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slides prepared by Miloud Ouadi

Hydrogen Production from Waste Biomass

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1. Biomass Basics

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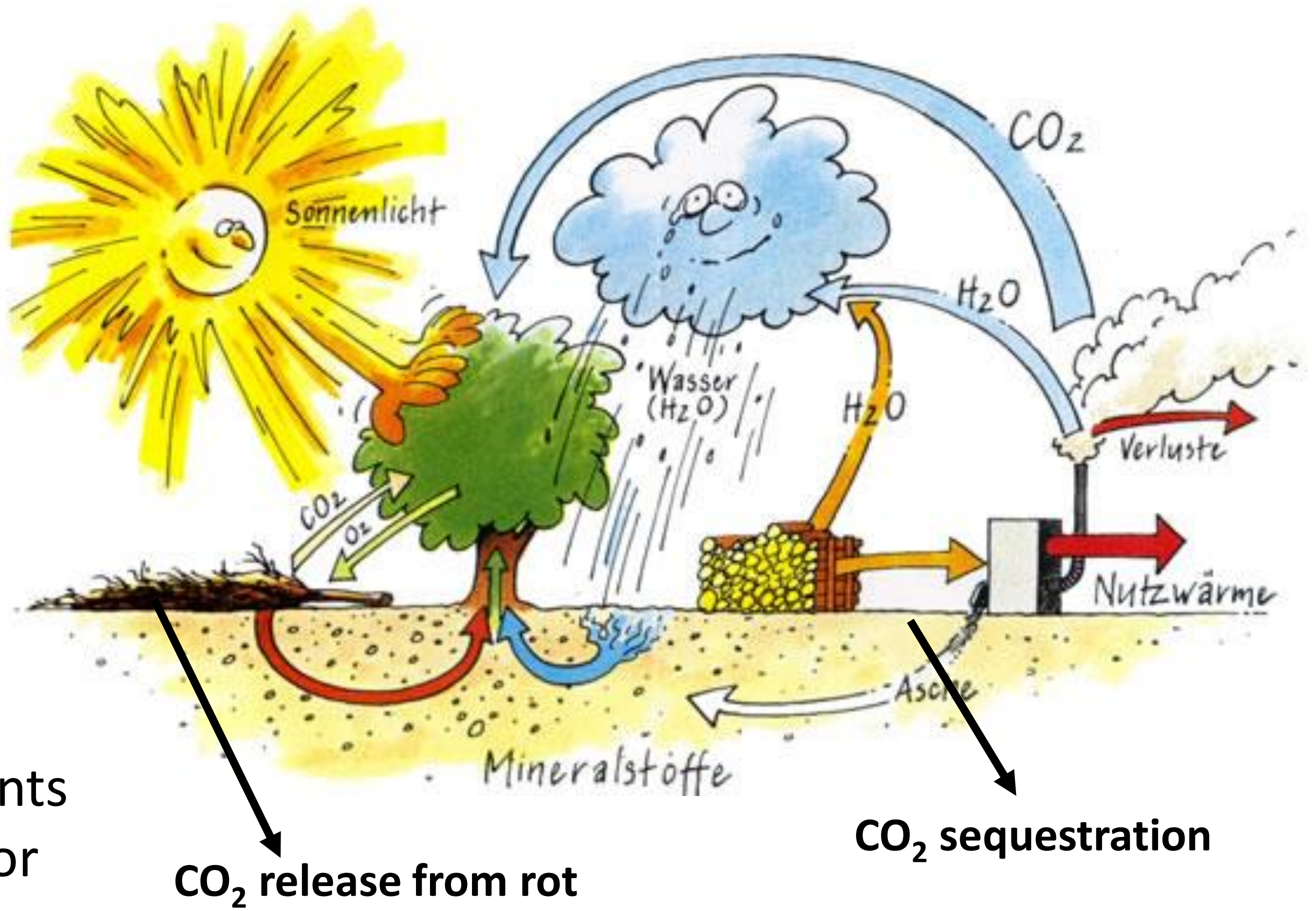
Natural CO_2 Recycling



- Biomass is:

  a renewable energy source

  produced from metabolic activities of plants and animals (biological material) and/or products of their decomposition or conversion

  household and commercial wastes may also in some cases be considered as ‚biomass'

Biomass Sources

UK has abundance of raw materials for biomass fuels production

It come from a large number of different sources and wide variety of forms

1. Virgin wood
2. Energy crops
3. Agricultural residues
4. Food waste
5. Industrial waste and co-products

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Drax Power Station, UK

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- supplies 6% of the UK's electricity needs
- including 11% of UK’s renewable power (14 TWh)
- four of six generators run on wood pellets,
- 20 train loads of wood pellets arrive at the Drax plant every day, most of them from the United States.

- The United Kingdom is the largest importer of wood pellets in the world (46%). In 2021, the UK imported over nine million metric tons of such products.
- the wood-burning Drax power station is the UK's largest source of CO_2 emissions at 12.1 million tonnes in 2022.

source
http://biomassmagazine.com/
https://bioenergyinternational.com/

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Hydrogen Pathways	Advantages	Disadvantages
Steam Methane Reforming / Pyrolysis $CH_4 + H_2O \rightarrow CO + 3H_2$	• Commercial, • widely used • low cost	• H_2 sustainable only if biomethane is used • GHG emissions from fossil CH_4 • CH_4 better fuel in its own right • Carbon must be captured at source
Electrolysis of Water $2H_2O$ + electricity $\rightarrow 2H_2 + O_2$	• Commercial • No GHG emissions providing green electricity is used	• High energy input • High capital cost
Biomass Gasification / Pyrolysis Reforming $C_nH_y + H_2O \rightarrow$ Syngas $(CO + H_2 + CO_2 + C_nH_y)$	• Commercial • Utilises renewable biomass as feedstock • No external electricity required	• Requires biomass drying • H_2 requires separation from syngas • requires gas purification steps • High capital cost
Ammonia Cracking $NH_3 \rightarrow N_2 + H_2$	• Commercial • Effective H_2 carrier in liquid form • High purity H_2 produced • Low energy consumption	• Requires a green source of H_2 for NH_3 production • NH_3 valuable as fertiliser (high price) • Gas separation required • NH_3 synthesis is energy intensive
Alkali Earth Metals/Water Reactions $2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2$	• Unexploited technology • No energy required • No emissions • Low cost • Utilises waste metals effectively	• Oxide layer can inhibit reactions • Residues require further recovery/utilisation • Catalyst NaOH/KOH consumption

