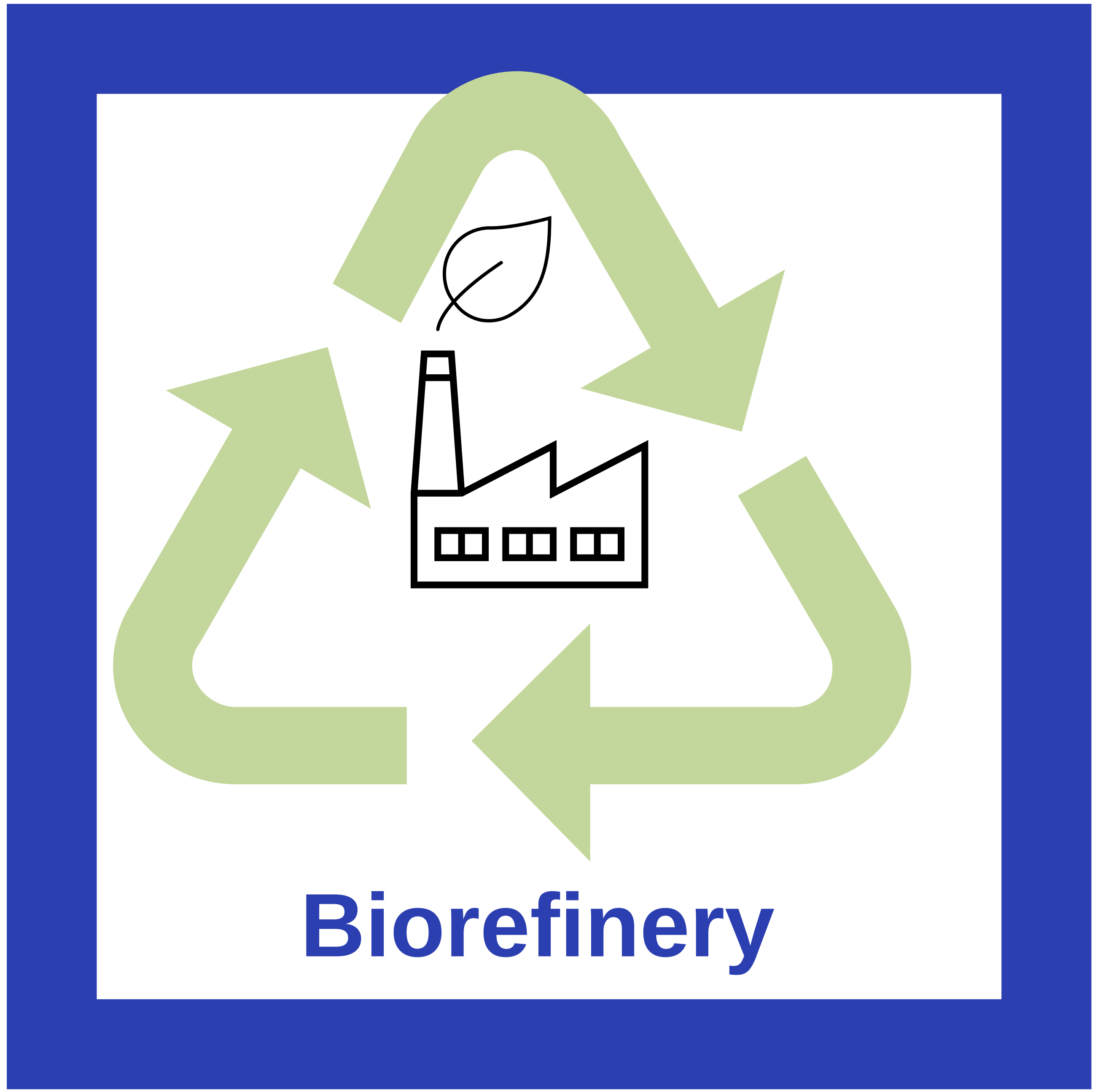
Ciências ULisboa

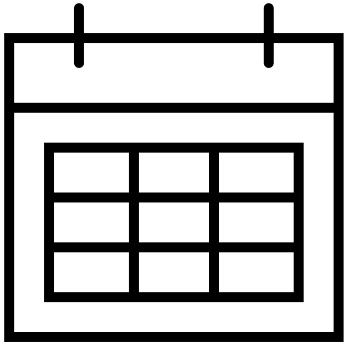
Faculdade
de Ciências
da Universidade
de Lisboa

Eng Energy & Environment


Biorefinery

Information

Professor: Carla Silva (camsilva@ciencias.ulisboa.pt)



Wednesdays

16h-19h00

Room: 8.2.13

Information

Professor: Carla Silva (camsilva@ciencias.ulisboa.pt)

5 challenges!

Oral evaluation: discussing the challenges

07-06-2022

27-06-2022

20-07-2022

Definition & examples

IEA Bioenergy

Technology Collaboration Programme

IEA Bioenergy Task 42
''Biorefineries"

''Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy".

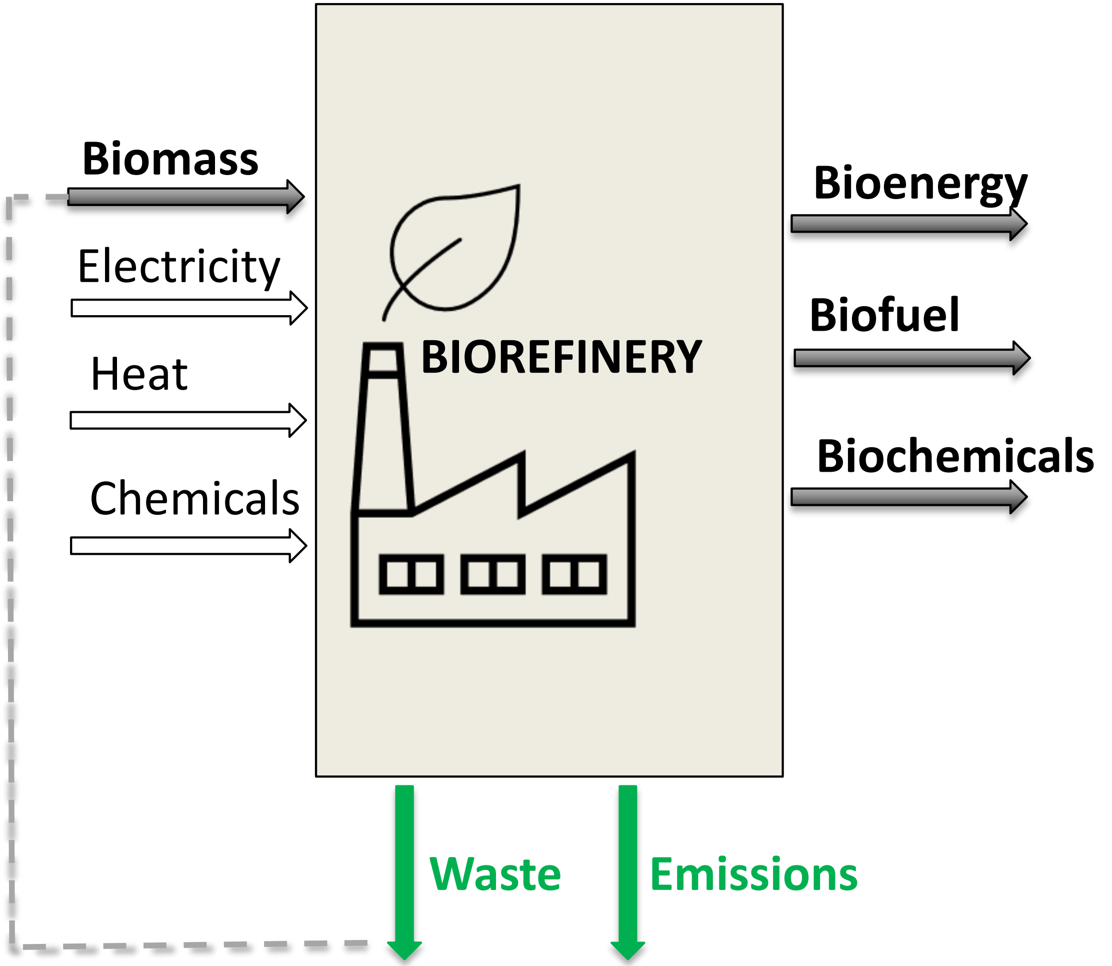
2007

Definition & examples

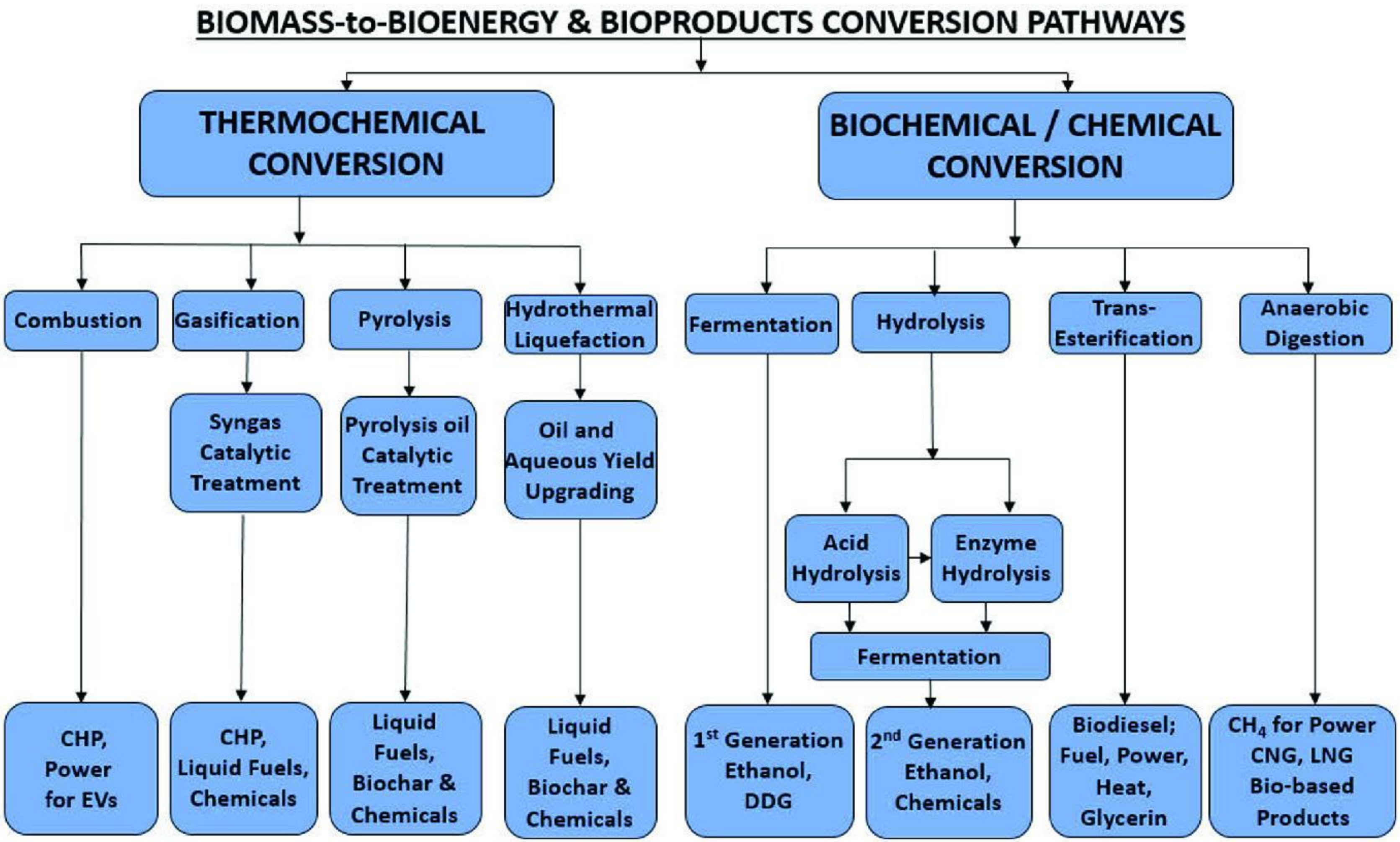
The biorefinery concept: Using biomass instead of oil for producing energy and chemicals, Energy Conversion and Management, Volume 51, Issue 7, 2010, Pages 1412-1421, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2010.01.015

Processes

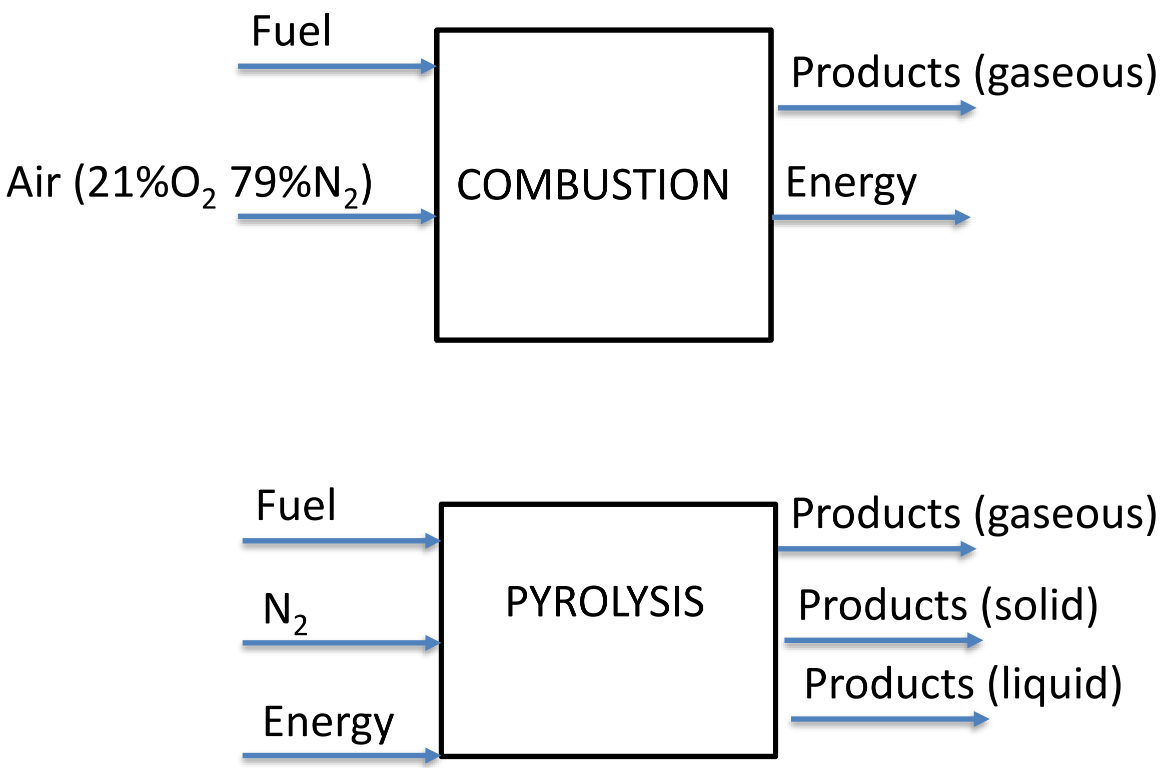
Collect and pre-treat: Decompose biomass in: Build products:



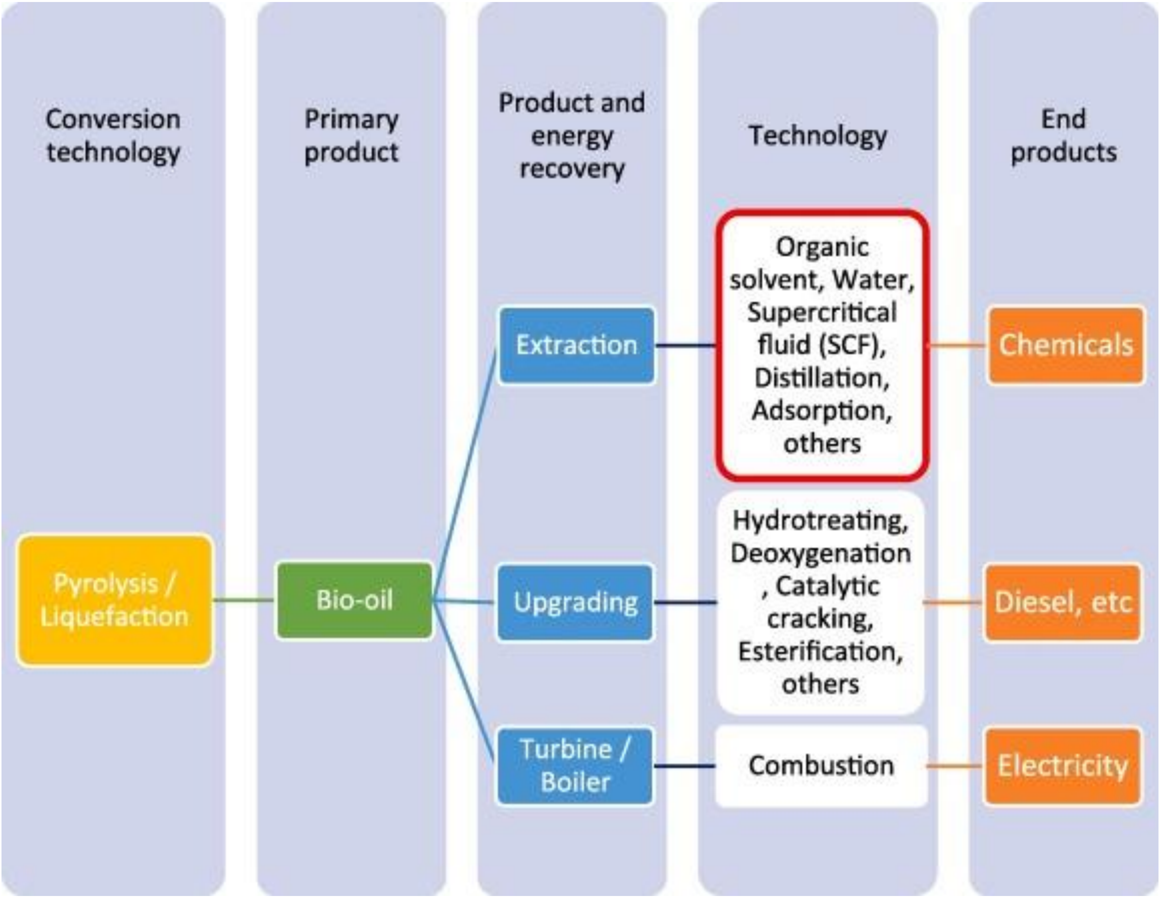
Processes – Conversion Technologies

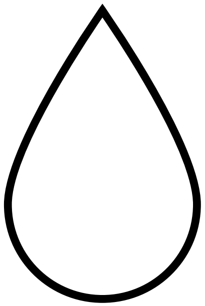


Processes – Conversion Technologies



Processes – Conversion Technologies

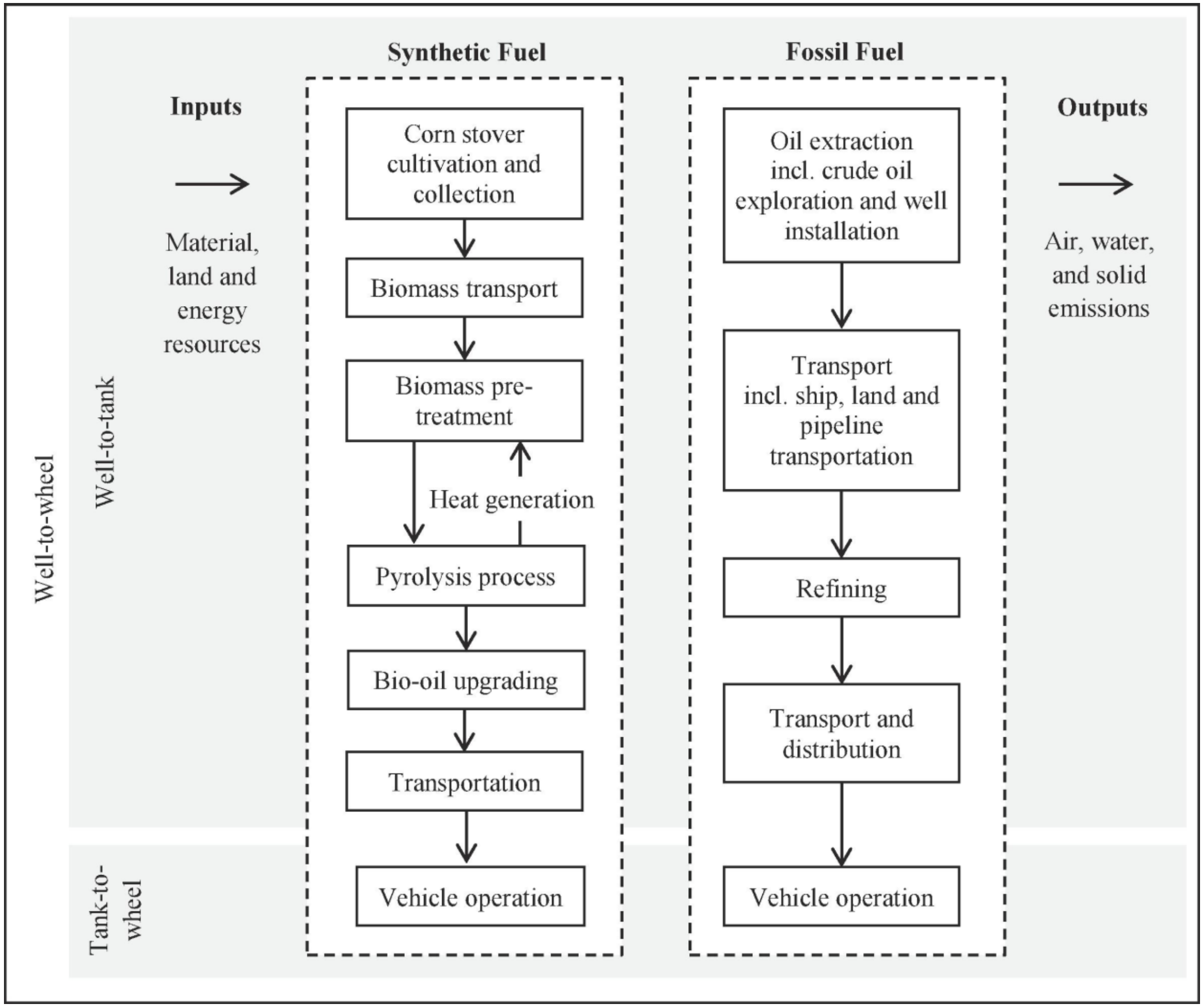


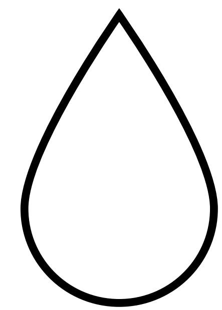


Bio-oil

https://doi.org/10.1016/j.cej.2020.125406

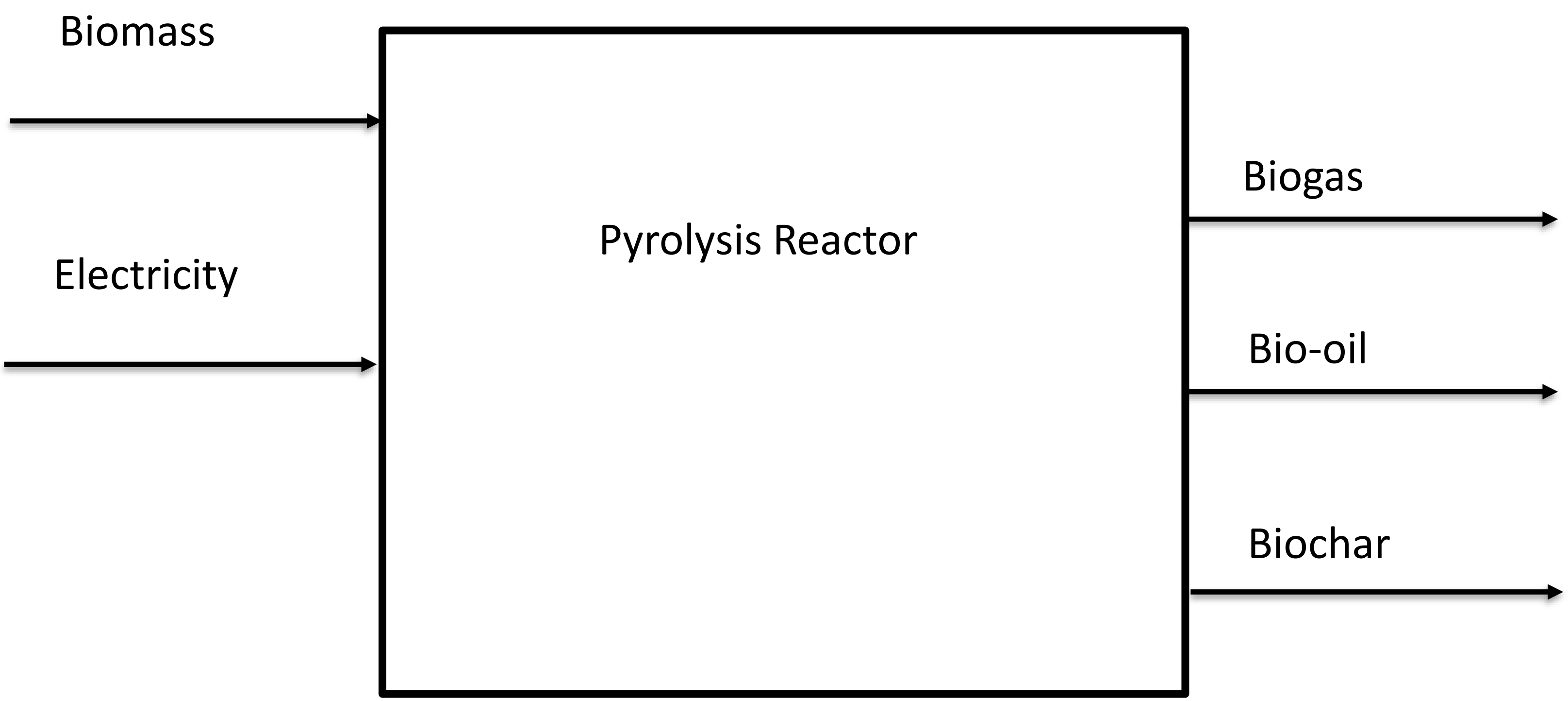
Processes – Conversion Technologies





Bio-oil

Processes - Pyrolysis



Processes - Pyrolysis

Features	Slow Pyrolysis	Fast pyrolysis
Temperature (°C)	300-700	600-1000
Heating rates (°Cmin^{-1})	0.1-10	10-10000
Aeration	Oxygen-free or limited	Oxygen-free
Residence Time	Minutes-hours	Seconds
Target product	Biochar	Bio-oil
Reactors	Fixed bed pyrolysis reactor, auger pyrolysis reactor	Bubbling fluidized bed, ablative reactor, rotary cone
Advantages	-The highest yield of biochar. -Can accept a wide range of particle size.	-A higher yield of bio-oil.
Disadvantages	Further treatment of gases is needed due to high CO concentrations	-Low biochar yield. -Fine particle of biomass feed (1-2mm) is required. -Prefer biomass with low moisture content (<10%)
References	Pandey *et al.* [14]	Pecha and Garcia-Perez [15]

