Supporting information

Greenhouse gas impact of algal bio-crude production for a range of CO_2 supply scenarios

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Methodology

The algae production, CO_2 production and delivery, HTL reactor, CHG reactor, and hydro-treating is modeled in ASPEN Plus® simulation software. The software platform has been used in previous studies to model similar algal growth processes [1][2]. The Redlich Kwong Soave (RKS) thermodynamic model has been utilized to estimate the thermodynamic properties of the different compounds modeled in the flowsheet. The algae production is modeled utilizing a methodology reported by NREL [1]. The model was validated against data reported by NREL, and subsequently, the model was updated to incorporate the selected Algenol algae strain [3]. The algae species was modeled to be composed of 50.2 % carbon, 6.8 % hydrogen, 24.4 % oxygen, 9.8 % nitrogen, 0.7 % sulphur, and 8.1 % ash. The algae are assumed to be grown in PBRs with a productivity of 25 $g/m^2/day$ [4] in a 2000 acre algae growth facility [5]. The CO_2 utilization efficiency of the PBRs is assumed to be 85 % with the remaining 15% released back to the atmosphere in a gas purge. The algae concentration in the PBRs is less than 1 %, which is concentrated to 21.4 % using filters and centrifuge. The excess water, along with the nutrients, is recycled back to the PBRs. The algae growth and concentration mechanism are assumed to consume 5.5 MW of electricity [4].

The harvested algae is used for the production of bio-crude through HTL occurring at 350 °C and 200 bar [4]. The HTL process leads to three components, namely the bio-crude, the aqueous phase, and the fuel-gas. The aqueous phase is subjected to CHG, leading to the production of syngas rich in methane. The syngas from the CHG and fuel gas from the HTL unit is combusted to provide the energy required for the operation of both the HTL and CHG units, thus making the thermo-chemical conversion process to be self-sufficient in terms of its heating requirement. The CO_2 produced from the combustion of these gases is recycled back to the PBRs. The only energy input to the HTL and CHG process is the electricity requirement by the different pumps used for pumping the algae slurry and the aqueous phase. The water left behind in the CHG process is recycled back to the PBRs. It is assumed that 70% of the nutrients required for algae growth are also recycled along with this water recycle [4].

The HTL and the CHG processes were simulated by updating the models proposed by PNNL [2]. The simulation incorporates separate day and night operations as well as recycling of CO_2, water, and nutrients. The separate day and night operations are needed to reconcile the daytime algae production limited by sunshine and the continuous day/night operation of the HTL and the CHG units. The HTL and CHG reactors are assumed to operate for 24 hrs./day, whereas the algae production is considered to occur for 12 hrs./day. Thus, the HTL units utilize half of the algae produced during the daytime, and half of it is utilized during night-time. The CO_2 recycle from syngas combustion takes place during the algae growth phase during the daytime. During night-time operations of the HTL and the CHG units, the CO_2 is vented to the atmosphere. The water recycle from the CHG unit, however, is assumed to take place continuously.

The bio-crude produced from the HTL process needs to be upgraded to be utilized as a substitute to either gasoline range or diesel range fuels. This up-grading is accomplished by the hydrotreating and the hydrocracking processes. In the hydrotreating process, the bio-crude is made to catalytically react with hydrogen at 500 ℃ and 100 bar to remove oxygen, nitrogen, and sulfur from bio-crude. Oxygen is converted into CO_2 and water, nitrogen is converted into ammonia, and sulfur is converted into hydrogen sulfide [2]. Ammonia is removed with the help of a water scrubber. The effluent from the hydrotreater is condensed to produce water and hydrocarbons. The hydrocarbons are then fractioned into different boiling point ranges, namely gas range, gasoline range, diesel range, and heavy-oil range, utilizing three distillation columns. The hydrocracking unit is utilized for converting the heavy-oil range product from the hydrotreater to diesel-range and gasoline range products via the addition of hydrogen. The hydrocracking reaction is assumed to occur at 400 ℃ and 70 bar. The study assumes that the hydrotreating and hydrocracking would be accomplished at a conventional crude refinery, and no separate infrastructure would be built for these catalytic conversion processes. The hydrogen utilized for these processes would be supplied through the steam methane reforming process at the conventional crude refinery [6]. A transportation distance of 100 km has been chosen to account for the transportation of bio-crude to the refinery and the transport of the diesel and gasoline range biofuels to the market.

