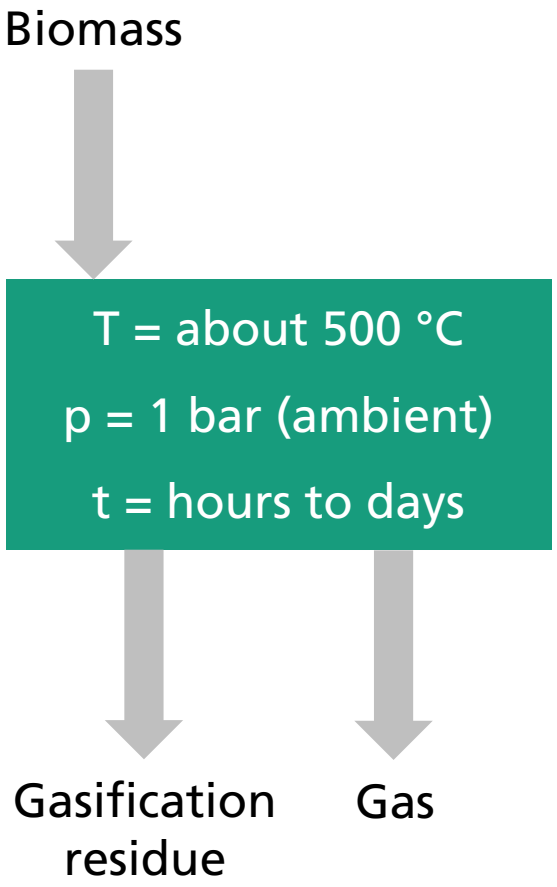
Processes
Slow pyrolysis



- Feedstock is shaped from briquette size to whole logs
- Usual process for charcoal production
- Pyrolysis vapors are almost used to heat the process
- Liquid products are acetic acid and alcohols
- Highest biochar yield compared to slow and intermediate pyloysis

Degussa process

Processes
Gasification



- Main product is the hydrogen and carbon monoxide rich gas
- Depending on gasification agent tar content can increase up to 100 g/m_N^3
- Process is optimized to reduce the carbon content in the solid gasification residue
- Gasification residue contains often higher concentration of PAHs (no biochar)

RENERGI

CHOREN *

TOTAL BioTFuel

Fulcrum BIOENERGY

*insolvent

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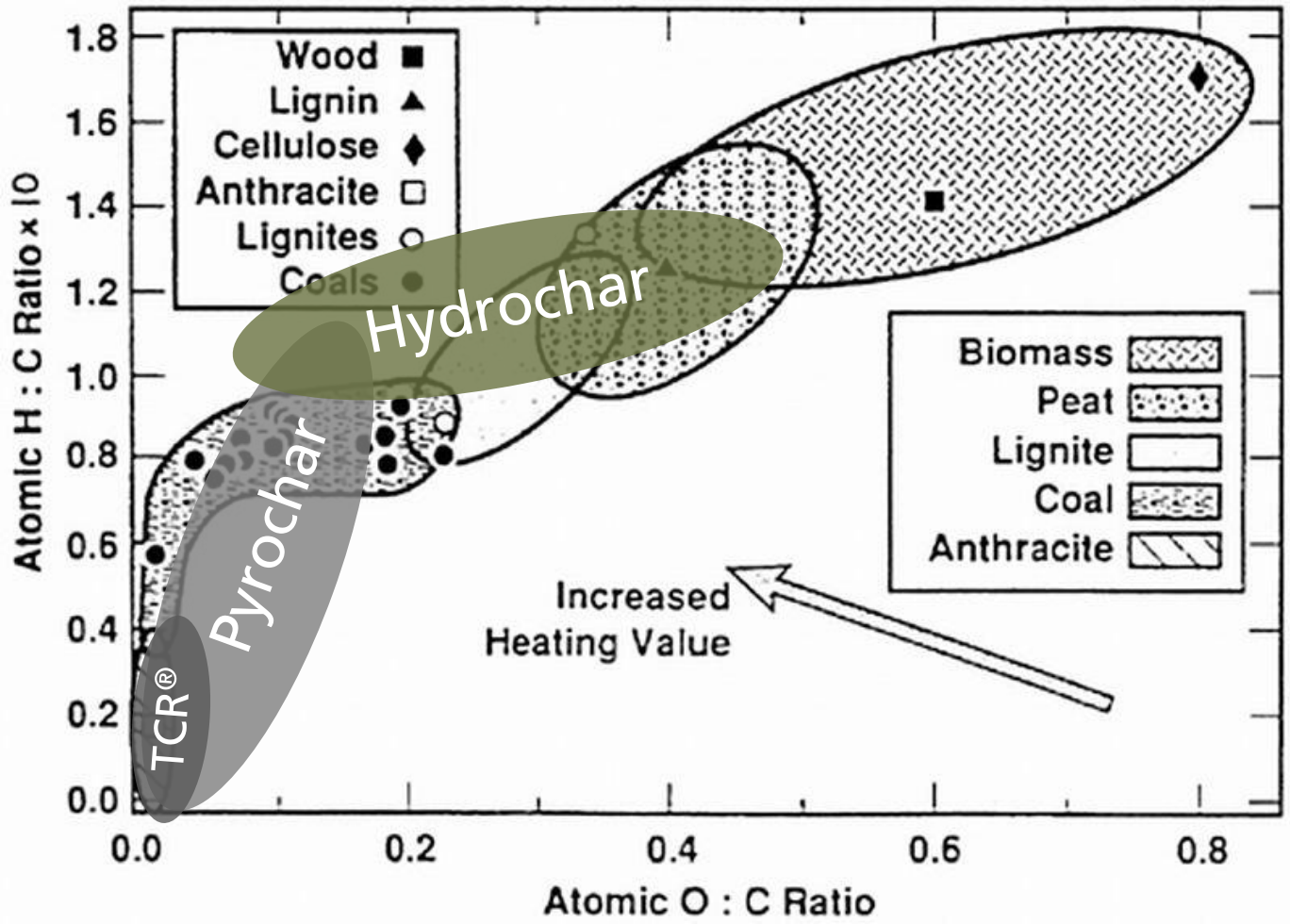
Properties
Degree of Carbonisation



