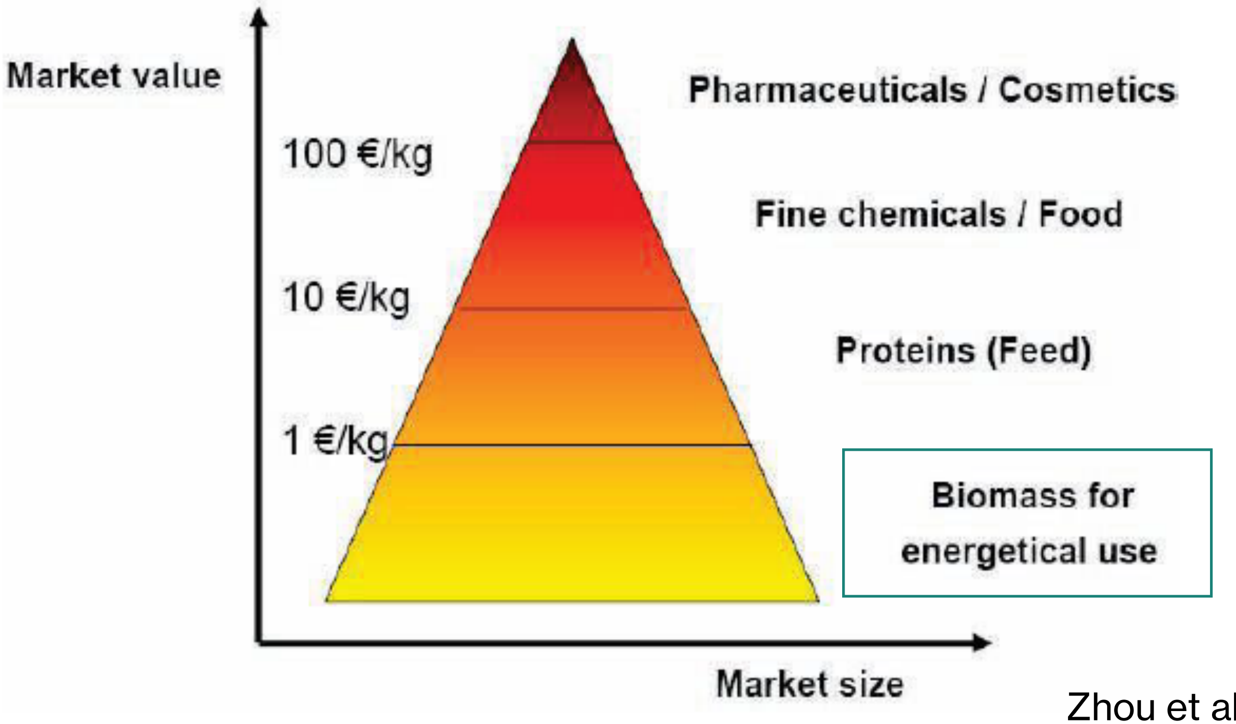
Microalgae

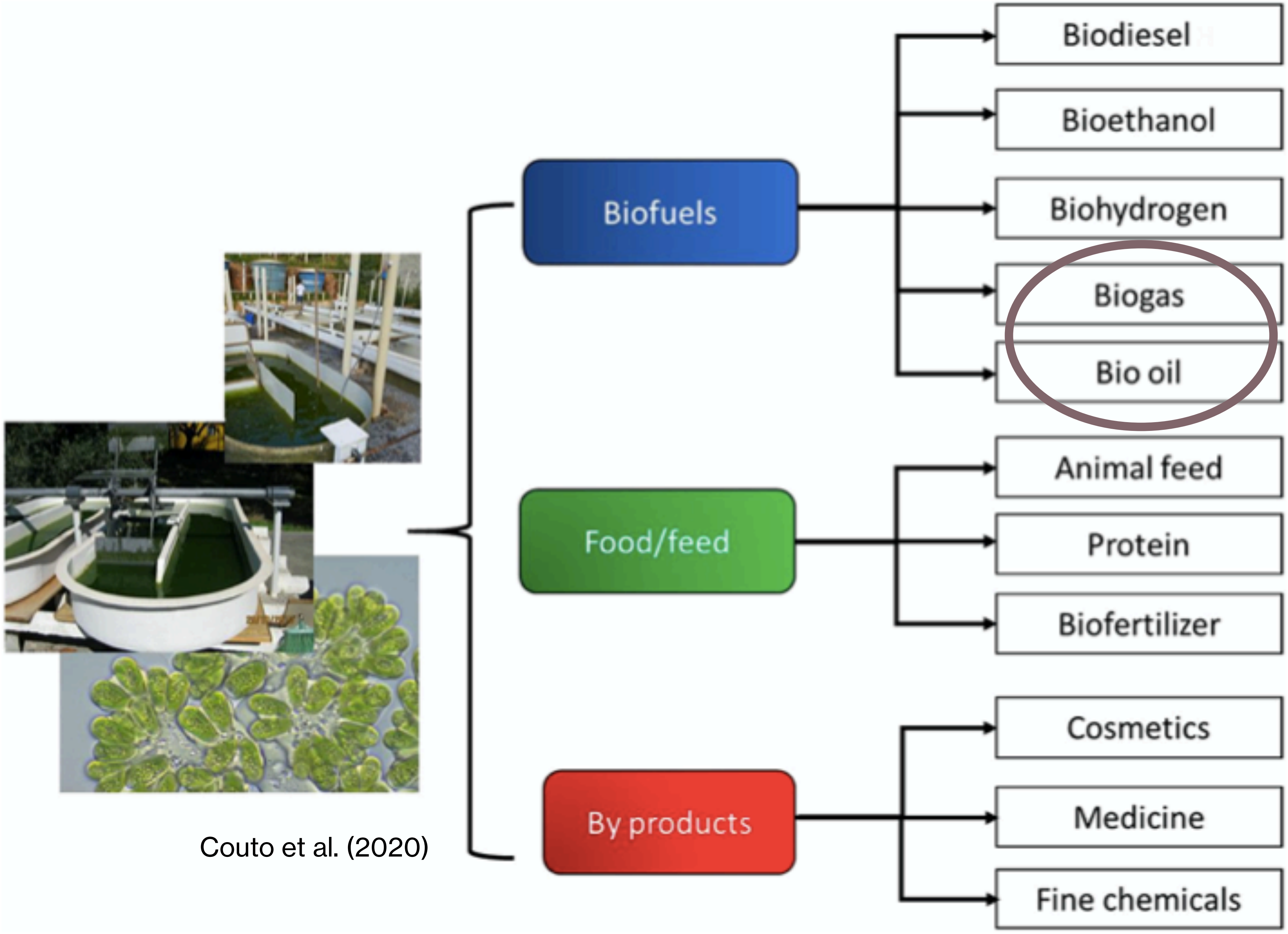
Energy valorization routes

Wastewater grown microalgae biomass for energy purposes

- Biomass composition as a function of specie, growth conditions…
- Low lipid content
- Less noble uses



Zhou et al. (2015)



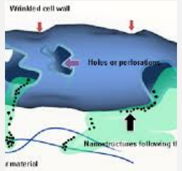
Couto et al. (2020)

Microalgae anaerobic digestion - challenges

Biomass	Methane (m^3/kg VS)
Solid waste	0.2-0.53
Vegetables waste	0.42
Microalgae	0.26
Wood waste	0.20
Corn waste	0.31

Kwietniewska and Tys (2014)

