

Life cycle and techno-economic assessment of bioresource production from wastewater

Supplemental Information

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Supplementary Table 1: Direct Landfill (LF) w/o LFG capture

Parameter	Quantity	Units	Reference
Wet weight of final residues			
TS_f/TS_i	1	Fraction	Assumed
MC_f	80%	Fraction	Assumed
WS_f/TS_i	5.00	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity production
VS_{LF}	80%	%	Zhao et al. 2019
R_{LFG}	0%	%	N/A; No LFG capture
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$ Belt press dewatering to 80% MC	60	kWh/t TS	Hao et al. 2020, Figure 1
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	677	kWh/t TS	Eq. 4
$E_{NG,in}$	0	MMBtu/t TS	N/A; No NG imports
E_{NET}	-876	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	5,000	kg CO ₂ /t TS	Eq. 5 & 9
$TS_{f,LA}/TS_i$	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	0	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}	5332	kg CO ₂ /t TS	Eq. 7
CAPEX			
Belt press dewatering equipment	35,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	35,805	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX	22	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	22.51	USD/t TS (FY 2019)	
TDC	288	USD/t TS	Eq. 15
Revenue from end-products	0	USD/t TS	N/A; Not product sale
Net Operating Profit	-311	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 2: Direct Landfill w/ LFG capture (LF, LFG)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
TS_f/TS_i	1	Fraction	Assumed
MC_f	80%	Fraction	Assumed
WS_f/TS_i	5.00	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity production
VS_{LF}	80%	%	Zhao et al. 2019
R_{LFG}	80%	%	Zhao et al. 2019
E_{LFG}	1,223	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$ Belt press dewatering to 80% MC	60	kWh/t TS	Hao et al. 2020, Figure 1
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	677	kWh/t TS	Eq. 4
$E_{NG,in}$	0	MMBtu/t TS	N/A; No NG imports
E_{NET}	423	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	1,000	kg CO ₂ /t TS	Eq. 5 & 9
$TS_{f,LA}/TS_i$	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	0	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}	826	kg CO ₂ /t TS	Eq. 7
CAPEX			
Belt press dewatering equipment	35,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	35,805	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX	22	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics

OPEX converted to FY 2019	22.51	USD/t TS (FY 2019)	
TDC	288	USD/t TS	Eq. 15
Revenue from end-products	0	USD/t TS	N/A; Not product sale
Net Operating Profit	-311	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	

Supplementary Table 3: Thermal Drying - Landfill (TD-LF)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
TS_f/TS_i	1	Fraction	Assumed
MC_f	50%	Fraction	Assumed
WS_f/TS_i	2.00	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity production
VS_{LF}	80%	%	Zhao et al. 2019
R_{LFG}	0%	%	Zhao et al. 2019
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$ Belt press dewatering to 80% MC	60	kWh/t TS	Hao et al. 2020, Figure 1
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	271	kWh/t TS	Eq. 4
$E_{NG,in}$	2500	kWh/t TS	Hao et al. 2020, Figure 1
$E_{NG,in}$	8.53	MMBtu/t TS	Conversion from kWh to MMBtu
E_{NET}	-3,036	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	5,000	kg CO ₂ /t TS	Eq. 5 & 9
$TS_{f,LA}/TS_i$	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	0	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}	6233	kg CO ₂ /t TS	Eq. 7
CAPEX			
Belt press dewatering equipment	35,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Thermal drying equipment	220,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	255,000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	260,865	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Belt press dewatering to 80% MC	22	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	147	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	169	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	172.89	USD/t TS (FY 2019)	
TDC	115	USD/t TS	Eq. 15
Revenue from end-products	0	USD/t TS	N/A; Not product sale
Net Operating Profit	-288	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	

Supplementary Table 4: Thermal Drying - Landfill w/ Landfill gas collection (TD-LF LFG)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
TS_f/TS_i	1	Fraction	Assumed
MC_f	50%	Fraction	Assumed
WS_f/TS_i	2.00	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity production
VS_{LF}	80%	%	Zhao et al. 2019
R_{LFG}	80%	%	Zhao et al. 2019
E_{LFG}	1,223	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$ Belt press dewatering to 80% MC	60	kWh/t TS	Hao et al. 2020, Figure 1
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	271	kWh/t TS	Eq. 4
$E_{NG,in}$ Thermal Drying	2500	kWh/t TS	Hao et al. 2020, Figure 1
$E_{NG,in}$ Thermal Drying	8.53	MMBtu/t TS	Conversion from kWh to MMBtu
E_{NET}	-1,736	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	1,000	kg CO ₂ /t TS	Eq. 5 & 9

$TS_{f,LA}/TS_i$	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	0	kg CO ₂ /t TS	E. 12
$CO_2e_{disp, fertilizers}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}	1726	kg CO ₂ /t TS	Eq. 7
CAPEX			
Belt press dewatering equipment	35,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Thermal drying equipment	220,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	255,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	260,865	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Belt press dewatering to 80% MC	22	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	147	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	169	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	172.89	USD/t TS (FY 2019)	
TDC	115	USD/t TS	Eq. 15
Revenue from end-products	0	USD/t TS	N/A; Not product sale
Net Operating Profit	-288	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 5: Land Application (LA)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
TS_f/TS_i	1	Fraction	Assumed
MC_f	80%	Fraction	Assumed
WS_f/TS_i	5.00	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity production
VS_{LF}	0%	%	N/A; No landfilled residues
R_{LFG}	0%	%	N/A; No landfilled residues
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$ Belt press dewatering to 80% MC	60	kWh/t TS	Hao et al. 2020, Figure 1
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	677	kWh/t TS	Eq. 4
$E_{NG,in}$ Thermal Drying	0	kWh/t TS	N/A; No NG imports
$E_{NG,in}$ Thermal Drying	0	MMBtu/t TS	Conversion from kWh to MMBtu
E_{NET}	-876	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	0	kg CO ₂ /t TS	Eq. 5 & 9
$TS_{f,LA}/TS_i$	1	Fraction	Assumed
$CO_2e_{N_2O,LA}$	225	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	0	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	130	kg CO ₂ /t TS	Zhao et al. 2019
CO_2e_{NET}	427	kg CO ₂ /t TS	Eq. 7
CAPEX			
Belt press dewatering equipment	35,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	35,805	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Belt press dewatering to 80% MC	22	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	22.51	USD/t TS (FY 2019)	
TDC	288	USD/t TS	Eq. 15
Revenue from end-products	0	USD/t TS	N/A; Not product sale
Net Operating Profit	-311	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 6: Thermal Drying - Land Application (TD-LA)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
TS_f/TS_i	1	Fraction	Assumed
MC_f	50%	Fraction	Assumed
WS_f/TS_i	2.00	Fraction	Eq. 1

Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity production
VS_{LF}	0%	%	N/A; No landfilled residues
R_{LFG}	0%	%	N/A; No landfilled residues
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$ Belt press dewatering to 80% MC	60	kWh/t TS	Hao et al. 2020, Figure 1
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	271	kWh/t TS	Eq. 4
$E_{NG,in}$	2500	kWh/t TS	Hao et al. 2020, Figure 1
$E_{NG,in}$	8.53	MMBtu/t TS	Conversion from kWh to MMBtu
E_{NET}	-3,036	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	0	kg CO ₂ /t TS	Eq. 5 & 9
TS_{fLA}/TS_i	1	Fraction	Assumed
$CO_2e_{N_2O,LA}$	225	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	0	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	130	kg CO ₂ /t TS	Zhao et al. 2019
CO_2e_{NET}	1328	kg CO ₂ /t TS	Eq. 7
CAPEX			
Belt press dewatering equipment	35,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Thermal drying equipment	220,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	255,000	USD/t TS·d (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	260,865	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Belt press dewatering to 80% MC	22	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	147	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	169	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	172.89	USD/t TS (FY 2019)	
TDC	115	USD/t TS	Eq. 15
Revenue from end-products	0	USD/t TS	N/A; Not product sale
Net Operating Profit	-288	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 7: Thermal Drying - Incineration - Landfill (TD-INC-LF)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
TS_f/TS_i	0.1	Fraction	Assumed
MC_f	5%	Fraction	Assumed
WS_f/TS_i	0.11	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	2,072	kWh/t TS	Hao et al. 2020, Figure 1
VS_{LF}	0%	%	Assumed no degradable organic carbon after incineration
R_{LFG}	0%	%	Zhao et al. 2019
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$ Belt press dewatering to 80% MC	60	kWh/t TS	Hao et al. 2020, Figure 1
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	14	kWh/t TS	Eq. 4
$E_{NG,in}$			
Thermal drying	2529	kWh/t TS	Hao et al. 2020, Figure 1 & Section 2.1.3
Heat from Incineration	408	kWh/t TS	Hao et al. 2020, Figure 1 & Section 2.1.3
Net heat import from NG	7.24	MMBtu/t TS	Conversion from kWh to MMBtu
E_{NET}	-126	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	0	kg CO ₂ /t TS	Eq. 5 & 9
TS_{fLA}/TS_i	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	1	Fraction	Assumed
$CO_2e_{N_2O,inc}$	7268	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	0	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}	7362	kg CO ₂ /t TS	Eq. 7
CAPEX			
Belt press dewatering equipment	35,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Thermal drying equipment	220,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3

Incinerator	295,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	550,000	USD/t TS·d (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	562,650	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Belt press dewatering to 80% MC	22	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	147	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Incineration	223	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	392	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	401.02	USD/t TS (FY 2019)	
TDC	6	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	141	USD/t TS	
Net Operating Profit	-266	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 8: Anaerobic Digestion - Combined Heat and Power - Landfill (AD-CHP-LF) w/o LFG capture

Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	80%	Fraction	Hunt et al. 2006
WS _f /TS _i	3.40	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	1284	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	449	kWh/t TS	Calculated
VS _{LF}	48%	%	Calculated from VS reduction in AD
R _{LFG}	0%	%	N/A; No LFG capture
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Gravity thickening	14	kWh/t TS	Hao et al. 2020, Figure 1
Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	74	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	460	kWh/t TS	Eq. 4
E _{NG,in}			
AD Energy input from NG	728	kWh/t TS	Hao et al. 2020, Figure 1
AD energy input from NG	2.48	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	487.92	kWh/t TS	Calculated
NG displaced by heat from biogas	1.66	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	0.82	MMBtu/t TS	Calculated
E _{NET}	-408	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	2,040	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	2198	kg CO ₂ /t TS	Eq. 7
CAPEX			
Gravity Thickening	60000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	370000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering equipment	25,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	455000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	465,465	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Gravity thickening	15	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	29	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	21	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	65	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	66.50	USD/t TS (FY 2019)	
TDC	196	USD/t TS	Eq. 15
Revenue from end-products			

Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	31	USD/t TS	
Net Operating Profit	-232	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	
Supplementary Table 9: Anaerobic Digestion - Combined Heat and Power - Landfill w/ LFG capture (AD-CHP-LF LFG)			
Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	80%	Fraction	Assumed
WS _f /TS _i	3.40	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	1284	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	449	kWh/t TS	Calculated
VS _{LF}	48%	%	Calculated from VS reduction in AD
R _{LFG}	80%	%	Zhao et al. 2019
E _{LFG}	499	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Gravity thickening	14	kWh/t TS	Hao et al. 2020, Figure 1
Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	74	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	460	kWh/t TS	Eq. 4
E _{NG,in}			
AD Energy input from NG	728	kWh/t TS	Hao et al. 2020, Figure 1
AD energy input from NG	2.48	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	487.92	kWh/t TS	Calculated
NG displaced by heat from biogas	1.66	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	0.82	MMBtu/t TS	Calculated
E _{NET}	122	kWh/t TS	Eq. 2
Net CO ₂ e emissions			
CO ₂ e _{LFG,rel}	408	kg CO ₂ /t TS	Eq. 5 & 9
TS _{ELA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	359	kg CO ₂ /t TS	Eq. 7
CAPEX			
Gravity Thickening	60000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	370000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering equipment	25,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	455000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	465,465	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Gravity thickening	15	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	29	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	21	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	65	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	66.50	USD/t TS (FY 2019)	
TDC	196	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	31	USD/t TS	
Net Operating Profit	-232	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	

Supplementary Table 10: Anaerobic Digestion - Combined Heat and Power - Land Application (AD-CHP-LA)			
Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	80%	Fraction	Assumed

WS _f /TS _i	3.40	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	1284	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	449	kWh/t TS	Calculated
VS _{LF}	0%	%	N/A; No landfilled residues
R _{LFG}	0%	%	N/A; No landfilled residues
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Gravity thickening	14	kWh/t TS	Hao et al. 2020, Figure 1
Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	74	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	460	kWh/t TS	Eq. 4
E _{NG,in}			
AD Energy input from NG	728	kWh/t TS	Hao et al. 2020, Figure 1
AD energy input from NG	2.48	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	487.92	kWh/t TS	Calculated
NG displaced by heat from biogas	1.66	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	0.82	MMBtu/t TS	Calculated
E _{NET}	-408	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	0.68	Fraction	Calculated from VS reduction rate
CO ₂ e _{N₂O,LA}	153	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	130	kg CO ₂ /t TS	Zhao et al. 2019
CO ₂ e _{NET}	181	kg CO ₂ /t TS	Eq. 7
CAPEX			
Gravity Thickening	60000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	370000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering equipment	25,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	455000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	465,465	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Gravity thickening	15	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	29	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	21	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	65	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	66.50	USD/t TS (FY 2019)	
TDC	196	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	31	USD/t TS	
Net Operating Profit	-232	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 11: Anaerobic Digestion - Combined Heat and Power - Thermal Drying - Landfill (AD-CHP-TD-LF) w/o LFG capture

Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	50%	Fraction	Assumed
WS _f /TS _i	1.36	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	1284	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	449	kWh/t TS	Calculated
VS _{LF}	48%	%	Calculated from VS reduction in AD
R _{LFG}	0%	%	N/A; No LFG capture
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Gravity thickening	14	kWh/t TS	Hao et al. 2020, Figure 1
Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	74	kWh/t TS	Calculated