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Properties
Contaminants – polyaromatic hydrocarbons (PAH)

- PAH formation during pyrolysis by two fundamental mechanisms
  1. Pyrosynthesis:
     gaseous hydrocarbon radicals generated >500 °C undergo reactions to form polyaromatic ring structures
  2. Low temperature formation:
     through condensation, carbonization and aromatization at <600 °C

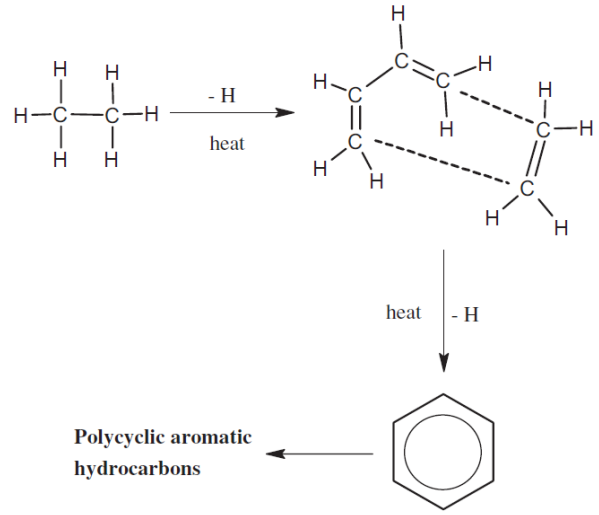

Fig. 2. Pyrosynthesis of PAHs starting with ethane.

- separation of gases from solids at high temperatures
- Controlled processes are needed

Source: IBI Biochar Course 2014

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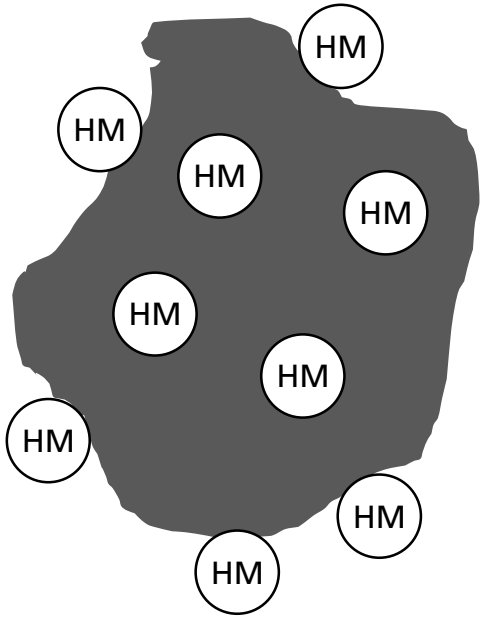
Properties
Contaminants – heavy metals

- More than 20 different kinds of heavy metals found in nature
- A few of them are toxic to human health (e.g. lead, cadmium, arsenic and mercury)
- Heavy metals are a part of the feedstock
- depending on the material different quantities are possible
  - Low quantities in biochar derived from wood
  - High quantities in biochar derived from sewage sludge
- Most of the heavy metals are concentrated during the conversion process
- Depending of process temperature some heavy metals are transferred into the gasphase, e.g. mercury
- Heavy metals are also found on the surface of biochar by adsorption effects



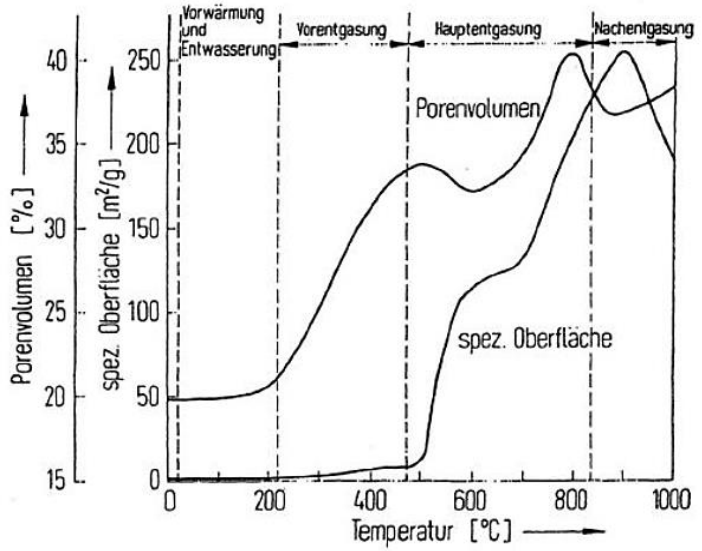
Properties
Surface structure

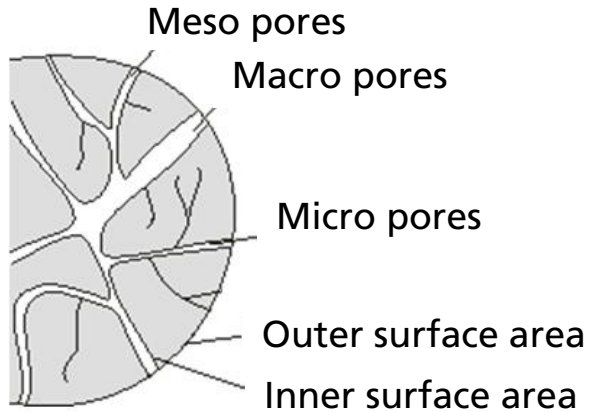
Influencing parameters for the quality of active carbon:

- Ash content (as low as possible)
- Volatile components (favorable between 8-15 %)
- Pyrolysis conditions (temperature)

Pore classification according to International Union of Pure and Applied Chemistry (IUPAC):

- Macro pores (dP > 50 nm)
- Meso pores (dP = 2-50 nm)
- Micro pores (dP < 2 nm)





Sources: **Benthaus, F. -** ***Rohstoff Kohle. Eigenschaft, Gewinnung, Veredelung 1978,*** Elke Heitling et.al. – Adsorbentien/Poren, www.chemgapedia.de (modified)

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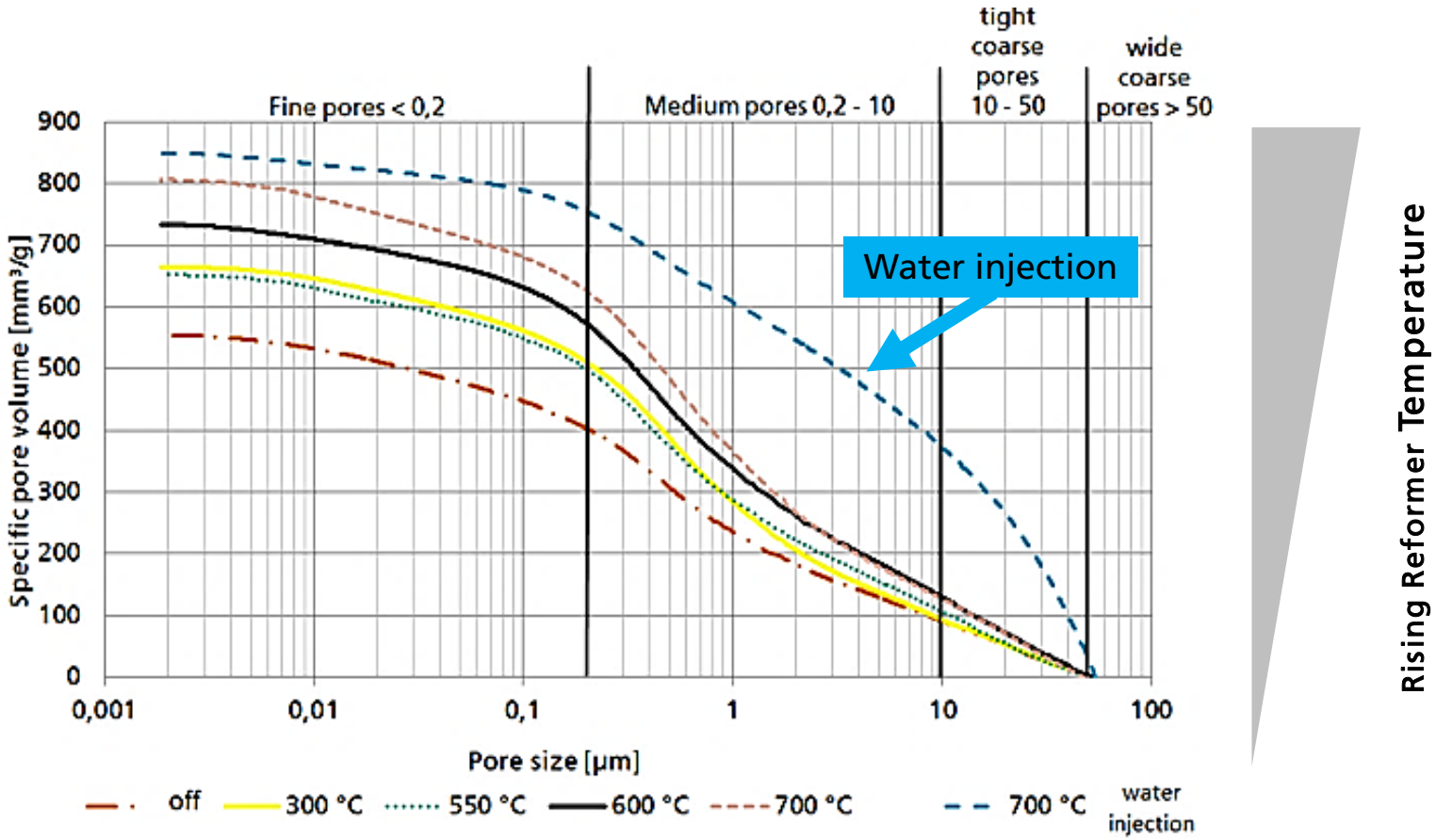
Modification examples
Pore size distribution



Pore size distribution of digestate TCR®-biochar by various reforming temperatures

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Application
Soil conditioner – legal regulation