Doi:10.1088/1757-899X/1051/1/012075

Processes - Pyrolysis

Biomass (2.85 ton Miscanthus)

Electricity (2086 kWh)

Pyrolysis Reactor

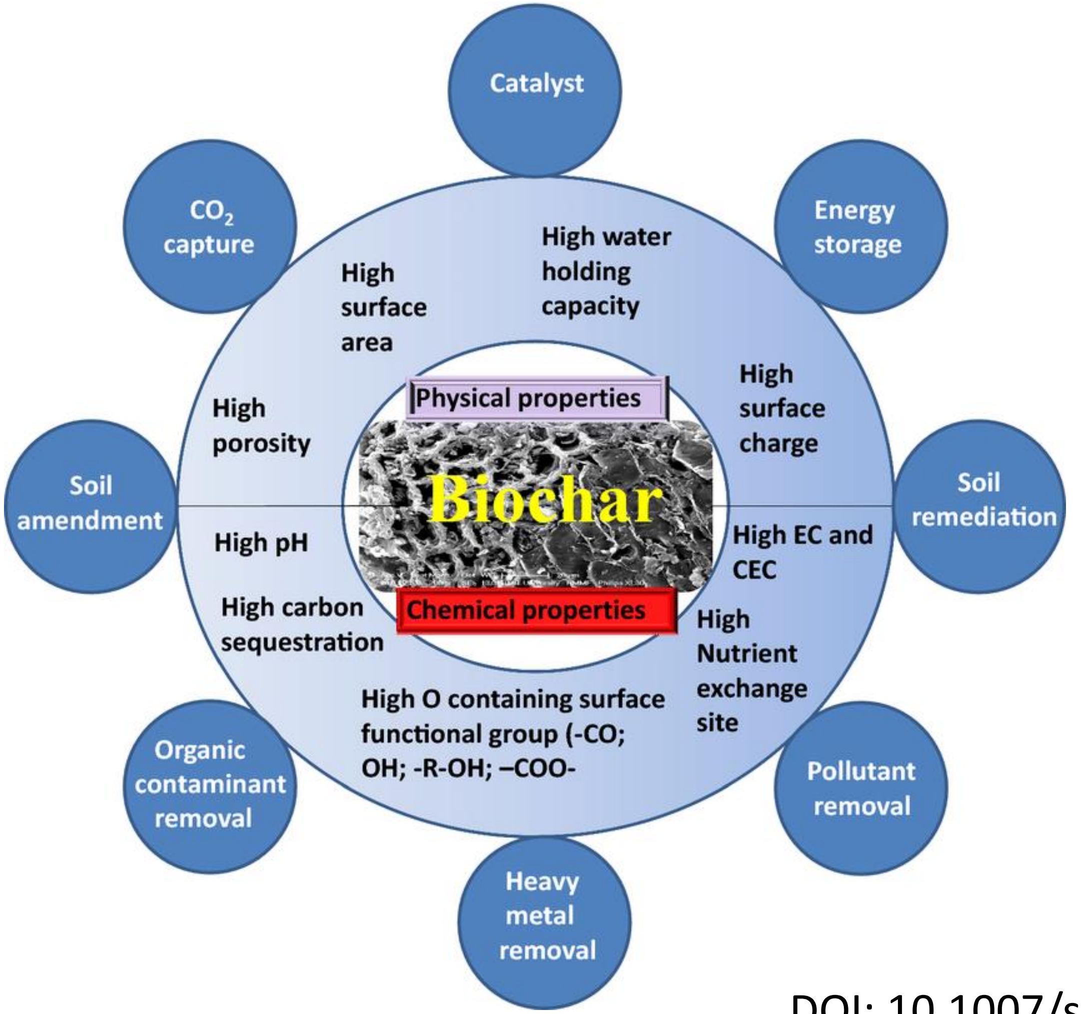
Biogas (0.85 ton)

Bio-oil (1 ton)

Biochar (1 ton)

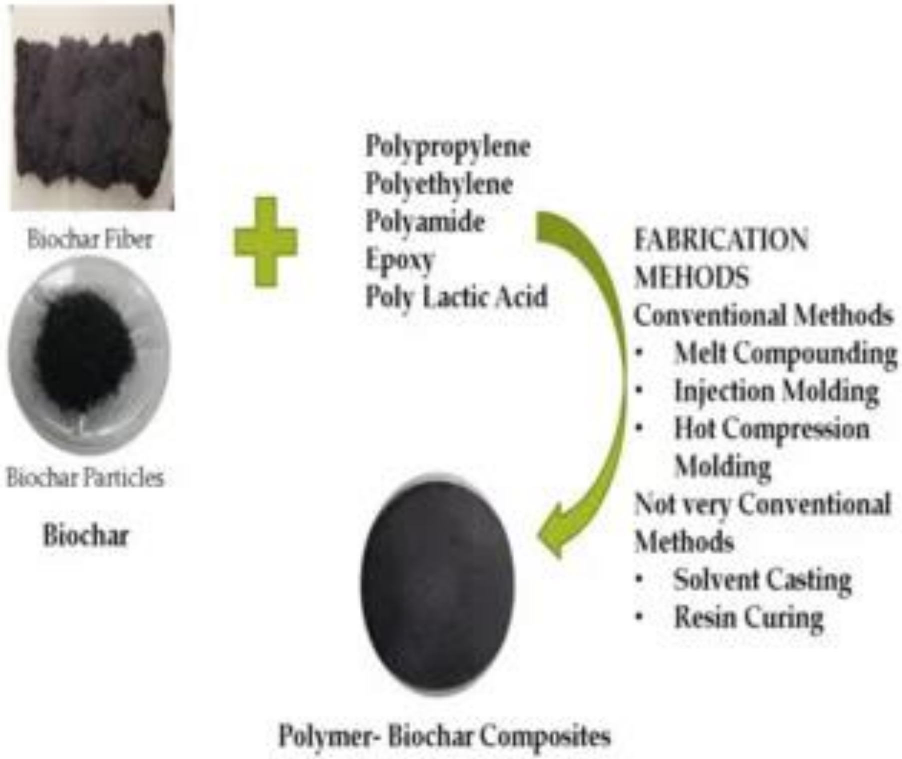
Doi:10.1088/1757-899X/1051/1/012075

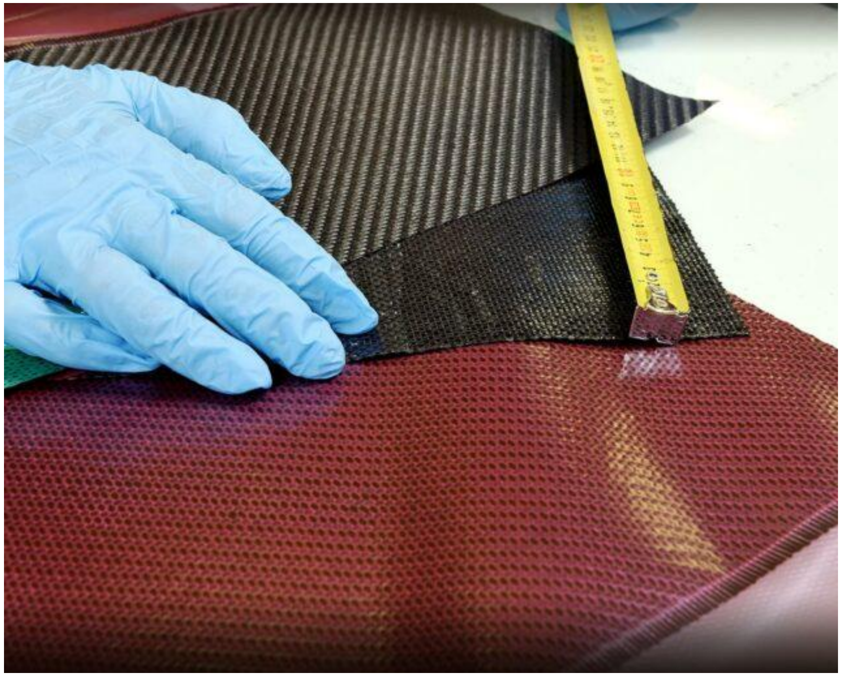
Product – Pyrolysis -Biochar



DOI: 10.1007/s11157-020-09553-x

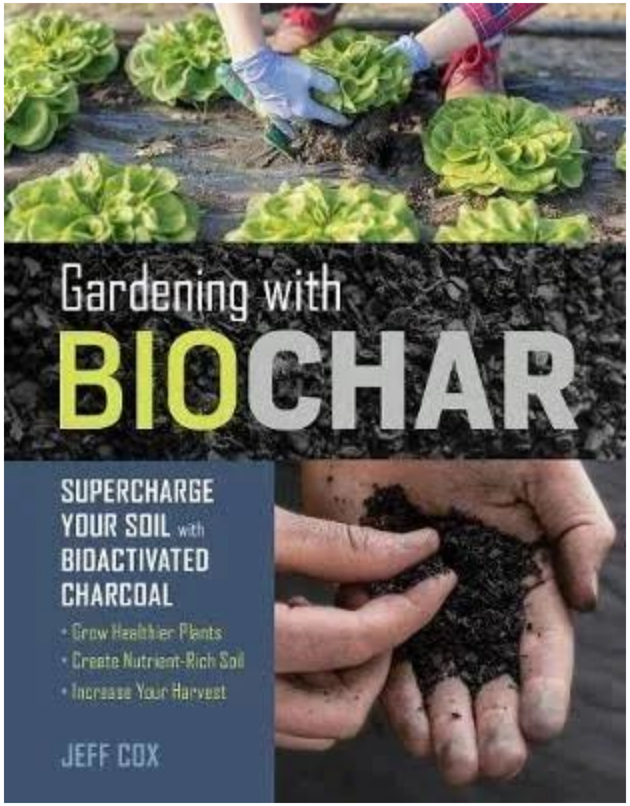
Product – Pyrolysis - Biochar





https://doi.org/10.3390/polym13162663

Product – Pyrolysis - Biochar



	Greenhouse				Field
	wood mixture	straw	vineyard pruning	vineyard pruning	ROMCHAR 80%beech, 20% other hard wood
pyrolysis temperature (°C)	525	525	525	400	500
heating rate (°C min^{-1})	10-20	10-20	2	2	
dwell time (h)	1	1	6	8	2
EC (mS cm^{-1})	1.6 ± 0.0	5.2 ± 0.1	1.1 ± 0.0	1.5 ± 0.0	
CEC(mmol$_c$ kg^{-1})	93.0 ± 1.9	148.5 ± 0.8	78.8 ±1.4	123.5 ± 1.3	
pH-value ($CaCl_2$)	8.9 ±0.1	9.7 ±0.0	8.8 ±0.1	8.3 ±0.0	
C_{tot} (%)	67.1 ± 1.3	56.3 ± 2.4	73.1 ± 0.9	69.3 ± 0.2	72.7
N_{tot} (%)	1.2 ± 0.03	0.9 ± 0.03	1.3 ± 0.03	1.3 ± 0.06	0.4
ash content (%)	15.2	28.1	7.7	4.3	15.2
BET-N_2 SA (m^{2}g^{-1})	26.41 ± 1	12.26 ± 1	4.85 ± 0	1.69 ± 0	

EC = electrical conductivity, CEC= cation exchange capacity, C_{tot} = total carbon content, N_{tot} = total nitrogen content, BET-N_2 SA= Brunauer-Emmett-Teller specific surface area (N_2 adsorption).

DOI: 10.23986/afsci.8095

Product – Pyrolysis - Biochar

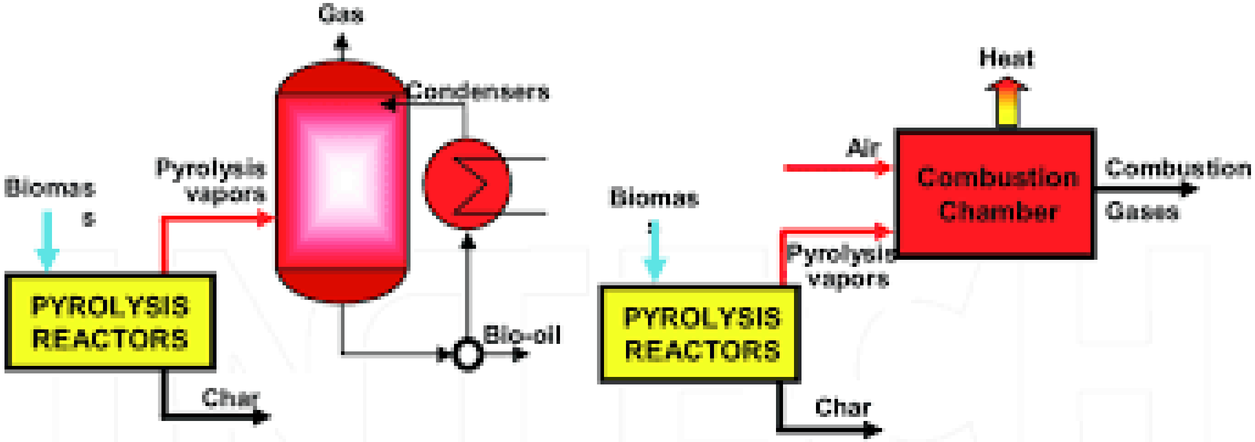
https://doi.org/10.1016/j.rser.2020.110464

Table 1
Applications and roles of biomass-derived biochars in electrochemical energy storage devices.