E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	184	kWh/t TS	Eq. 4
$E_{\text{NG,in}}$			
AD Energy input from NG	728	kWh/t TS	Hao et al. 2020, Figure 1
AD energy input from NG	2.48	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	488	kWh/t TS	Calculated
NG displaced by heat from biogas	1.66	MMBtu/t TS	Conversion from kWh to MMBtu
TD energy input from NG	2459	kWh/t TS	Hao et al. 2020, Figure 1
TD energy input from NG	8.39	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	9.21	MMBtu/t TS	Calculated
E_{NET}	-2,680	kWh/t TS	Eq. 2
Net CO₂e emissions			
$\text{CO}_2\epsilon_{\text{LFG,rel}}$	2,040	kg CO ₂ /t TS	Eq. 5 & 9
$\text{TS}_{\text{fLA}}/\text{TS}_i$	0	Fraction	N/A; No land-applied residues
$\text{CO}_2\epsilon_{\text{N}_2\text{O,LA}}$	0	kg CO ₂ /t TS	Eq. 10
$\text{TS}_{\text{INC}}/\text{TS}_i$	0	Fraction	N/A; No incinerated residues
$\text{CO}_2\epsilon_{\text{N}_2\text{O,inc}}$	0	kg CO ₂ /t TS	Eq. 11
$\text{CO}_2\epsilon_{\text{disp, fuels}}$	0	kg CO ₂ /t TS	Eq. 12
$\text{CO}_2\epsilon_{\text{disp, fertilizers}}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
$\text{CO}_2\epsilon_{\text{NET}}$	3140	kg CO ₂ /t TS	Eq. 7
CAPEX			
Gravity Thickening	60000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	370000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering equipment	25,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	170,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	625000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	639,375	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Gravity thickening	15	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	29	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	21	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	132	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	197	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	201.53	USD/t TS (FY 2019)	
TDC	78	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	31	USD/t TS	
Net Operating Profit	-249	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 12: Anaerobic Digestion - Combined Heat and Power - Thermal Drying - Landfill w/ LFG capture (AD-CHP-TD-LF LFG)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS_f/TS_i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS_f/TS_i	0.68	Fraction	Calculated from VS reduction in AD
MC_f	50%	Fraction	Assumed
WS_f/TS_i	1.36	Fraction	Eq. 1
Net energy balance			
$E_{\text{elec,out}}$			
Energy from AD biogas	1284	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	449	kWh/t TS	Calculated
VS_{LF}	48%	%	Calculated from VS reduction in AD
R_{LFG}	80%	%	Zhao et al. 2019
E_{LFG}	499	kWh/t TS	Eq. 5 & 6
$E_{\text{elec,in}}$			
Gravity thickening	14	kWh/t TS	Hao et al. 2020, Figure 1
Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	74	kWh/t TS	Calculated
E_{prod}	0	kWh/t TS	N/A; No end products
E_{diesel}	184	kWh/t TS	Eq. 4
$E_{\text{NG,in}}$			
AD Energy input from NG	728	kWh/t TS	Hao et al. 2020, Figure 1
AD energy input from NG	2.48	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	487.92	kWh/t TS	Calculated
NG displaced by heat from biogas	1.66	MMBtu/t TS	Conversion from kWh to MMBtu
TD energy input from NG	2459.00	kWh/t TS	Hao et al. 2020, Figure 1

	TD energy input from NG	8.39	MMBtu/t TS	Conversion from kWh to MMBtu
	Net heat import from NG	9.21	MMBtu/t TS	Calculated
E_{NET}		-2,150	kWh/t TS	Eq. 2
Net CO₂e emissions				
	CO ₂ e _{LFG,rel}	408	kg CO ₂ /t TS	Eq. 5 & 9
	TS _{FLA} /TS _i	0	Fraction	N/A; No land-applied residues
	CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
	TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
	CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
	CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
	CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
	CO ₂ e _{NET}	1301	kg CO ₂ /t TS	Eq. 7
CAPEX				
	Gravity Thickening	60000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
	Anaerobic Digestion	370000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
	Belt press dewatering equipment	25,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
	Thermal drying	170,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
	Total CAPEX	625000	USD/t TS·d (FY 2018)	Calculated
	2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
	CAPEX converted to FY 2019	639,375	USD/t TS·d (FY 2019)	
Net Operating Profit				
	OPEX			
	Gravity thickening	15	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
	Anaerobic Digestion	29	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
	Belt press dewatering	21	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
	Thermal drying	132	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
	Total OPEX	197	USD/t TS (FY 2018)	
	2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
	OPEX converted to FY 2019	201.53	USD/t TS (FY 2019)	
	TDC	78	USD/t TS	Eq. 15
	Revenue from end-products			
	Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
	Revenue from electricity export	31	USD/t TS	
	Net Operating Profit	-249	USD/t TS	Eq. 14
Technology Readiness Level				
	TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 13: Anaerobic Digestion - Combined Heat and Power - Thermal Drying - Land Application (AD-CHP-TD-LA)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	50%	Fraction	Assumed
WS _f /TS _i	1.36	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$			
	Energy from AD biogas	1284	kWh/t TS
	% energy from biogas as electricity	35%	%
	Total electricity export	449	kWh/t TS
VS _{LF}	0%	%	N/A; No landfilled residues
R _{LFG}	0%	%	N/A; No LFG capture
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$			
	Gravity thickening	14	kWh/t TS
	Belt press dewatering	60	kWh/t TS
	Total electricity import	74	kWh/t TS
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	0	kWh/t TS	Eq. 4
$E_{NG,in}$			
	AD Energy input from NG	728	kWh/t TS
	AD energy input from NG	2.48	MMBtu/t TS
	% energy from biogas as useable heat	38%	%
	heat recovery from biogas	487.92	kWh/t TS
	NG displaced by heat from biogas	1.66	MMBtu/t TS
	TD energy input from NG	2459.00	kWh/t TS
	TD energy input from NG	8.39	MMBtu/t TS
	Net heat import from NG	9.21	MMBtu/t TS
E_{NET}	-2,680	kWh/t TS	Eq. 2
Net CO₂e emissions			
	CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS
	TS _{FLA} /TS _i	0.68	Fraction
	CO ₂ e _{N2O,LA}	153	kg CO ₂ /t TS
	TS _{INC} /TS _i	0	Fraction

CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	130	kg CO ₂ /t TS	Zhao et al. 2019
CO ₂ e _{NET}	1122	kg CO ₂ /t TS	Eq. 7
CAPEX			
Gravity Thickening	60000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	370000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering equipment	25,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	170,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	625000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	639,375	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Gravity thickening	15	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	29	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	21	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	132	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	197	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	201.53	USD/t TS (FY 2019)	
TDC	78	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	31	USD/t TS	
Net Operating Profit	-249	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	
Supplementary Table 14: Anaerobic Digestion - Combined Heat and Power - Thermal Drying - Incineration - Landfill (AD-CHP-TD-INC-LF) w/o LFG capture			
Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _{INC} /TS _i	0.68	Fraction	Calculated from VS reduction in AD
TS _f /TS _i	0.1	Fraction	Assumed
MC _f	5%	Fraction	Assumed
WS _f /TS _i	0.11	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	1284	kWh/t TS	Hao et al. 2020, Figure 1
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Electricity export from biogas	449	kWh/t TS	Calculated
Total usable energy from incineration	1,653	kWh/t TS	Hao et al. 2020, Figure 1
% of usable energy as electricity	84%	%	Hao et al. 2020, Section 2.1.3
Electricity export from incineration	1,381	kWh/t TS	Calculated
Total electricity export	1,830	kWh/t TS	Calculated
VS _{LF}	0%	%	Assumed no degradable organic carbon after incineration
R _{LFG}	0%	%	N/A; No LFG capture
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Gravity thickening	14	kWh/t TS	Hao et al. 2020, Figure 1
Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	74	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	14	kWh/t TS	Eq. 4
E _{NG,in}			
AD Energy input from NG	728	kWh/t TS	Hao et al. 2020, Figure 1
AD energy input from NG	2.48	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	488	kWh/t TS	Calculated
NG displaced by heat from biogas	1.66	MMBtu/t TS	Conversion from kWh to MMBtu
% of usable energy from incineration as heat	16%	%	Hao et al. 2020, Section 2.1.3
Usable heat from incineration	272	kWh/t TS	Calculated
NG displaced by heat from incineration	0.93	MMBtu/t TS	Conversion from kWh to MMBtu
TD energy input from NG	2459	kWh/t TS	Hao et al. 2020, Figure 1
TD energy input from NG	8.39	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	8.28	MMBtu/t TS	Calculated
E _{NET}	-721	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{ELA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0.68	Fraction	Calculated from VS reduction rate

CO ₂ e _{N2O,inc}	4942	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	5275	kg CO ₂ /t TS	Eq. 7
CAPEX			
Gravity Thickening	60000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	370000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	25,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	170,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Incineration	235,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	860000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	879,780	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Gravity thickening	15	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	29	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	21	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Thermal drying	132	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Incineration	201	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	398	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	407.15	USD/t TS (FY 2019)	
TDC	6	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	125	USD/t TS	
Net Operating Profit	-289	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	

Supplementary Table 15: Thermal Hydrolysis - Anaerobic Digestion - Combined Heat and Power - Landfill (TH-AD-CHP-LF) w/o LFG capture

Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	80%	Fraction	Assumed
WS _f /TS _i	3.40	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	2130	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	746	kWh/t TS	Calculated
VS _{LF}	48%	%	Calculated from VS reduction in AD
R _{LFG}	0%	%	N/A; No LFG capture
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Belt press dewatering phase I	60	kWh/t TS	Hao et al. 2020, Figure 1
Belt press dewatering phase II	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	120	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	460	kWh/t TS	Eq. 4
E _{NG,in}			
TH Energy input from NG	1278	kWh/t TS	Hao et al. 2020, Figure 1
TH energy input from NG	4.36	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	809	kWh/t TS	Calculated
NG displaced by heat from biogas	2.76	MMBtu/t TS	Conversion from kWh to MMBtu
heat recovered from TH heat exchanger	426	kWh/t TS	Hao et al. 2020, Figure 1
NG displaced by heat from TH heat exchanger	1.45	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	0.15	MMBtu/t TS	Calculated
E _{NET}	67	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	2,040	kg CO ₂ /t TS	Eq. 5 & 9
TS _{ELA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	2009	kg CO ₂ /t TS	Eq. 7
CAPEX			
Thermal Hydrolysis	300000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	320000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3

Belt press dewatering equipment	10,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	630000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	644,490	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Thermal Hydrolysis	119	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	23	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	18	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	160	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	164	USD/t TS (FY 2019)	
TDC	196	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	51	USD/t TS	
Net Operating Profit	-309	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9		Actual system "proven" through successful system and/or mission operations

Supplementary Table 16: Thermal Hydrolysis - Anaerobic Digestion - Combined Heat and Power - Landfill w/ LFG capture (TH-AD-CHP-LF LFG)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _i /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	80%	Fraction	Assumed
WS _f /TS _i	3.40	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	2130	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	746	kWh/t TS	Calculated
VS _{LF}	48%	%	Calculated from VS reduction in AD
R _{LFG}	80%	%	Zhao et al. 2019
E _{LFG}	499	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Belt press dewatering phase I	60		
Belt press dewatering phase II	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	120	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	460	kWh/t TS	Eq. 4
E _{NG,in}			
TH Energy input from NG	1278	kWh/t TS	Hao et al. 2020, Figure 1
TH energy input from NG	4.36	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	809	kWh/t TS	Calculated
NG displaced by heat from biogas	2.76	MMBtu/t TS	Conversion from kWh to MMBtu
heat recovered from TH heat exchanger	426	kWh/t TS	Hao et al. 2020, Figure 1
NG displaced by heat from TH heat exchanger	1.45	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	0.15	MMBtu/t TS	Calculated
E _{NET}	597	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	408	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	170	kg CO ₂ /t TS	Eq. 7
CAPEX			
Thermal Hydrolysis	300000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	320000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering equipment	10,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	630000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	644,490	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Thermal Hydrolysis	119	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	23	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	18	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	160	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	163.68	USD/t TS (FY 2019)	

TDC	196	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	51	USD/t TS	
Net Operating Profit	-309	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	

Supplementary Table 17: Thermal Hydrolysis - Anaerobic Digestion - Combined Heat and Power - Land application (TH-AD-CHP-LA)

Parameter	Quantity	Units	Reference
Wet weight of final residues			
VS _f /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _f /TS _i	0.68	Fraction	Calculated from VS reduction in AD
MC _f	80%	Fraction	Assumed
WS _f /TS _i	3.40	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	2130	kWh/t TS	Hao et al. 2020, Table S3
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Total electricity export	746	kWh/t TS	Calculated
VS _{LF}	0%	%	N/A; No landfilled residues
R _{LFG}	0%	%	N/A; No landfilled residues
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Belt press dewatering phase I	60		
Belt press dewatering phase II	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	120	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	460	kWh/t TS	Eq. 4
E _{NG,in}			
TH Energy input from NG	1278	kWh/t TS	Hao et al. 2020, Figure 1
TH energy input from NG	4.36	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	350	kWh/t TS	Calculated
NG displaced by heat from biogas	1.20	MMBtu/t TS	Conversion from kWh to MMBtu
heat recovered from TH heat exchanger	426	kWh/t TS	Hao et al. 2020, Figure 1
NG displaced by heat from TH heat exchanger	1.45	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	1.71	MMBtu/t TS	Calculated
E _{NET}	-419	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{LLA} /TS _i	0.68	Fraction	Calculated from VS reduction rates
CO ₂ e _{N2O,LA}	153	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	130	kg CO ₂ /t TS	Zhao et al. 2019
CO ₂ e _{NET}	191	kg CO ₂ /t TS	Eq. 7
CAPEX			
Thermal Hydrolysis	300000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	320000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering equipment	10,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	630000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	644,490	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Thermal Hydrolysis	119	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	23	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	18	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	160	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	164	USD/t TS (FY 2019)	
TDC	196	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	51	USD/t TS	
Net Operating Profit	0	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	9	Actual system "proven" through successful system and/or mission operations	

Supplementary Table 18: Thermal Hydrolysis - Anaerobic Digestion - Combined Heat and Power - Thermal Drying - Incineration - Landfill (TH-AD-CHP-TD-INC-LF) w/o LFG capture