- Regulations on European and country level
  - Biochar is not listed as a fertilizer product in the European fertilizer ordinance (amended in 2019)
  - Recycling products like biochar, ashes and struvite will be added by the end of 2019
- Restrictions in feedstock, e.g.
  - Germany: only untreated clean wood
  - Italy: agricultural residues (plant material)
- Requirements to nutrients content
- Limits for organic and inorganic pollutants

Application
Soil conditioner – International Biochar Initiative (IBI)

- IBI was formed in 2006, Philadelphia, PA.
- The vision: One billion t of biochar produced within 50 years.
- Standardized Product Definition and Product testing Guidelines for Biochar that is used in Soil are developed in 2015
- Requirements to biochar are defined to ensure the quality for use in soil
  - Test category A – basic utility properties
  - Test category B – toxicant assessment
  - Test category C – advanced analysis and soil enhancement properties
- Product classification:
  Class 1: >60%, Class 2: <60% and 30%, Class 3: <30 % (C_{org})
- After certification process is successfully passed, the IBI Certiefied™ biochar seal is valid for one year
- Implemented in United States and Canada only

Application
Soil conditioner – European Biochar Certificate (EBC)

- Certification is optional in Europe and mandatory in Switzerland
- Guidelines for the European Biochar Certificate from 2019
- Requirements to biochar are defined to ensure the quality for use in soil
  - Test category A – basic utility properties
  - Test category B – toxicant assessment
  - Test category C – advanced analysis and soil enhancement properties
- Guidelines also for production of biochar as feed additive
- Product classification: Basic, Premium and Fodder (different thresholds for pollutants)
- Only biomass from Europe can be used

Application
Soil conditioner – Australien New Zealand Biochar Initiative (ANZBI)

- ANZBI was formed in 2017, Murwillumbah, N.S.W.
- Australian Biochar for Soils Standard was developed in 2019 (draft version)
- Testing criteria quite similar to IBI standards
- Standard based on:
  - Australian Compost Standard AS4454-2012
  - European Biochar Certificate Guidelines 2019
  - IBI Standardized Product Definition and Product Testing Guidelines for Biochar that is used in Soil
- Product classification:
  - High Carbon Biochar (HCB) >70 % C_{org}
  - Medium Carbon Biochar (MCB) 50-70 % C_{org}
  - Low Carbon Biochar (LCB) 30-55 % C_{org}
  - Partially Combusted Organic Material (not biochar) <30 % C_{org}
- Developed for Australia and New Zealand

AUSTRALIA NEW ZEALAND
BIOCHAR INITIATIVE Inc. ANZBI

Application
Feed additive – Good Manufacturing Practice (GMP+)

- GMP+ is a Feed Safety Assurance (FSA) certification process
- The whole production chain needs to be GMP+ certified:
  feedstock → conversion → storage → transport
- There is an optional “Feed Responsibility Assurance” (GMP+ FRA) as additional sustainability certification
- Standards from existing initiatives are applied, e.g. Association Food without Genetic Engineering (VLOG e.V.)
- No feedstock restrictions by certification body
- all commercial chars certified by GMP+ and used as feed additive derived from untreated wood

Application
Activated carbon

- Requirements are listed in European standards, e.g.
  - EN 12903 – Powdered Activated Carbon
  - EN 12915 – Granular Activated Carbon
- Any carbon containing feedstock is possible, including coconut shells, wood, peat and coal
- Thresholds for water and ash content are applied
- For the application in water treatment, the content of water extractible substances (heavy metals and PAHs) is limited too



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Application
Market survey

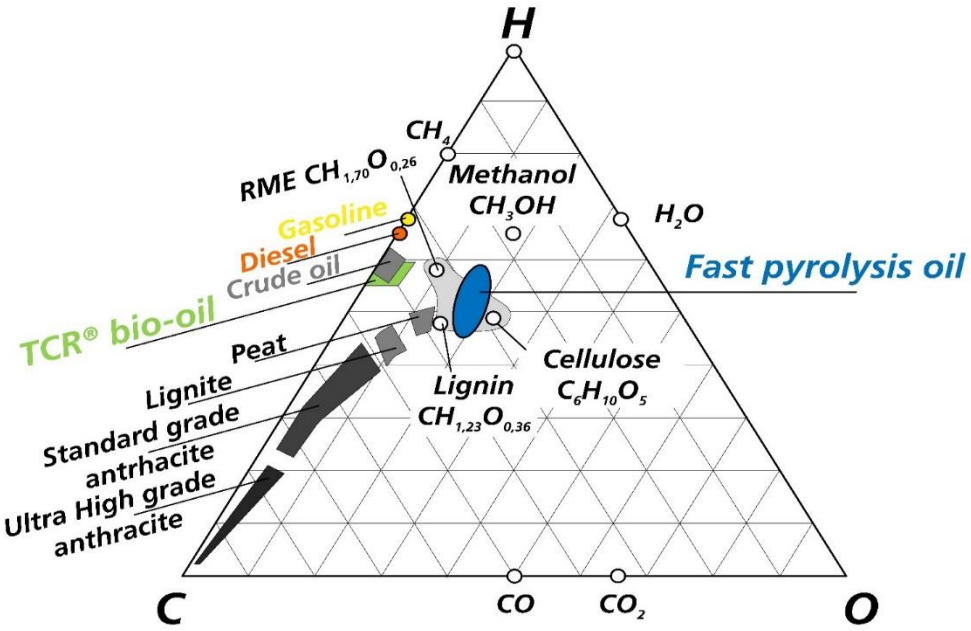
- Price for biochar as soil amendment ranges from 200-2,000 €/t depending on quality and market situation
- European market size in 2018 was 0.31 billion US$, forecast for 2023 is 0.59 billion US$
- Global market size in 2018 was 1.48 billion US$, forecast for 2025 is 3.82 billion US$