Scenario 1: CO_2 from a coal-based power plant

This is the standard baseline scenario as most algal biorefinery-based studies assume a CO_2 supply from coal-based power plants. A coal-based power plant is considered to be located at a distance of 2 miles from the biorefinery. The flue gases (available at a temperature of 60°C and with 11.9 % CO_2 by weight) from the power plant are cooled and compressed before being transported. The flowsheet is designed to deliver CO_2 to the biorefinery at a pressure of 2 bar, and a pressure drop of 0.055 bar per mile is assumed. The gas is scrubbed twice, once at the power plant and then again at the biorefinery to reduce the moisture content. The only energy requirement is the compression of flue gas. The process flowsheet highlighting the CO_2 delivery section is presented in Figure 1. The electricity requirement of the biorefinery is met through a relatively small onsite natural gas combined cycle (NGCC) plant.

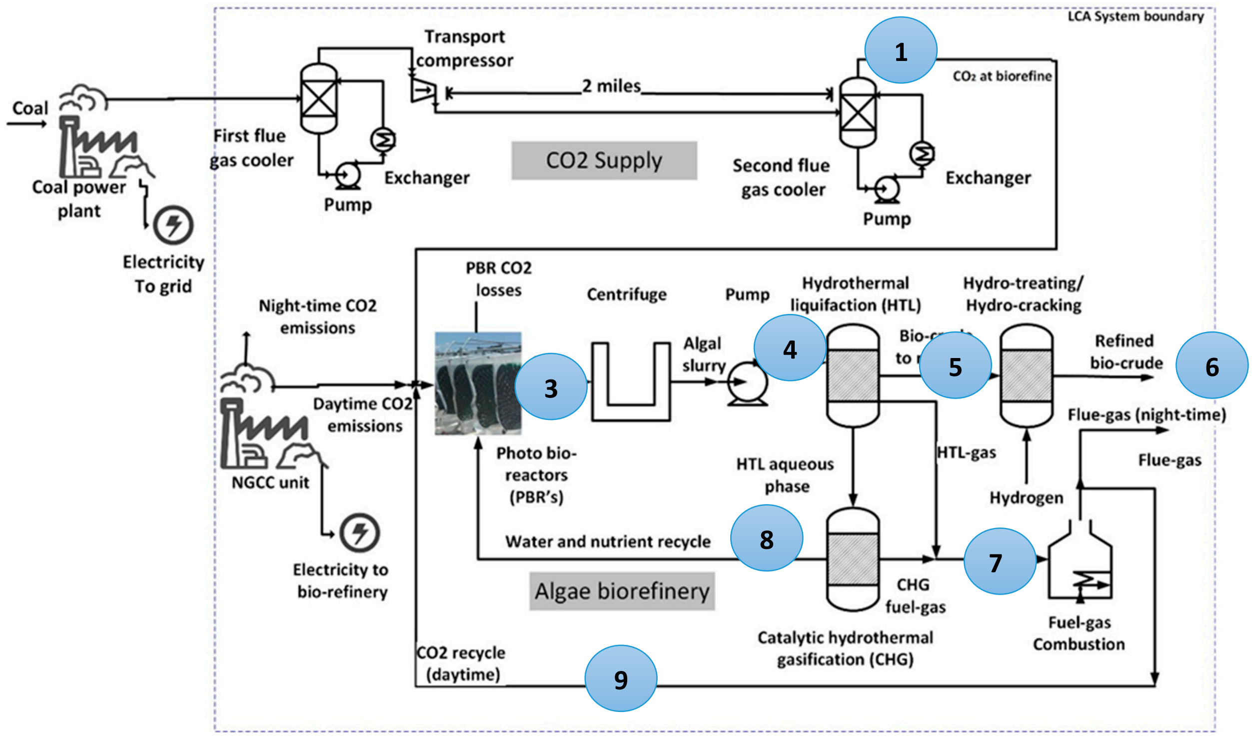

Figure S1: CO_2 from a coal-based power plant

Electricity export from the NGCC unit

Day-time: 0.44 MWh/h

Night-time: 13.31 MWh/h

Natural gas input to NGCC unit: 2500 kg/h

Table S1: Mass balance: CO_2 from a coal-based power plant

		1	2	3	4	5	6	7	8	9
Temperature	C	30.00	30.00	30.00	30.00	60.00	30.00	60.00	60.00	30.00