Energy storage device	Role of biomass-derived carbon	Type of biochar	Properties of the biomass
Supercapacitor	Electrodes	Activated carbon	High surface area, porous, conducting, heteroatom dopant
	Binder	Chitin, Chitosan, Cellulose	Polymeric nature, chemical stability
	Separator	Cellulose	Insulator, flexibility, mechanical strength, chemical stability, wettability
	Electrolyte	Organic acids	Ionic conductivity, stable at wide operating voltage limit,
Lithium-ion battery	Anode material	Hard/Soft carbon Activated carbon	Conductivity, defect sites, porous, surface area
	Dopant	Chitosan	Heteroatoms like N and O dopant
	Binder	Chitin, Chitosan	Polymeric nature, chemical stability
	Separator	Cellulose	Insulator, flexibility, mechanical strength, chemical stability, wettability
	Current collector	Carbon cloth	Conducting, thin film, chemical stability, mechanical strength
Sodium-ion battery	Anode material	Hard/Soft carbon Activated carbon	Defective storage, conducting, porous
Lithium-Sulphur battery	Sulphur host	Porous carbon	Conducting, porous, high surface area
	Conducting agent	Porous activated carbon	Highly conductive, high surface area
	Binder	Cellulose, Gum	Insulator, flexibility, mechanical strength, chemical stability, wettability
Metal-air battery	Electrocatalyst, Catalyst support	Porous activated carbon	Catalytic activity, chemical stability, mechanical stability

Processes – Pyrolysis - Biogas

Non-condensable gases



(a) Biochar and bio-oil production (b) Biochar and heat production

DOI: 10.5772/intechopen.69036

https://www.youtube.com/watch?v=Ut3I7OIPFR8

Product – Pyrolysis -Biogas

Temperature (°C)	Gas composition[a]	% of catalyst[b]		
		0.25	0.5	1
200	%Paraffin	52.5	72.1	83.1
	%Olefin	45.4	25.5	14
	%CO2	2.1	2.4	2.9
	Caloric value	34	42	60
300	%Paraffin	51.9	65.1	80.9
	%Olefin	43.8	27.6	13.7
	%CO2	4.3	7.3	5.4
	Caloric value	45	56	71
400	%Paraffin	56.9	72.1	83.7
	%Olefin	36.4	19.9	7
	%CO2	6.7	8	9.3
	Caloric value	47.2	59	74.9

[a] At the end of the experiment, i.e. after 8 h. $\%CO_2 = 100 - (\%paraffins + \%olefins)$.
[b] According to the total weight of the reactants.

10.1016/j.enconman.2010.01.007

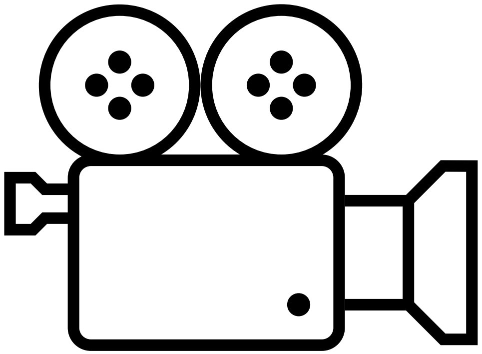
Feedstock:
scrap tyres and waste lubricating oil

Product – Pyrolysis –Bio-oil

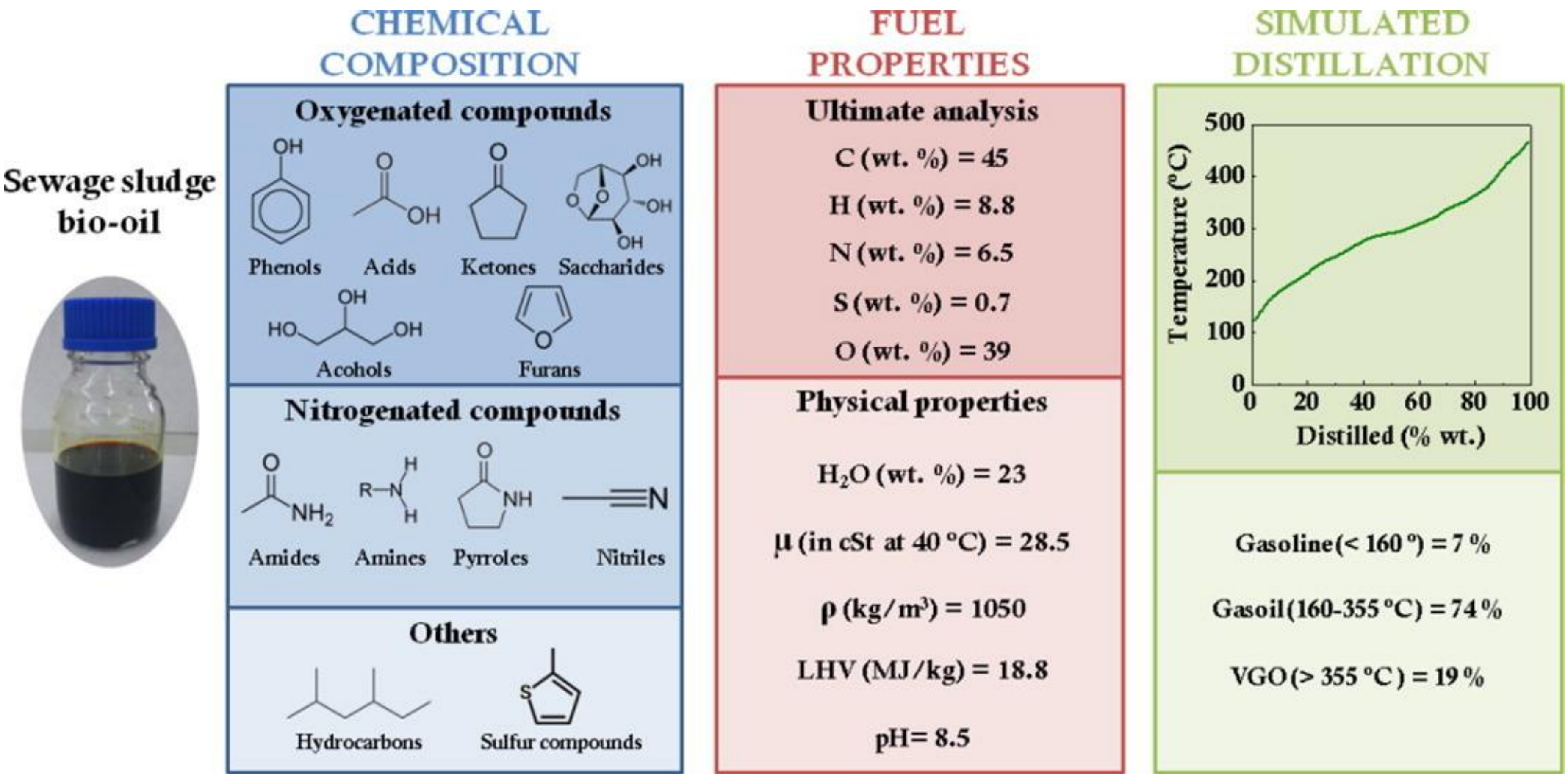
Analysis	Typical bio-oil
Water, wt %	20–30
Solids, wt %	0.01–0.5
Ash, wt %	0.01–0.2
Nitrogen, wt %	0–0.4
Sulfur, wt %	0–0.05
Stability	Unstable*
Viscosity (40 °C), cSt	15–35
Density (15 °C), kg/dm^3	1.10–1.30
Flash point, °C	40–110
Pour point, °C	−9 to −36
LHV, MJ/kg	13–18
pH	2–3
Distillability	Not distillable

DOI: 10.1002/ep.10382

Processes – Pyrolysis – Bio-oil

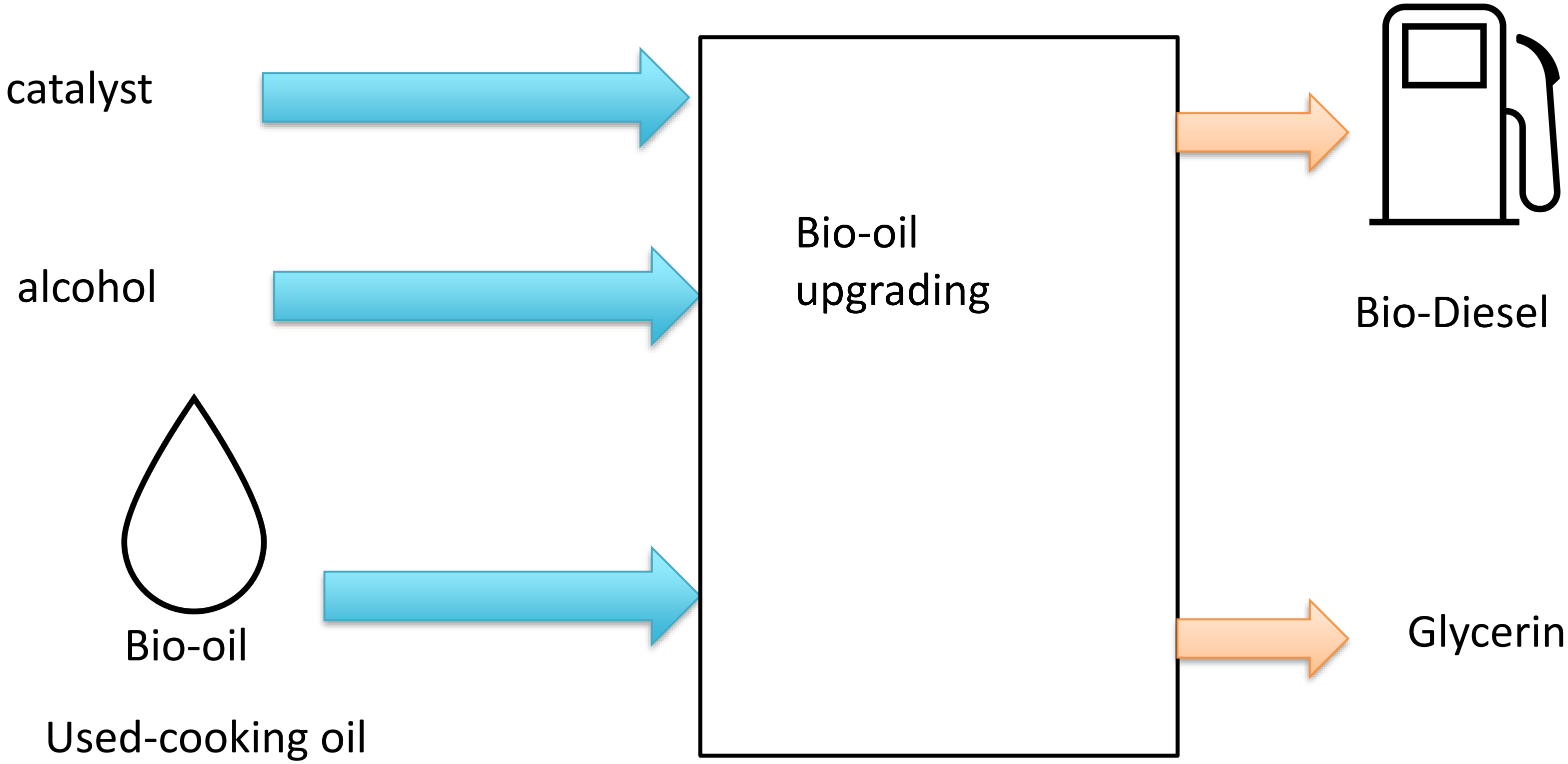


Product – Pyrolysis –Bio-oil



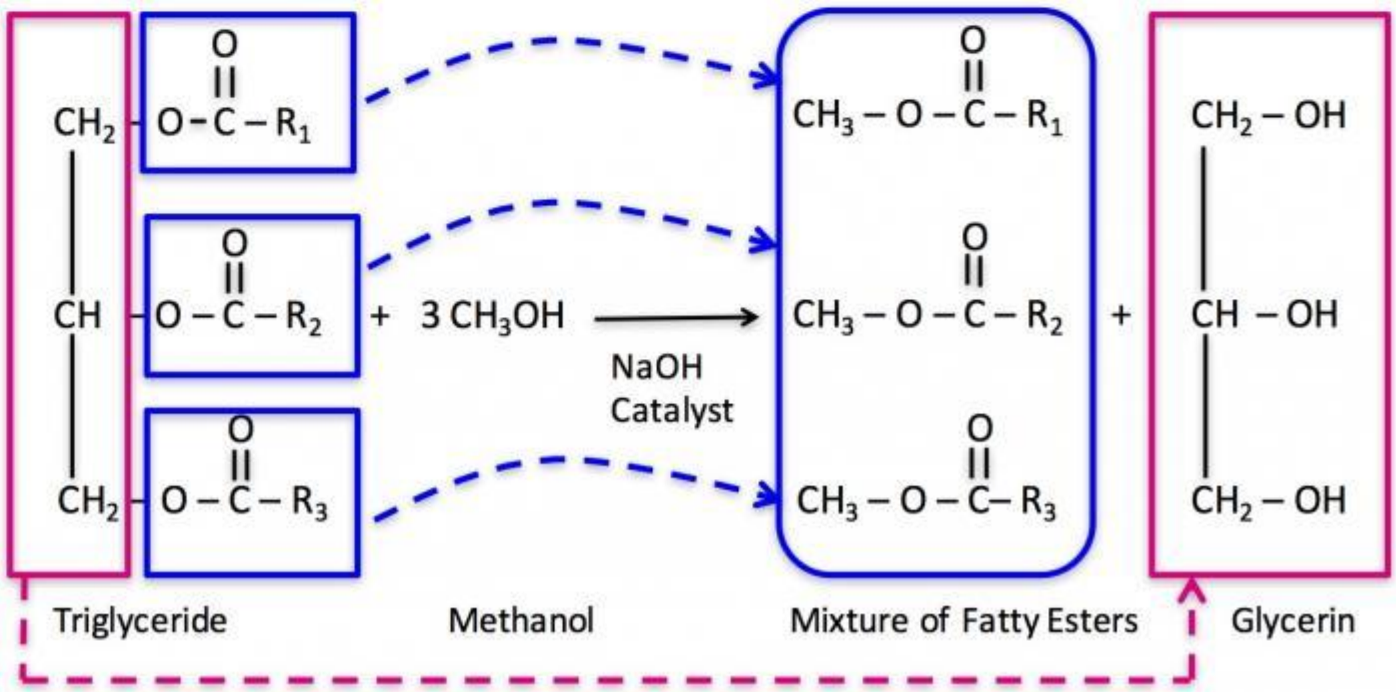
https://doi.org/10.1016/j.fuproc.2016.04.015