- Typical price for biochar as feed additive: 1,000 €/t, depending on quality and market situation the price ranges from 500-1,300 €/t

- Activated carbon is available on the market in a range from 700-1,800 €/t
- The total market value worldwide for activated carbon was estimated on 2.35 billion US$ in 2017

Sustainable transportation fuels by co-processing of TCR®-bio-oil in conventional petroleum refineries, production of hydrogen and biochar

- Comparable to crude oil
- High carbon content
- Low water content
- Low total acid number
- Miscible with fossile fuels and biofuels
- High heating value
- Anthracite char



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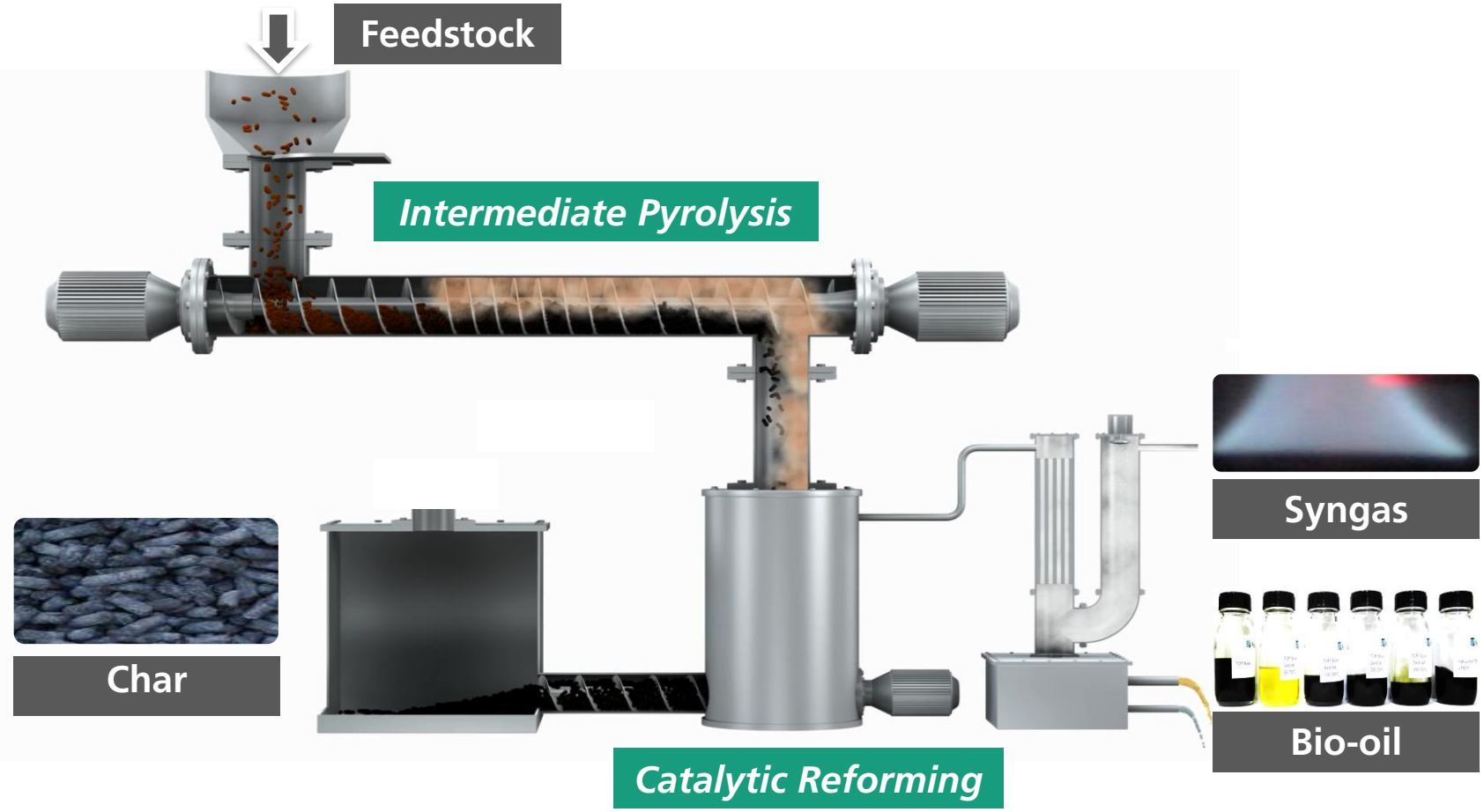
The Thermo-Catalytic Reforming (TCR®) technology



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High quality of all product fractions

BIO-OIL

High quality, engine-ready

- Miscible with common fuels
- Engine application also as blended fuel
- No tar issues
- High calorific value
- Low acid number

SYNGAS

Engine-ready gas

- Tar and dust free syngas
- Direct engine-ready
- adjustable hydrogen content
- practically free of aromatic-compounds

BIOCHAR

Transportable and storable biochar

- meets nutrient requirements and specifications of PK fertilisers
- High soil stability
- Very low H and O content
- High calorific value
- Significant ash content

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Conversion of Sewage Sludge
Analytics of educts and products

SEWAGE SLUDGE

C	26,2 m%
H	4,3 m%
N	3,7 m%
S	0,6 m%
O (Diff.)	27,3 m%
Ash	37,9 m%
H_2O	10,7 m%
LHV	12,2 MJ/kg