Parameter	Quantity	Units	Reference
Wet weight of final residues			

VS _i /TS _i	0.8	Fraction	Zhao et al. 2019, Table S15
VS reduction rate	0.6	Fraction	Zhao et al. 2019, Table S15
TS _{INC} /TS _i	0.68	Fraction	Calculated from VS reduction in AD
TS _f /TS _i	0.1	Fraction	Assumed
MC _f	5%	Fraction	Assumed
WS _f /TS _i	0.11	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Energy from AD biogas	2130	kWh/t TS	Hao et al. 2020, Figure 1
% energy from biogas as electricity	35%	%	Hunt et al. 2006
Electricity export from biogas	746	kWh/t TS	Calculated
Total usable energy from incineration	1,111	kWh/t TS	Hao et al. 2020, Figure 1
% of usable energy as electricity	84%	%	Hao et al. 2020, Section 2.1.3
Electricity export from incineration	928	kWh/t TS	Calculated
Total electricity export	1,674	kWh/t TS	Calculated
VS _{LF}	0%	%	Assumed no organic carbon remains after incineration
R _{LFG}	0%	%	N/A; No landfilled residues
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Belt press dewatering phase I	60		
Belt press dewatering phase II	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	120	kWh/t TS	Calculated
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	14	kWh/t TS	Eq. 4
E _{NG,in}			
TH Energy input from NG	1278	kWh/t TS	Hao et al. 2020, Figure 1
TH energy input from NG	4.36	MMBtu/t TS	Conversion from kWh to MMBtu
% energy from biogas as useable heat	38%	%	Hunt et al. 2006
heat recovery from biogas	809	kWh/t TS	Calculated
NG displaced by heat from biogas	2.76	MMBtu/t TS	Conversion from kWh to MMBtu
heat recovered from TH heat exchanger	426	kWh/t TS	Hao et al. 2020, Figure 1
NG displaced by heat from TH heat exchanger	1.45	MMBtu/t TS	Conversion from kWh to MMBtu
% of usable energy from incineration as heat	16%	%	Hao et al. 2020, Section 2.1.3
Usable heat from incineration	183	kWh/t TS	Calculated
NG displaced by heat from incineration	0.62	MMBtu/t TS	Conversion from kWh to MMBtu
TD energy input from NG	2153	kWh/t TS	Hao et al. 2020, Figure 1
TD energy input from NG	7.35	MMBtu/t TS	Conversion from kWh to MMBtu
Incineration energy input from NG	429	kWh/t TS	Hao et al. 2020, Figure 1
Incineration energy input from NG	1.46	MMBtu/t TS	Conversion from kWh to MMBtu
Net heat import from NG	8.33	MMBtu/t TS	Calculated
E _{NET}	-952	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	0.00	Fraction	N/A; No land-applied residues
CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0.68	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	4942	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	5365	kg CO ₂ /t TS	Eq. 7
CAPEX			
Thermal Hydrolysis	300000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	320000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	10,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Drying	100,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Incineration	170,000	USD/t TS·d (FY 2018)	Hao et al. 2020, Table S3
Total CAPEX	900000	USD/t TS·d (FY 2018)	Calculated
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	920,700	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Thermal Hydrolysis	119	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Anaerobic Digestion	23	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Belt press dewatering	18	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Drying	112	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Incineration	173	USD/t TS (FY 2018)	Hao et al. 2020, Table S3
Total OPEX	445	USD/t TS (FY 2018)	
2018-19 rate of inflation	2.3%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	455	USD/t TS (FY 2019)	
TDC	6	USD/t TS	Eq. 15
Revenue from end-products			
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from electricity export	114	USD/t TS	
Net Operating Profit	-347	USD/t TS	Eq. 14
Technology Readiness Level			

Supplementary Table 19: Hydrothermal Liquefaction - Conventional Activated Sludge for aqueous products- Biocrude (HTL-CAS_BC)

Parameter	Quantity	Units	Reference
HTL loading rate	110	dry short ton/day	Snowden-Swan et al. 2017, Figure ES.1
HTL loading rate	100	t TS/day	Conversion to dry metric tons/d
HTL Loading rate	32931	t TS/yr	Conversion to dry metric tons/yr
Ash content	15%	%wt	Snowden-Swan et al. 2017, Figure ES.1
HTL loading rate	93.5	short ton/day	Snowden-Swan et al. 2017, Figure ES.1
Operating hours per year	7920	hr/yr	Snowden-Swan et al. 2017, Figure ES.1
Operating hours per typ day	24	hr/day	Assumed
Operating days per year	330	day/yr	Calculated
Wet weight of final residues			
Solid phase yield (% dry ash free)	9%	%	Snowden-Swan et al. 2017, Table 5
Solid phase remaining (% dry solids), TS _f /TS _i	7.7%	%	Conversion to total dry solids
MC _f	70%	%	Snowden-Swan et al. 2027
WS _f /TS _i	0.26	Fraction	Eq. 1
Net energy balance			
E _{elec,out}	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Annual electricity cost for HTL	100000	USD/yr	Snowden-Swan et al. 2017, Table 18
Annual electricity cost for extra aeration	360000	USD/yr	
cost of electricity	0.0709	USD/kWh	Snowden-Swan et al. 2017, Table 18
Electricity consumption for HTL and aeration	197	kWh/t TS	
Belt press dewatering of initial solids	60	kWh/t TS	From Hao et al. 2020 Figure 1
Total electricity consumption for HTL-CAS_BC	257.02	kWh/t TS	Calculated
E _{prod}			
Biocrude yield from HTL Plant	44%	% wt Dry Ash Free	Snowden-Swan et al. 2017, Table 5
Biocrude yield from HTL Plant	37.4%	% wt	Conversion to total dry solids
Wet biocrude specific density (4% MC)	0.98	kg/m ³	Snowden-Swan et al. 2017, Table 5
Density of water	999.974	kg/m ³	
Density of Biocrude	979.975	kg/m ³	Calculated
Density of Biocrude	8.178	lb/gal	Conversion to lb/gal
LHV of Biocrude	124990	Btu/gal	Snowden-Swan et al. 2017 Section 3.1.3
Energy density of biocrude from HTL plant	9875	kWh/t	Conversion to kWh/t
Energy eqv of biocrude from HTL plant	3693	kWh/t TS	Calculated
Heat content of crude oil	5.8	MMBtu/barrel	EPA 2020
LHV of biocrude	124990	Btu/gal	
LHV of biocrude	5.2	MMBtu/barrel	
LHVbio/LHVfossil	0.91	-	
E _{diesel}	35	kWh/t TS	Eq. 4
E _{NG,in}			
Natural gas consumption for HTL	390000	USD/yr	Snowden-Swan et al. 2017, Table 18
Natural gas consumption for THROX unit	180000	USD/yr	Snowden-Swan et al. 2017, Table 18
Total cost of natural gas	570000	USD/yr	Calculated
Cost of Natural Gas	5.62	USD/1000 scf	Snowden-Swan et al. 2017, Table 18
Total NG consumption for HTL	3080	scf/t TS	Calculated
Total NG consumption for HTL	3.19	MMBtu/t TS	Conversion from scf to MMBtu
E _{NET}	2,542	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{LLA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}			
LHVbio/LHVfossil	0.91	-	
EF _{crude}	319	kg CO ₂ /t TS	Rahman et al. 2015
CO ₂ eqv of biocrude	1066	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	-650	kg CO ₂ /t TS	Eq. 7
CAPEX			
Total Installed Cost of HTL plant	18200000	USD (FY 2014)	Snowden-Swan et al. 2017, Table 17
Total Installed Cost of HTL plant	182382	USD/t TS·d (FY 2014)	Calculated
2014-19 rate of inflation	7.69%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	196,407	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Variable Costs (USD/yr) =	1780000	USD/yr (FY 2014)	Snowden-Swan et al. 2017, Table 19
Fixed Costs (USD/yr) =	2760000	USD/yr (FY 2014)	Snowden-Swan et al. 2017, Table 19
OPEX of HTL Plant	138	USD/t TS·d	
2014-19 rate of inflation	7.69%	%	US Bureau of Labor Statistics

OPEX converted to FY 2019	148.5	USD/t TS (FY 2019)	
TDC	14.69	USD/t TS	Eq. 15
Revenue from end-products			
Biocrude market value (USD/barrel) =	50	USD/barrel	Estimated from US EIA
Biocrude market value (USD/kg) =	0.32	USD/kg	Conversion to USD/kg
Revenue from Biocrude (USD/t TS) =	120.0	USD/t TS	Calculated
Net Operating Profit	-43	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	7		System prototype demonstration in the planned operational environment, Mankins 2009

Supplementary Table 20: Hydrothermal Liquefaction - Conventional Activated Sludge for aqueous products- Fuel Products (HTL-CAS_FP)

Parameter	Quantity	Units	Reference
Biocrude Feed Rate	296200000	lbs/yr	Snowden-Swan et al. 2017, Table 21
Dry sludge equivalent feed rate	1200	short ton TS/day	Calculated from Biocrude yield (Snowden-Swan et al. 2017, Table 5)
Dry sludge equivalent feed rate	1089	t TS/day	Conversion to from short tons to metric tons
Dry sludge equivalent feed rate	359236	t TS/yr	Calculated from annual operating days
Operating hours per year =	7920	hr/yr	Snowden-Swan et al. 2017, Figure ES.1
Operating hours per typ day =	24	hr/day	Assumed
Operating days per year =	330	day/yr	Calculated
Wet weight of final residues			
Solid phase yield (% dry ash free) =	9%	%	Snowden-Swan et al. 2017, Table 5
Solid phase remaining (% dry solids), TS_f/TS_i =	7.7%	%	Conversion to total dry solids
MC_f	70%	%	Snowden-Swan et al. 2027
WS_f/TS_i	0.26	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity exports
VS_{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R_{LFG}	0%	%	Assumed
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$			
Annual cost of electricity for biocrude upgradation	920000	USD/yr (FY 2014)	Snowden-Swan et al. 2017, Table 23
Price of electricity	0.0709	USD/kWh	Snowden-Swan et al. 2017, Table 23
Electricity consumption for biocrude upgradation	36	kWh/t TS	Calculated
Electricity consumption from HTL-CAS_BC	257	kWh/t TS	Calculated in HTL-CAS_BC scenario
Total electricity consumption for HTL-CAS_FP	293	kWh/t TS	Calculated
E_{prod}			
Biocrude yield from HTL plant	37.4%	%wt TS	Snowden-Swan et al. 2017, Table 5 - Converted to total dry solids
Diesel production rate	183800000	lb/yr	Snowden-Swan et al. 2017, Table 21
Diesel yield	62.05%	%wt of biocrude	Calculated from biocrude feed rate
Diesel yield	23.21%	%wt TS	Calculated from biocrude yield
LHV of diesel (Btu/gal) =	124394	Btu/gal	Snowden-Swan et al. 2020
Density of diesel (lb/gal) =	6.66	lb/gal	Snowden-Swan et al. 2020
Energy density of diesel (kWh/kg) =	12.07	kWh/kg	Calculated
Energy equivalent of diesel (kWh/t TS) =	2800.80	kWh/t TS	Calculated
Naphtha production rate	56500000	lb/yr	Snowden-Swan et al. 2017, Table 21
Naphtha yield	19.07%	%wt of biocrude	Calculated from biocrude feed rate
Naphtha yield	7.13%	%wt TS	Calculated from biocrude yield
LHV of naphtha	114650	Btu/gal	Snowden-Swan et al. 2020
Density of naphtha	6.13	lb/gal	Snowden-Swan et al. 2020
Energy density of naphtha	12.08	kWh/kg	Calculated
Energy equivalent of naphtha	862.13	kWh/t TS	Calculated
Total energy equivalent of upgraded fuel products	3663	kWh/t TS	Calculated
E_{diesel}	35	kWh/t TS	Eq. 4
$E_{NG,in}$			
Annual cost of natural gas for biocrude upgradation	2790000	USD/yr (FY 2014)	Snowden-Swan et al. 2017, Table 23
Price of natural gas	5.62	USD/1000scf	Snowden-Swan et al. 2017, Table 23
Natural gas consumption biocrude upgradation	1382	scf/t TS	Calculated
Natural gas consumption for HTL-CAS_BC	3080	scf/t TS	Calculated in HTL-CAS_BC scenario
Total natural gas consumption for HTL-CAS_FP	4462	scf/t TS	Calculated
Total natural gas consumption for HTL-CAS_CP	4.63	MMBtu/t TS	Conversion from scf to MMBtu
E_{NET}	2,478	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	0	kg CO ₂ /t TS	Eq. 5 & 9
$TS_{f,LA}/TS_i$	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$			Eq. 12
Co2 eqv of diesel	10.16	kg CO ₂ /gal	US EIA
Density of diesel	6.66	lb/gal	Snowden-Swan et al. 2020
CO2 eqv of diesel	3.36	kg CO ₂ /kg	Calculated
CO2 eqv of diesel	781	kg CO ₂ /t TS	Calculated
CO2 eqv of naphtha	9.10	kg CO ₂ /gal	US EIA

Density of naphtha	6.13	lb/gal	Snowden-Swan et al. 2020
CO ₂ eqv of naphtha	3.27	kg CO ₂ /kg	Calculated
CO ₂ eqv of naphtha	233	kg CO ₂ /t TS	Calculated
Total CO ₂ eqv of upgraded fuel products	1014	kg CO ₂ /t TS	Calculated
CO ₂ e _{disp} , fertilizers	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	-943	kg CO ₂ /t TS	Eq. 7
CAPEX			
Total Installed Cost for biocrude upgrading plant	75600000	USD (FY 2014)	Snowden-Swan et al. 2017, Table 22
Total Installed Cost for biocrude upgrading plant	69447	USD/t TS·d (FY 2014)	Calculated from biocrude feed rate
Total Installed Cost for HTL plant	182382	USD/t TS·d (FY 2014)	Calculated in HTL-CAS_BC scenario
Total Installed Cost for HTL-CAS_FP scenario	251830	USD/t TS·d (FY 2014)	Calculated
2014-19 rate of inflation	7.69%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	271,195	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Variable Costs for biocrude upgradation	4300000	USD/yr (FY 2014)	Snowden-Swan et al. 2017, Table 23
Fixed Costs for biocrude upgradation	9180000	USD/yr (FY 2014)	Snowden-Swan et al. 2017, Table 23
OPEX for biocrude upgradation plant	38	USD/t TS	Calculated from biosolids feed rate
OPEX of HTL Plant	138	USD/t TS	Calculated in HTL-CAS_BC scenario
Total OPEX for HTL-CAS_FP	175	USD/t TS	Calculated
2014-19 rate of inflation	7.69%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	188.88	USD/t TS (FY 2019)	
TDC	\$ 14.69		Eq. 15
Revenue from end-products			
Selling price of diesel (USD/gal) =	3.124	USD/gal	EIA April 19, 2021 Diesel price
Selling price of diesel (USD/kg) =	1.03	USD/kg	Conversion from gal to kg
Revenue from diesel (USD/t TS) =	240.00	USD/t TS	Calculated
Selling price of naphtha (USD/tonne) =	550	USD/tonne	Trading Economics 2021
Selling price of naphtha (USD/kg) =	0.55	USD/kg	Conversion from tonne to kg
Revenue from naphtha (USD/t TS) =	39.24	USD/t TS	Calculated
Total revenue from end-products	279.23		
Net Operating Profit	76	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	6		System/subsystem model or prototype demonstration in a relevant environment