Low C/N ratio: co-digestion



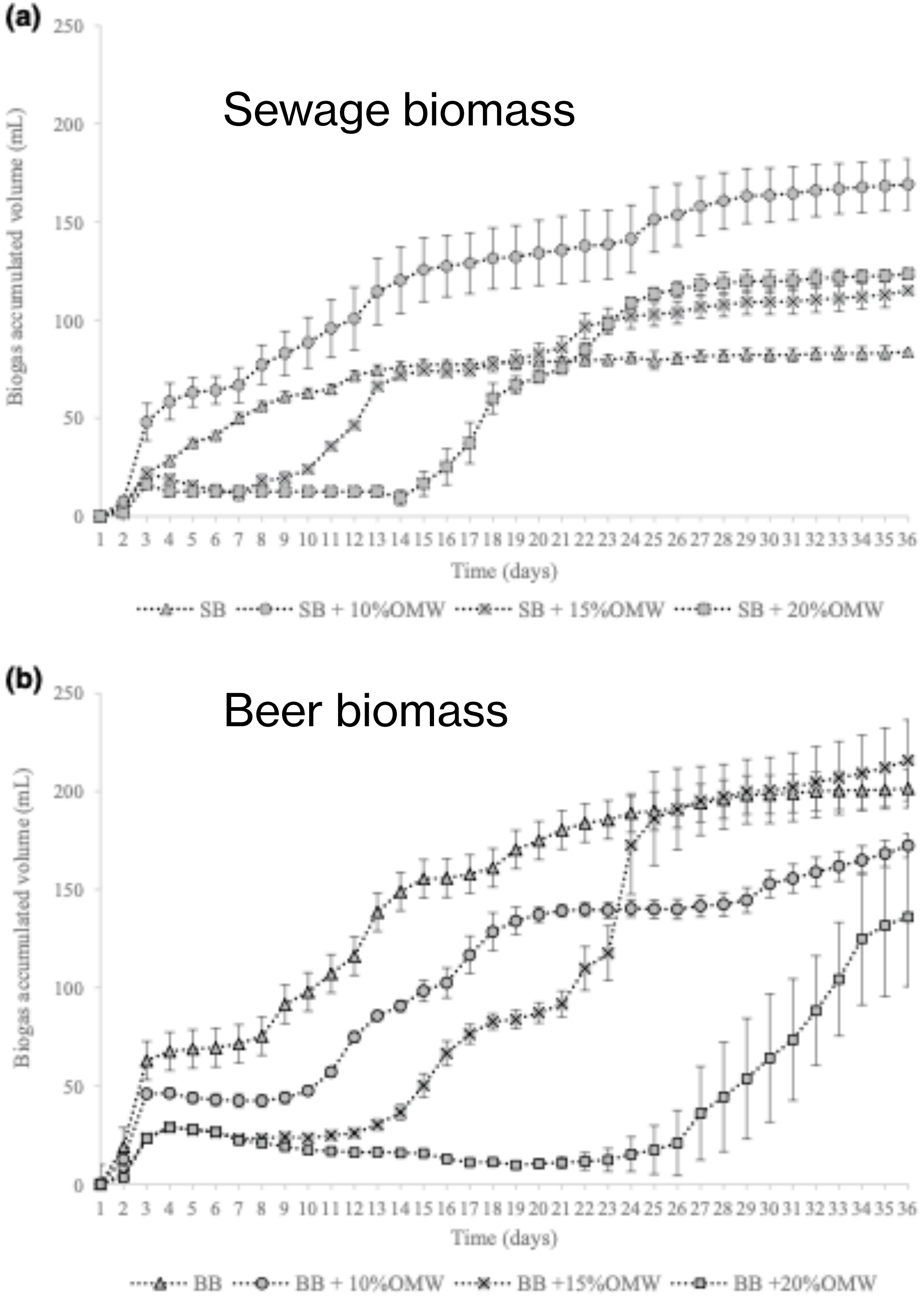
Cell wall: pre-treatment

Table 4
Effect of physical and chemical pre-treatment of wastewater grown microalgae on methane yield during anaerobic digestion (AD).

Pre-treatment method	Operational conditions	Microalgae, cultivation medium	Methane yield (m^3 CH_4/kg VS)	Yield improvement	References
Physical, ultrasound	67 MJ/kg TS, 20 kHz	*Scenedesmus*, *Chlorella*, domestic sewage	0.169	33%	Passos et al., 2014a
Physical, microwave	110,500 kJ/kg VS, 900 W (output power), 3 min (exposure time)	*Monoraphidium* sp., *Stigeoclonium* sp., *Scenedesmus* sp., *Nitzchia* sp. domestic sewage	0.20	60%	Passos et al., 2014c
Physical, microwave	2450 MHz, 700 W (output power), 840 s (exposure time)	Microalgal bacterial flocs, pikeperch aquaculture wastewater	0.19	7%	Van Den Hende et al., 2015
Chemical, acid	Addition of HNO_3 to pH 6.3	Microalgal bacterial flocs, Pikeperch aquaculture wastewater	0.17	34%	Van Den Hende et al., 2015
Chemical, lipid extraction	Addition of H_2SO_4 + lipid extraction	*Scenedesmus* sp., meat processing industry wastewater	2.4[a]	5 times	Assemany et al., 2016
Chemical, lipid extraction	Addition of H_2SO_4 + lipid extraction	*Scenedesmus* sp. *Chlorella vulgaris*, domestic sewage	2.6[a]	10 times	Assemany et al., 2018a, 2018b
Chemical, alkaline	Addition of 4% CaO	*Chlorella* sp. and *Scenedesmus* sp., synthetic wastewater	0.282	19.8%	Solé-Bundó et al., 2017a
Chemical, alkaline	Addition of 10% CaO	*Chlorella* sp. and *Scenedesmus* sp., synthetic wastewater	0.259	14.9%	Solé-Bundó et al., 2017a
Chemical, thermo-alkaline	Addition of 10% CaO + 72 °C	*Chlorella* sp., *Monoraphidium* sp. and diatoms, domestic sewage	0.287	9%	Solé-Bundó et al., 2017b

[a] Biogas yield.