Pressure	bar	2.00	2.00	1.00	1.00	2.00	1.00	3.45	1.00	2.00
Mass Vapor Fraction		1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Mass Flows	kg/hr	151279.35	108773.00	102216.21	51108.10	4161.85	3111.81	2375.58	84244.13	5065.34
Mass Fractions										
H2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N2		0.73	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O2		0.05	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2		0.21	0.06	0.00	0.00	0.00	0.00	0.41	0.00	1.00
H2O		0.01	0.02	0.79	0.79	0.05	0.00	0.05	0.83	0.00
NH3		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
CH4		0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00
C2H6		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3H8		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-C4H10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-PENTAN		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEXANE		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
NH4+		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
H3O+		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
HCO3-		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00
C5H9NS		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
TOLUENE		0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00
RYRO3ETM		0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
PHENO4M		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
AMIPHENO		0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
INDOLE		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
2-PYTENE		0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
C15OLEF		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
MC12AMID		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16AMIDE		0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
C18AMIDE		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16:0FA		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
C18:1FA		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
C13H18		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
HEVOIL1		0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
HEVOIL2		0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
2MPENTA		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
CC5-METH		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2MHEXAN		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEPTANE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC6-METH		0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00

PIPERDIN		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3MHEPTA		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
OCTANE		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHCYC6		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHBENZ		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
O-XYLENE		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C9H20		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
CC6-PRO		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C3BENZ		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
4MNONAN		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C10H22		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C4BENZ		0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C11H24		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C10H12		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C12H26		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
1234NA		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
CC6-HEX		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
14DMNAPH		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C13H28		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C7BENZ		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C8BENZ		0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
TETMC16		0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
C22H42O4		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C14H30		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C15H32		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C16H34		0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
C17H36		0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C18H38		0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C19H40		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20H42		0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
C22H46		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24H50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C28H58		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C30H62		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH4HS		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2*NH4CO3		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALGAE		0.00	0.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00

Scenario 2: CO_2 from a natural gas-based power plant

A natural gas-based power plant differs significantly from a coal-based power plant in terms of CO_2 concentration and water saturation in the flue gas. The flue gas is assumed to be available at a temperature of 80 °C and has 4.3 % CO_2 by weight. Standard amine-based solvents would be used to capture the CO_2 from the flue gas. The capture is necessary due to the low concentration of CO_2 in the flue gas. A 90 % CO_2 capture efficiency is assumed for delivering gas with a CO_2 concentration of more than 95 %. The heat required by the capture system is supplied through a natural gas-fired package boiler. The inherent complexity of a natural gas-based power plant would make it difficult to extract the required heat from the power plant. The process flowsheet highlighting the CO_2 delivery section is presented in Figure 2.