Supplementary Table 21: Hydrothermal Liquefaction - Ammonia Stripping - Conventional Activated Sludge for aqueous products - Biocrude (HTL-NH₃-CAS_BC)

Parameter	Quantity	Units	Reference
HTL loading rate	110	dry short ton/day	Snowden-Swan et al. 2020
HTL loading rate	100	t TS/day	Conversion from short ton to metric ton
HTL loading rate	32931	t TS/yr	Snowden-Swan et al. 2020
Ash content	15%	%wt	Snowden-Swan et al. 2020
HTL loading rate	93.5	short ton/day	Snowden-Swan et al. 2020
Operating hours per year	7920	hrs/yr	Snowden-Swan et al. 2020
Operating hours per typ day	24	hrs/day	Snowden-Swan et al. 2020
Operating days per year	330	days/yr	Snowden-Swan et al. 2020
Wet weight of final residues			
Solid phase yield (% dry ash free)	12%	%	Snowden-Swan et al. 2020, Table 2
Solid phase remaining (% dry solids), TS _f /TS _i	10.2%	%	Conversion to total dry solids
MC _f	60%	%	Snowden-Swan et al. 2020, Table C.1.
WS _f /TS _i	0.26	Fraction	Eq. 1
Net energy balance			
E _{elec,out}	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E_{elec,in}			
Electricity demand for HTL process	297	kW	Snowden-Swan et al. 2020, Table C.1.
Electricity demand for aeration	849	kW	Snowden-Swan et al. 2020, Table C.1.
Electricity demand for HTL plant	275.62	kWh/t TS	
Total electricity consumption	276	kWh/t TS	Calculated
E_{prod}			
Biocrude yield from HTL Plant	44%	% wt Dry Ash Free	Snowden-Swan et al. 2020, Table 2
Biocrude yield from HTL Plant	37.4%	% wt	Conversion to total dry solids
Density of Biocrude	8.150	lb/gal	Snowden-Swan et al. 2020, Table C.1.
LHV of Biocrude	124943	Btu/gal	Snowden-Swan et al. 2020, Table C.1.
Energy density of biocrude from HTL plant	9.905	kWh/kg	Calculated
Energy eqv of biocrude from HTL plant	3705	kWh/t TS	Calculated
Heat content of crude oil	5.8	MMBtu/barrel	EPA 2020
LHV of biocrude	124943	Btu/gal	Snowden-Swan et al. 2020 Table C.1
LHV of biocrude	5.2	MMBtu/barrel	
E _{diesel}	35	kWh/t TS	Eq. 4
E_{NG,in}			
Natural gas usage fir HTL process	3760	scf/AFDW	Snowden-Swan et al. 2020, Table B.2.
Natural gas consumption	3523	scf/t TS	Conversion from ash free short ton to metric ton total solids
NG consumption	3.65	MMBtu/t TS	Conversion from scf to MMBtu
E _{NET}	2,391	kWh/t TS	Eq. 2

Net CO ₂ e emissions				
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9	
TS _{ELA} /TS _i	0	Fraction	N/A; No land-applied residues	
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS	Eq. 10	
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues	
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS	Eq. 11	
CO ₂ e _{disp, fuels}	1182	kg CO ₂ /t TS	Eq. 12	
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues	
CO ₂ e _{NET}	-587	kg CO ₂ /t TS	Eq. 7	
CAPEX				
Total Installed Cost of HTL plant	24200000	USD (FY 2019)	Snowden-Swan et al. 2020, Table 5	
Total Installed Cost of HTL plant	242508	USD/t TS·d (FY 2019)	Calculated	
Net Operating Profit				
OPEX				
OPEX for HTL Plant	4900000	USD/yr (FY 2019)	Snowden-Swan et al. 2020, Table 5	
OPEX of HTL Plant	149	USD/t TS	Calculated from HTL loading rate	
TDC	14.69	USD/t TS	Eq. 15	
Revenue from end-products				
Biocrude market value	50	USD/barrel	Estimated from US EIA	
Biocrude market value	0.32	USD/kg	Conversion to USD/kg	
Revenue from Biocrude	120	USD/t TS	Calculated	
Net Operating Profit	-43	USD/t TS	Eq. 14	
Technology Readiness Level				
TRL	6		System/subsystem model or prototype demonstration in a relevant environment	

Supplementary Table 22: Hydrothermal Liquefaction - Ammonia Stripping - Conventional Activated Sludge for aqueous products - Fuel Products (HTL-NH ₃ -CAS_FP)				
Parameter	Quantity	Units	Reference	
Operating hours per year	7920	hours/year	Snowden-Swan et al. 2020	
Operating hours per typ day	24	hours/day	Snowden-Swan et al. 2020	
Operating days per year	330	days/yr	Snowden-Swan et al. 2020	
Biocrude feed rate	38961	lb/hr	Snowden-Swan et al. 2020, Table C.2	
Dry solids feed rate equivalent	1134	t TS/day	Calculated from biocrude yield	
Wet weight of final residues				
Solid phase yield (% dry ash free)	12%	%	Snowden-Swan et al. 2020, Table 2	
Solid phase remaining (% dry solids)	10.2%	%	Conversion to total dry solids	
MC _f	60%	%	Snowden-Swan et al. 2020, Table C.1.	
WS _f /TS _i	0.26	Fraction	Eq. 1	
Net energy balance				
E _{elec,out}	0	kWh/t TS	N/A; No electricity exports	
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL	
R _{LFG}	0%	%	Assumed	
E _{LFG}	0	kWh/t TS	Eq. 5 & 6	
E _{elec,in}				
Electricity usage for biocrude upgradation	1673	kW	Snowden-Swan et al. 2020, Table C.2	
Electricity usage for biocrude upgradation	35	kWh/t TS	Calculated from biosolids loading rate	
Electricity usage for HTL plant	276	kWh/t TS	Calculated in HTL-NH ₃ rem-CAS_BC process scenario	
Total electricity usage for HTL-NH ₃ -CAS_FP	311	kWh/t TS	Calculated	
E _{prod}				
Biocrude yield from HTL plant	37.4%	%wt	Conversion from total dry solids	
Diesel production rate	22577	lb/hr	Snowden-Swan et al. 2020, Table C.2	
Diesel yield from biocrude	57.95%	%wt biocrude	Calculated from diesel production rate	
Diesel yield from biosolids	21.67%	%wt biosolids	Calculated from biosolids loading rate	
LHV of diesel	124394	Btu/gal	Snowden-Swan et al. 2020	
Density of diesel	6.66	lb/gal	Snowden-Swan et al. 2020	
Energy density of diesel	12.07	kWh/kg	Conversion from lb/gal to kWh/kg	
Energy equivalent of diesel	2615	kWh/t TS	Calculated	
Naphtha production rate	7124	lb/hr	Snowden-Swan et al. 2020, Table C.2	
Naphtha yield	18.28%	%wt biocrude	Calculated from naphtha production rate	
Naphtha yield	6.84%	%wt biosolids	Calculated from biosolids loading rate	
LHV of naphtha	114650	Btu/gal	Snowden-Swan et al. 2020	
Density of naphtha	6.13	lb/gal	Snowden-Swan et al. 2020	
Energy density of naphtha	12	kWh/kg	Conversion from lb/gal to kWh/kg	
Energy equivalent of naphtha	826	kWh/t TS	Calculated	
Total energy equivalent of end products	3442	kWh/t TS	Calculated	
E _{diesel}	35	kWh/t TS	Eq. 4	
E _{NG,in}				
Natural gas consumption for biocrude upgradation	1191	scf/AFDW	Snowden-Swan et al. 2020, Table B.1 & B.2	
Natural gas consumption for biocrude upgradation	1116	scf/t TS	conversion from short ton to metric ton total solids	
Natural gas usage for biocrude upgradation	1.16	MMBtu/t TS	Conversion from scf to MMBtu	
Natural gas usage for HTL plant	3.65	MMBtu/t TS	Calculated in HTL-NH ₃ rem-CAS_BC process scenario	
Total natural gas usage for HTL-NH ₃ -CAS-FP	4.81	MMBtu/t TS	Calculated	

E_{NET}	2,142	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rel}$	0	kg CO ₂ /t TS	Eq. 5 & 9
$TS_{f,LA}/TS_i$	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	1568	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}	-811	kg CO ₂ /t TS	Eq. 7
CAPEX			
Total Installed Cost for biocrude upgrading plant	82200000	USD (FY 2019)	Snowden-Swan et al. 2017, Table 22
Total Installed Cost for biocrude upgrading plant	72483	USD/t TS-d (FY 2019)	Calculated from biocrude feed rate
Total Installed Cost for HTL plant	242508	USD/t TS-d (FY 2019)	Calculated in HTL-CAS_BC scenario
Total Installed Cost for HTL-NH ₃ rem-CAS_FP scenario	314991	USD/t TS-d (FY 2019)	Calculated
Net Operating Profit			
OPEX			
OPEX for biocrude upgradation plant	44200000	USD/yr (FY 2019)	Snowden-Swan et al. 2017, Table 23
OPEX for biocrude upgradation plant	118	USD/t TS	Calculated from biosolids feed rate
OPEX of HTL Plant	149	USD/t TS	Calculated in HTL-NH ₃ rem-CAS_BC scenario
Total OPEX for HTL-NH ₃ rem-CAS_FP	267	USD/t TS	Calculated
TDC	\$ 14.69		Eq. 15
Revenue from end-products			
Selling price of diesel	3.124	USD/gal	EIA April 19, 2021 Diesel price
Density of diesel	6.66	lb/gal	Snowden-Swan et al. 2020
Selling price of diesel	1.034	USD/kg	Conversion from gal to kg
Revenue from diesel	224	USD/t TS	Calculated
Selling price of naphtha	550	USD/tonne	Trading Economics 2021
Selling price of naphtha	1	USD/kg	Conversion from tonne to kg
Revenue from naphtha	38	USD/t TS	Calculated
Total revenue from end-products	262		
Net Operating Profit	-20	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	6		System/subsystem model or prototype demonstration in a relevant environment
Supplementary Table 23: Supercritical Hydrothermal Liquefaction-Conventional Activated Sludge for aqueous products Bioheavy Oil (SupCrit HTL-CAS_BHO)			
Parameter	Quantity	Units	Reference
HTL Loading Rate (80% MC)	100	metric ton/day	Do et al. 2020
Moisture content	0.8	%wt	Do et al. 2020
HTL dry solids loading rate	20	t TS/d	Calculated from moisture content
HTL dry solids loading rate	6667	t TS/yr	Calculated from operating days
Operating hours	8000	hrs/yr	
Operating hours per typ day	24	hrs/day	
Wet weight of final residues			
Solid residue remaining	292	kg/hr	Do et al. 2020, Table 5
HTL loading rate	4167	kg/hr	Do et al. 2020, Table 5
MC of influent solids	80%	%	Do et al. 2020, Table 5
Solid phase remaining	35%	%	Calculated from solid residue yield
MC _f	0%	%	Do et al. 2020 Table 5
WS _f /TS _i	0.35	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$			
Electricity annual expense	100000	USD/yr	Do et al. 2020, Table 10
Electricity cost	0.0980	USD/kWh	Do et al. 2020, Table 1
Annual electricity consumption	1020408	kWh/yr	Calculated
Electricity consumption	153	kWh/t TS	Calculated from solids loading rate
Belt press dewatering	60	kWh/t TS	Hao et al. 2020 Figure 1
Electricity consumption	213	kWh/t TS	
E_{prod}			
BHO yield from supercritical plant	8%	%wt	Do et al. 2020 Table 5
BHO yield from supercritical plant	40%	%wt	Calculated from biosolids loading rate
Supercritical BHO HHV	36	MJ/kg	Do et al. 2020 Table 3
Supercritical BHO HHV	10.00	kWh/kg	Conversion from MJ to kWh
Energy eqv. of supercritical BHO	4000	kWh/t TS	Calculated from solids loading rate
E_{diesel}	47	kWh/t TS	Eq. 4
$E_{NG,in}$			
LNG expense	350000	USD/yr	Do et al. 2020, Table 10
LNG price	0.45	USD/kg	Do et al. 2020, Table 1
LNG consumption	781250	kg/yr	Calculated

LNG energy content	21240	BTU/lb
LNG energy content	46826	BTU/kg
LNG consumption	36583	MMBtu/yr
LNG energy equivalent	5.49	MMBtu/t TS
E_{NET}	2,181	kWh/t TS
Net CO₂e emissions		
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS
TS _{f,LA} /TS _i	0	Fraction
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS
TS _{INC} /TS _i	0	Fraction
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS
CO ₂ e _{disp, fuels}	1276	kg CO ₂ /t TS
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS
CO ₂ e _{NET}	-468	kg CO ₂ /t TS
CAPEX		
Total Installed Cost of supercritical HTL plant	8550000	USD (FY 2017)
Total Installed Cost of supercritical HTL plant	427500	USD/t TS·d (FY 2017)
2017-19 rate of inflation	4.81%	%
CAPEX converted to FY 2019	448,063	USD/t TS·d (FY 2019)
Net Operating Profit		
OPEX		
Supercritical plant Total Production Cost	2650000	USD/yr (FY 2017)
Supercritical plant Total Production Cost	398	USD/t TS (FY 2017)
2017-19 rate of inflation	4.81%	%
OPEX converted to FY 2019	416.62	USD/t TS (FY 2019)
TDC	20.17	USD/t TS
Revenue from end-products		
Price of BHO from supercritical plant	0.575	USD/kg BHO (FY 2017)
Revenue from supercritical plant BHO	230	USD/t TS (FY 2017)
2017-19 rate of inflation	4.81%	%
Revenue converted to FY 2019	241.06	USD/t TS (FY 2019)
Net Operating Profit	-196	USD/t TS

Eq. 5 & 9
 N/A; No land-applied residues
 Eq. 10
 N/A; No incinerated residues
 Eq. 11
 Eq. 12
 N/A; No land-applied residues
 Eq. 7
 Do et al. 2020, Table 10
 Calculated
 US Bureau of Labor Statistics
 Do et al. 2020, Table 10
 Calculated from HTL loading rate
 US Bureau of Labor Statistics
 Eq. 15
 Do et al. 2020, Table 10
 US Bureau of Labor Statistics
 Eq. 14

