

Thermo-Catalytic Reforming of sewage sludge and hydrogenation of resulting TCR[®]-oil – A route to renewable chemicals and fuels



E-EUBCE: 28th European Biomass
Conference & Exhibition

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From solid waste Biomass to Bio-fuels

Analysis of the products – TCR[®]-oil



High quality,
engine-ready

LHV:
≈34 MJ/kg

C	76.6 wt. %
H	9.0 wt. %
N	7.3 wt. %
S	1.6 wt. %
O (diff.)	3.5 wt. %
H ₂ O	2.0 wt. %
TAN	0.6 mg KOH/g
Ash	< 0.005 wt. %

- Thermal stable
- Low in O;S;N
- Low water content
- High heating value



**Excellent
Precursor for
Hydrogenation**

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Analysis of the products – TCR[®]-gas



Engine-ready gas

HHV:
≈14-18 MJ/m³

H ₂	38 ± 3 v/v%
CO	8 ± 2 v/v%
CO ₂	30 ± 3 v/v%
CH ₄	14 ± 2 v/v%
C _x H _y	3 ± 1 v/v%

- Required hydrogen for the hydrogenation can be used from TCR[®]-gas
- No further hydrogen source is needed

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Product application – TCR[®]-oil and hydrogenated TCR[®]-oil

TCR[®]-oil

CHP Engine

Dual Fuel Engine (with Syngas)

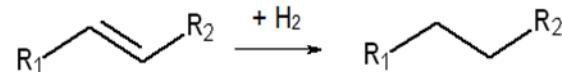
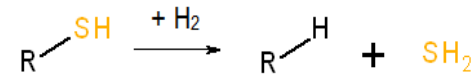
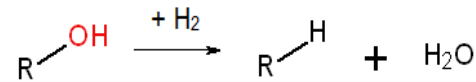
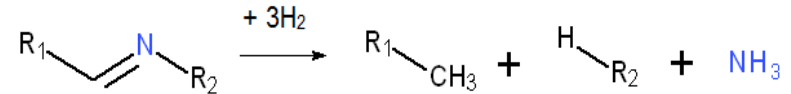
Fuel Blends



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Upgrading of TCR[®]-oil - Catalytic hydrogenation

- Removal of N, O, S, Water
 - C & H content increase
- Saturation of double bounds
- NiMo or CoMo on Al₂O₃
- T = 240 - 400°C
- p = 40 - 150 bar
- Hydrogen consumption: 34.4 mmol H₂/g_{oil}



From solid waste Biomass to Bio-fuels

Product application – TCR®-oil and hydrogenated TCR®-oil

TCR®-oil

CHP Engine

Dual Fuel Engine (with Syngas)

Fuel Blends



hydrogenated TCR®-oil

Green Diesel

Green crude Naphtha

Green Chemicals

ASG Analytik-Service
Gesellschaft

Prüfbericht : 2307169-1

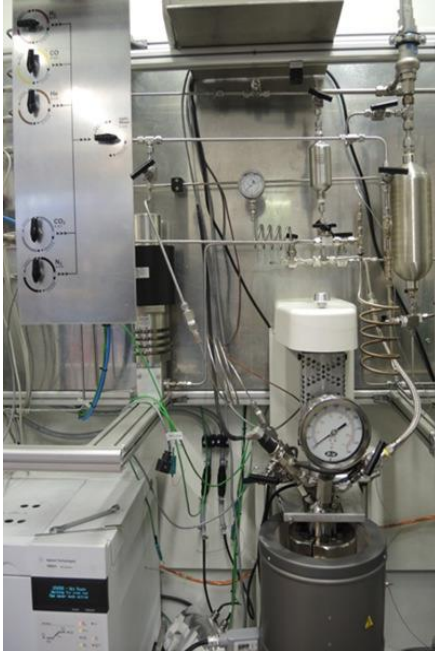
Prüfparameter	Prüfverfahren	Prüfergebnis	Grenzwert DIN EN ISO 2194:04	Einheit
Chemie (LPG)	ISO 2194:2016	800,0	800	kg/m ³
Dichte (15 °C)	DN EN ISO 2194	800,0	800	kg/m ³
Wassergehalt (KOH)	-	0,0	-	% (m/m)
Elementarische KW	-	0,0	-	% (m/m)
Chlorwasserstoff (KOH)	DN EN 12416	0,0	-	% (m/m)
Fluorwasserstoff (KOH)	-	0,0	-	% (m/m)
Schwefelgehalt	DN EN ISO 2194	0,0	10	mg/kg
Phosphorgehalt	DN EN ISO 2194	0,0	10	mg/kg
Metallbestandteil	DN EN ISO 2194	0,0	10	% (m/m)
Partikelgehalt	DN EN ISO 2194	0,0	100	mg/kg
Partikelgehalt (abgesaugt bei 100 °C)	DN EN ISO 2194-1	0,0	400	mg
Wassersäure (0,1 N)	DN EN ISO 2194	0,0	0,30	cm ³ /kg
Kohlensäuregehalt	DN EN ISO 2194	0,0	-	% (m/m)
Wassergehalt	DN EN ISO 2194	0,0	-	% (m/m)
Schwefelgehalt	DN EN ISO 2194	0,0	-	% (m/m)
Benzengehalt (HPL)	DN EN ISO 2194	0,0	-	% (m/m)
Ungekühlt (Total)	DN EN 116	0	0	°C
Chlorwasserstoff	DN EN ISO 2194	0,0	-	% (m/m)
Fluorwasserstoff	DN EN ISO 2194	0,0	-	% (m/m)
Metallbestandteil	DN EN ISO 2194	0,0	-	% (m/m)
Partikelgehalt	DN EN ISO 2194	0,0	-	% (m/m)
Partikelgehalt (abgesaugt bei 100 °C)	DN EN ISO 2194-1	0,0	-	% (m/m)
Wassersäure	DN EN ISO 2194	0,0	-	% (m/m)
Kohlensäure	DN EN ISO 2194	0,0	-	% (m/m)
Wassergehalt	DN EN ISO 2194	0,0	-	% (m/m)