Choudhary et al. (2020)



SB+10%OMW: 0.10 m³ CH_4/kg VS

SB: 0.06 m³ CH_4/kg VS

BB: 0.16 m³ CH_4/kg VS

BB +10% OMW: 0.13 m³ CH_4/kg VS

Assemany et al. (2019)

Anaerobic digestion: next steps

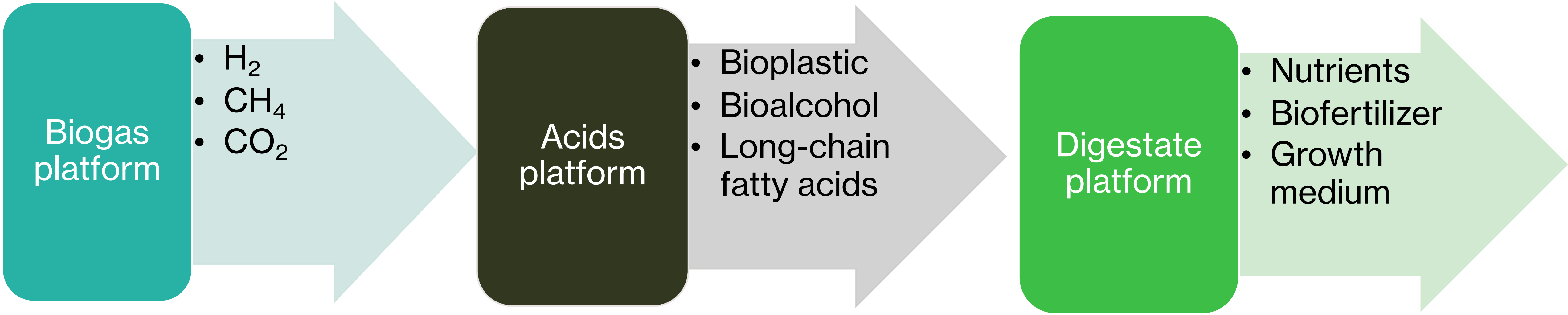
Less energy demand pre-treatment methods