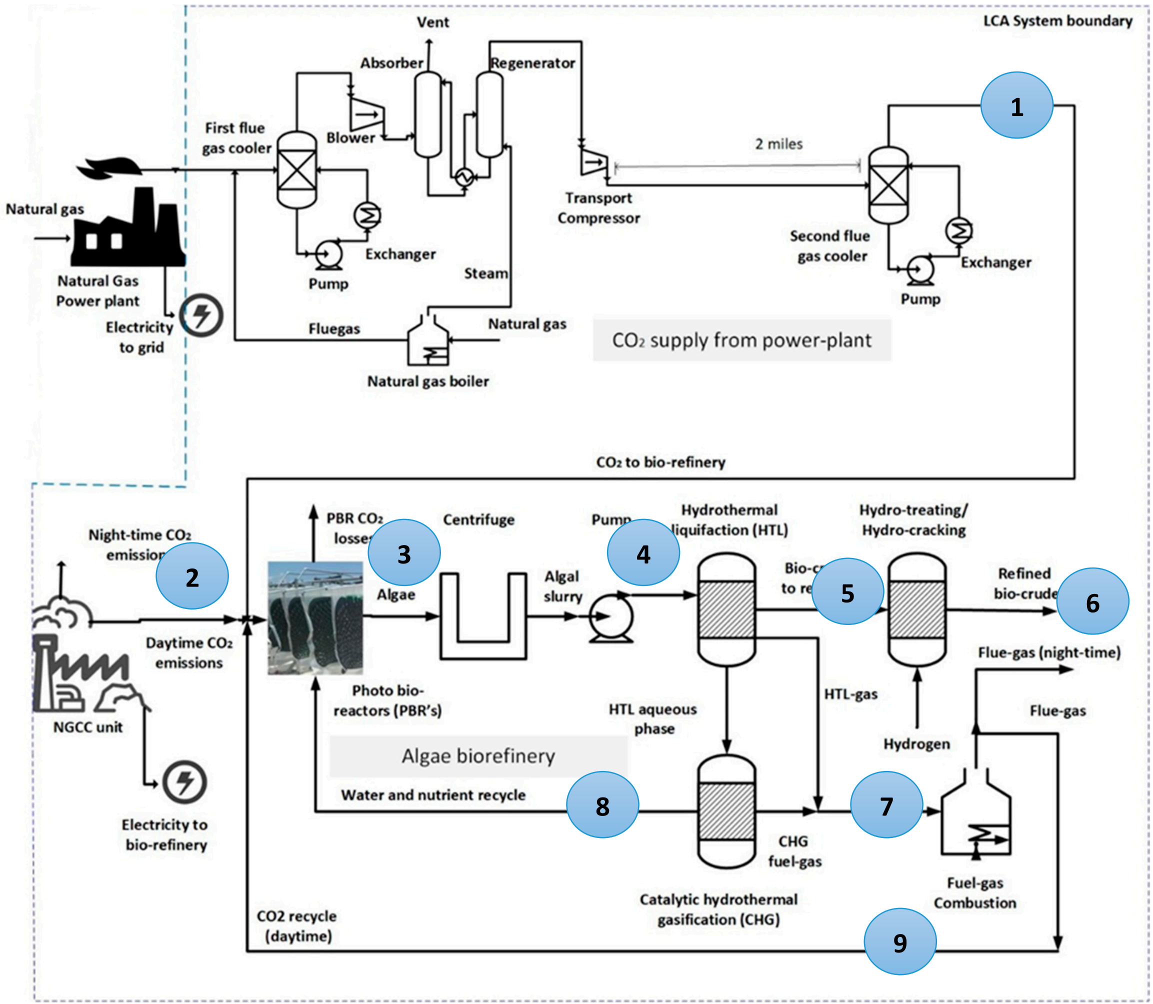

Figure S2: CO_2 from a natural gas-based power plant

Electricity export from the NGCC unit

Day-time: 0.34 MWh/h

Night-time: 7.69 MWh/h

Natural gas intake for carbon-capture boiler: 1987 kg/h

Natural gas input to NGCC unit: 2343 kg/h

Table S2:Mass balance: CO_2 from a natural gas-based power plant

	Units	1	2	3	4	5	6	7	8	9
Temperature	C	30.00	30.00	30.00	30.00	60.00	30.00	60.00	60.00	30.00
Pressure	bar	2.00	2.00	1.00	1.00	2.00	1.00	3.45	1.00	2.00
Mass Flows	kg/hr	477779.30	110201.71	101890.25	50945.13	4147.18	3101.45	2367.90	83932.54	5047.85
Mass Fractions										
H2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N2		0.78	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O2		0.14	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2		0.07	0.03	0.00	0.00	0.00	0.00	0.41	0.00	1.00
H2O		0.01	0.02	0.79	0.79	0.05	0.00	0.05	0.83	0.00
NH3		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
NO2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CH4		0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00
C2H6		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3H8		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-C4H10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-PENTAN		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEXANE		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
NH4+		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
H3O+		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
HCO3-		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00
C5H9NS		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00

TOLUENE		0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00
RYRO3ETM		0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
PHENO4M		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
AMIPHENO		0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
INDOLE		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
2-PYTENE		0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
C15OLEF		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
MC12AMID		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16AMIDE		0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
C18AMIDE		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16:0FA		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
C18:1FA		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
C13H18		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
HEVOIL1		0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
HEVOIL2		0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
2MPENTA		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
CC5-METH		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2MHEXAN		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEPTANE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC6-METH		0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
PIPERDIN		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3MHEPTA		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
OCTANE		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHCYC6		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHBENZ		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
O-XYLENE		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C9H20		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
CC6-PRO		0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C3BENZ		0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00