Processes – Esterification/Transesterification



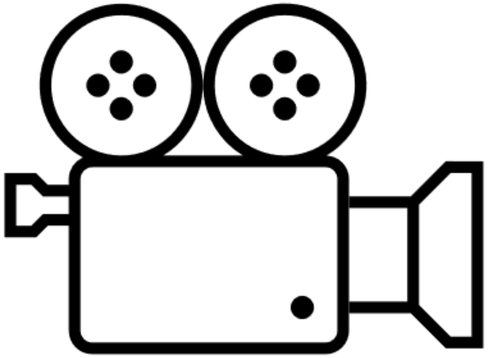
https://www.youtube.com/watch?v=rrldwVGmmy4

Processes - Transesterification

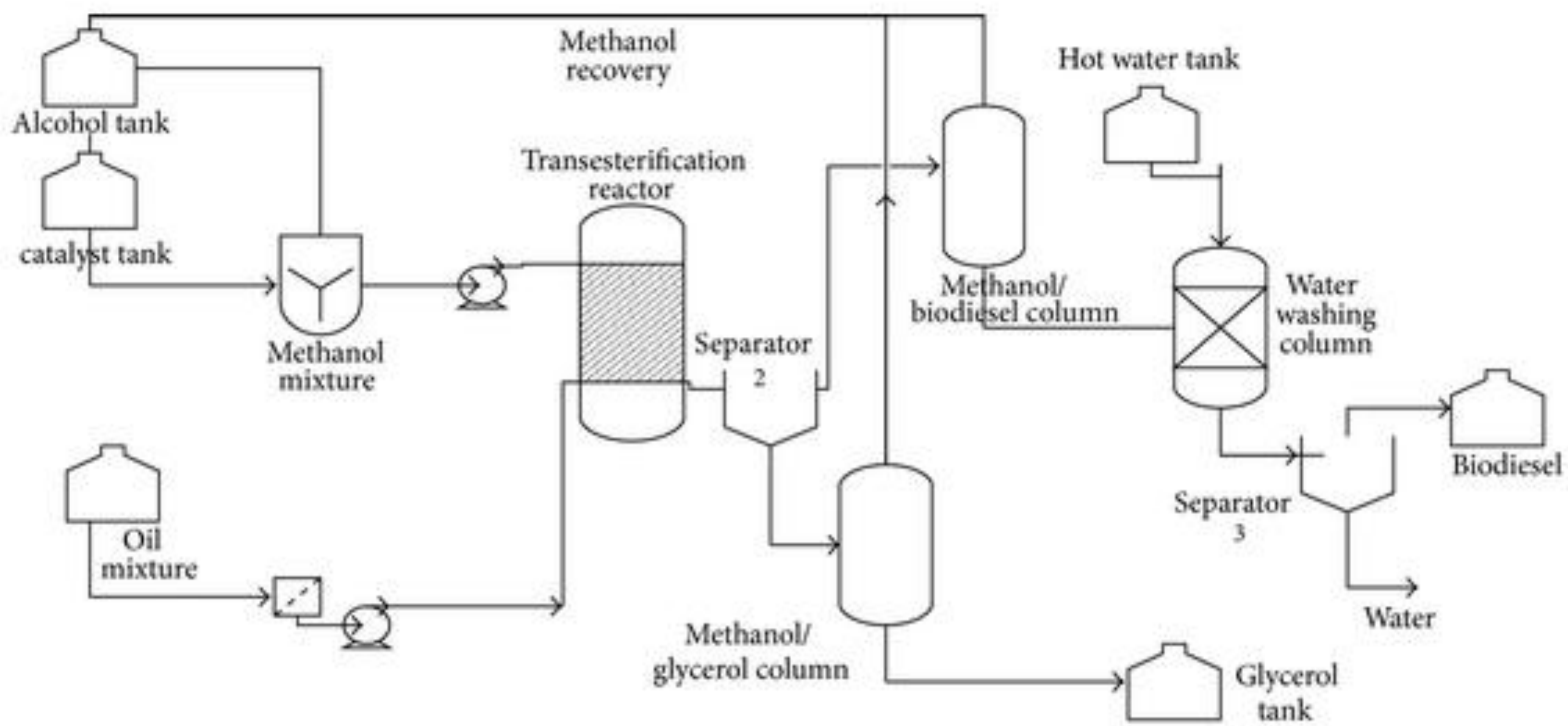


~ 40-65°C

Processes - Transesterification



Processes - Transesterification



A scheme is interesting but for sustainability evaluation we need quantification!!!!

Processes - Transesterification

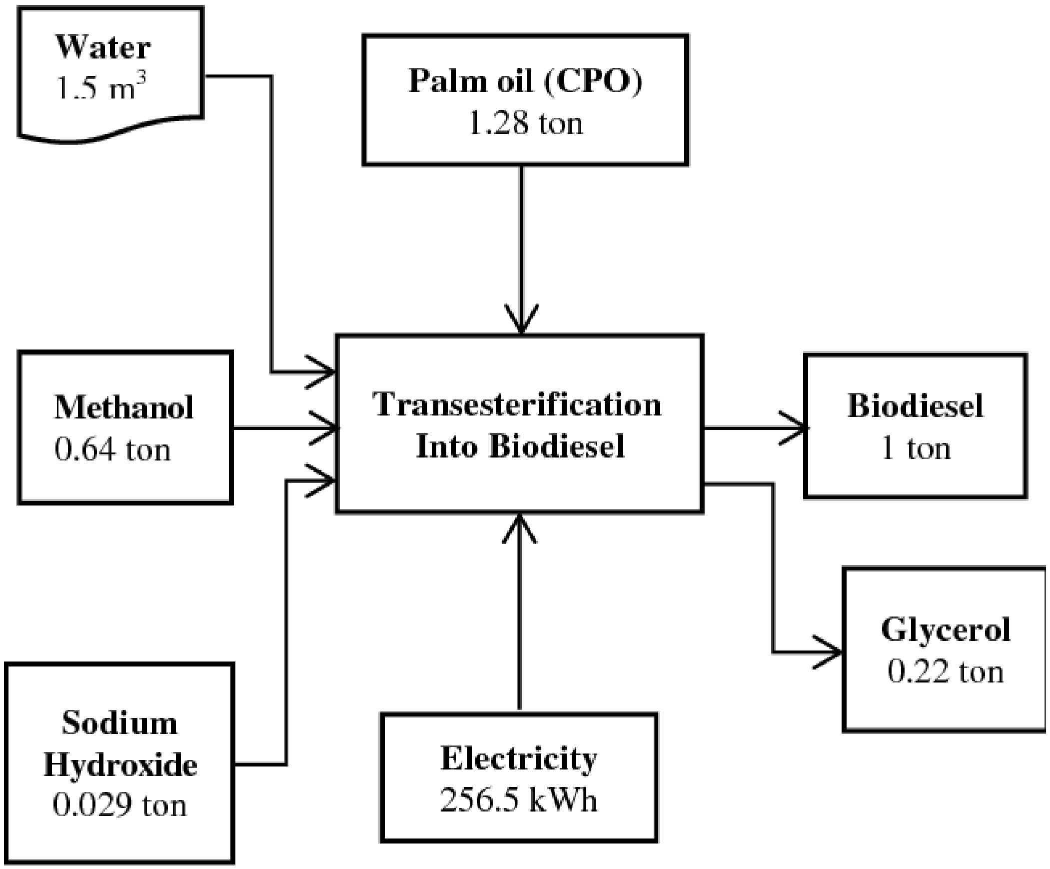
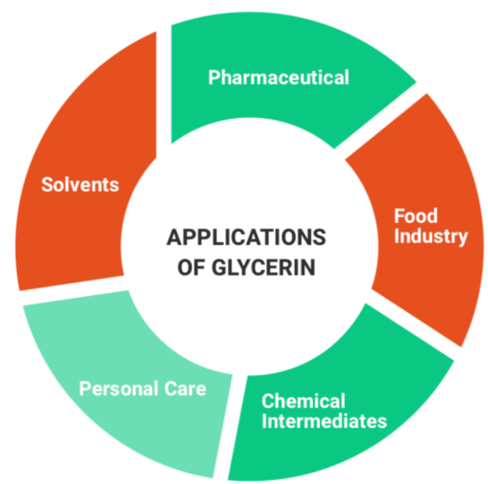


Figure 4. Unit Process of Biodiesel Production.

Processes - Transesterification

Stage	Input/Output	FAME
Input	Palm oil	
	RBDPO	24.6
	FAME	
FAME conversion		
	Methanol	3.47
	Steam	1.84
	Electricity (grid)	0.52
	Phosphoric acid	0.11
	Potassium hydroxide	0.27
	Tap water	0.40
	Cooling water	0.01
Output		
Product		
	FAME	26.3
	H-FAME	
	BHD	
Co-products		
	Crude glycerine	3.78
	Fuel gas	
	Bio-gasoline	

Biodiesel



Processes - Transesterification

Fuel Property	ASTM method	Petro-diesel (D975)	Biodiesel standard (D6751)	WCO biodiesel
Flash point [oC]	D 93	60-80	100-170	152
Ash contents [wt %]	D 482	0.01	0.01	0.003
Kinematic viscosity [40oC, mm2/sec]	D 445	1.9-4.1	1.9-6.0	3.256
Sulphur contents [wt%]	D 4294	0.05	0.05	0.015
Cloud point [oC]	D 2500	-15 to 5	-3 to 12	10
Pour point [oC]	D 97	-35 to -15	-15 to 16	4
Cetane number	D 613	> 46	47 min	47.171
Density [40oC, g/cm3]	D 5002	0.834	0.86-0.90	863.64
Acid value [mg KOH/g]	D 664	0.50	0.80 max	0.471

WCO- Waste Cooking Oil

THE HIGHER Cetane number THE HIGHER THE AUTO-IGNITION

Processes – Esterification&Transesterification

https://doi.org/10.1016/j.renene.2011.07.016

Inputs

Feedstock

Chemicals

Energy

	Biodiesel production from:				
	Waste vegetable oils	Rendered beef tallow	Rendered poultry fat	Dried sewage sludges	
Inputs					
Materials					
Lipid feedstock	1205.12	1015.36	1013.00	10,000.00	kg
Methanol	112.67	113.32	99.00	670.18	kg
Sulphuric acid	0.15	–	–	76.35	kg
Calcium oxide	0.10	–	–	–	kg
Water	56.08	71.32	32.00	0.88	kg
Sodium hydroxide	9.80	4.00	5.00	–	kg
Sodium methoxide	–	11.00	12.00	–	kg
Phosphoric acid	7.95	–	–	–	kg
Hydrogen chloride	–	6.00	7.00	–	kg
Hexane	–	–	–	76.28	kg
Energy					
Thermal energy (rendering)	1628.93	–	–	–	MJ
Electric energy (rendering)	133.12	–	–	–	kWh
Thermal energy (esterification)	222.30	175.94	90.04	–	MJ
Electric energy (esterification)	31.43	28.93	10.08	–	kWh
Thermal energy (transesterification)	1650.84	1733.48	1886.96	2542.95	MJ
Electric energy (transesterification)	20.34	30.36	28.98	28.47	kWh

Processes – Esterification & Transesterification

https://doi.org/10.1016/j.renene.2011.07.016

Ouputs

Biodiesel

Chemicals (Glycerin)

Wastes

	Biodiesel production from:				
	Waste vegetable oils	Rendered beef tallow	Rendered poultry fat	Dried sewage sludges	
Outputs					
Products					
Biodiesel	1.00	1.00	1.00	1.00	t
Glycerol	102.21	115.64	109.00	129.05	kg
Wastes to treatment					
Salts to landfill	16.00	9.00	10.00	–	kg
Hazardous liquid waste	30.46	24.00	26.00	–	kg
Organic waste to landfill	85.40	–	–	–	kg
Sludge	–	–	–	2.00	t

Processes – Esterification & Transesterification

https://doi.org/10.1016/j.renene.2011.07.016

Inputs

Oil intake to Alcohol ratio: ~ 11

NaOH to oil ratio: ~ 1% w/w

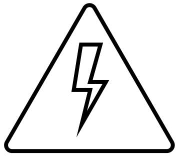
Ouputs

99% Biodiesel to Oil intake

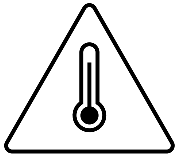
Chemicals (Glycerin) typically 10% of biodiesel produced

Processes – Esterification & Transesterification

ENERGY NEEDS, waste vegetable oils upgrading, 1205.12 kg



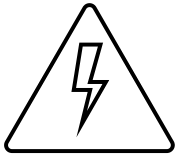
133.12 kWh + 31.43 kWh + 20.34 kWh = 184.89 kWh



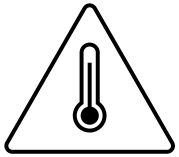
1628.93 MJ + 222.3 MJ + 1650.84 MJ = 3502.07 MJ

Processes – Esterification & Transesterification

CARBON FOOTPRINT ELECTRICITY/ NATURAL GAS



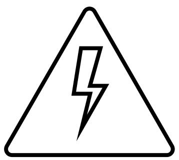
How is generated 1 kWh of electricity?



How is generated locally 1 MJ of heat?