BIO-OIL

C	77,0 m%
H	7,08 m%
N	8,53 m%
S	1,02 m%
O (Diff.)	6,3 m%
TAN	4,45 mg KOH/g
LHV	33,8 MJ/kg

SYNGAS

H_2	39 v/v%
CO	10 v/v%
CO_2	22 v/v%
CH_4	8,7 ± 1 v/v%
C_xH_y	1,5 ± 1 v/v%
LHV	17,7 MJ/m³

CHAR

C	23,8 m%
H	0,7 m%
N	1,9 m%
S	0,7 m%
O (Diff.)	1,2 m%
Ash	74,1 m%
LHV	9,0 MJ/kg

EDUCT | **PRODUCTS**

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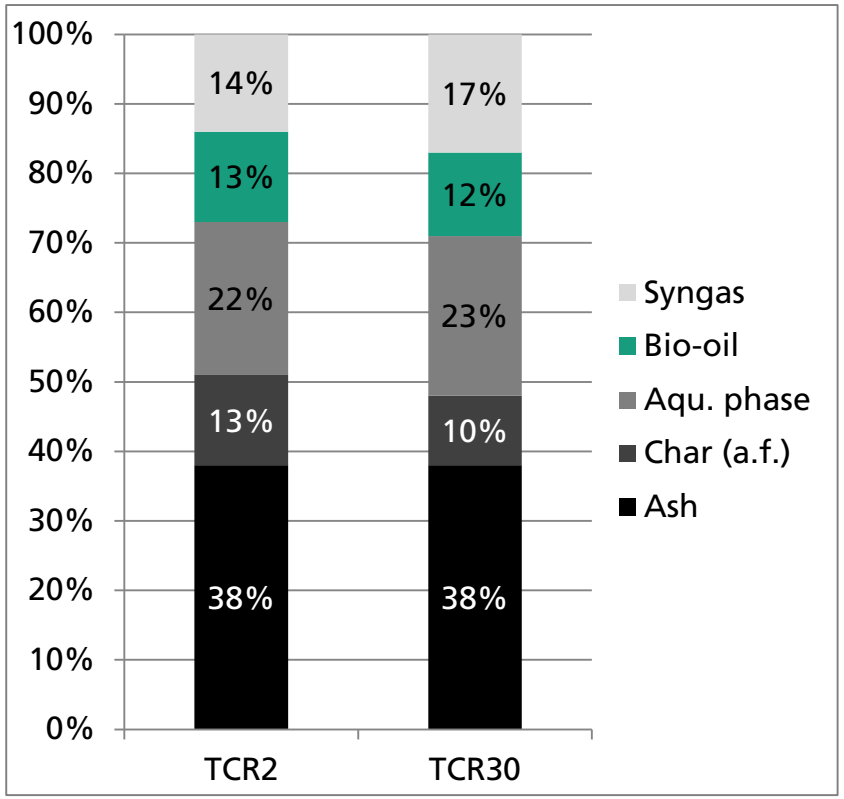
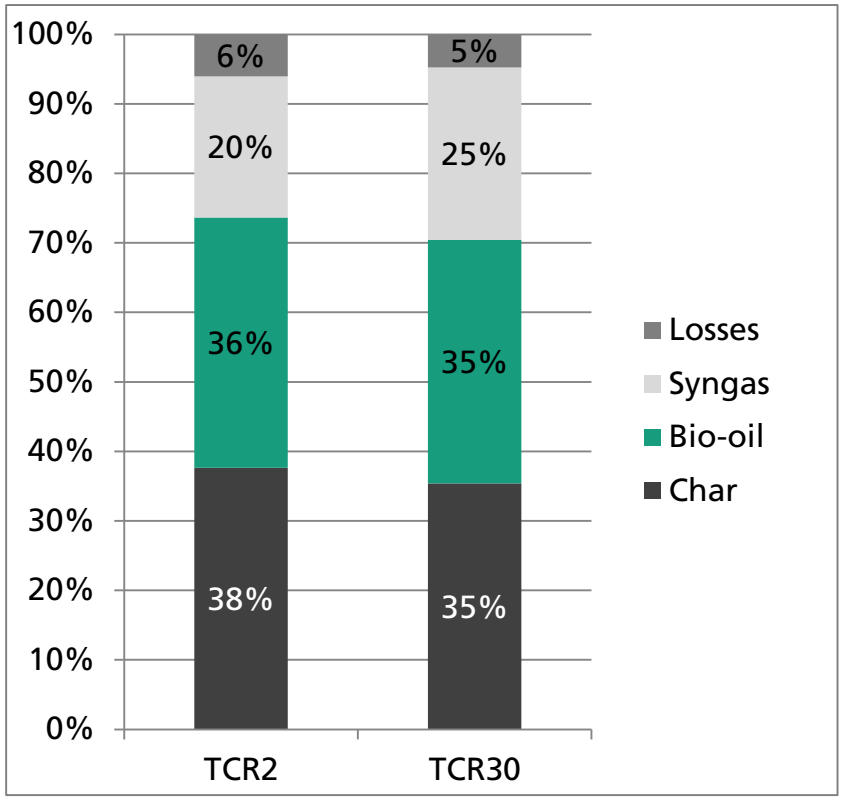
Thermo-Catalytic Reforming TCR®

Energy and Mass Balance (for sewage sludge)