4MNONAN	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C10H22	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C4BENZ	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C11H24	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C10H12	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C12H26	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
1234NA	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
CC6-HEX	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
14DMNAPH	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C13H28	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C7BENZ	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C8BENZ	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
TETMC16	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
C22H42O4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C14H30	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C15H32	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C16H34	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
C17H36	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C18H38	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C19H40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20H42	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
C22H46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24H50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C28H58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C30H62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH4HS	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2*NH4CO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALGAE	0.00	0.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00

Scenario 3: CO_2 from an NGCC unit with carbon capture and refrigeration

A power plant may not always be available in the areas surrounding a biorefinery. In such cases, a new natural gas combined cycle (NGCC) plant can be built near the biorefinery (Figure 3). The NGCC plant can provide the CO_2 and steam for the biorefinery. This study considers a 34 MW plant operating throughout the day. A carbon capture facility, similar to scenario 2, would be utilized to increase the concentration of CO_2 to approximately 95 %. Additionally, this scenario would include a refrigeration unit to capture the night-time emissions from the NGCC plant. During the night, the NGCC plant would be run at full load, and the flue gas emissions would be captured and refrigerated. During the day, the refrigerated CO_2 would be supplied to the biorefinery along with the daytime emissions from the NGCC unit (after carbon capture). The energy requirement for the carbon capture and refrigeration unit is provided by the NGCC unit. After accounting for the energy requirement of the CO_2 delivery, the capture unit, and the biorefinery, the remaining electricity would be exported to the grid.