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Biomass conversion chain

Biomass resources	*Supply systems*	*Conversion*	*End products*
Oil bearing plants	Harvesting,	Chemical (transesterification)	Transportation fuels (biodiesel, bioethanol)
Agricultural crops and residues	collection,	Physical chemical (extraction)	Solid fuels (wood pellets, charcoal)
Woody biomass	handling,	Biochemical (fermentation)	Heat Electricity
Industrial and municipal waste	and storage	Thermochemical (gasification)	High added-value chemicals (pharmaceuticals, polymers)

byproducts

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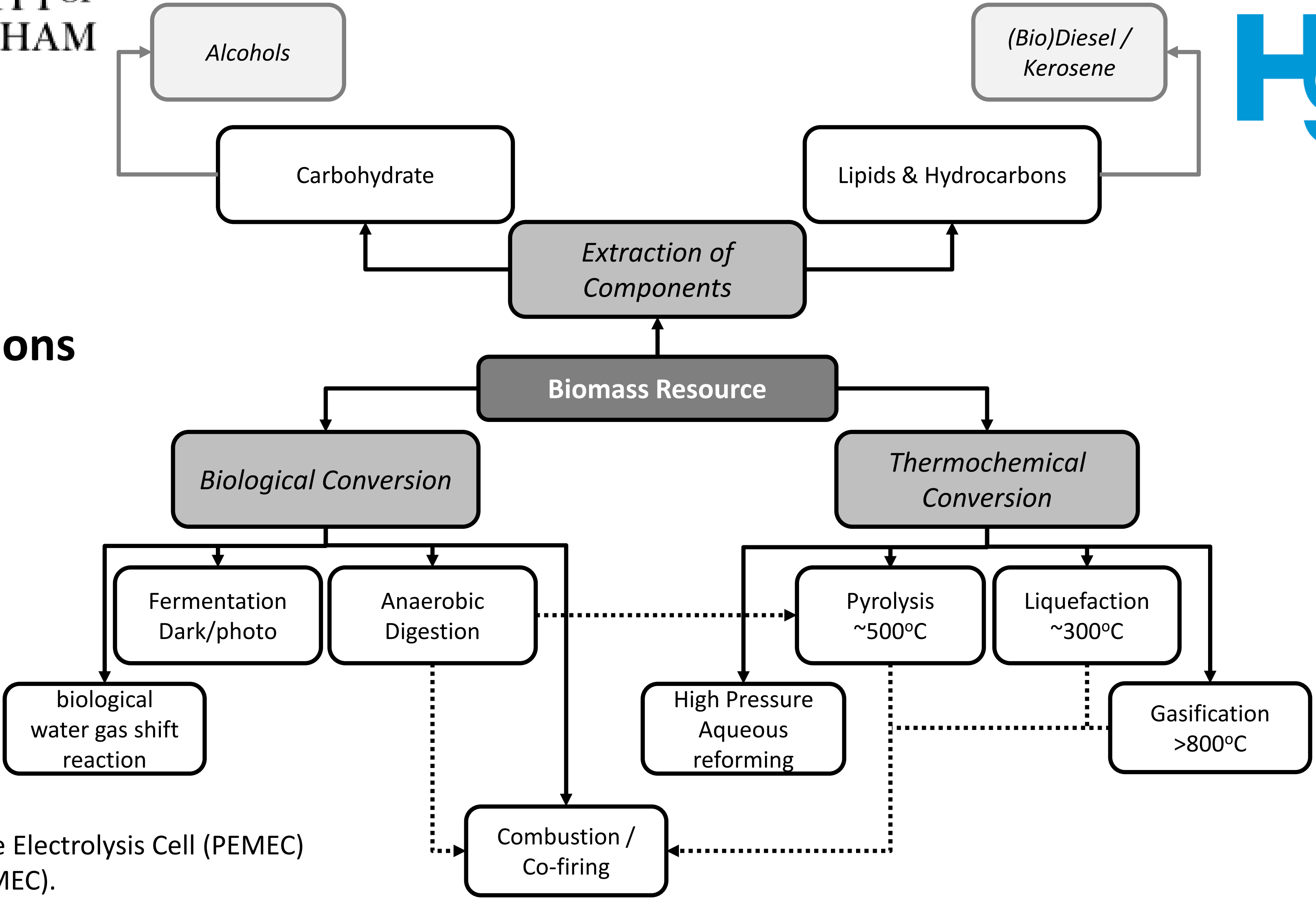
Biomass conversion options



Electrochemical conversion
- Proton Exchange Membrane Electrolysis Cell (PEMEC)
- Microbial Electrolysis Cell (MEC).

source: PhD Sophie Archer

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2. Gasification

Gasification

Conversion of biomass into carbon- and hydrogen-rich fuel gases (carbon monoxide, hydrogen, methane)

Products of gasification :

- ✓ Hydrocarbon gases (also called syngas)
- ✓ Hydrocarbon liquids (oils)
- ✓ Char (carbon black and ash)

$$Biomass + Air \rightarrow N_2 + CO + H_2 + CO_2 + CH_4 + H_2O + LHC + Tar + Char$$

$$Biomass + Steam \rightarrow H_2 + CO + CO_2 + CH_4 + HC + Tar + Char$$

Syngas is primarily carbon monoxide and hydrogen (more than 85 percent by volume) and smaller quantities of carbon dioxide and methane

Types of Gasifiers

- Updraft Gasifier
- Downdraft Gasifier
- Twin-fire (two-stage) Gasifier
- Circulating Bed Gasifiers