MASS BALANCE



ENERGY BALANCE



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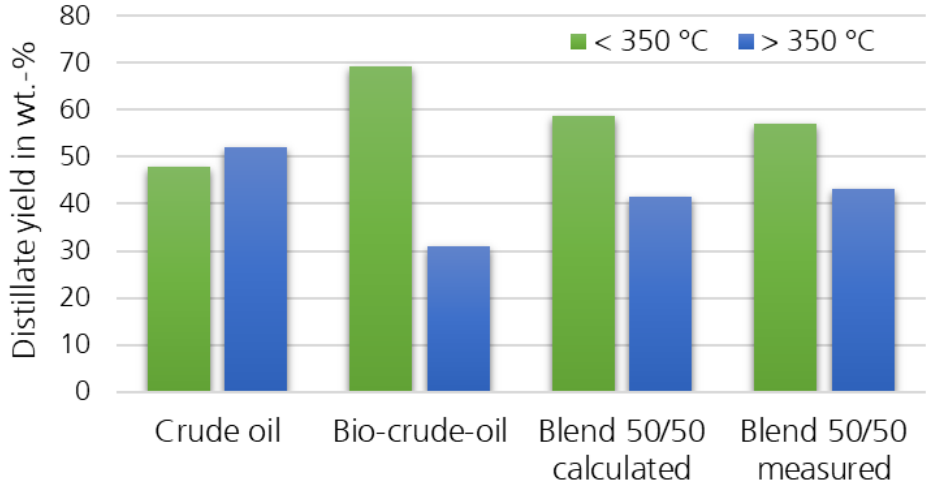
Sustainable transportation of fuels by co-processing of TCR®-bio-oil in conventional petroleum refineries

Distillation summary for crude oil and TCR®-bio-crude-oil

- More atmospheric distillable compounds in bio-oil than in the used crude oil
- Distillation results are comparable to calculated distributions (blend 50:50)
- Hydrotreatment removes 99.99 % of sulfur content
- No polymerization or coking during the upgrade



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Thermo-Catalytic Reforming TCR®

Level of development: 2017

Scale Up x10

TCR300

Demonstration

Operational capacity: 300 kg/h

Heat Source: flue gas

Purpose: scale-up, sludge treatment

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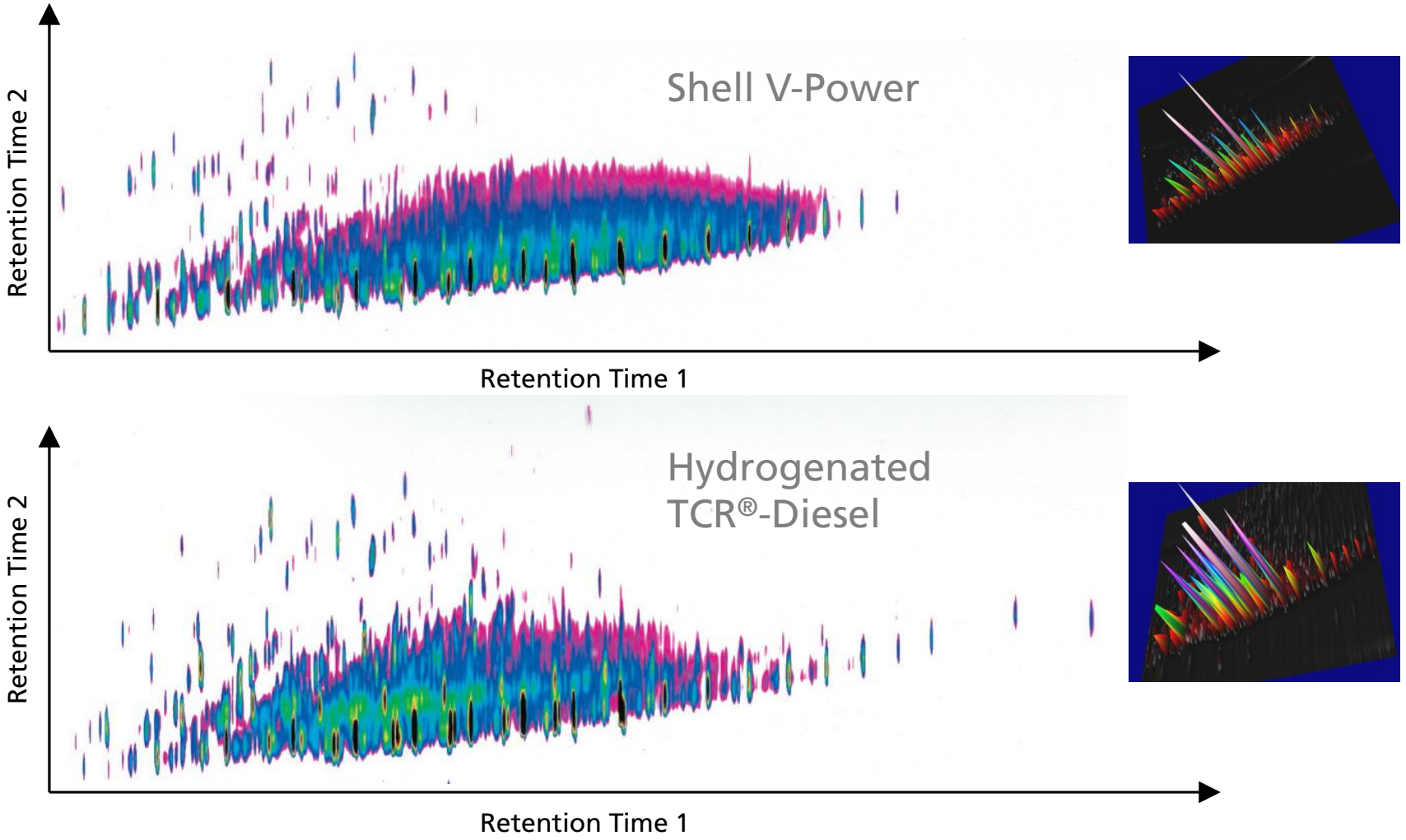
TCR®-Fuel