Dr. Thomas Weismann
Dr. Thomas Weismann (Gesellschaftsleiter)



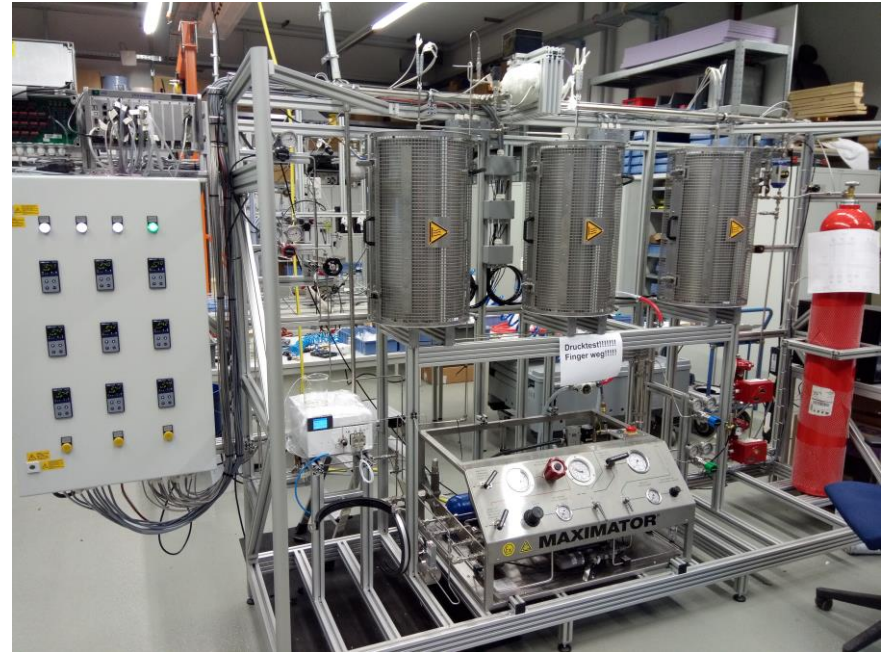
From solid waste Biomass to Bio-fuels

Hydrogenation plant – Batch and continuous plant



Batch-Reactor

- 500 ml reactor volume
- 30 ml sample volume



Continuous Reactor system

- 3 reactors with volume of 2.5 liter per reactor
- 3 kg/h feedstock input
- Gas recycling, GC online analysis

From solid waste Biomass to Bio-fuels

Analysis of TCR[®]-oil and hydrogenated TCR[®]-oil made of sewage sludge

TCR[®]-OIL



C	76.6 wt%
H	9.0 wt%
N	7.3 wt%
S	1.6 wt%
O (diff.)	3.5 wt%
H₂O	2.0 wt%
Ash	< 0.005 wt%

LHV	34.8 MJ/kg
TAN	4.2 mg KOH/g
Viscosity	9,1 mm ² /s
Density	960 kg/m ³

HYDROGENATION

HYDROGENATED TCR[®]-OIL



C	86.2 wt%
H	13.8 wt%
N	< 0.1 wt%
S	0.0015 wt%
O (diff.)	< 0.1 wt%
H₂O	0.0016 wt%
Ash	< 0.005 wt%