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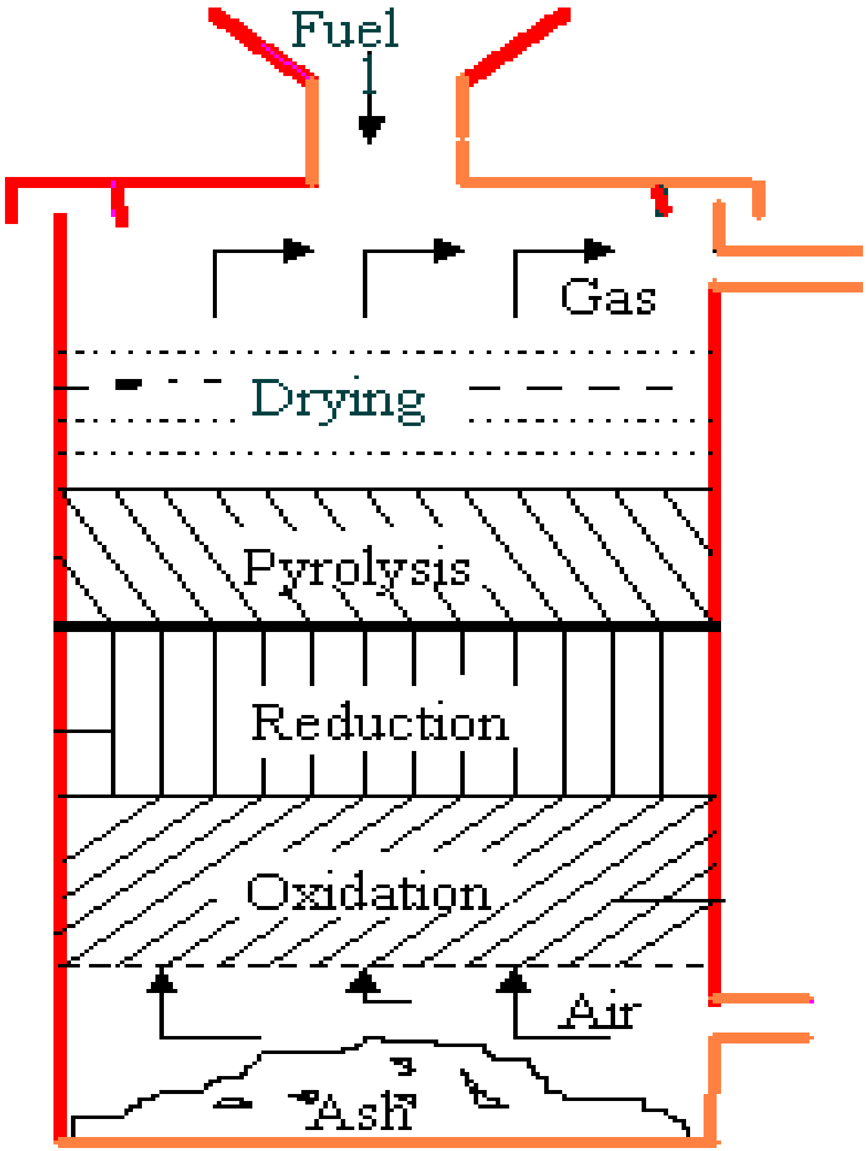
Updraft Gasifier



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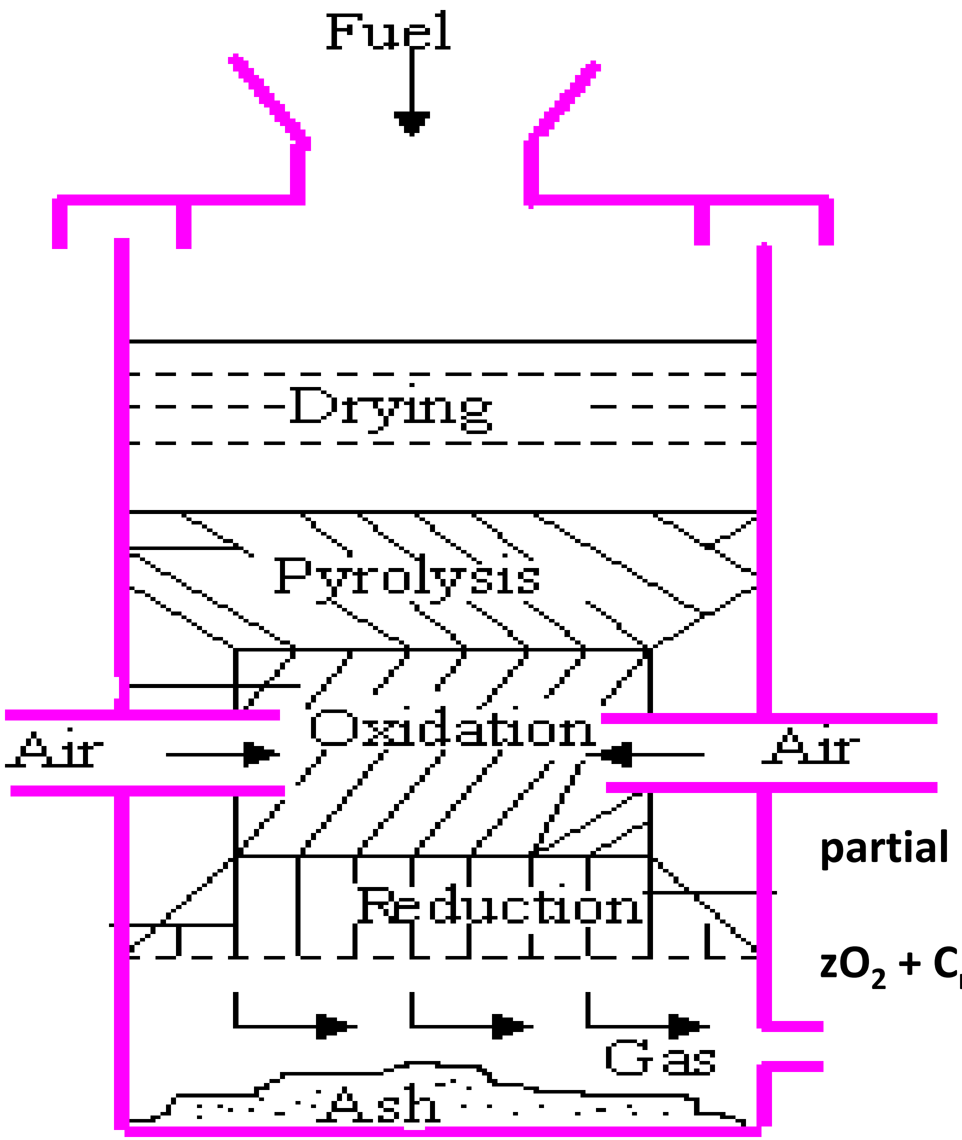
Downdraft Gasifier