Spectra of Diesel: Shell V-Power vs. TCR®-Diesel



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Product application

Pre-commercial demonstrator within ToSynFuel-project

Former rally world champion **Walter Röhrl** at ground breaking ceremony

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Conversion – To-Syn-Fuel

Demonstration of Waste Biomass to Synthetic Fuels

2synfuel

Turning sewage sludge into fuels and hydrogen

Budget: 14,5 Mio. €

Partner:

ENGIE, LEITAT Technological Center, University of Birmingham, eni, Susteen Technologies GmbH, GrantG, etaflorence, VTS, HYGEAR, SNB

FlexJet:
Sustainable Jet Fuel from Flexible Waste Biomass

Start: May 2018 (Horizon 2020)
13 partners
13,4 Mio. € (10 Mio. € funding)
Content: TCR®500 for the production of **1.200 tons green jet fuel**

Europäische Kommission

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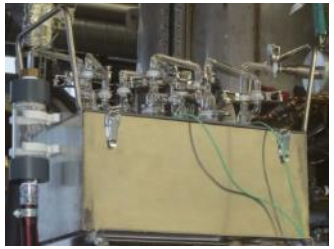
Thermochemical Gasification



Thermochemical Gasification

- Char from Sewage Sludge treated by TCR has been applied.
- No tar formation in up-draft gasification
- The phosphate rich ash stays as a powdeder.
- Plants can take up 80% of this phosphate without further treatment of the ash.

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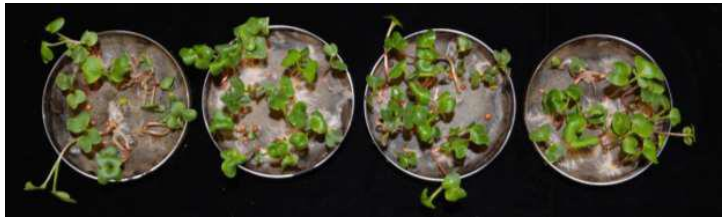
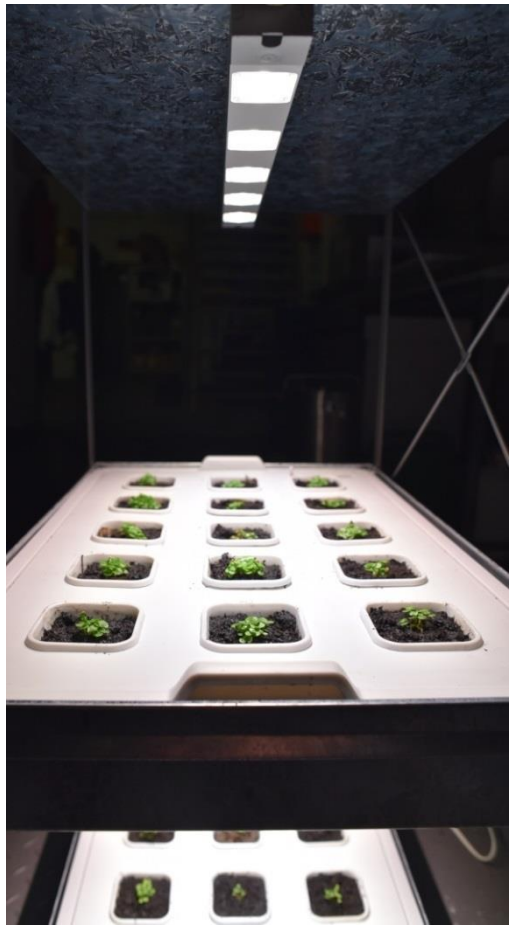
Application – Biochar/Ash



Germination test on biochar-based planting substrate

Sewage Sludge		Digestate		Brewer Spent Grain		Wood	
C	**22.2 wt.-%**	**C**	**64.0 wt.-%**	**C**	**72.6 wt.-%**	**C**	**89.8 wt.-%**
H	0.9 wt.-%	H	1.0 wt.-%	H	0.1 wt.-%	H	2,2 wt.-%
N	2.0 wt.-%	N	1.4 wt.-%	N	4.6 wt.-%	N	0.3 wt.-%
S	1.0 wt.-%	S	0.5 wt.-%	S	0.4 wt.-%	S	0.1 wt.-%
O	0.0 wt.-%	O	0.7 wt.-%	O	4.9 wt.-%	O	4.5 wt.-%
Ash	**74.4 wt.-%**	**Ash**	**32.0 wt.-%**	**Ash**	**17.5 wt.-%**	**Ash**	**3.1 wt.-%**
LHV 8.2 MJ/kg		LHV 23.0 MJ/kg		LHV 26.0 MJ/kg		LHV 34.4 MJ/kg	



Pot trials with lamb's lettuce and rocket

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Team in Sulzbach-Rosenberg

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BIOCHAR – JUST A BLACK MATTER IS NOT ENOUGH!

Thank You!

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