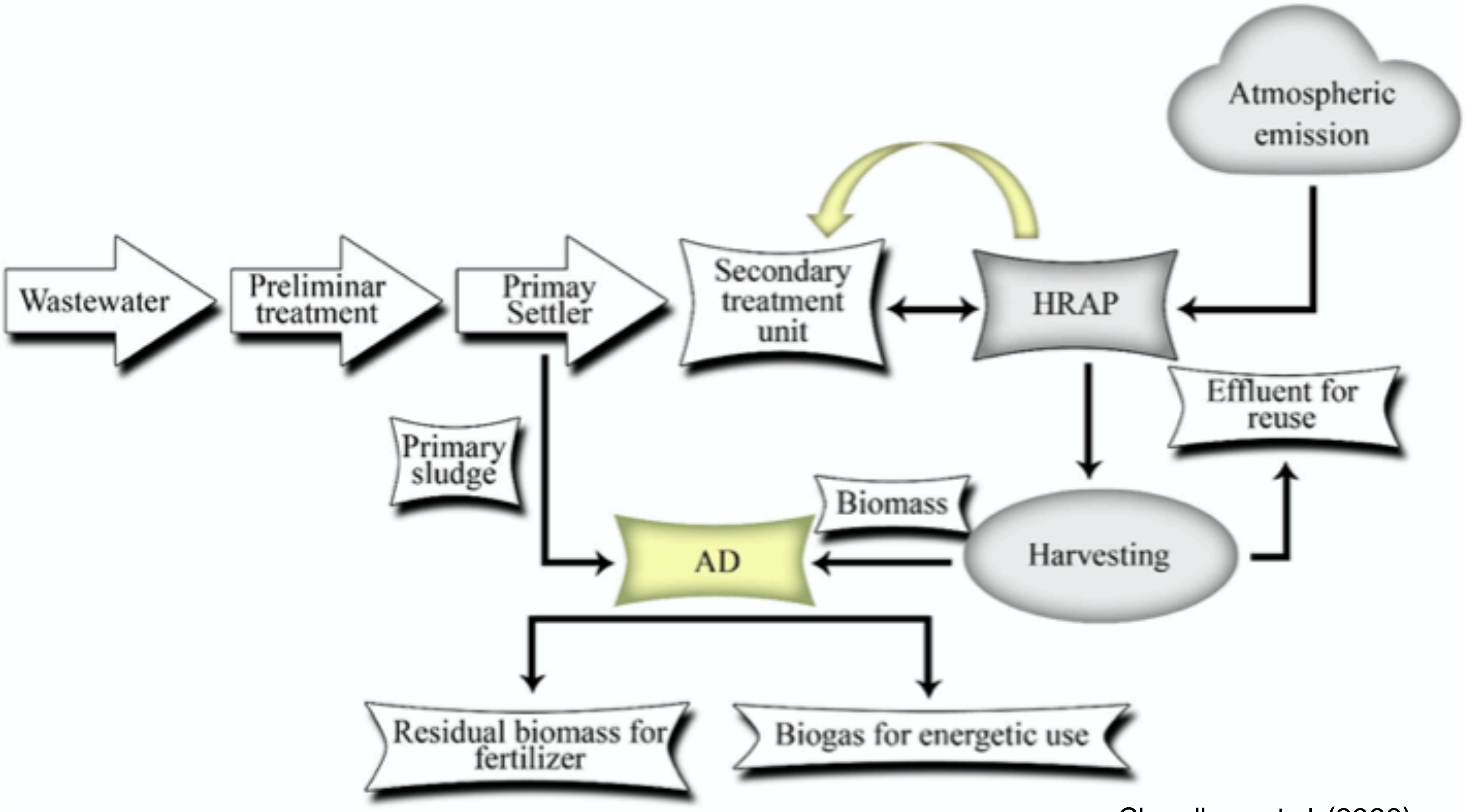
Reactors designed for algal biomass digestion

Full scale

Anaerobic digestion as a biorefinery – new routes, new by-products

Anaerobic digestion as an industrial process





Choudhary et al. (2020)