partial oxidation

$$zO_2 + C_nH_m \rightarrow CO + H_2 + xxx$$

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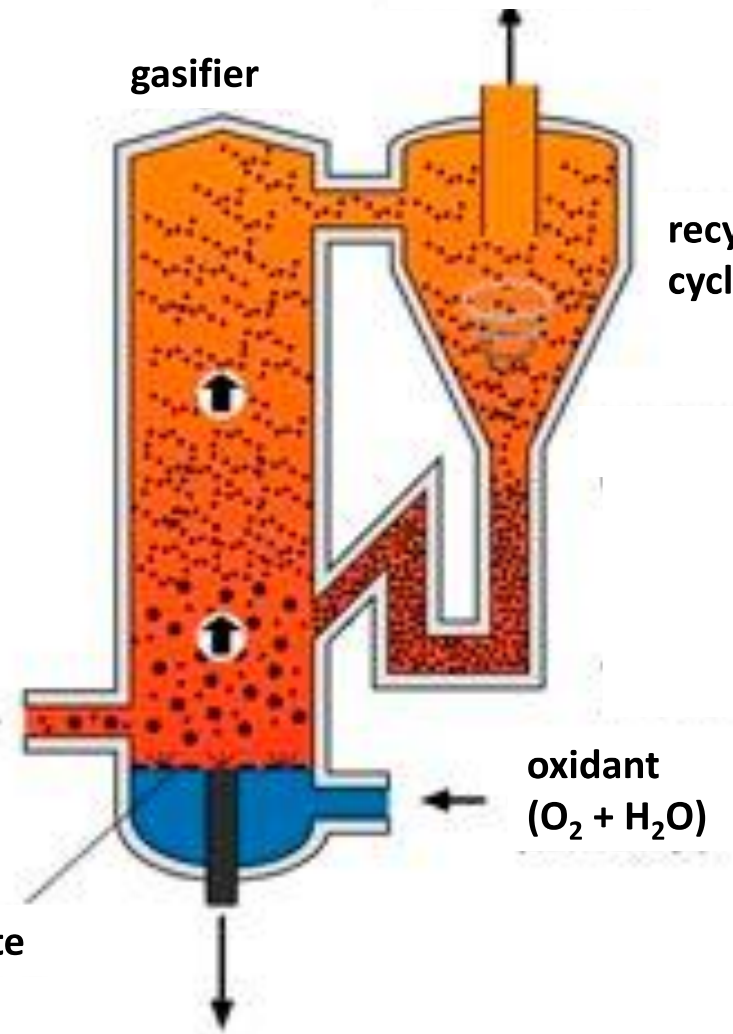
Circulating Fluidized Boiler (CFB)



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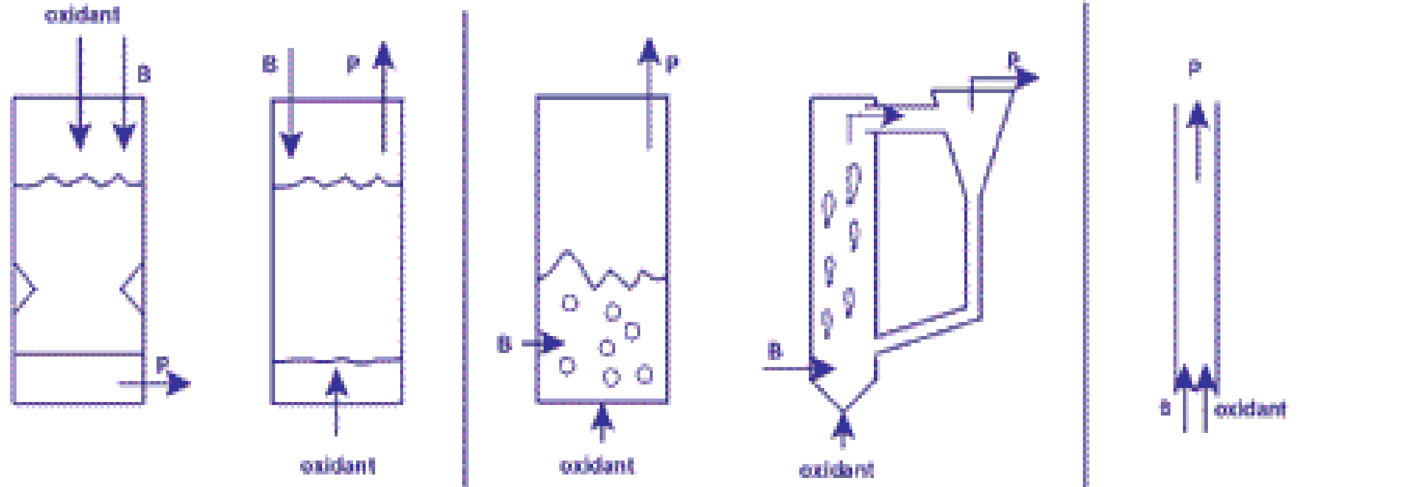
Biomass Gasification

Gasifier types



	Fixed beds		Fluid beds		Entrained beds
	Co-current	Counter current	dense	circulating	
T°C	700-1200	700-900	< 900	< 900	[illegible]1500
tars	low	very high	intermediate	intermediate	absent
control	easy	very easy	intermediate	intermediate	very complex
scale	$< 5\ MW_t$	$< 20\ M_t$	$10<MW_t<100$	$20<MW_t<?$	$> 100\ MW_t$
feedstock	very critical	critical	less critical	less critical	very fine particles

Graphics courtesy BTG

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3. Pyrolysis

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PYROLYSIS

Heating of biomass in the complete absence of oxygen

Three different categories of pyrolysis

$$Biomass + heat \rightarrow H_2 + CO + CO_2 + CH_4 + H_2O + \text{bio} - \text{oil} + \text{charcoal}$$

Fast pyrolysis
Intermediate pyrolysis
Slow pyrolysis

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Pyrolysis Reactors

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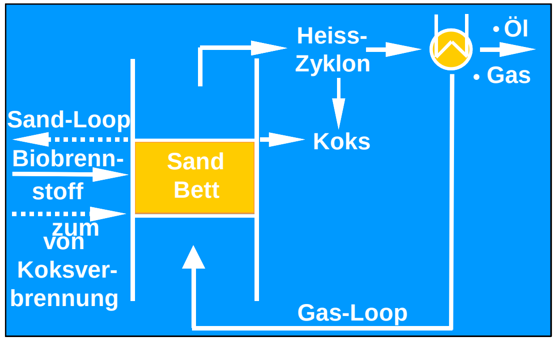
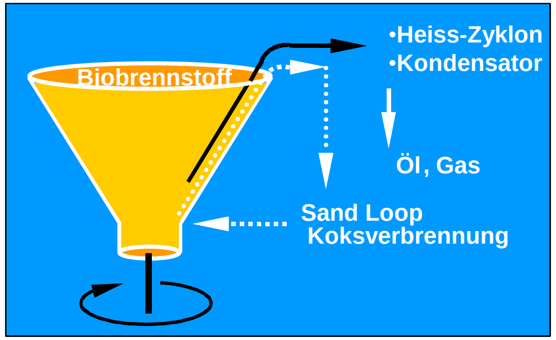
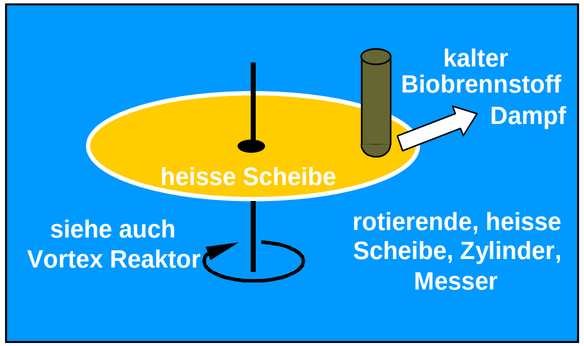
Fluidised bed