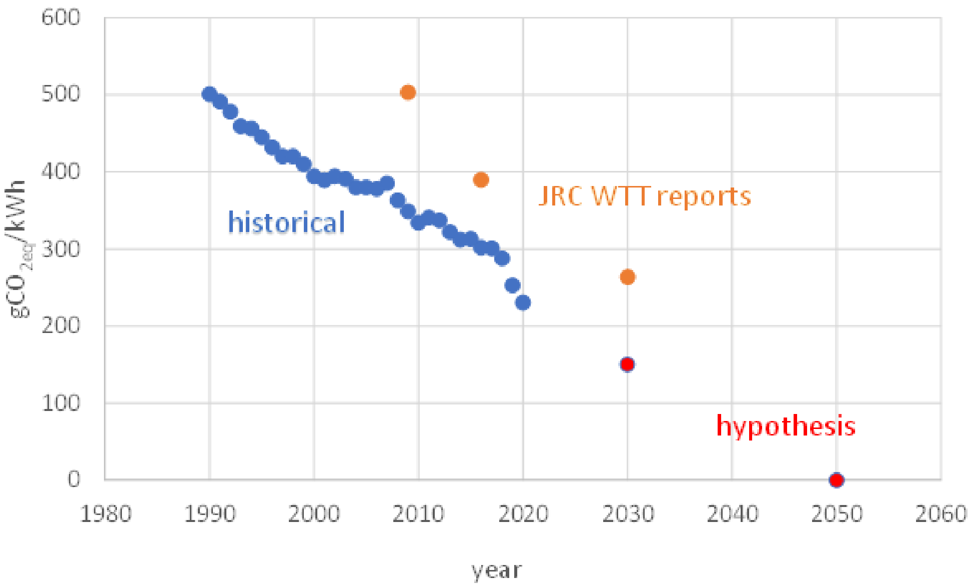
Processes – Esterification & Transesterification

CARBON FOOTPRINT ELECTRICITY



How is generated 1 kWh of electricity?

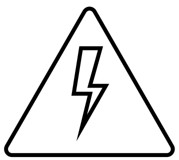
European average context



Prussi, M., Yugo, M., Padella, M., Edwards, R., Lonza, L and De Prada, L., JEC Well-to-Tank report v5: Annexes, Hamje, H., editor, EUR 30269 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21707-7, doi:10.2760/06704, JRC119036.

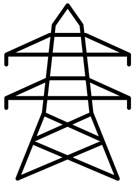
Processes – Esterification & Transesterification

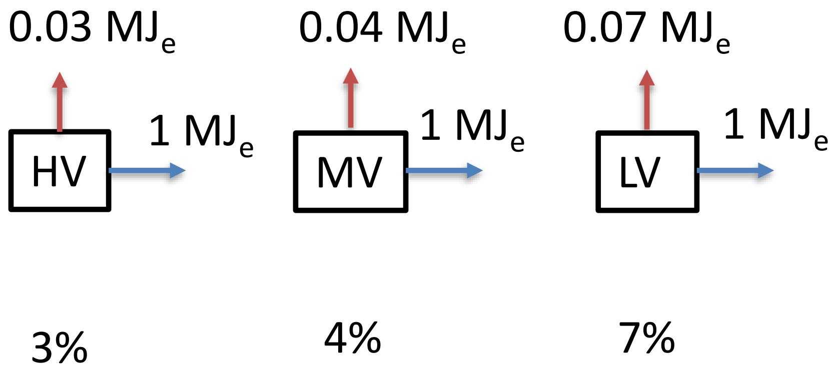
CARBON FOOTPRINT ELECTRICITY



Transmission losses 1 kWh of electricity?

European average context





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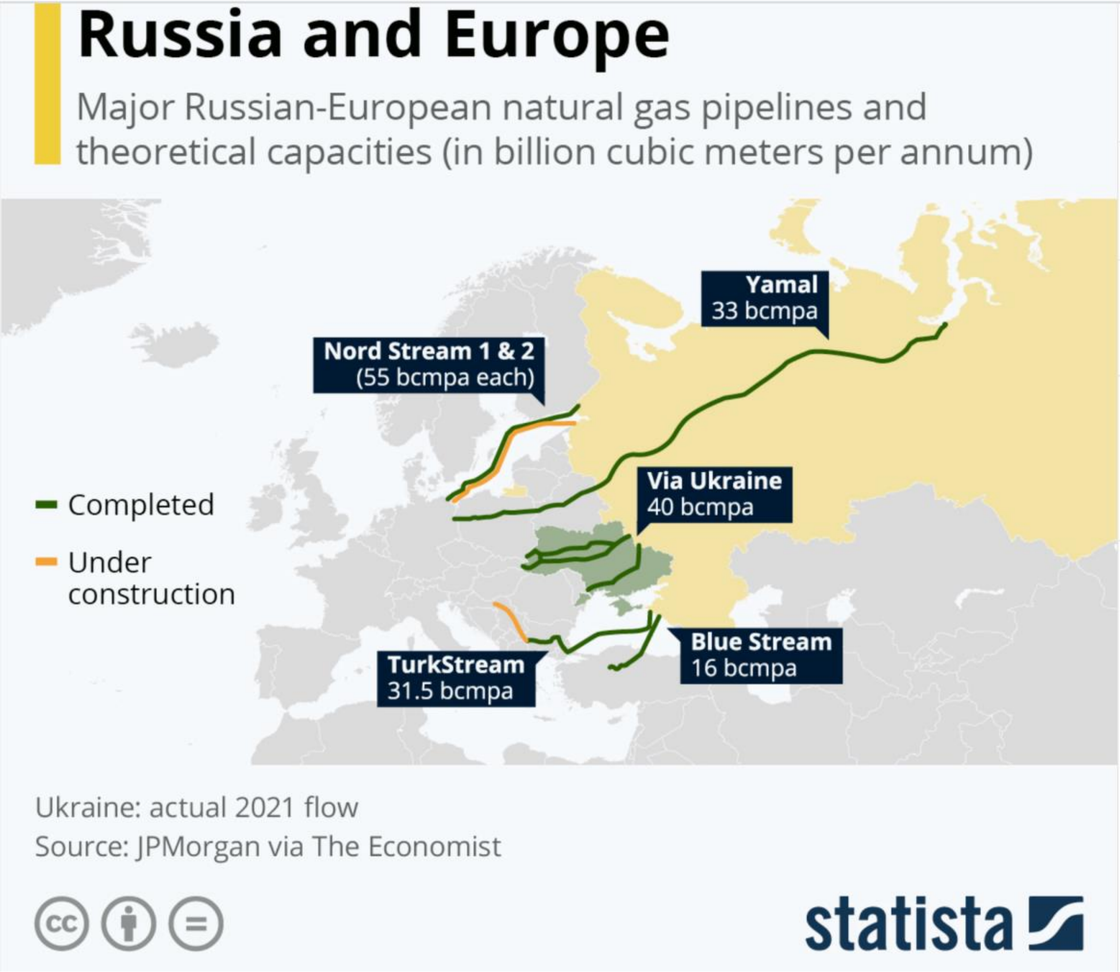
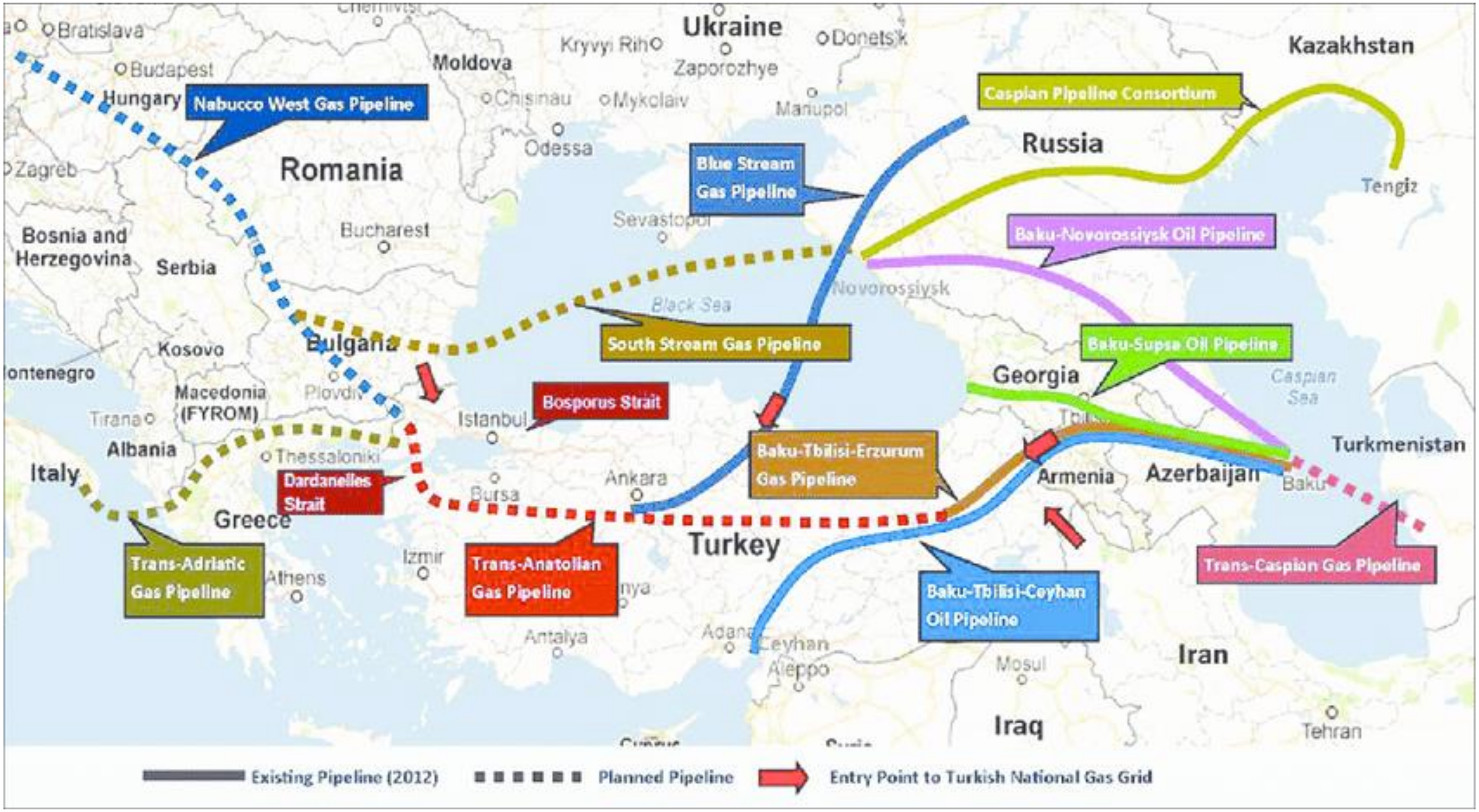
CARBON FOOTPRINT NATURAL GAS



Processes – Esterification & Transesterification

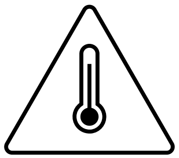
CARBON FOOTPRINT NATURAL GAS



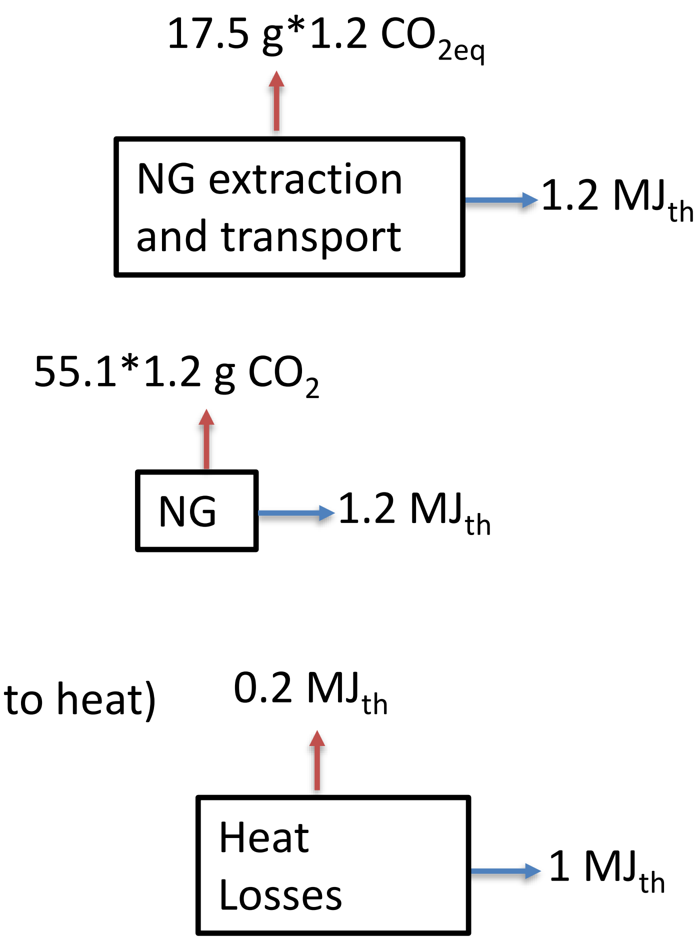
Processes – Esterification & Transesterification

CARBON FOOTPRINT NATURAL GAS

Natural gas from Russia, transport to EU by pipeline (a, 4300 km to EU border and 700 km inside EU)



How is generated locally 1 MJ of heat?