Hydrothermal carbonization and liquefaction

High ash content

N in the bio-oil

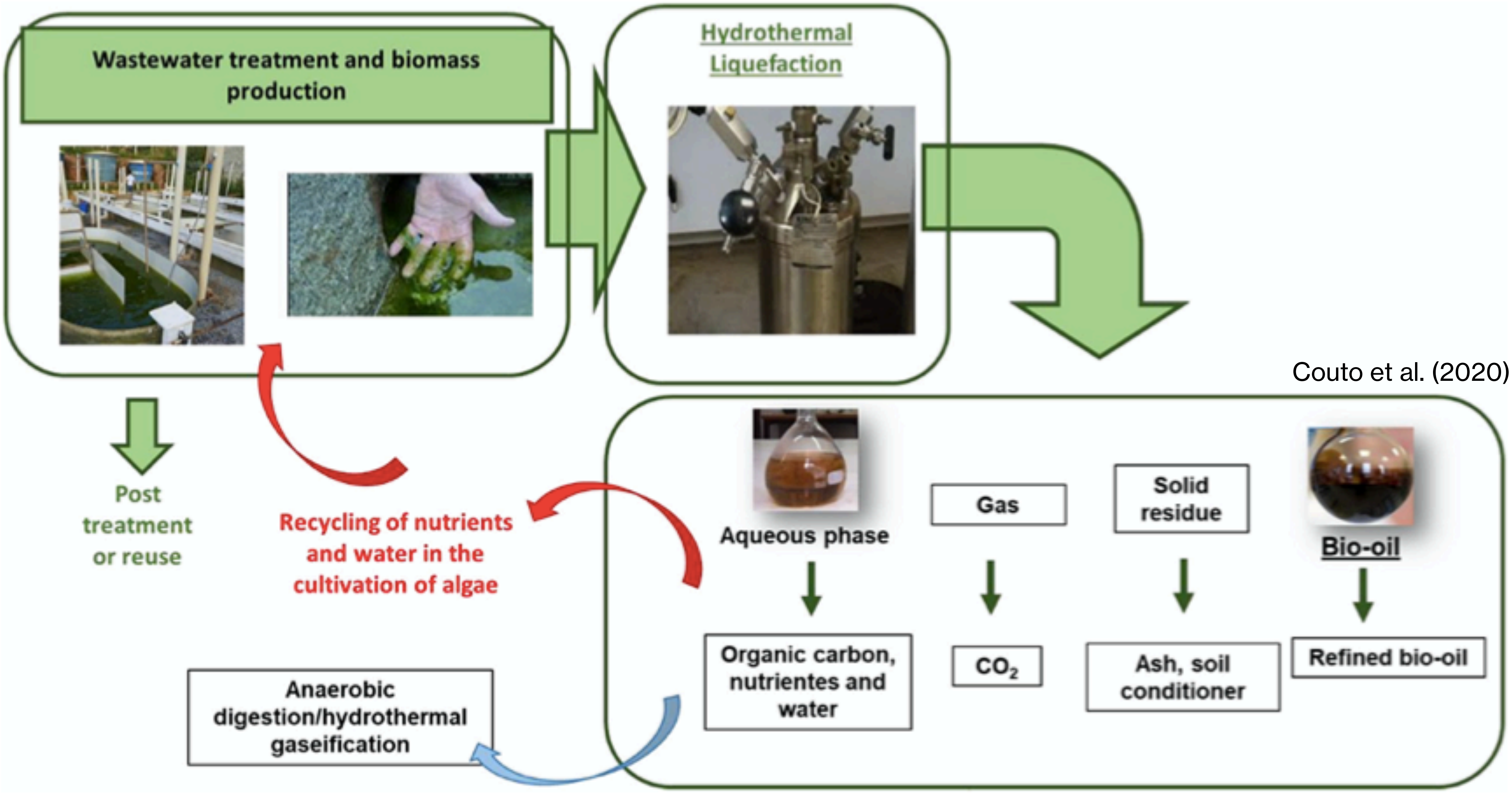
Catalysts

Subproducts valorization

Table 1
Comparative performance of different catalysts for the production of biocrude obtained from HTL of algal biomass grown under varied nutrient medium.

Catalyst	Reaction conditions	Microalgae	Nutrient medium/wastewater	Biocrude yield (%) & HHV (MJ/kg)	Reference
K_2CO_3	T= 200 (°C), P= 2.5 (MPa N_2), t= 20 (min)	A consortium of *Chlorella &Phormidium sp.*	Artificial medium	42.0 & 33.10	Choudhary et al., 2020
		Chlorella &Phormidium	Wastewater		Naaz et al., 2019
Cerium oxide (CeO_2)	T= 250 (°C) ; t= 30 (min)	*Spirulina Platensis*	Artificial medium	26.0 & 27.15	Kandasamy et al., 2020
CaO	T= 320 (°C) ; t= 10 (min)	*Nannochloropsis gaditana*	Commercial source	49.73 & 31.47	Sánchez-Bayo et al., 2020
Pt/C	T= 350 (°C), P=0.3 (MPa H_2), t= 30 (min)	*Chlorella* sp.	Commercial source	37.09 & 29.73	Xu et al., 2019
ZrO_2/SO_4^{-2} , HZSM-5, MgO/MCM-41 KtB	T= 350 (°C); t= 60 (min)	*Dunaliella tertiolecta*	Commercial source	28.0 & 33.24 30.0 & 33.67 35.0 & 33.17 49.0 & 32.36	Chen et al., 2015
K_2CO_3 HZSM-5	T=260-320 (°C); t= 10-40 (min)	*Chlorella vulgaris* *Spirulina* *Raceway biomass*	Anaerobic digestion effluent (ADE) grown (5% conc.)	41.2 27.7 31.4	(Liang et al., 2015)