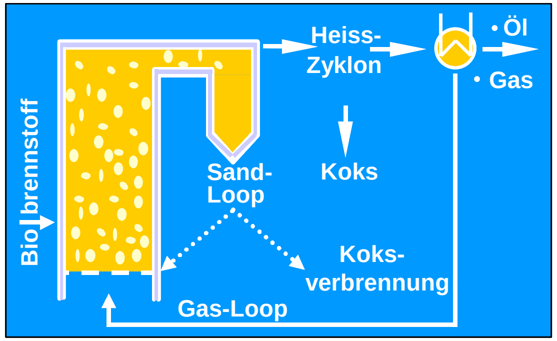
Rotating cone



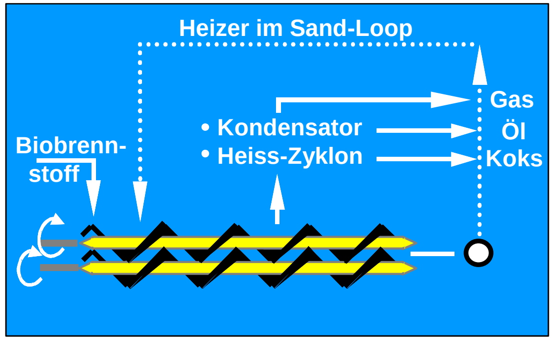
ablative reactor



Circulated/Bubbling fluidised bed



Twin screw



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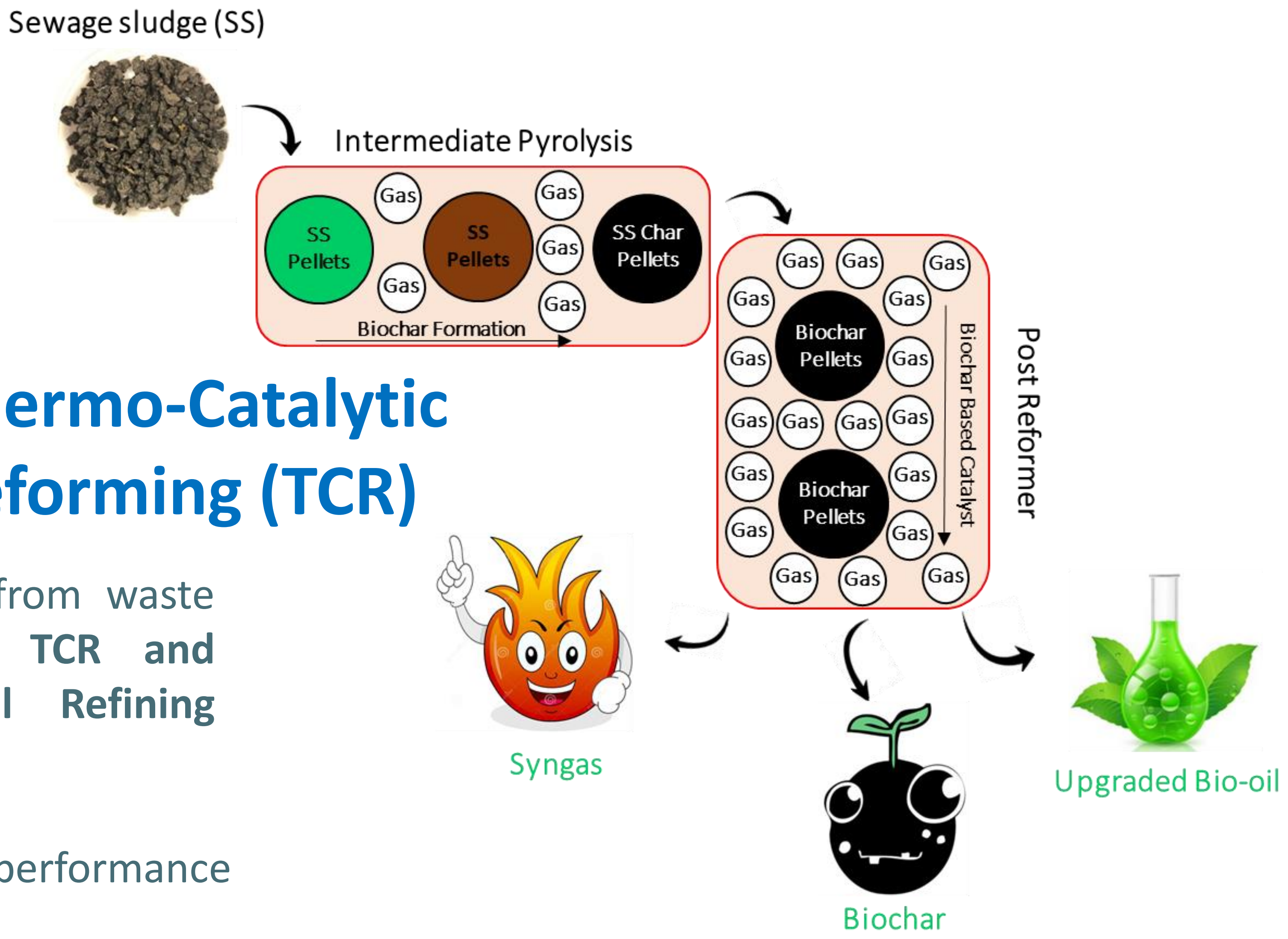
2synfuel

- Production of green hydrogen, diesel and gasoline from sewage sludge via **Thermo-Catalytic Reforming (TCR)** technology.

Thermo-Catalytic Reforming (TCR)



Green FlexJET project

- Production of sustainable aviation fuel from waste cooking oil and waste biomass via **TCR and Sustainable Aviation Through Biofuel Refining (SABR).**

- Flagship commercialization and fuel performance certification.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792216.