Technology Readiness Level

TRL	4	Component and/or breadboard validation in 'laboratory' environment
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Supplementary Table 24: Subcritical Hydrothermal Liquefaction - Conventional Activated Sludge for aqueous products - Bioheavy Oil (SubCrit HTL-CAS BHO)

Parameter	Quantity	Units	Reference
HTL Loading Rate (80% MC)	100	metric ton/day	Do et al. 2020
Moisture content	0.8	%wt	Do et al. 2020
HTL dry solids loading rate	20	t TS/d	Calculated from moisture content
HTL dry solids loading rate	6667	t TS/yr	Calculated from operating days
Operating hours	8000	hrs/yr	Do et al. 2020
Operating hours per typ day	24	hrs/day	Do et al. 2020
Wet weight of final residues			
Solid residue remaining	292	kg/hr	Do et al. 2020, Table 5
HTL loading rate	4167	kg/hr	Do et al. 2020, Table 5
MC of influent solids	80%	%	Do et al. 2020, Table 5
Solid phase remaining	35.0%	%	Calculated from solid residue yield
MC _f	0%	%	Do et al. 2020 Table 5
WS _f /TS _i	0.35	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$			
Electricity annual expense	70000	USD/yr	Do et al. 2020, Table 10
Electricity cost	0.098	USD/kWh	Do et al. 2020, Table 1
Annual electricity consumption	714286	kWh/yr	Calculated
Electricity consumption	107	kWh/t TS	Calculated from solids loading rate
Belt press dewatering	60	kWh/t TS	From Hao et alo. 2020 Figure 1
Electricity consumption	167	kWh/t TS	Calculated
E_{prod}			
BHO yield from subcritical plant	9%	%wt	Do et al. 2020 Table 5
BHO yield from subcritical plant	45%	%wt	Calculated from biosolids loading rate
subcritical BHO HHV	33.9	MJ/kg	Do et al. 2020 Table 3
subcritical BHO HHV	9.42	kWh/kg	Conversion from MJ to kWh
Energy eqv. of subcritical BHO	4238	kWh/t TS	Calculated from solids loading rate
HHV _{bio} /HHV _{fossil}	#REF!	-	
E_{diesel}	47	kWh/t TS	Eq. 4
$E_{NG,in}$			
LNG expense	370000	USD/yr	Do et al. 2020, Table 10
LNG price	0.448	USD/kg	Do et al. 2020, Table 1
LNG consumption	825893	kg/yr	Calculated

LNG energy content	21240	BTU/lb
LNG energy content	46826	BTU/kg
LNG consumption	38673	MMBtu/yr
LNG energy equivalent	5.80	MMBtu/t TS
E_{NET}	2,379	kWh/t TS
Net CO₂e emissions		
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS
TS _{f,LA} /TS _i	0	Fraction
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS
TS _{INC} /TS _i	0	Fraction
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS
CO ₂ e _{disp, fuels}	1352	kg CO ₂ /t TS
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS
CO ₂ e _{NET}	-523	kg CO ₂ /t TS
CAPEX		
Total Installed Cost of subcritical HTL plant	8030000	USD (FY 2017)
Total Installed Cost of subcritical HTL plant	401500	USD/t TS-d (FY 2017)
2017-19 rate of inflation	4.81%	%
CAPEX converted to FY 2019	420,812	USD/t TS-d (FY 2019)
Net Operating Profit		
OPEX		
Supercritical plant Total Production Cost	2610000	USD/yr (FY 2017)
Supercritical plant Total Production Cost	392	USD/t TS (FY 2017)
2017-19 rate of inflation	4.81%	%
OPEX converted to FY 2019	410.33	USD/t TS (FY 2019)
TDC	20.17	USD/t TS
Revenue from end-products		
Price of BHO from supercritical plant	0.525	USD/kg BHO
Revenue from supercritical plant BHO	236	USD/t TS
2017-19 rate of inflation	4.81%	%
Revenue converted to FY 2019	247.61	USD/t TS (FY 2019)
Net Operating Profit	-183	USD/t TS

Eq. 5 & 9
 N/A; No land-applied residues
 Eq. 10
 N/A; No incinerated residues
 Eq. 11
 Eq. 12
 N/A; No land-applied residues
 Eq. 7
 Do et al. 2020, Table 10
 Calculated
 US Bureau of Labor Statistics
 Do et al. 2020, Table 10
 Calculated from HTL loading rate
 US Bureau of Labor Statistics
 Eq. 15
 Do et al. 2020, Table 10
 US Bureau of Labor Statistics
 Eq. 14

Technology Readiness Level

TRL

7

System prototype demonstration in the planned operational environment,
 Mankins 2009

Supplementary Table 25: Hydrothermal Liquefaction - Anaerobic Digestion of aqueous coproduct - combined heat and power of biogas - biocrude (HTL-AD-CHP BC)

Parameter	Quantity	Units	Reference
Operating days per year	365	days/yr	Assumed
Capacity factor (reference case)	0.9	Fraction	Doren et al. 2017, Table 1
Estimated Operating Days (reference case)	328.5	days/yr	Calculated from capacity factor
Operating hours	24	hrs/day	
HTL Loading Rate	1000	kg/hr	Doren et al. 2017
Solids content	20%	%	Doren et al. 2017
Feed rate	200	kg TS/hr	Doren et al. 2017
Feed rate	4.8	t TS/d	Calculated from solids loading rate
Wet weight of final residues			
Solid residue remaining	25.11	kg/hr	Doren et al. 2017, Table S2
Solid phase remaining	12.6%	%	Calculated from solid residue yield
MC _f	0%	%	Doren et al. 2017, Table S2
WS _i /TS _i	0.13	Fraction	Eq. 1
Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$			
Electricity import	8070	USD/yr	Doren et al. 2017, Table S12
Electricity price	0.07	USD/kWh	Doren et al. 2017, Table 1
Electricity import	115286	kWh/yr	Calculated
Electricity import	73	kWh/t TS	Calculated from solids loading rate
Belt-press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	133	kWh/t TS	Calculated
E_{prod}			
Biocrude yield	102	kg/hr	Doren et al. 2017, Table S1
Biocrude yield	51%	%wt	
Density of Biocrude	8.150	lb/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
LHV of Biocrude	124943	Btu/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
Energy density of biocrude from HTL plant	9.906	kWh/kg	Conversion from lb/gal to kWh/kg
Energy eqv of biocrude from HTL plant	5052	kWh/t TS	Calculated from solids loading rate
E_{diesel}	17	kWh/t TS	Eq. 4
$E_{NG,in}$			
External heat (natural gas)	5480	USD/yr	Doren et al. 2017, Table S12
Natural gas price	0.01	USD/kWh	Doren et al. 2017, Table 1

Natural gas import	548000	kWh/yr	Calculated
Natural gas import	348	kWh/t TS	Calculated from solids loading rate
Natural gas import	1.19	MMBtu/t TS	Conversion from kWh to MMBtu
E_{NET}	4,733	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	1612	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	-1398	kg CO ₂ /t TS	Eq. 7
CAPEX			
Heat exchangers	1530000	USD (FY 2016)	Doren et al. 2017, Table S12
Separation after HTL	215000	USD (FY 2016)	Doren et al. 2017, Table S12
HTL reactor	956000	USD (FY 2016)	Doren et al. 2017, Table S12
AD reactor (incl. mixing)	203000	USD (FY 2016)	Doren et al. 2017, Table S12
Pump system for HTL	991000	USD (FY 2016)	Doren et al. 2017, Table S12
Engine for CHP from syngas	77300	USD (FY 2016)	Doren et al. 2017, Table S12
Gas boiler (natural gas and/or syngas)	17500	USD (FY 2016)	Doren et al. 2017, Table S12
Total CAPEX	3989800	USD (FY 2016)	Calculated
Total CAPEX	831208	USD/t TS·d (FY 2016)	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	886,317	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Electricity import	8070	USD/yr	Doren et al. 2017, Table S12
External heat (natural gas)	5480	USD/yr	Doren et al. 2017, Table S12
Equipment maintenance	199000	USD/yr	Doren et al. 2017, Table S12
Labor cost	399000	USD/yr	Doren et al. 2017, Table S12
Total OPEX	611550	USD/yr	Calculated
Total OPEX	388	USD/t TS (FY 2016)	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	413.56	USD/t TS (FY 2019)	
TDC	7.23	USD/t TS	Eq. 15
Revenue from end-products			
Market value of biocrude	0.55	USD/L	EIA 2016, referenced in paper
Revenue from Biocrude	467000	USD/yr	Doren et al. 2017, Table S12
Revenue from Biocrude	296	USD/t TS	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
Revenue converted to FY 2019	315.81	USD/t TS (FY 2019)	
Net Operating Profit	-105	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	7		System prototype demonstration in the planned operational environment, Mankins 2009

Supplementary Table 26: Hydrothermal Liquefaction - Anaerobic Digestion of aqueous products - Boiler combustion of biogas - Biocrude (HTL-AD-Boiler BC)

Parameter	Quantity	Units	Reference
Operating days per year	365	days/yr	Assumed
Capacity factor (reference case)	0.9	Fraction	Doren et al. 2017, Table 1
Estimated Operating Days (reference case)	328.5	days/yr	Calculated from capacity factor
Operating hours	24	hrs/day	
HTL Loading Rate	1000	kg/hr	Doren et al. 2017
Solids content	20%	%	Doren et al. 2017
Feed rate	200	kg TS/hr	Doren et al. 2017
Feed rate	4.8	t TS/d	Calculated from solids loading rate
Wet weight of final residues			
Solid residue remaining	25.11	kg/hr	Doren et al. 2017, Table S2
Solid phase remaining	12.6%	%	Calculated from solid residue yield
MC _f	0%	%	Doren et al. 2017, Table S2
WS _f /TS _i	0.13	Fraction	Eq. 1
Net energy balance			
E _{elec,out}	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Electricity import	21600	USD/yr	Doren et al. 2017, Table S12
Electricity price	0.07	USD/kWh	Doren et al. 2017, Table 1
Electricity import	308571	kWh/yr	Calculated
Electricity import	196	kWh/t TS	Calculated from solids loading rate
Belt-press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	256	kWh/t TS	Calculated
E _{prod}			
Biocrude yield	102	kg/hr	Doren et al. 2017, Teble S1
Biocrude yield	51%	%wt	

	Density of Biocrude	8.150	lb/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
	LHV of Biocrude	124943	Btu/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
	Energy density of biocrude from HTL plant	9.906	kWh/kg	Conversion from lb/gal to kWh/kg
	Energy eqv of biocrude from HTL plant	5052	kWh/t TS	Calculated from solids loading rate
E_{diesel}		17	kWh/t TS	Eq. 4
$E_{\text{NG,in}}$				
	External heat (natural gas)	205	USD/yr	Doren et al. 2017, Table S12
	Natural gas price	0.01	USD/kWh	Doren et al. 2017, Table 1
	Natural gas import	20500	kWh/yr	Calculated
	Natural gas import	13	kWh/t TS	Calculated from solids loading rate
	Natural gas import	0.04	MMBtu/t TS	Conversion from kWh to MMBtu
E_{NET}		4,957	kWh/t TS	Eq. 2
Net CO₂e emissions				
	CO ₂ e _{LFG,rd}	0	kg CO ₂ /t TS	Eq. 5 & 9
	TS _{ELA} /TS _i	0	Fraction	N/A; No land-applied residues
	CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
	TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
	CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
	CO ₂ e _{disp, fuels}	1612	kg CO ₂ /t TS	Eq. 12
	CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
	CO ₂ e _{NET}	-1492	kg CO ₂ /t TS	Eq. 7
CAPEX				
	Heat exchangers	1490000	USD	Doren et al. 2017, Table S12
	Separation after HTL	215000	USD	Doren et al. 2017, Table S12
	HTL reactor	956000	USD	Doren et al. 2017, Table S12
	AD reactor (incl. mixing)	203000	USD	Doren et al. 2017, Table S12
	Pump system for HTL	991000	USD	Doren et al. 2017, Table S12
	Gas boiler (natural gas and/or syngas)	22600	USD	Doren et al. 2017, Table S12
	Total CAPEX	3877600	USD	Calculated
	Total CAPEX	807833	USD/t TS·d	Calculated from solids loading rate
	2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
	CAPEX converted to FY 2019	861,393	USD/t TS·d (FY 2019)	
Net Operating Profit				
	OPEX			
	Electricity import	21600	USD/yr	Doren et al. 2017, Table S12
	External heat (natural gas)	205	USD/yr	Doren et al. 2017, Table S12
	Equipment maintenance	194000	USD/yr	Doren et al. 2017, Table S12
	Labor cost	388000	USD/yr	Doren et al. 2017, Table S12
	Total OPEX	603805	USD/yr	Calculated
	Total OPEX	383	USD/t TS	Calculated from solids loading rate
	2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
	OPEX converted to FY 2019	408.32	USD/t TS (FY 2019)	
	TDC	7.23	USD/t TS	Eq. 15
	Revenue from end-products			
	Market value of biocrude	0.55	USD/L	EIA 2016, referenced in paper
	Revenue from Biocrude	467000	USD/yr	Doren et al. 2017, Table S12
	Revenue from Biocrude	296	USD/t TS	Calculated from solids loading rate
	2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
	Revenue converted to FY 2019	315.81	USD/t TS (FY 2019)	
	Net Operating Profit	-100	USD/t TS	Eq. 14
Technology Readiness Level				
	TRL	7		System prototype demonstration in the planned operational environment, Mankins 2009

Supplementary Table 27: Hydrothermal Liquefaction - Catalytic Hydrothermal Gasification of aqueous products - Combined Heat and Power of biogas - Biocrude (HTL-CHG-CHP BC)

Parameter	Quantity	Units	Reference
Operating days per year	365	days/yr	Assumed
Capacity factor (reference case)	0.9	Fraction	Doren et al. 2017, Table 1
Estimated Operating Days (reference case)	328.5	days/yr	Calculated from capacity factor
Operating hours	24	hrs/day	
HTL Loading Rate	1000	kg/hr	Doren et al. 2017
Solids content	20%	%	Doren et al. 2017
Feed rate	200	kg TS/hr	Doren et al. 2017
Feed rate	4.8	t TS/d	Calculated from solids loading rate
Wet weight of final residues			
Solid residue remaining	25.11	kg/hr	Doren et al. 2017, Table S2
Solid phase remaining	12.6%	%	Calculated from solid residue yield
MC _f	0%	%	Doren et al. 2017, Table S2
WS _f /TS _i	0.13	Fraction	Eq. 1
Net energy balance			
$E_{\text{elec,out}}$			
Electricity export	14300	USD/yr	Doren et al. 2017, Table S12
Electricity price	0.07	USD/kWh	Doren et al. 2017, Table 1
Electricity export	204286	kWh/yr	Calculated
Electricity export	130	kWh/t TS	Calculated from solids loading rate

VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Belt-press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	60	kWh/t TS	Calculated
E _{prod}			
Biocrude yield	102	kg/hr	Doren et al. 2017, Table S1
Biocrude yield	51%	%wt	
Density of Biocrude	8.150	lb/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
LHV of Biocrude	124943	Btu/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
Energy density of biocrude from HTL plant	9.906	kWh/kg	Conversion from lb/gal to kWh/kg
Energy eqv of biocrude from HTL plant	5052	kWh/t TS	Calculated from solids loading rate
E _{diesel}	17	kWh/t TS	Eq. 4
E _{NG,in}			
External heat (natural gas)	10800	USD/yr	Doren et al. 2017, Table S12
Natural gas price	0.01	USD/kWh	Doren et al. 2017, Table 1
Natural gas import	1080000	kWh/yr	Calculated
Natural gas import	685	kWh/t TS	Calculated from solids loading rate
Natural gas import	2.34	MMBtu/t TS	Conversion from kWh to MMBtu
E _{NET}	4,591	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{ELA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	1612	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	-1335	kg CO ₂ /t TS	Eq. 7
CAPEX			
Heat exchangers	2600000	USD (FY 2016)	Doren et al. 2017, Table S12
Separation after HTL	215000	USD (FY 2016)	Doren et al. 2017, Table S12
Separation after CHG	215000	USD (FY 2016)	Doren et al. 2017, Table S12
HTL reactor	956000	USD (FY 2016)	Doren et al. 2017, Table S12
CHG reactor	956000	USD (FY 2016)	Doren et al. 2017, Table S12
Pump system for HTL	991000	USD (FY 2016)	Doren et al. 2017, Table S12
Pump system for CHG	1160000	USD (FY 2016)	Doren et al. 2017, Table S12
Engine for CHP from syngas	162000	USD (FY 2016)	Doren et al. 2017, Table S12
Gas boiler (natural gas and/or syngas)	40700	USD (FY 2016)	Doren et al. 2017, Table S12
Total CAPEX	7295700	USD (FY 2016)	Calculated
Total CAPEX	1519938	USD/t TS-d (FY 2016)	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	1,620,709	USD/t TS-d (FY 2019)	
Net Operating Profit			
OPEX			
Electricity import	0	USD/yr	Doren et al. 2017, Table S12
External heat (natural gas)	10800	USD/yr	Doren et al. 2017, Table S12
Equipment maintenance	365000	USD/yr	Doren et al. 2017, Table S12
Labor cost	730000	USD/yr	Doren et al. 2017, Table S12
Total OPEX	1105800	USD/yr	Calculated
Total OPEX	701	USD/t TS (FY 2016)	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	747.79	USD/t TS (FY 2019)	
TDC	7.23	USD/t TS	Eq. 15
Revenue from end-products			
Market value of biocrude	0.55	USD/L	EIA 2016, referenced in paper
Revenue from Biocrude	467000	USD/yr	Doren et al. 2017, Table S12
Revenue from Electricity Export	14300	USD/yr	Doren et al. 2017, Table S12
Total Annual Revenue	481300	USD/yr	Calculated
Total Revenue	305	USD/t TS	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
Revenue converted to FY 2019	325.48	USD/t TS (FY 2019)	
Net Operating Profit	-430	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	6		System/subsystem model or prototype demonstration in a relevant environment

Supplementary Table 28: Hydrothermal Liquefaction - Catalytic Hydrothermal Gasification of aqueous products - Boiler combustion of biogas - Biocrude (HTL-CHG-Boiler BC)

Parameter	Quantity	Units	Reference
Operating days per year	365	days/yr	Assumed
Capacity factor (reference case)	0.9	Fraction	Doren et al. 2017, Table 1
Estimated Operating Days (reference case)	328.5	days/yr	Calculated from capacity factor
Operating hours	24	hrs/day	
HTL Loading Rate	1000	kg/hr	Doren et al. 2017

Solids content	20%	%	Doren et al. 2017
Feed rate	200	kg TS/hr	Doren et al. 2017
Feed rate	4.8	t TS/d	Calculated from solids loading rate
Wet weight of final residues			
Solid residue remaining	25.11	kg/hr	Doren et al. 2017, Table S2
Solid phase remaining	12.6%	%	Calculated from solid residue yield
MC _f	0%	%	Doren et al. 2017, Table S2
WS _f /TS _i	0.13	Fraction	Eq. 1
Net energy balance			
E _{elec,out}	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after HTL
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Electricity import	17900	USD/yr	Doren et al. 2017, Table S12
Electricity price	0.07	USD/kWh	Doren et al. 2017, Table 1
Electricity import	255714	kWh/yr	Calculated
Electricity import	162	kWh/t TS	Calculated from solids loading rate
Belt-press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	222	kWh/t TS	Calculated
E _{prod}			
Biocrude yield	102	kg/hr	Doren et al. 2017, Table S1
Biocrude yield	51%	%wt	
Density of Biocrude	8.150	lb/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
LHV of Biocrude	124943	Btu/gal	Not reported in study. Used values from Snowden-Swan et al. 2020
Energy density of biocrude from HTL plant	9.906	kWh/kg	Conversion from lb/gal to kWh/kg
Energy eqv of biocrude from HTL plant	5052	kWh/t TS	Calculated from solids loading rate
E _{diesel}	17	kWh/t TS	Eq. 4
E _{NG,in}			
External heat (natural gas)	0	USD/yr	Doren et al. 2017, Table S12
Natural gas price	0.01	USD/kWh	Doren et al. 2017, Table 1
Natural gas import	0	kWh/yr	Calculated
Natural gas import	0	kWh/t TS	Calculated from solids loading rate
Natural gas import	0.00	MMBtu/t TS	Conversion from kWh to MMBtu
E _{NET}	5,006	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	1612	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	-1512	kg CO ₂ /t TS	Eq. 7
CAPEX			
Heat exchangers	2550000	USD	Doren et al. 2017, Table S12
Separation after HTL	215000	USD	Doren et al. 2017, Table S12
Separation after CHG	215000	USD	Doren et al. 2017, Table S12
HTL reactor	956000	USD	Doren et al. 2017, Table S12
CHG reactor	956000	USD	Doren et al. 2017, Table S12
Pump system for HTL	991000	USD	Doren et al. 2017, Table S12
Pump system for CHG	1160000	USD	Doren et al. 2017, Table S12
Gas boiler (natural gas and/or syngas)	33500	USD	Doren et al. 2017, Table S12
Total CAPEX	7076500	USD	Calculated
Total CAPEX	1474271	USD/t TS·d (FY 2016)	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	1,572,015	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Electricity import	17900	USD/yr	Doren et al. 2017, Table S12
External heat (natural gas)	0	USD/yr	Doren et al. 2017, Table S12
Equipment maintenance	354000	USD/yr	Doren et al. 2017, Table S12
Labor cost	708000	USD/yr	Doren et al. 2017, Table S12
Total OPEX	1079900	USD/yr	Calculated
Total OPEX	685	USD/t TS (FY 2016)	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	730.27	USD/t TS (FY 2019)	
TDC	7.23	USD/t TS	Eq. 15
Revenue from end-products			
Market value of biocrude	0.55	USD/L	EIA 2016
Revenue from Biocrude	467000	USD/yr	Doren et al. 2017, Table S12
Revenue from Biocrude	296	USD/t TS (FY 2016)	Calculated from solids loading rate
2016-19 rate of inflation	6.63%	%	US Bureau of Labor Statistics
Revenue converted to FY 2019	315.81	USD/t TS (FY 2019)	

Net Operating Profit	-422	USD/t TS	Eq. 14
Technology Readiness Level			System/subsystem model or prototype demonstration in a relevant environment
TRL	6		

Supplementary Table 29: Thermal Drying - Air Gasification (TD-AirGs-CHP)			
Parameter	Quantity	Units	Reference
Operating days per year	365	days/yr	Assumed
Capacity factor (reference case)	0.9	Fraction	Lumely et al. 2014, Section 2.3
Estimated Operating Days (reference case)	328.5	days/yr	Calculated from capacity factor
Operating hours	24	hrs/day	Assumed
Operating hours w/ capacity factor	21.6	hrs/day	Calculated
Feed rate	5	t TS/d	Lumely et al. 2014, Section 3.2
Wet weight of final residues			
Solid phase remaining	5%	%	Watson et al. 2018, Section 2.2
MC _f	0%	%	Assumed minimal moisture after gasification
WS _f /TS _i	0.05	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			N/A; No electricity exports
Electric power output	153	kW	Lumely et al. 2014, Table 4
Electric power output	661	kWh/t TS	Calculated from solids loading rate
VS _{LF}	0%	%	Assumed no organic carbon in sold residues after Gasification
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in} Energy demand for belt press dewatering	60	kWh/t TS	Hao et al. 2020, Table 1
E _{prod}	0	kWh/t TS	N/A; No end products
E _{diesel}	7	kWh/t TS	Eq. 4 & 8
E _{NG,in}	0	Mmbtu/t TS	N/A; No natural gas import
E _{NET}	630	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N₂O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N₂O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	0	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	-246	kg CO ₂ /t TS	Eq. 7
CAPEX			
CAPEX	1885000	USD	Lumely et al. 2014, Table 4
Total CAPEX	377000	USD/t TS·d (FY 2010)	Calculated from solid loading rate
2010-19 rate of inflation	17.69%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	443,691	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Sum of direct cost factors	0.96	N/A	Lumely et al. 2014, Table 2
Sum of indirect cost factors	0.66	N/A	Lumely et al. 2014, Table 2
Sum of fixed cost factors	0.38	N/A	Lumely et al. 2014, Table 2
TPEC	627418	USD	Lumely et al. 2014, Eq. 6
Annual OPEX	241164	USD/yr	Lumely et al. 2014, Eq. 6
Daily OPEX	734	USD/day	Calculated from capacity factor
OPEX	147	USD/t TS (FY 2010)	Calculated from solids loading rate
2010-19 rate of inflation	17.69%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	172.80	USD/t TS (FY 2019)	
TDC	2.88	USD/t TS	Eq. 15
Revenue from end-products			
Net power output	601	kWh/t TS	
Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
Revenue from net electrical output	41	USD/t TS (FY 2019)	Calculated from solids loading rate
Net Operating Profit	-135	USD/t TS	Eq. 14
Technology Readiness Level			System prototype demonstration in the planned operational environment,
TRL	7		Mankins 2009

Supplementary Table 30: Thermal Drying - Steam Gasification (TD-StmGs-CHP)			
Parameter	Quantity	Units	Reference
Operating days per year	365	days/yr	Assumed
Capacity factor (reference case)	0.9	Fraction	Lumely et al. 2014, Section 2.3
Estimated Operating Days (reference case)	328.5	days/yr	Calculated from capacity factor
Operating hours	24	hrs/day	Assumed
Operating hours w/ capacity factor	21.6	hrs/day	Calculated
Feed rate	5	t TS/d	Lumely et al. 2014, Section 3.2
Wet weight of final residues			
Solid phase remaining	8%	%	Watson et al. 2018, Section 2.2
MC _f	0%	%	Assumed minimal moisture after gasification
WS _f /TS _i	0.08	Fraction	Eq. 1

Net energy balance

$E_{elec,out}$				N/A; No electricity exports
	Electric power output	123.7	kW	Lumely et al. 2014, Table 4
	Electric power output	534	kWh/t TS	Calculated from solids loading rate
VS_{LF}		0%	%	Assumed no organic carbon in sold residues after Gasification
R_{LFG}		0%	%	Assumed
E_{LFG}		0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$	Energy demand for belt press dewatering	60	kWh/t TS	Hao et al. 2020, Table 1
E_{prod}		0	kWh/t TS	N/A; No end products
E_{diesel}		11	kWh/t TS	Eq. 4
$E_{NG,in}$		0	Mmbtu/t TS	N/A; No natural gas import
E_{NET}		491	kWh/t TS	Eq. 2

Net CO₂e emissions

$CO_2e_{LFG,rel}$		0	kg CO ₂ /t TS	Eq. 5 & 9
$TS_{f,LA}/TS_i$		0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$		0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i		0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$		0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$		0	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$		0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}		-191	kg CO ₂ /t TS	Eq. 7

CAPEX

CAPEX	1885000	USD	Lumely et al. 2014, Table 4
Total CAPEX	377000	USD/t TS·d (FY 2010)	Calculated from solid loading rate
2010-19 rate of inflation	17.69%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	443,691	USD/t TS·d (FY 2019)	

Net Operating Profit

OPEX				
	Sum of direct cost factors	0.96	N/A	Lumely et al. 2014, Table 2
	Sum of indirect cost factors	0.66	N/A	Lumely et al. 2014, Table 2
	Sum of fixed cost factors	0.38	N/A	Lumely et al. 2014, Table 2
	TPEC	627418	USD	Lumely et al. 2014, Eq. 6
	Annual OPEX	241164	USD/yr	Lumely et al. 2014, Eq. 6
	Daily OPEX	734	USD/day	Calculated from capacity factor
	OPEX	147	USD/t TS (FY 2010)	Calculated from solids loading rate
2010-19 rate of inflation	17.69%	%	US Bureau of Labor Statistics	
OPEX converted to FY 2019	172.80	USD/t TS (FY 2019)		
TDC	4.61	USD/t TS		Eq. 15
Revenue from end-products				
	Net power output	474	kWh/t TS	
	Avg industrial price of electricity in FY 2019	0.0681	USD/kWh	US EIA
	Revenue from net electrical output	32	USD/t TS (FY 2019)	Calculated from solids loading rate
Net Operating Profit	-145	USD/t TS		Eq. 14

Technology Readiness Level

TRL	7	System prototype demonstration in the planned operational environment, Mankins 2009
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Supplementary Table 31: Fry Dry-Torrefaction-Combustion (FD-Torr-Comb BSF)