Ru/C	T= 320-400 (°C); t= 20 (min)	*Nannochloropsis* sp.	Commercial source	45.0 & 38.92	(Xu and Savage, 2015)
Catalyst	**Reaction conditions**	**Microalgae**	**Nutrient medium/wastewater**	**Biocrude yield (%) & HHV (MJ/kg)**	**Reference**
$Co/Mo/Al_2O_3$ $Ni/Al/Al_2O_3$ $Pt/Al/Al_2O_3$	T= 350 (°C); t= 60 (min)	*Chlorella vulgaris* *Nannochloropsis occulta*	Effluent from wastewater treatment plant (WWTP)	38.7 & 39.7 30.0 & 42.0 38.9 & 38.2	(Roberts et al., 2013)
Non-catalytic	T=325 (°C), t=45 (min); P= 12 (MPa)	*Monoraphidium sp.* + domestic sewage sludge (DSS)	Sewage treatment plant effluent	39.38 & 39.47	Mishra and Mohanty, 2020
Non-catalytic	T= 260-320(°C), t=45 (min); P= 12 (MPa)	*Nannochloropsis sp. and Sargassum sp.,*	Fish Park aquarium	39.05-54.11 & 35.92-37.88 3.11-9.49 & 33.63-35.23	He et al., 2020
Non-catalytic	T= 325–350 (°C), P=20 MPa; t= 3-9 (min)	*Galdieria sulphuraria (monoculture & polyculture)*	Municipal wastewater	28.1 & 39	Cheng et al., 2019
Non-catalytic	T= 275-350 (°C), t = 30 (min); P= 0.6-0.8 (MPa)	*Tetraselmis*	Sea-water	26.3-31.0 & 29.5-33.3	Han et al., 2019
Non-catalytic	T= 300 (°C); P= 9 MPa; t= 30 (min)	*Kirchneriella sp.*	Commercial source	45.5 & 37.52	Dandamudi et al., 2019
Non-catalytic	T= 150-300 (°C); t= 60 (min)	Algal consortia *(Pediastrum sp., Micractinium sp., and Desmodesmus sp.)*	Effluent from WWT HRAPs	24.89 & 38.9	(Mehrabadi et al., 2017)