LHV	42.8 MJ/kg
TAN	< 0.1 mg KOH/g
Copper corr.	Grade 1
Flash point	< - 20 °C
Yield	~ 80 %

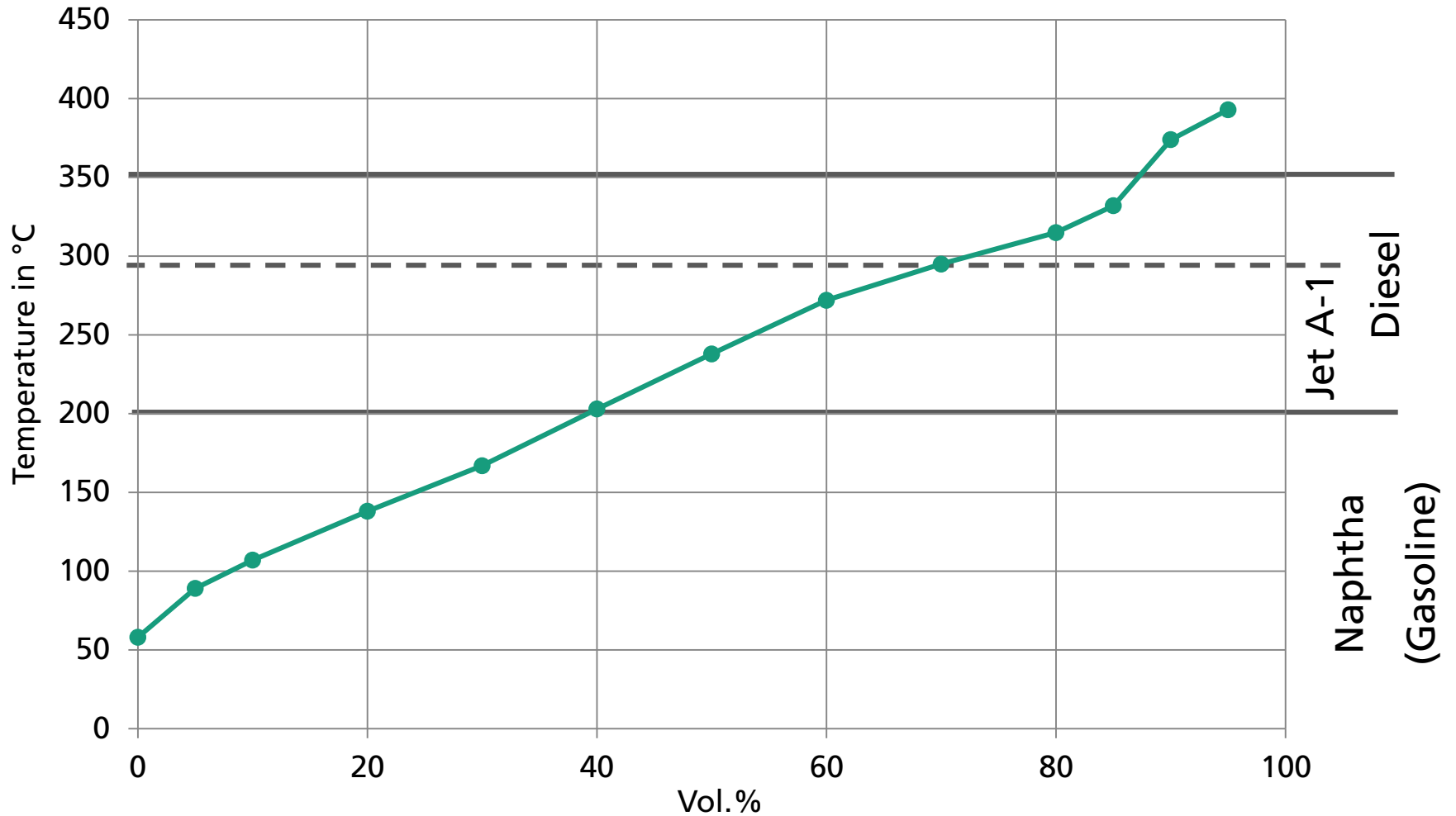
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GC-analysis off-gas of the hydrogenation step

Species	Amount	Units [vol.-% /ppm]
H ₂	96.01	vol.-%
NH ₃	2.1	vol.-%
H ₂ S	1.0	vol.-%
CO	0.01	vol.-%
CO ₂	0.01	vol.-%
C ₁ -C ₅	1.76	vol.-%