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TCR Feedstocks

Over 50 different feedstocks tested in TCR

- Feedstock pre-conditioning steps
- Drying
- Granulating and pelleting
- For sewage sludge only drying is necessary

4 Products always produced from TCR

- Bio oil
- Water
- Syngas
- Char

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TCR PRODUCTS - Conversion of Sewage Sludge

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

FEEDSTOCK

PRODUCTS

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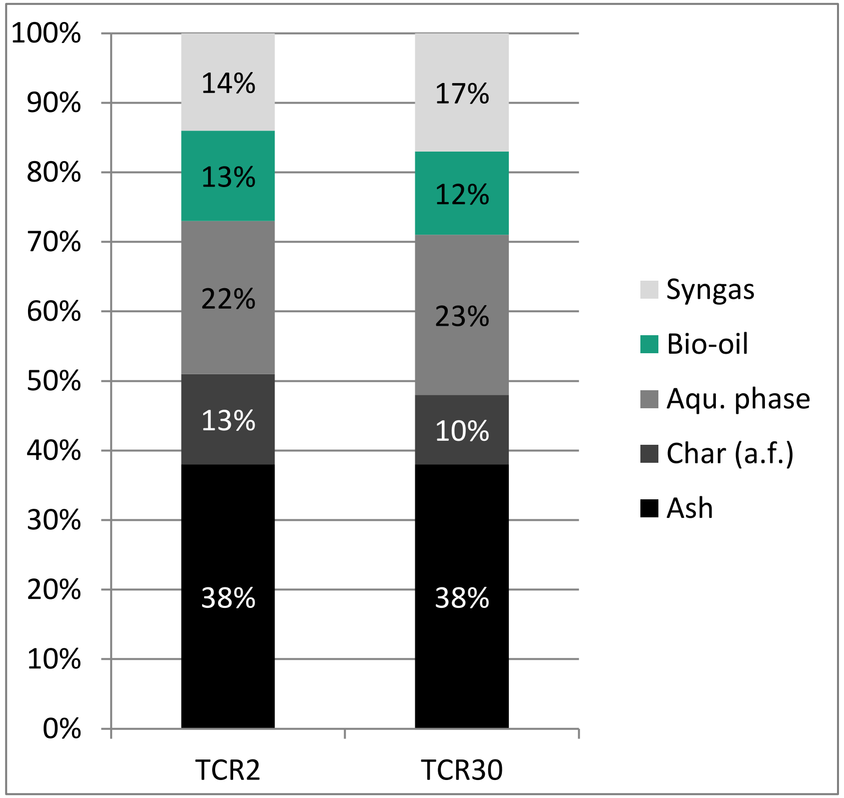
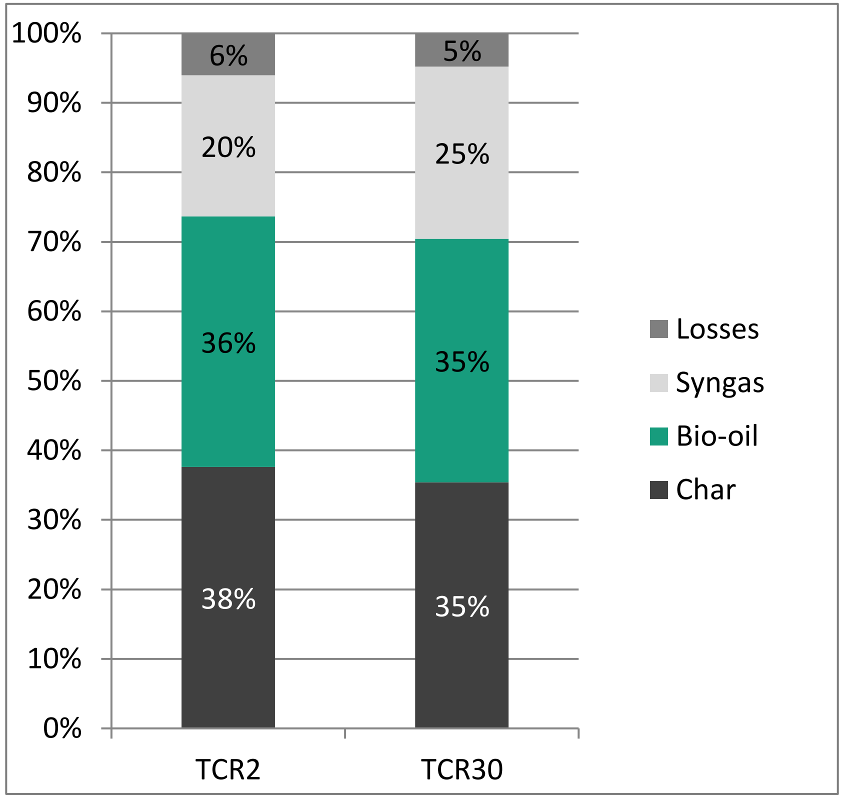
TCR
MASS AND ENERGY BALANCE