Choudhary et al. (2020)



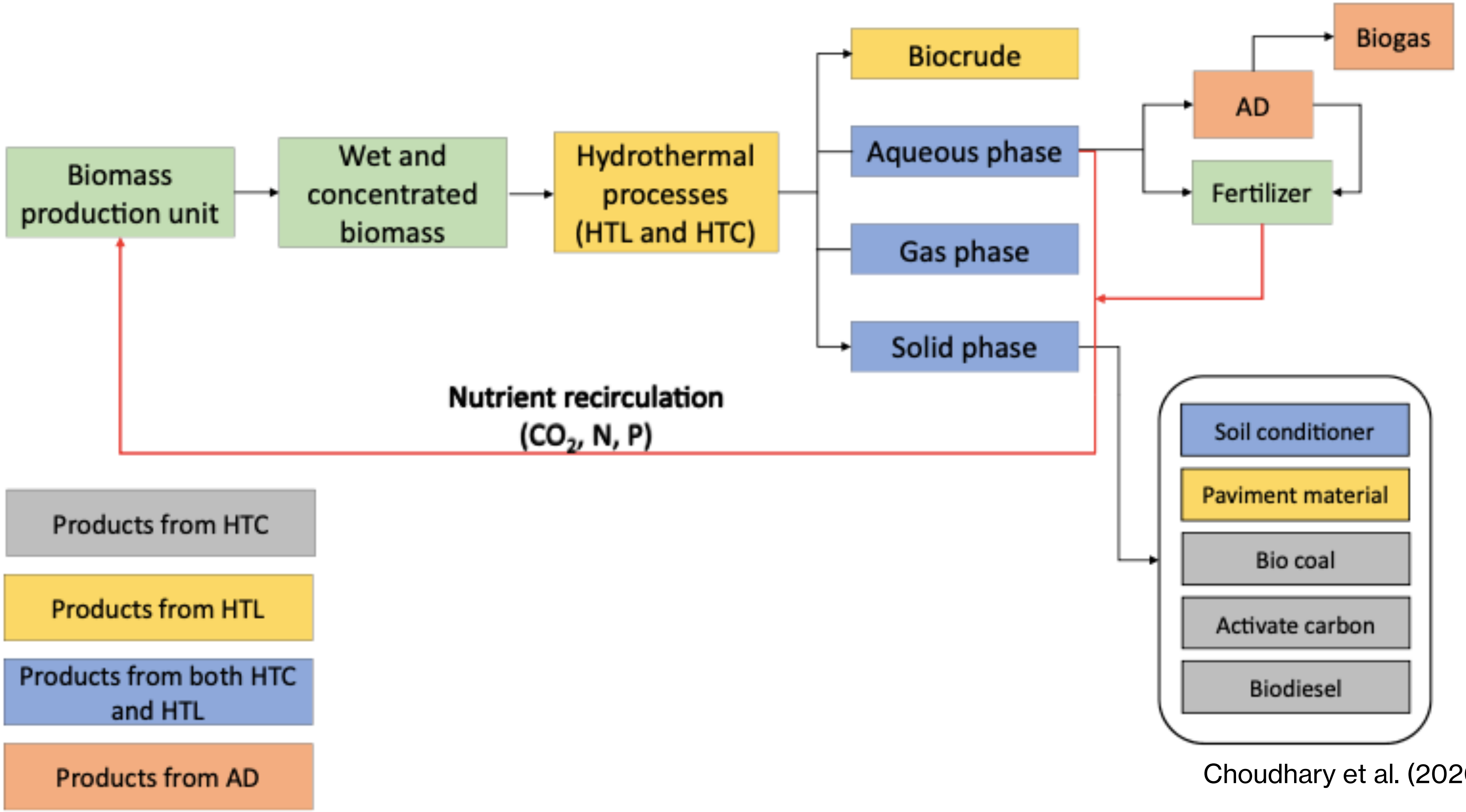
Couto et al. (2020)