Supplementary Table S1: Fly Ash-Torrefaction-Combustion (1D-Tor-Comb-BS1)			
Parameter	Quantity	Units	Reference
Operating hrs per year	8000	hrs/yr	Do et al. 2018, Table 1
Operating hrs per day	24	hrs/day	Do et al. 2018
Solids loading rate (wet basis 80% MC)	1875	kg/hr	Do et al. 2018, Table S1.1
Solids loading rate (dry basis)	375	kg/hr	Do et al. 2018, Table S1.1
Solids loading rate (wet basis)	45	t/d	Do et al. 2018
Moisture content	80%	%wt	Do et al. 2018
Dry solids loading rate (daily)	9	t TS/d	Calculated from dry solids feed rate
Dry solids loading rate (annual)	3000	t TS/yr	Calculated from dry solids feed rate
Wet weight of final residues			
Waste residues (wet basis)	1.9	kg/hr	Do et al. 2018, Table S1.1
Water content	1.76	kg/hr	Do et al. 2018, Table S1.1
Solids residue production	0.14	kg/hr	Calculated from water content
Dry solid residue yield	0.04%	%wt	Calculated
Moisture content of waste residues	93%	%wt	Calculated from water content
WS _f /TS _i	0.01	Fraction	Eq. 1
Net energy balance			
E _{elec,out}	0	kWh/t TS	N/A; No electricity exports
VS _{LF}	0%	%	Assumed no remaining organic carbon after torrefaction
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}			
Electricity input to process	746300	kWh/yr	Do et al. 2018, Table 4
Electricity input to process	249	kWh/t TS	Calculated from solids loading rate
Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
Total electricity import	309	kWh/t TS	Calculated

E _{prod}	BioSolid fuel sold	1107200	kg/yr	Do et al. 2018, Table S1.7
	BioSolid fuel yield	37%	%wt	Calculated from annual dry solids loading rate
	LHV of Biosolid fuel	16.7	MJ/kg	Do et al. 2018, Section 2
	LHV of Biosolid fuel	15.83	MMBtu/t	Conversion from MJ/kg to MMBtu/t
	Energy equivalent of BS fuel sold	18490240	MJ/yr	Calculated from LHV and BSF yield
	Energy equivalent of BS fuel sold	5136178	kWh/yr	Conversion from MJ/kWh
	Energy equivalent of BS fuel sold	1712	kWh/t TS	Calculated from solids loading rate
	Average heat content of US coal	19.260	MMBtu/short ton	US EIA
	Average heat content of US coal	21.230	MMBtu/t	converted to metric ton
E _{diesel}		1	kWh/t TS	Eq. 4
E _{NG,in}		0	MMBtu/t TS	N/A; No natural gas import
E _{NET}		1,424	kWh/t TS	Eq. 2
Net CO ₂ e emissions				
	CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
	TS _{LLA} /TS _i	0	Fraction	N/A; No land-applied residues
	CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
	TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
	CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
	CO ₂ e _{disp, fuels}	1751	kg CO ₂ /t TS	Eq. 12
	CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
	CO ₂ e _{NET}	-1623	kg CO ₂ /t TS	Eq. 7
CAPEX				
	Total Installed Cost (TIC)	2397462	USD	Do et al. 2018, Table S3.1
	Total CAPEX	266385	USD/t TS-d (FY 2015)	Calculated from solids loading rate
	2015-19 rate of inflation	7.51%	%	US Bureau of Labor Statistics
	CAPEX converted to FY 2019	286,390	USD/t TS-d (FY 2019)	
Net Operating Profit				
OPEX				
	Total Production Cost	1015000	USD/yr	Do et al. 2018, Table 4
	Total OPEX	338	USD/t TS (FY 2015)	Calculated from solids loading rate
	2015-19 rate of inflation	7.51%	%	US Bureau of Labor Statistics
	OPEX converted to FY 2019	363.74	USD/t TS (FY 2019)	
	TDC	0.29	USD/t TS	Eq. 15
	Revenue from end-products			
	Selling price of BS fuel	0.07	USD/kg	Do et al. 2018, Table 4
	Revenue from BS fuel	77504	USD/yr	Calculated from BS fuel sales
	Revenue from BS fuel	25.83	USD/t TS (FY 2015)	
	2015-19 rate of inflation	7.51%	%	US Bureau of Labor Statistics
	Revenue converted to FY 2019	27.77	USD/t TS (FY 2019)	
	Net Operating Profit	-336	USD/t TS	Eq. 14
Technology Readiness Level				
	TRL	7		System prototype demonstration in the planned operational environment, Mankins 2009

Supplementary Table 32: Fry Dry-Torrefaction (FD-Torr BSF)				
Parameter	Quantity	Units	Reference	
Operating hrs per year	8000	hrs/yr	Do et al. 2018, Table 1	
Operating hrs per day	24	hrs/day	Do et al. 2018	
Solids loading rate (wet basis 80% MC)	1875	kg/hr	Do et al. 2018, Table S1.1	
Solids loading rate (dry basis)	375	kg/hr	Do et al. 2018, Table S1.1	
Solids loading rate (wet basis)	45	t/d	Do et al. 2018	
Moisture content	80%	%wt	Do et al. 2018	
Dry solids loading rate (daily)	9	t TS/d	Calculated from dry solids feed rate	
Dry solids loading rate (annual)	3000	t TS/yr	Calculated from dry solids feed rate	
Wet weight of final residues				
	Waste residues (wet basis)	1.9	kg/hr	Do et al. 2018, Table S1.1
	Water content	1.76	kg/hr	Do et al. 2018, Table S1.1
	Solids residue production	0.14	kg/hr	Calculated from water content
	Dry solid residue yield	0.04%	%wt	Calculated
	Moisture content of waste residues	93%	%wt	Calculated from water content
	WS _f /TS _i	0.01	Fraction	Eq. 1
Net energy balance				
	E _{elec,out}	0	kWh/t TS	N/A; No electricity exports
	VS _{LF}	0%	%	Assumed no remaining organic carbon after torrefaction
	R _{LFG}	0%	%	Assumed
	E _{LFG}	0	kWh/t TS	Eq. 5 & 6
	E _{elec,in}			
	Electricity input to process	746300	kWh/yr	Do et al. 2018, Table 4
	Electricity input to process	249	kWh/t TS	Calculated from solids loading rate
	Belt press dewatering	60	kWh/t TS	Hao et al. 2020, Figure 1
	Total electricity import	309	kWh/t TS	Calculated
E _{prod}				
	BioSolid fuel sold	3307200	kg/yr	Do et al. 2018, Table S1.7
	BioSolid fuel yield	110%	%wt	Calculated from annual dry solids loading rate
	LHV of Biosolid fuel	16.7	MJ/kg	Do et al. 2018, Section 2

	LHV of Biosolid fuel	15.83	MMBtu/t	Conversion from MJ/kg to MMBtu/t
	Energy equivalent of BS fuel sold	55230240	MJ/yr	Calculated from LHV and BSF yield
	Energy equivalent of BS fuel sold	15341733	kWh/yr	Conversion from MJ/kWh
	Energy equivalent of BS fuel sold	5114	kWh/t TS	Calculated from solids loading rate
	Average heat content of US coal	19,260	MMBtu/short ton	US EIA
	Average heat content of US coal	21,230	MMBtu/t	converted to metric ton
E_{diesel}		1	kWh/t TS	Eq. 4
$E_{\text{NG,in}}$				
	LNG consumption	752000	kg/yr	Table 4
				NIST Handbook 44 – Mass Flow Meters Appendix E -
				https://www.nist.gov/file/323701
	LNG energy content	21240	Btu/lb	Conversion from lb to kg
	LNG energy content	46826	Btu/kg	Calculated
	LNG consumption	35213	MMBtu/yr	Calculated from solids loading rate
	LNG consumption	11.74	MMBtu/t TS	Eq. 2
E_{NET}		1,264	kWh/t TS	
Net CO₂e emissions				
	$\text{CO}_2\text{e}_{\text{LFG,rel}}$	0	kg CO ₂ /t TS	Eq. 5 & 9
	$\text{TS}_{\text{fLLA}}/\text{TS}_i$	0	Fraction	N/A; No land-applied residues
	$\text{CO}_2\text{e}_{\text{N}_2\text{O,LA}}$	0	kg CO ₂ /t TS	Eq. 10
	$\text{TS}_{\text{INC}}/\text{TS}_i$	0	Fraction	N/A; No incinerated residues
	$\text{CO}_2\text{e}_{\text{N}_2\text{O,inc}}$	0	kg CO ₂ /t TS	Eq. 11
	$\text{CO}_2\text{e}_{\text{disp, fuels}}$	5232	kg CO ₂ /t TS	Eq. 12
	$\text{CO}_2\text{e}_{\text{disp, fertilizers}}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
	$\text{CO}_2\text{e}_{\text{NET}}$	-3610	kg CO ₂ /t TS	Eq. 7
CAPEX				
	Total Installed Cost (TIC)	2268862	USD	Do et al. 2018, Table S3.2
	Total CAPEX	252096	USD/t TS·d (FY 2015)	Calculated from solids loading rate
	2015-19 rate of inflation	7.51%	%	US Bureau of Labor Statistics
	CAPEX converted to FY 2019	271,028	USD/t TS·d (FY 2019)	
Net Operating Profit				
	OPEX			
	Total Production Cost	1517000	USD/yr	Do et al. 2018, Table 4
	Total OPEX	506	USD/t TS (FY 2015)	Calculated from solids loading rate
	2015-19 rate of inflation	7.51%	%	US Bureau of Labor Statistics
	OPEX converted to FY 2019	543.64	USD/t TS (FY 2019)	
	TDC	0.29	USD/t TS	Eq. 15
	Revenue from end-products			
	Selling price of BS fuel	0.07	USD/kg	Do et al. 2018, Table 4
	Revenue from BS fuel	231504	USD/yr	Calculated from BS fuel sales
	Revenue from BS fuel	77	USD/t TS (FY 2015)	
	2015-19 rate of inflation	7.51%	%	US Bureau of Labor Statistics
	Revenue converted to FY 2019	82.96	USD/t TS (FY 2019)	
	Net Operating Profit	-461	USD/t TS	Eq. 14
Technology Readiness Level				
	TRL	7		System prototype demonstration in the planned operational environment, Mankins 2009

Supplementary Table 33: Scum Transesterification-Photo algal bio reactor-Thermal Drying - Microwave Pyrolysis (TE-PBR-TD-MWPy)

Parameter	Quantity	Units	Reference
Operating days per year	320	days/yr	Xin et al. 2018, Table A.3
Scum feed rate (wet basis)	3174.5	kg/d	Xin et al. 2018, Table A.1
Sludge feed rate	265	t TS/d	Xin et al. 2018 Table A.1
Sludge feed rate	84800	t TS/yr	Calculated from operating days
Algae biomass feed rate	10.81	t TS/d	Xin et al. 2018 Table A.1
Wet weight of final residues			
Solid waste produced (wet basis)	308.52	kg/d	Xin et al. 2018 Table A.1
Solid waste produced (t/t TS) =	0.1%	t/t TS	Calculated from water content
Moisture content of waste residues	0%	%wt	
WS_i/TS_i	0.00	Fraction	Eq. 1
Net energy balance			
$E_{\text{elec,out}}$	0	kWh/t TS	N/A; No electricity exports
VS_{LF}	0%	%	Assumed no remaining volatile solids in waste residues
R_{LFG}	0%	%	Assumed
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{\text{elec,in}}$			
Transesterification Electricity Req	5.54	kWh/d	Xin et al. 2018 Table A.1
Algae cultivation electricity req	764.22	kWh/d	Xin et al. 2018 Table A.1
Pyrolysis electricity req	153536	kWh/d	Xin et al. 2018 Table A.1
Total electricity import	154305.76	kWh/d	
Total electricity import	582	kWh/t TS	Calculated from solids loading rate
E_{prod}			
Biodiesel from Trans	137220	gal/yr	Xin et al. 2018, Table A.4
Energy content of biodiesel	137,381	Btu/gal	EIA
Energy content of biodiesel	40	kWh/gal	
Energy content of biodiesel	5,525,035	kWh/yr	
Energy eqv of biodiesel	65	kWh/t TS	
Bio-oil yield from algae	28.60%	%wt	Xin et al. 2018, Table A.4

Bio-oil yield from algae	3092	kg/d	
LHV of bio-oil from algae	30.7	MJ/kg	Xin et al. 2018, Table A.4
LHV of bio-oil from algae	8.5	kWh/kg	Conversion from MJ to kWh
Energy eqv of bio-oil from algae	26365	kWh/d	
Energy eqv of bio-oil from algae	99.5	kWh/t TS	
Bio-oil yield from sludge	20.74%	%wt	Xin et al. 2018, Table A.4
Bio-oil yield from sludge	54961	kg/d	
LHV of bio-oil from sludge	31.53	MJ/kg	
LHV of bio-oil from sludge	8.8	kWh/kg	Conversion from MJ to kWh
Energy eqv of bio-oil from sludge	481367	kWh/d	
Energy eqv of bio-oil from sludge	1816.5	kWh/t TS	
Total energy eqv of bio-oil	1916.0	kWh/t TS	
Syngas yield from algae	26.00%	%wt	
LHV of syngas from algae	15.5	MJ/kg	Xin et al. 2018, Table A.4
syngas from algae	43564.3	MJ/day	
syngas from algae	12101.2	kWh/day	
Syngas yield from sludge	28.73%	%wt	
LHV of syngas from sludge	9.46	MJ/kg	Xin et al. 2018, Table A.4
syngas from sludge	720232	MJ/day	
syngas from sludge	200065	kWh/day	Conversion from MJ to kWh
Total energy eqv of syngas	801	kWh/t TS	
Total energy eqv of end-products	2782	kWh/t TS	
E _{diesel}	0	kWh/t TS	Eq. 4
E _{NG,in}			
Scum Trans Heat Req	1055	MJ/day	Xin et al. 2018 Table A.1
Scum Trans Heat Req	293	kWh/d	Conversion from MJ to kWh
Scum Trans Heat Req	0	MMBtu/t TS	Calculated from solids loading rate
E _{NET}	2,302	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{ELA} /TS _i	0	Fraction	N/A; No land-applied residues
CO ₂ e _{N2O,LA}	0	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	988	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO ₂ e _{NET}	-747	kg CO ₂ /t TS	Eq. 7
CAPEX			
Total Installed Cost (TIC)	35678607	USD	Xin et al. 2018, Table A.2
Total CAPEX	134636	USD/t TS·d (FY 2014)	Calculated from solids loading rate
2014-19 rate of inflation	7.69%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	144,990	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
Total Operating Costs (TOC)	8445532	USD/yr	Do et al. 2018, Table 4
Total OPEX	100	USD/t TS (FY 2014)	Calculated from solids loading rate
2014-19 rate of inflation	7.69%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	107.25	USD/t TS (FY 2019)	
TDC	0.07	USD/t TS	Eq. 15
Revenue from end-products			
Biodiesel selling price	3.095	USD/gal	Xin et al. 2018, Table A.4
Biodiesel revenue	424696	USD/yr	
Biodiesel revenue	5	USD/t TS	
Crude oil selling price	50	USD/bbl	US EIA
Crude oil LHV	43	MJ/kg	Xin et al. 2018, Table A.4
Density of bio-oil	7	bbl/ton	Xin et al. 2018, Table A.4
Energy content of bio-oil from algae	30.7	MJ/kg	Xin et al. 2018, Table A.4
Bio-oil from algae revenue	3.05	USD/t TS	Calculated
Bio-oil from sludge revenue	56	USD/t TS	Calculated
Revenue from P fertilizer	1229305	USD/yr	Xin et al. 2018, Table A.4
Revenue from P fertilizer	14	USD/t TS	Calculated
Revenue from syngas	1324874	USD/yr	Xin et al. 2018, Table A.4
Revenue from syngas	16	USD/t TS	
Total revenue from end-products	94	USD/t TS (FY 2014)	
2014-19 rate of inflation	7.69%	%	US Bureau of Labor Statistics
Revenue converted to FY 2019	101.14	USD/t TS (FY 2019)	
Net Operating Profit	-6	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	3		Analytical and experimental critical function and/or characteristic proof-of-concept