MASS BALANCE



ENERGY BALANCE



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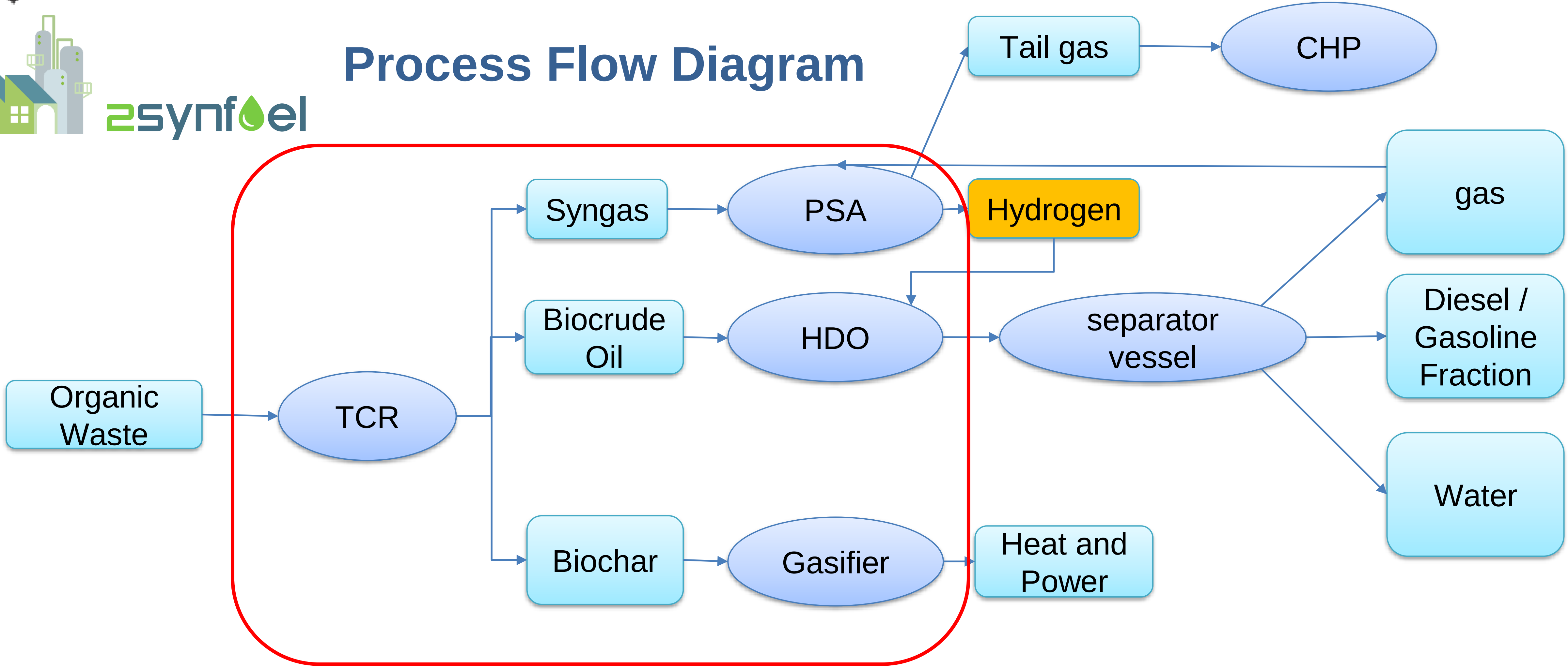
2synfuel

Process Flow Diagram



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ToSynFuel plant

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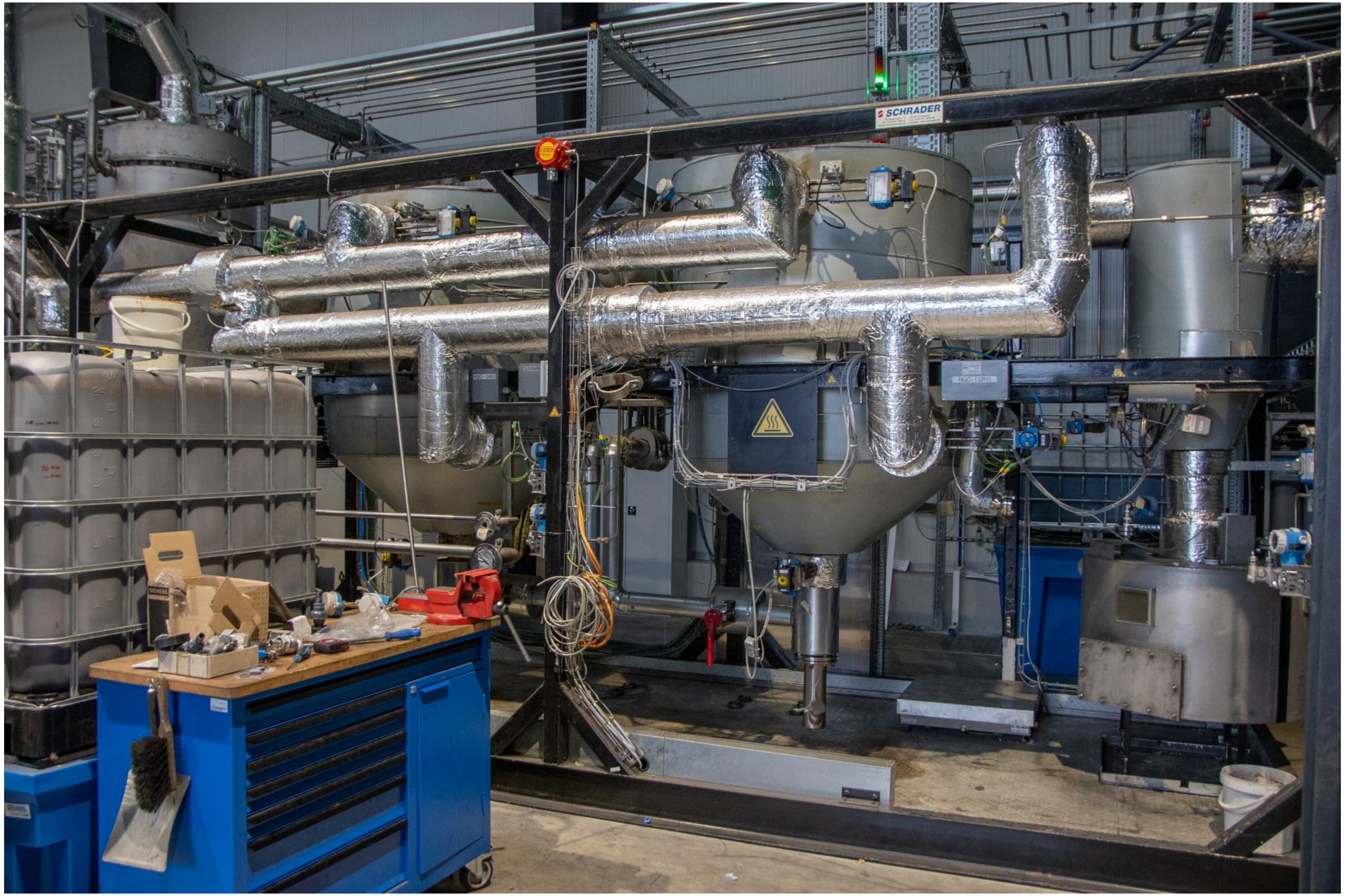

Gas treatment ToSynFuel

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PSA ToSynFuel

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Compressors, H_2 tank ToSynFuel

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Hydro-treating Diesel Fraction Meets EN590 Standard for all properties