Table 2
Studies on hydrothermal carbonization (HTC) of synthetic media grown algal biomass.

Biomass	Reaction conditions	Catalyst	HHV (MJ/kg)	Yield (%)	References
Aphanizomenon flos-aquae – char	213 °C; 120 min	Citric acid	–	16.0	Heilmann et al., 2010
Synechocystis sp. – char	213 °C; 120 min	Citric acid	–	18.0	
Spirulina sp. - char	213 °C; 180 min	Oxalic acid	–	27.0	
Chlorella sp. - char	200 °C; 180 min	Oxalic acid	–	39.5	
Dunaliella salina - char	200 °C; 180 min	Oxalic or acid citric	30.5	36.0	
Chlamydomonas reinhardtii - raw biomass	–	–	18.0	–	Levine et al., 2013
Chlamydomonas reinhardtii - char	200 °C; 120 min	Oxalic acid	31.6	39.0	
Nannochloropsis oculata - raw biomass	–	–	20.6	–	
Nannochloropsis oculata - char	180 °C; 15 min	–	26.3	51.0	
Nannochloropsis oculata - char	180 °C; 30 min	–	26.9	49.0	
Nannochloropsis oculata - char	190 °C; 15 min	–	26.8	51.0	
Nannochloropsis oculata - char	190 °C; 30 min	–	27.1	47.0	
Nannochloropsis oculata - char	200 °C; 15 min	–	27.3	47.0	Levine et al., 2013
Nannochloropsis oculata - char	200 °C; 30 min	–	27.3	44.0	
Nannochloropsis oculata - char	210 °C; 15 min	–	28.0	45.0	
Nannochloropsis oculata - char	210 °C; 30 min	–	28.4	41.0	Bach et al., 2013
Chlorella vulgaris - raw biomass	–	–	22.0[daf]	–	
Chlorella vulgaris - char	160 °C; 10 min	–	23.8[daf]	61.7	
Chlorella vulgaris - char	170 °C; 10 min	–	24.2[daf]	~59.0	
Chlorella vulgaris - char	180 °C; 10 min	–	24.5[daf]	52.6	
Chlorella vulgaris - char	170 °C; 5 min	–	23.6[daf]	62.9	
Chlorella vulgaris – char	170 °C; 30 min	–	26.0[daf]	51.8	
Chlorella vulgaris - raw biomass	–		21.1	–	Ekpo et al., 2016
Chlorella vulgaris - char	250 °C; 60 min	–	14.4	~15.0	
Lipid extracted *Chlorella vulgaris* – raw biomass	–	–	–	–	Lee et al., 2018
Lipid extracted *Chlorella vulgaris* – char	180 °C; 30 min	–	~25.00	74.53	
Lipid extracted *Chlorella vulgaris* – char	200 °C; 30 min	–	~27.00	72.56	
Lipid extracted *Chlorella vulgaris* – char	240 °C; 30 min	–	~23.00	51.84	Lee et al., 2018
Spirulina platensis – raw biomass	190 °C; 60 min	–	21.64	–	Zhao et al., 2019
Spirulina platensis – char	190 °C; 60 min	–	29.63	~30.00	
Chlorella vulgaris - raw biomass	190 °C; 60 min	–	27.00	–	
Chlorella vulgaris - char	190 °C; 60 min	–	20.79	~37.00	

[daf] Dry-ash-free-basis; — indicates that the data was not available.

Choudhary et al. (2020)



Choudhary et al. (2020)

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Thank you!