Fossil Natural Gas combustion

LHV = 46.6 MJ/kg

Efficiency = 0.8 (80% energy released converting to heat)

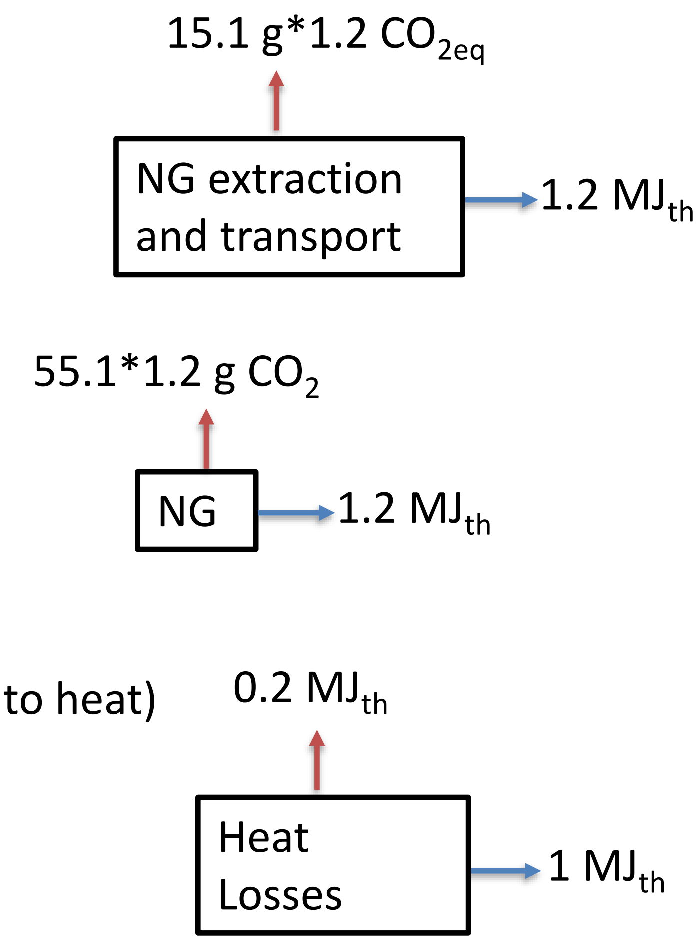
$CO_{2combustion}$ = 55.1 g/MJ

$CO_{2\ upstream\ natural\ gas\ production}$ = 17.5 g /MJ

CARBON FOOTPRINT NATURAL GAS

Southern Asia / Middle East (b, 4000 km), distribution through gas high pressure trunk lines and low pressure grid, compression to CNG at retail point

How is generated locally 1 MJ of heat?



Fossil Natural Gas combustion

LHV = 46.6 MJ/kg

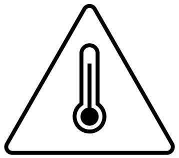
Efficiency = 0.8 (80% energy released converting to heat)

$CO_{2combustion}$ = 55.1 g/MJ

$CO_{2\ \text{upstream natural gas production}}$ = 15.1 g /MJ

Processes – Esterification & Transesterification

CARBON FOOTPRINT NATURAL GAS



How is generated locally 1 MJ of heat?

European average context

		Share NG total 2015	Share piped gas (Except LNG)
Local production	Germany	1.9%	2%
	Denmark	1.0%	1%
	Netherlands	11.7%	13%
	Poland	1.3%	1%
	Hungary	0.4%	0%
	Italy	1.5%	2%
	Romania	2.4%	3%
	UK	9.1%	10%
Transport by pipeline	Russia	30.8%	34%
	Norway	22.4%	25%
	Algeria	5.9%	7%
	Libya	1.7%	2%
LNG transported by marine vessels	Algeria	2.2%	
	Norway	0.7%	
	Nigeria	1.5%	
	Qatar	5.6%	

Source: [IEA 2016] [NVGA/Thinkstep report 2017].

Note. EU mix estimated including UK as part of Europe (figures calculated before *Brexit*).

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Processes – Esterification & Transesterification

2.5.3 Fuel properties

As a summary of the properties of the fuel used for the integration of the Well-To-Wheels pathways and the Tank-To-Wheels ones are detailed in the Table 8:

Table 8. Summary of fuel properties used for the Well-To-Wheels integration (Liquids)

Fuel	Density	RON / CN	LHV	Elemental composition of Carbon	CO_2 emission factor (Fuel combustion Note)	
	kg/m³	---	MJ/kg	%m	g/MJ	kg/kg
Gasoline 2016 (E0)	743	95	43.2	86.4	73.4	3.17
Gasoline 2016 (E5)	746	95	42.3	84.7	73.3	3.10
Gasoline E10	748	95	41.5	82.8	73.3	3.04
Gasoline High Octane. Case 1 (100 RON)	761	100	42.4	84.8	73.3	3.11
Gasoline High Octane. Case 2 (102 RON / E5eq)	759	102	42.4	84.8	73.3	3.11
Gasoline High Octane. Case 3 (102 RON/ E10eq)	759	102	41.6	83.3	73.4	3.05
Pyrolysis-based Naphtha	745	95	43.2	86.4	73.4	3.17
Ethanol	794	108	26.8	52.2	71.4	1.91
Methanol	793	132	19.9	37.5	68.9	1.37
MTBE	745	118	35.1	68.2	71.2	2.50
ETBE	750	119	36.3	70.6	71.3	2.59
Diesel (B0)	832	51	43.1	86.1	73.2	3.16
Pyrolysis-based Diesel	832	51	43.1	86.1	73.2	3.2
Diesel B7 market blend	836	53	42.7	85.4	73.4	3.13
FAME	890	56	37.2	77.3	76.2	2.83
ED95	820	n. a.	25.4	49.4	71.3	1.81
FT Diesel	780	70	44.0	85.0	70.8	3.12
HVO	780	70	44.0	85.0	70.8	3.12
OME	1067	84	19.2	43.5	83.3	1.60

Note) CO_2 emission factor refers to the emissions released during the total combustion (full oxidation) of the carbon contained in the fuel molecules (expressed per MJ (or kg) of a certain fuel burnt). Therefore, the factor is not linked to the production process but to the chemical composition, carbon content, of the fuel itself.

Estimation of CO_2 emissions from fuel combustion for a given fuel can be summarised as follows:

CO_2 emissions from fuel combustion = Fuel consumption * CO_2 Emission factor.

In the case of fuels from biogenic origin (biofuels), the emissions during combustion can be offset (net zero) as the carbon released during combustion is equal to the carbon captured by the plant/tree during its growing process). See Figure 8.

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Processes – Esterification & Transesterification

Table 9. Summary of fuel properties used for the Well-To-Wheels integration (Gases)

Fuel	Density	RON / CN	LHV	Elemental composition of Carbon	CO₂ emission factor (Fuel combustion)	
	kg/ m³i.N.*	---	MJ/kg	%m	g/MJ	kg/ kg
DME (liquefied via pressurisation at 288.15 K)	670	55	28.4	52.2	67.3	1.91
LPG (liquefied via pressurisation at 288.15 K)	550	**	46.0	82.4	65.7	3.02
CNG (EU mix piped NG)	0.780	**	46.6	70.8	56.1	2.60
CNG (2016 Mix)	0.782	**	46.6	71.3	56.2	2.62
CNG (2030 Mix average)	0.782	**	46.8	71.7	56.2	2.63
H-CNG (2016)	0.775	**	48.0	73.5	56.2	2.69
H-CNG (2030)	0.775	**	48.0	73.5	56.2	2.70
CNG (Russian NG quality)	0.727	**	49.2	73.9	55.1	2.71
CNG (upgraded biogas)	0.752	**	46.1	71.3	56.7	2.61
LNG (EU mix. 2016/2030)	0.798	**	49.1	75.6	56.4	2.77
LNG (Upgraded biogas 2016/2030)	0.716	**	50.0	74.9	54.9	2.74
Shale gas	0.727	**	49.2	73.9	55.1	2.71
Hydrogen (CGH2 & cCGH2)	0.090***	#	120.0	0.0	0.0	0.00
Liquid Hydrogen			120.0	0.0	0.0	0.00

Notes:
*) All values are related to standard conditions according to DIN 1343 (0.1013 MPa; 273.15 K) & ISO 2533 (288.15 K);
**) can vary significantly;
***) 0.084 kg/m³ @ 288.15 K (as indicated in the TTW report). The pressure of the CGH2 at the refueling station amounts to 88 MPa. CGH2 is stored in the vehicle at a pressure of maximum 70 MPa at 15°C.
The pressure of the CNG in the stationary CNG storage at the refueling station amounts to 25 MPa. CNG is stored at a pressure of maximum 20 MPa in the vehicle at 15°C.

Additional components:

- AdBlue CO_2 emission factor: 0.24 kg/kg

Prussi, M., Yugo, M., Padella, M., Edwards, R., Lonza, L and De Prada, L., JEC Well-to-Tank report v5: Annexes, Hamje, H., editor, EUR 30269 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21707-7, doi:10.2760/06704, JRC119036.

Processes – Esterification & Transesterification

Table10. Summary ethanol, biodiesel and HVO EU mix

gCO_{2eq}/MJ	2017		2025+
Ethanol - EU mix	52		44
Biodiesel – EU mix	39	37*	39
HVO – EU mix	30		27

* 83% is biodiesel and 17% is HVO on the basis of USDA, 2018

Note. **Appendix 2** describes the assumptions considered for the above estimate.

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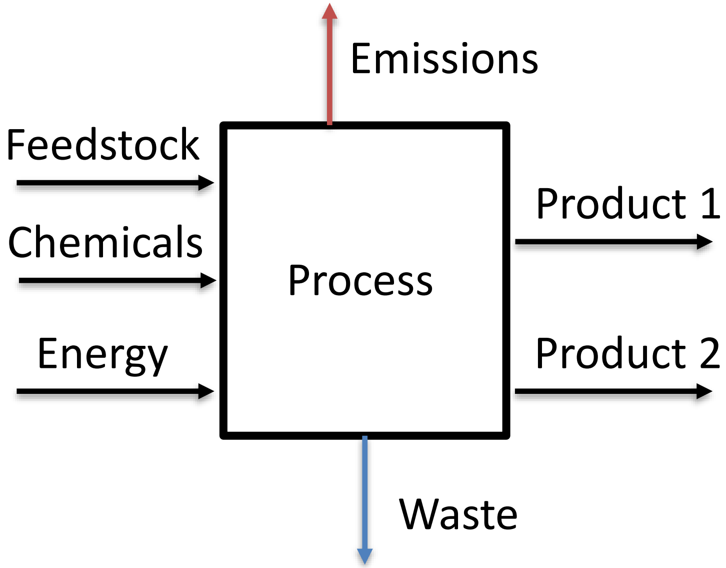
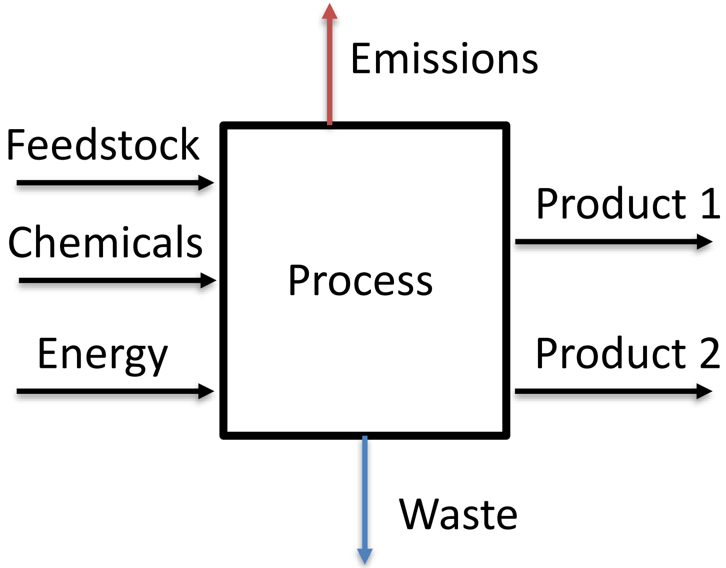
Processes – Esterification & Transesterification

ALLOCATION



Processes – Esterification & Transesterification

ALLOCATION – MASS BASIS

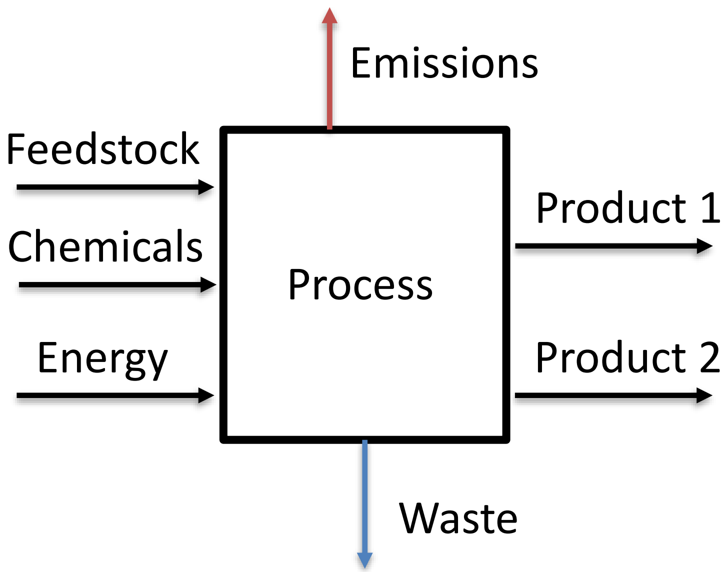


EP1= Emissions*massP1/(massP1+massP2)

EP2= Emissions*massP2/(massP1+massP2)

Processes – Esterification & Transesterification

ALLOCATION – ENERGY BASIS



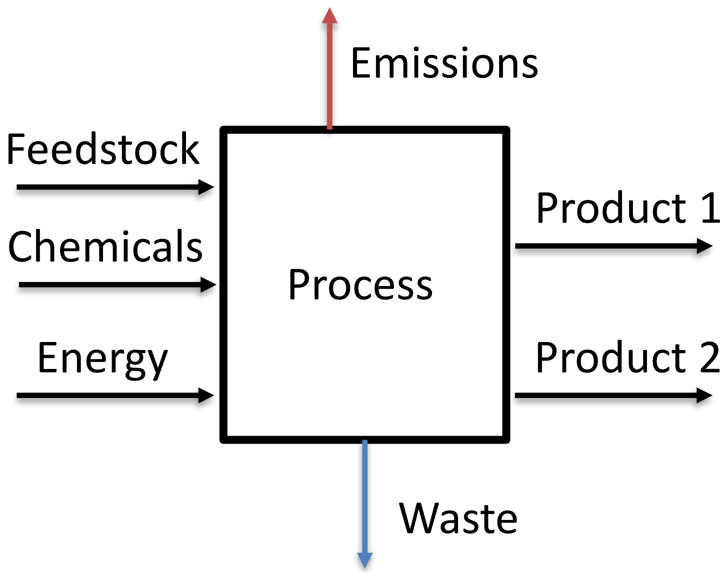
EP1= Emissions*energyP1/(energyP1+energyP2)