Supplementary Table 34: Thermal Drying - Pyrolysis (TD-Py)

Parameter	Quantity	Units	Reference
Feed rate	50	kg/hr	
Operating hours	4725	hr/yr	
Feed rate	236.25	t TS/yr	
Feed rate	1.2	t TS/d	
Wet weight of final residues			
Waste residues sent to disposal	0%	%wt	N/A, No waste residues sent to landfill
Moisture content of waste residues	0%	%wt	N/A, No waste residues sent to landfill
WS _i /TS _i	0.00	Fraction	Eq. 1

Net energy balance			
$E_{elec,out}$	0	kWh/t TS	N/A; No electricity exports
VS_{LF}	0%	%	Assumed no remaining volatile solids in waste residues
R_{LFG}	0%	%	Assumed
E_{LFG}	0	kWh/t TS	Eq. 5 & 6
$E_{elec,in}$			
Dewatering	0.89	MJ/hr	Shahbeig and Nosrati, 2020, Table 4
Dryer	1.78	MJ/hr	Shahbeig and Nosrati, 2020, Table 4
Pyrolysis Reactor	34	MJ/hr	Shahbeig and Nosrati, 2020, Table 4
Cyclone	0.56	MJ/hr	Shahbeig and Nosrati, 2020, Table 4
Condenser	15.8	MJ/hr	Shahbeig and Nosrati, 2020, Table 4
Total	53.03	MJ/hr	Calculated
Total Energy Input	14.73	kW	Conversion from MJ/hr to kW
Total Energy Input	69601.88	kWh/yr	Calculated from operating hours
Total Electricity Input	294.61	kWh/t TS	Calculated
E_{prod}			
Bio-char yield	66.15	t/yr	Shahbeig and Nosrati, 2020, Table 5
Bio-char yield	28%	%wt	Calculated from solids loading rate
Energy density of bio-char	14	MJ/kg	Han et al. 2013
Energy density of bio-char	13.27	MMBtu/t	
Energy Eqv of Bio-char	1089	kWh/t TS	Conversion from MJ to kWh
Average heat content of US coal	19.260	MMBtu/short ton	US EIA
Average heat content of US coal	21.230	MMBtu/t	converted to metric ton
Bio-gas yield	63.787	t/yr	Shahbeig and Nosrati, 2020, Table 5
Bio-gas yield	27%	%wt	Calculated from solids loading rate
Energy density of bio-gas	9.46	MJ/kg	Xin et al. 2018 Table A4
Energy Eqv of bio-gas	709	kWh/t TS	Conversion from MJ to kWh
Bio-oil yield	106.312	t/yr	Shahbeig and Nosrati, 2020, Table 5
Bio-oil yield	45%	%wt	Calculated from solids loading rate
Energy density of Bio-oil	16.5	MJ/kg	Sharifzadeh et al. 2019
Energy Eqv of Bio-oil	2062	kWh/t TS	Conversion from MJ to kWh
Total energy content of end-products	3861	kWh/t TS	Calculated
E_{diesel}	0	kWh/t TS	Eq. 4
$E_{NG,in}$			
Natural Gas	4.70	kW	Shahbeig and Nosrati, 2020, Table 4
Natural Gas	22208	kWh/yr	Calculated from operating days
Natural Gas Input	94	kWh/t TS	Calculated from solids loading rate
Natural gas input	0.32	MMBtu/t TS	Calculated
E_{NET}	3,602	kWh/t TS	Eq. 2
Net CO₂e emissions			
$CO_2e_{LFG,rd}$	0	kg CO ₂ /t TS	Eq. 5 & 9
TS_{fLA}/TS_i	0	Fraction	N/A; No land-applied residues
$CO_2e_{N_2O,LA}$	0	kg CO ₂ /t TS	Eq. 10
TS_{INC}/TS_i	0	Fraction	N/A; No incinerated residues
$CO_2e_{N_2O,inc}$	0	kg CO ₂ /t TS	Eq. 11
$CO_2e_{disp, fuels}$	2080	kg CO ₂ /t TS	Eq. 12
$CO_2e_{disp, fertilizers}$	0	kg CO ₂ /t TS	N/A; No land-applied residues
CO_2e_{NET}	-1917	kg CO ₂ /t TS	Eq. 7
CAPEX			
Equipment Cost	19378	€	Shahbeig and Nosrati 2020, Table 4
Instillation	49825	€	Shahbeig and Nosrati 2020, Table 4
Total CAPEX	69203	€	Shahbeig and Nosrati 2020, Table 4
USD/€ (2018) conversion	1.17	USD/€ (FY 2018)	
Total CAPEX	80968	USD	Conversion to USD
Total CAPEX	67473	USD/t TS (FY 2018)	
2018-19 rate of inflation	1.81%	%	US Bureau of Labor Statistics
CAPEX converted to FY 2019	68,694	USD/t TS-d (FY 2019)	
Net Operating Profit			
OPEX			
Utilities	4218	€/yr	Shahbeig and Nosrati 2020, Table 4
Operating Labor	152901	€/yr	Shahbeig and Nosrati 2020, Table 4
Maintenance	9129	€/yr	Shahbeig and Nosrati 2020, Table 4
Operating supplies	4149	€/yr	Shahbeig and Nosrati 2020, Table 4
Lab charges	15290	€/yr	Shahbeig and Nosrati 2020, Table 4
Total OPEX	185687	€/yr	
USD/€ (2018) conversion	1.17	USD/€ (FY 2018)	
Total OPEX	217254	USD/yr	
OPEX	920	USD/t TS (FY 2018)	
2018-19 rate of inflation	1.81%	%	US Bureau of Labor Statistics
OPEX converted to FY 2019	936.24	USD/t TS (FY 2019)	
TDC	0.06	USD/t TS	Eq. 15
Revenue from end-products			
Selling price of bio-char	0.037	€/kg	Shahbeig and Nosrati 2020, Table 5
Selling price of bio-gas	0.045	€/kg	Shahbeig and Nosrati 2020, Table 5
Selling price of bio-crude	292	USD/ton	Xin et al. 2018 Table A4
USD/€ (2018) conversion	1.17	USD/€ (FY 2018)	
Revenue from Bio-char	12.12	USD/t TS	Calculated from total solids loading

Revenue from Bio-gas	14.22	USD/t TS	Calculated from total solids loading
Revenue from Bio-oil	131	USD/t TS	Calculated from total solids loading
Total Revenue from end-products	158	USD/t TS (FY 2018)	Calculated
2018-19 rate of inflation	1.81%	%	US Bureau of Labor Statistics
Revenue converted to FY 2019	160.57	USD/t TS (FY 2019)	
Net Operating Profit	-776	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	7		System prototype demonstration in the planned operational environment, Mankins 2009
Supplementary Table 35: Hydrothermal Carbonization - Anaerobic Digestion of aqueous products - Combined heat and power - Land Application (HTC-AD-CHP-LA)			
Parameter	Quantity	Units	Reference
Operating days per year	365	days/yr	Medina-Martos et al. 2020, Table 5 & S2
OPEX over 20 years	68500000	€	Medina-Martos et al. 2020, Table 5
Annual OPEX	68.5	€/t dry solids	
Solids loading rate (wet basis)	50000	t WS/yr	Calculated from OPEX values reported in Medina-Martos et al. 2020, Table 5
Wet sludge feed rate	137	t/day	Calculated
Moisture content of sludge	85%	%wt	Medina-Martos et al. 2020, Table 1
Dry sludge feed rate	20.5	t TS/day	Calculated
Wet weight of final residues			
digestate yield	6%	%wt	Medina-Martos et al. 2020, Section 2
digestate yield	0.852	%wt (wet basis)	Medina-Martos et al. 2020, Figure 3
digestate yield	34%	%wt (dry basis)	Calculated from digestate yield
Moisture content of waste residues	80%	%wt	Assumed
WS _f /TS _i	1.70	Fraction	Eq. 1
Net energy balance			
E _{elec,out}			
Electricity export	26.8	kWh/t WS	Medina-Martos et al. 2020, Figure 3
Electricity export	179	kWh/t TS	Calculated from solids moisture content
VS _{LF}	0%	%	N/A; Not landfilled residues
R _{LFG}	0%	%	Assumed
E _{LFG}	0	kWh/t TS	Eq. 5 & 6
E _{elec,in}	0	kWh/t TS	N/A; No electricity import, Medina-Martos et al. 2020, Section 3
E _{prod}			
Heat export as LPS	5.97	MJ/t WS	Medina-Martos et al. 2020, Figure 3
Heat export as LPS	1.66	kWh/t TS	Calculated based on solids moisture content
Heat export as HPS	61.7	MJ/t WS	Medina-Martos et al. 2020, Figure 3
Heat export as HPS	17.14	kWh/t TS	Calculated based on solids moisture content
wet Sludge feed	1000	kg	Medina-Martos et al. 2020, Figure 3
dry sludge feed	150	kg	Calculated from solids moisture content
Hydrochar produced	26	kg	Medina-Martos et al. 2020, Section 3.1
Hydrochar yield	17.3%	%wt	Calculated from solids moisture content
Energy from hydrochar	562	MJ/t wet sludge	Medina-Martos et al. 2020, Section 3.2
Energy from hydrochar	3747	MJ/t TS	Calculated based on solids moisture content
Energy from hydrochar	1041	kWh/t TS	Conversion from MJ to kWh
Total energy equivalent of end-products	1060	kWh/t TS	Calculated
E _{diesel}	231	kWh/t TS	Eq. 4
E _{NG,in}	0	MMBtu/t TS	N/A; No natural gas import, Medina-Martos et al. 2020, Section 3
E _{NET}	978	kWh/t TS	Eq. 2
Net CO₂e emissions			
CO ₂ e _{LFG,rel}	0	kg CO ₂ /t TS	Eq. 5 & 9
TS _{f,LA} /TS _i	34%	Fraction	Calculated from digestate yield
CO ₂ e _{N2O,LA}	77	kg CO ₂ /t TS	Eq. 10
TS _{INC} /TS _i	0	Fraction	N/A; No incinerated residues
CO ₂ e _{N2O,inc}	0	kg CO ₂ /t TS	Eq. 11
CO ₂ e _{disp, fuels}	1065	kg CO ₂ /t TS	Eq. 12
CO ₂ e _{disp, fertilizers}	130	kg CO ₂ /t TS	Zhao et al. 2019
CO ₂ e _{NET}	-1087	kg CO ₂ /t TS	Eq. 7
CAPEX			
CAPEX over 20 years	25700000	€ (FY 2019)	
€ to USD conversion	0.88	FY 2019	Medina-Martos et al. 2020, Table 3
CAPEX over 20 years	29171396	USD (FY 2019)	
CAPEX	1419675	USD/t TS·d (FY 2019)	
Net Operating Profit			
OPEX			
OPEX over 20 years	68500000	€	Medina-Martos et al. 2020, Table 5
OPEX	3425000	€/yr	
OPEX (USD/d)	9384	€/day	Calculated from operating days
OPEX (USD/t TS)	457	€/t TS	Calculated from solids loading rate
OPEX	518	USD/t TS	
TDC	98.18	USD/t TS	Eq. 15
Revenue from end-products			
Revenue from Hydrochar	2.68	€/t wet sludge	Medina-Martos et al. 2020, Table 5
Revenue from LPS	0.04	€/t wet sludge	Medina-Martos et al. 2020, Table 5
Revenue from HPS	0.60	€/t wet sludge	Medina-Martos et al. 2020, Table 5

Revenue from Electricity Export	1.54	€/t wet sludge	Medina-Martos et al. 2020, Table 5
Total revenue from end products	4.86	€/t wet sludge	Medina-Martos et al. 2020, Table 5
Total revenue from end products	36.78	USD/t TS	Calculated from solids moisture content
Net Operating Profit	-580	USD/t TS	Eq. 14
Technology Readiness Level			
TRL	4	Component and/or breadboard validation in 'laboratory' environment	
Supplementary Table 36: CO₂e of Land Applied Biosolids			
WAS Feed rate (m ³ /d)	26172		Zhao et al. 2019, Table S2
WAS %TS	0.84%		Zhao et al. 2019, Table S2
WAS Specific gravity	1.005		M&E 5th ed.
WAS Feed rate (t TS/d)	221		
PS feed rate (m3/d)	2562		Zhao et al. 2019, Table S2
PS %TS	3.68%		Zhao et al. 2019, Table S2
PS Specific gravity	1.03		M&E 5th ed.
PS Feed rate (t TS/d)	97		Calculated
Operating days per year	365		Zhao et al. 2019
Operating hrs per day	24		Zhao et al. 2019
Total sludge feed rate (t TS/d)	28734		Calculated
Total sludge feed rate (t TS/d)	318		Calculated
CO ₂ eqv of land applied sludge (kg CO ₂ /m ³ sludge treated)	1.5		Zhao et al. 2019
CO ₂ eqv of land applied sludge (kg CO ₂ /t TS)	136		Calculated
Estimated CO ₂ eqv of land applied sludge (kg CO ₂ /t TS)	130		Approximated for purpose of this TEA reaview.