Standard Value				Reference Product	TCR®-Product
Diesel EN 590				Diesel B7	Fractionated TCR®-HBO
min	max	Property	Unit	EN590	
51	-	Cetane Number		54	✓
820	845	Density at 15 °C	kg/m^3	842,5	✓
-	8	PAH	% (m/m)	4	n.a.
-	10	Sulphur	mg/kg	n.a.	✓
55	-	Flash point	°C	67	✓
-	0,01	Ash content	% (m/m)	n.a.	✓
-	200	Water content	mg/kg	n.a.	✓
Class 1	Class 1	Copper strip corrosion (3 hours at 50 °C)	Class	n.a.	✓
-	460	Lubricity at 60 °C	µm	165	✓
2	4,5	Viscosity at 40 °C	mm^2/s	3,3	✓
-20 (Winter)	0 (Summer)	CFPP	°C	n.a.	✓
-	< 65	Volume at 250 °C	%V/V		✓
85	-	Volume at 350 °C	%V/V		✓
-	360	95 %(V/V) recovered at	°C	360	✓
		Lower Heating Value	MJ/kg	42,49	✓
		Carbon	% (m/m)	86,5	✓
		Hydrogen	% (m/m)	13,4	✓
		Nitrogen	% (m/m)	n.a.	✓
		Oxygen	% (m/m)	0,1	✓

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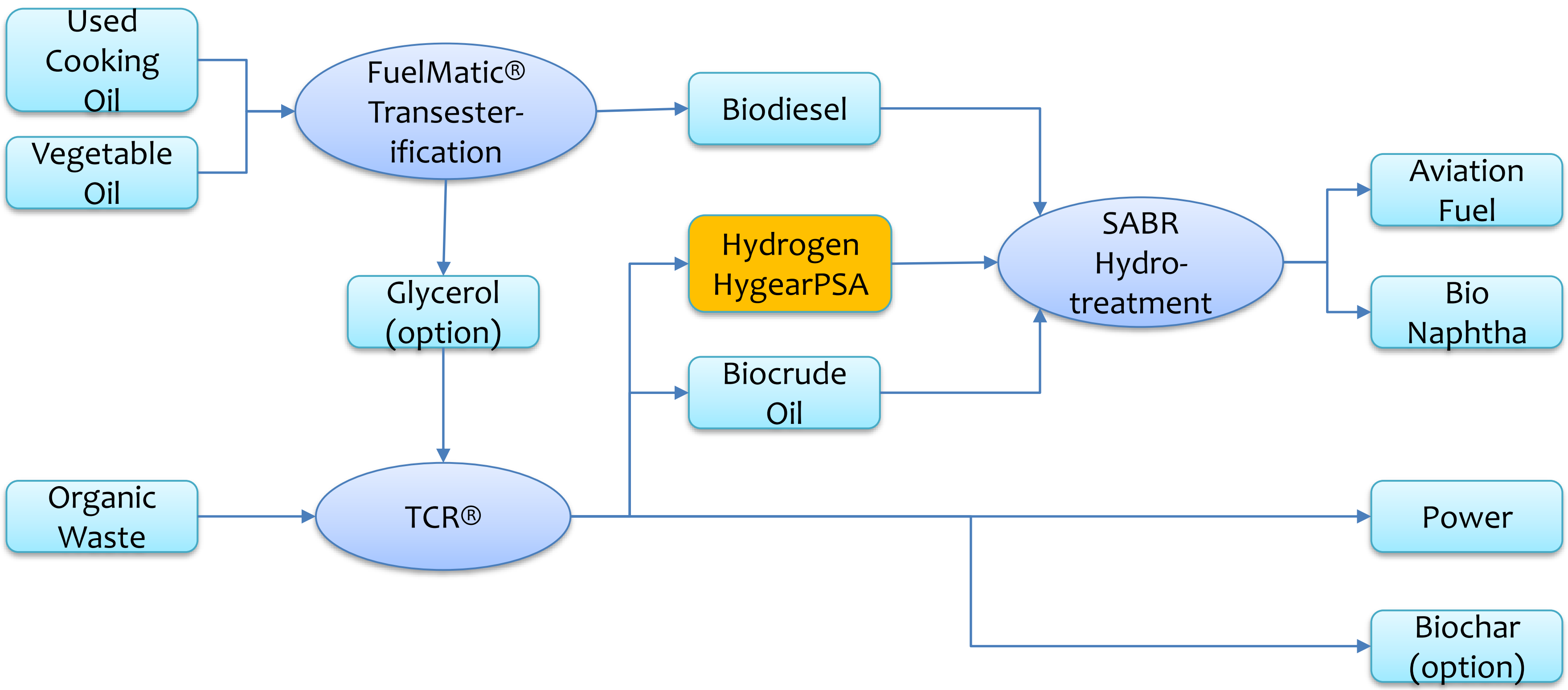
GREEN-FLEXJET PROCESS FLOWSHEET



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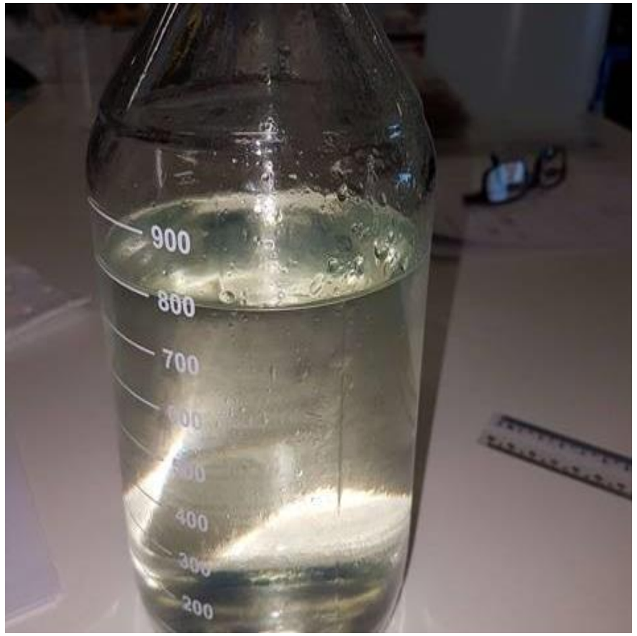
Kerosene fraction meets majority of ASTM D7566 Specifications



Specification	ASTM D7566	TCR Jet Fuel
HHV (MJ/Kg)	Min 42.8	43.4
S (wt%)	Max 0.3	< 0.1
Freezing Point (°C)	Max − 47	-50
Density, 15 °C (g/cm^3)	0.75–0.84	0.84
TAN (mg KOH/g)	Max 0.1	0.6
Viscosity, − 20 °C (cSt)	Max 8	3.2
Smoke Point (mm)	Min 25	13
Flash Point (°C)	Min 38	< 38

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www.hydex.ac.uk

Thank you

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