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Distillation of hydrogenated TCR[®]-oil sewage sludge



From solid waste Biomass to Bio-fuels

Comparison of the diesel fraction with EN 590

Test parameters	Test result	DIN EN 590 :2014	Unit
Cetane number (ICZ)	49,9 *	≥ 51	--
Cetane index (including density and distillation)	48,5	≥ 46	--
Density at 15 °C	824	820 - 845	kg/m ³
Polycyclic aromatic hydrocarbons	1,7	≤ 8,0	% (m/m)
Sulphur content	19,1 *	≤ 10,0	mg/kg
Flash point Pensky-Martens	69	> 55	°C
Coke residue (from 10% dest. residue)	< 0,10	≤ 0,30	% (m/m)
Ash content (775 °C)	< 0,001	≤ 0,01	% (m/m)
water content	101	≤ 200	mg/kg
Total Pollution	< 12	≤ 24	mg/kg
Corrosion effect on copper (3 h, 50 °C)	1	1	Korr.Grad
Fatty acid methyl ester content	< 0,1	≤ 7,0	% (V/V)
Oxidation stability (DIN EN ISO 12156-1 :2016)	5	≤ 25	g/m ³
Oxidation stability (DIN EN 15751 :2014)	> 48	≥ 20	h
HFRR (lubricity) at 60 °C	320	≤ 460	µm
Kinematic viscosity at 40 °C	1,861 *	2,00 - 4,50	mm ² /s
% (V/V) collected at 250 °C	66,7 *	≤ 65	% (V/V)
% (V/V) collected at 350 °C	> 98	≥ 85	% (V/V)
95 % (V/V) collected from	295,9	≤ 360	°C
CFPP / melting point (16.11-28.02)	-28	-20	°C
CFPP / melting point (01.10-15.11)	-28	-10	°C
CFPP / melting point (15.04-30.09)	-28	0	°C
Manganese content	< 0,5	≤ 2	mg/l
* Achievable by an adjustment of the hydrogenation			

From solid waste Biomass to Bio-fuels

Comparison of the crude gasoline fraction with EN 228

Test parameters	Test result	DIN EN 228 :2014	Unit
ROZ	61 *	≥ 95	--
MOZ	< 60 *	≥ 85	--
Lead content	--	≤ 5,0	mg/kg
Density [15 °C]	772,9	720,0 - 775,0	kg/m³
sulfur content	5,5	≤ 10,0	mg/kg
Manganese	< 0,5	≤ 2,0	mg/l
Oxidation stability	> 360	≥ 360	min
Evaporation residue	< 0,5	≤ 5,0	mg/100 ml
Corrosion effect on copper	1	Klasse 1	Korr.Grad
Olefin content	0,54	≤ 18,0	% (V/V)
aromatics content	21,66	≤ 35,0	% (V/V)
benzene content	0,52	≤ 1,0	% (V/V)
Total oxygen OK	< 0,01	≤ 2,7	% (m/m)
methanol	< 0,01	≤ 3,0	% (V/V)
ethanol	< 0,01	≤ 5,0	% (V/V)
Isopropanol	< 0,01	up to max. 2.7% (m/m) Total oxygen content	% (V/V)
isobutanol	< 0,01		% (V/V)
tert-butanol	< 0,01		% (V/V)
ether (≥ 5 C-Atoms)	< 0,01		% (V/V)
Other oxygenated compounds	< 0,01		% (V/V)
Vapour pressure DVPE	9,3		45/60 - 60/90
Start of distillation	94,3	--	°C
Evaporated quantity at 70 °C	0 **	20/22 - 48/50	% (V/V)
Evaporated quantity at 100 °C	0,8 **	46/46 - 71/71	% (V/V)
Evaporated quantity at 150 °C	84,7	≥ 75/75	% (V/V)
Boiling end point	190,5	≤ 210,0	°C
Distillation residue	1	≤ 2,0	% (V/V)

* Achievable by further Catalytic reforming during the refinery process
 ** Lack of light boilers due to laboratory distillation without cryocooler

Conclusion

- Crude TCR[®]-oil highlights
 - Thermally stable (atmospheric distillation)
 - Directly suitable for hydrogenation
 - Required hydrogen can be used from TCR[®]-gas

- Hydrogenation highlights
 - Renewable chemicals extractable
 - Renewable crude gasoline and diesel (EN 590)
 - TCR[®] / Hydrogenation demonstration EU-project: To-Syn-Fuel



Thermo-Catalytic Reforming of sewage sludge and hydrogenation of resulting TCR[®]-oils – A route to renewable chemicals and fuels

Thank you for your Attention

Contact

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