EP2= Emissions*energyP2/(energyP1+energyP2)

Energy content based on LHV = Lower Heating Value

Processes – Esterification & Transesterification

ALLOCATION – ECONOMIC BASIS



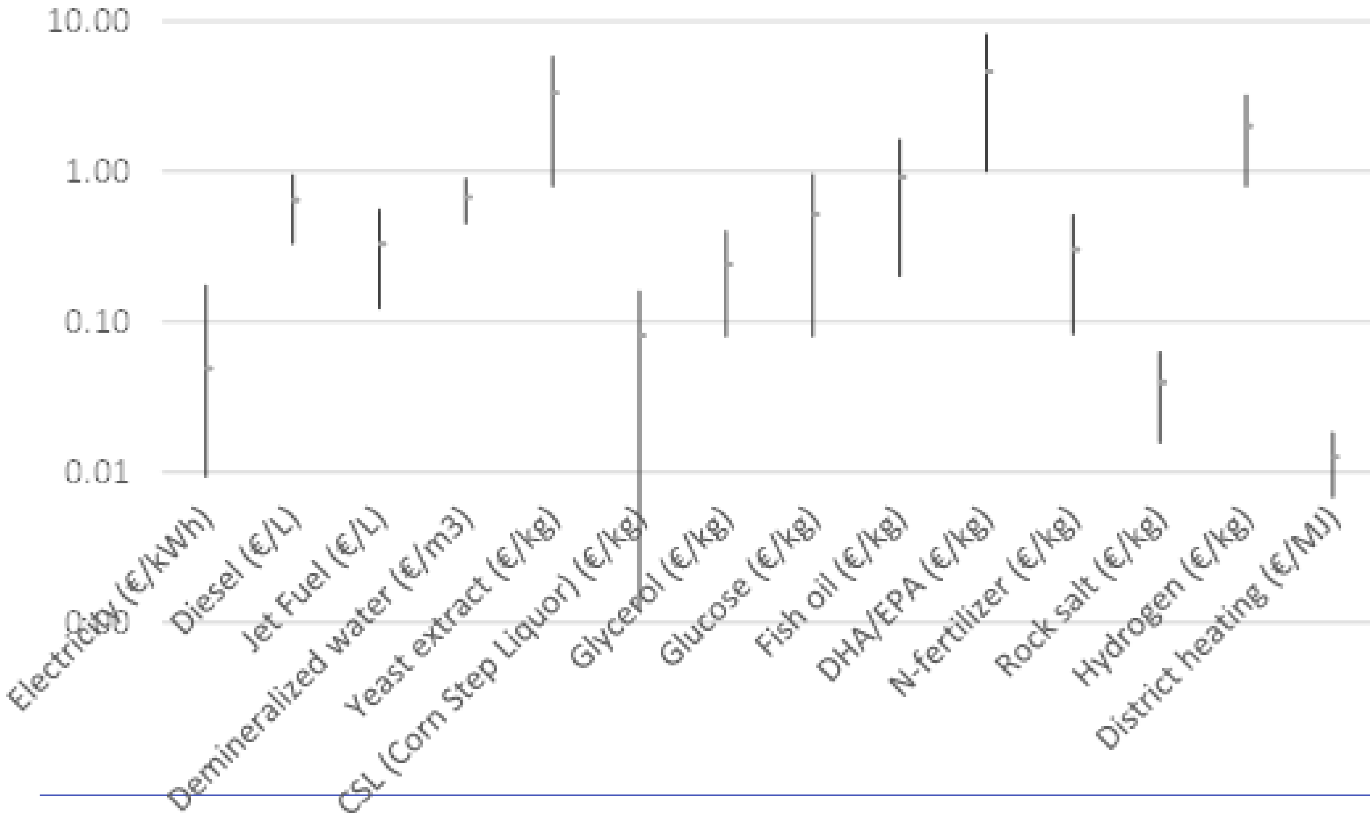
EP1= Emissions*costP1/(costP1+costP2)

EP2= Emissions*costP2/(costP1+costP2)

Processes – Esterification & Transesterification

COST – ECONOMIC BASIS

Cost and price depend on the market….and year

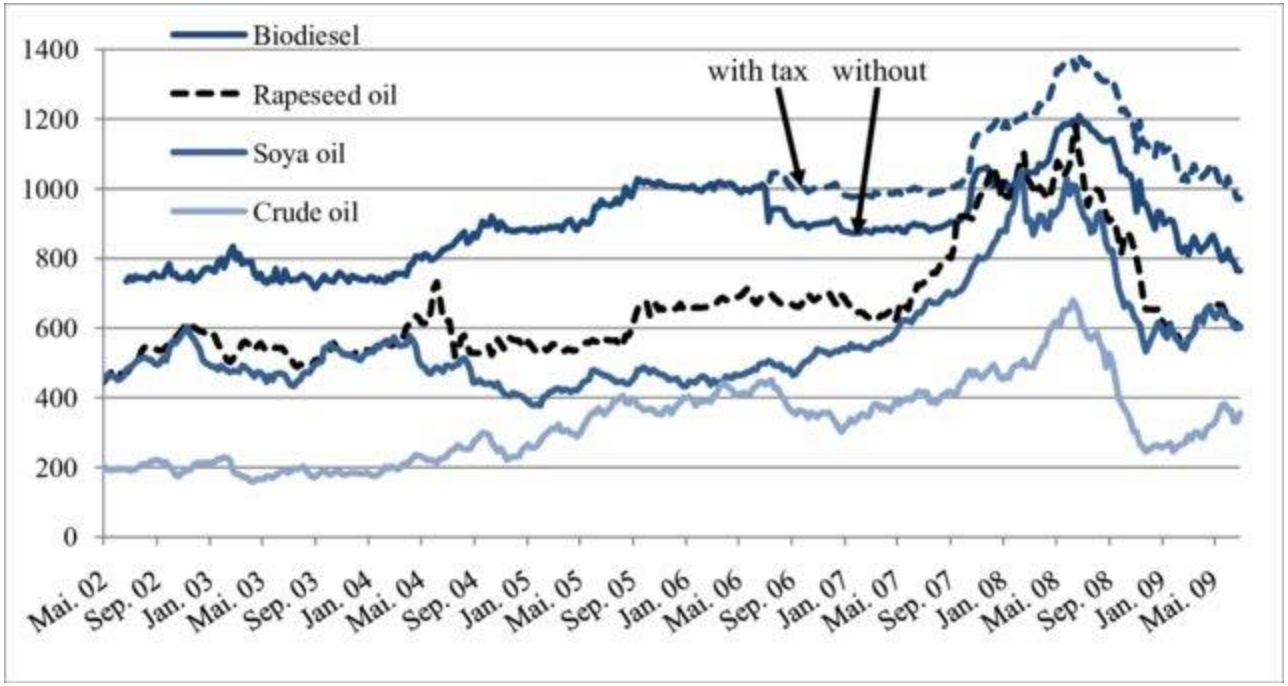


Processes – Esterification & Transesterification

COST – ECONOMIC BASIS

The development of weekly crude oil, biodiesel, rapeseed oil and soya oil prices between July 2002 and July 2009 is depicted in Figure (358 observations in total).

Biodiesel



German biodiesel market

Processes – Esterification & Transesterification

COST – ECONOMIC BASIS

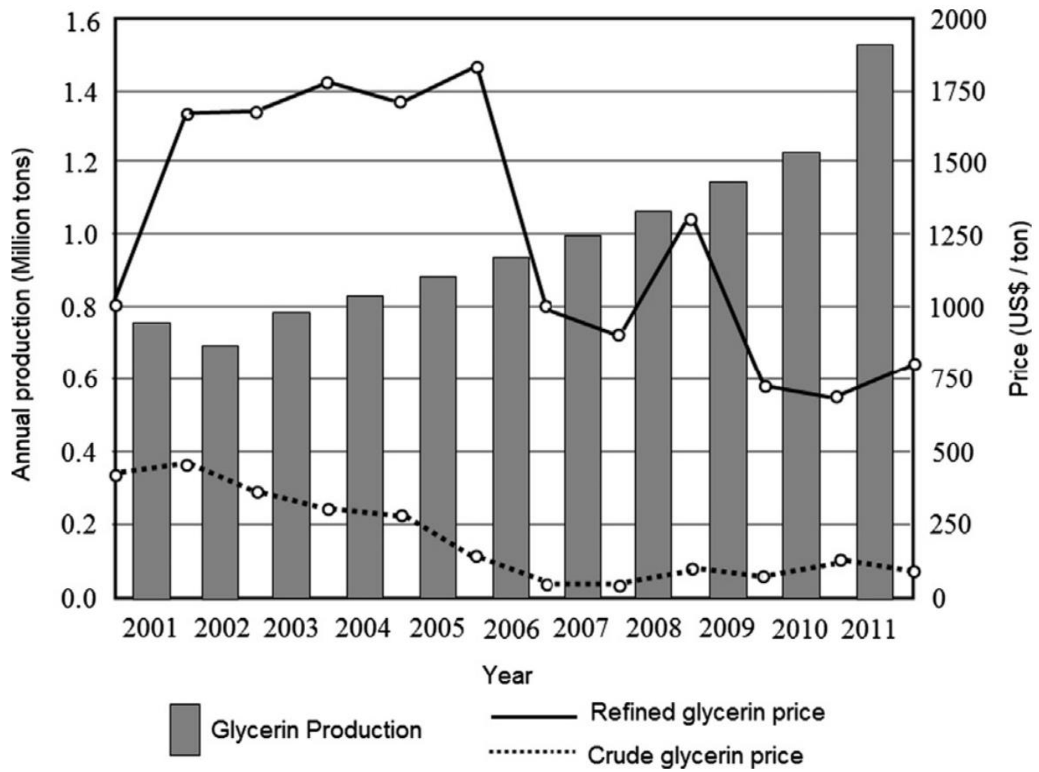


Fig. 3. Projection of global glycerol production and prices.

Glycerin

https://doi.org/10.1016/j.rser.2013.06.017

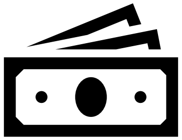
Processes – Esterification & Transesterification

COST – ECONOMIC BASIS

€2020???

Biodiesel 750€2002/ton

Glycerin 400 $2002/ton



Glycerin 400*1.06 €2002/ton

https://www.poundsterlinglive.com/bank-of-england-spot/historical-spot-exchange-rates/usd/USD-to-EUR-2002

Processes – Esterification & Transesterification

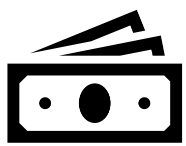
COST – ECONOMIC BASIS

€2020???

Biodiesel 750€2002/ton

Biodiesel 750€*1.3 2020/ton

Glycerin 400*1.06 €2002/ton



Glycerin 400*1.06*1.3 €2020/ton

https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ipc

1€2002 = 1,30267102018347 1€2020

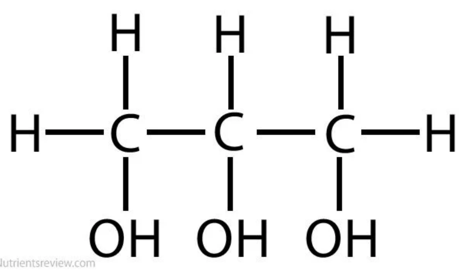
Processes – Esterification & Transesterification

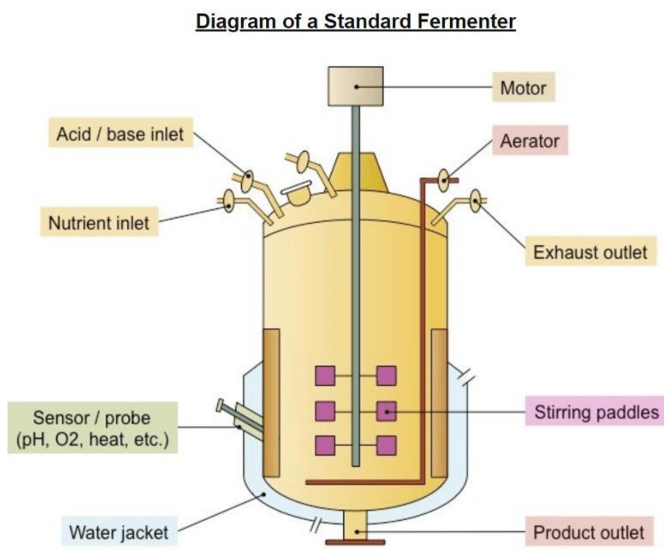
Product 1

Product 2

Biodiesel

Glycerin





Carbon source fermentation

Challenge #2

Observe the input/output inventory for oil upgrading of beef tallow, poultry fat and sewage sludges.

i) Calculate the fossil CO_{2eq} emitted by the energy needs of each process due to energy consumption. a) assume NG from Russia b) due to war assume NG from Middle East

ii) Allocate emissions to biodiesel and glycerin, mass basis, energy basis and economic basis.

Challenge #2

iii) Discuss which biodiesel comes with higher carbon footprint.

iv) If the electricity was provided locally by solar PV how would change the biodiesel carbon footprint? Calculate the new data for biodiesel and glycerin.

Deadline: 23 March

Send: pdf and excel by e-mail camsilva@fc.ul.pt

Thanks

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