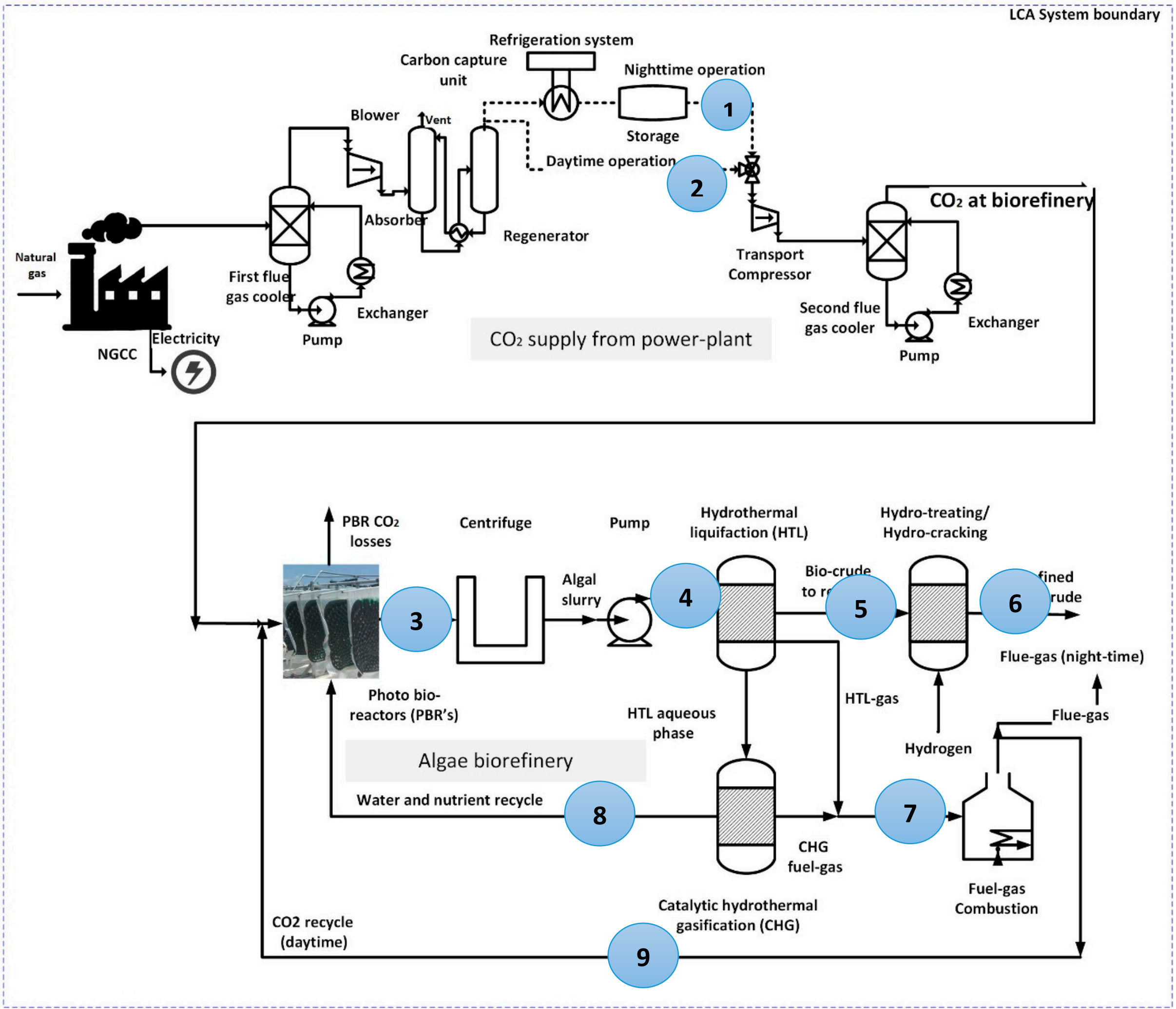

Figure S3: CO_2 from an NGCC unit with carbon capture and refrigeration

Electricity export from the NGCC unit

Day-time: 18.79 MW

Night-time: 24.32 MW

Natural gas intake: 7987 kg/h

Table S3: Mass balance: CO_2 from an NGCC unit with carbon capture and refrigeration

	Units	1	2	3	4	5	6	7	8	9
Temperature	C	30.00	30.00	30.00	30.00	60.00	30.00	60.00	60.00	30.00
Pressure	bar	1.00	1.00	1.00	1.00	2.00	1.00	3.45	1.00	2.00
Mass Vapor Fraction		1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Mass Flows	kg/hr	20155.11	18609.20	101106.53	50553.27	4114.63	3078.45	2349.21	83271.57	5008.10
Mass Fractions										
N2		0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2		0.97	0.99	0.00	0.00	0.00	0.00	0.41	0.00	1.00
H2O		0.02	0.00	0.79	0.79	0.05	0.00	0.05	0.83	0.00
NH3		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
CH4		0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00
C2H6		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3H8		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-C4H10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-PENTAN		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEXANE		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C5H9NS		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
TOLUENE		0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00

RYRO3ETM	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
PHENO4M	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
AMIPHENO	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
INDOLE	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
2-PYTENE	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
C15OLEF	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
MC12AMID	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16AMIDE	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
C18AMIDE	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16:0FA	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
C18:1FA	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
C13H18	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
HEVOIL1	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
HEVOIL2	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
2MPENTA	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
CC5-METH	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2MHEXAN	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEPTANE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC6-METH	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
PIPERDIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3MHEPTA	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
OCTANE	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHCYC6	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHBENZ	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
O-XYLENE	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C9H20	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
CC6-PRO	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C3BENZ	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00

4MNONAN	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C10H22	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C4BENZ	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C11H24	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C10H12	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C12H26	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
1234NA	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
CC6-HEX	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
14DMNAPH	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C13H28	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C7BENZ	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C8BENZ	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
TETMC16	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
C22H42O4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C14H30	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C15H32	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C16H34	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
C17H36	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C18H38	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C19H40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20H42	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
C22H46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24H50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C28H58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C30H62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH4HS	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2*NH4CO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALGAE	0.00	0.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00

Scenario 4: CO_2 from a biomass combustion plant

A renewable source of energy, namely, a biomass-based boiler, can be used to meet the CO_2 and energy requirements (Figure 4). Electricity is produced from the steam produced in the boilers, and the flue gas, which is rich in biogenic carbon, is supplied to the biorefinery. The plant produces 16 MW of electricity. The daytime emissions are utilized for algae growth, whereas the night-time emissions are vented off to the atmosphere. The simulation predicted a CO_2 concentration in the flue gas of 18 % by weight, which is above the requirements for the biorefinery, thus eliminating the need for a carbon capture unit. In this scenario, the carbon is routed from a biogenic source, i.e., biomass as compared to fossil-based carbon sources utilized in the other three scenarios. Another advantage of this process would be the production of cleaner electricity, which would replace fossil fuel-based grid electricity.

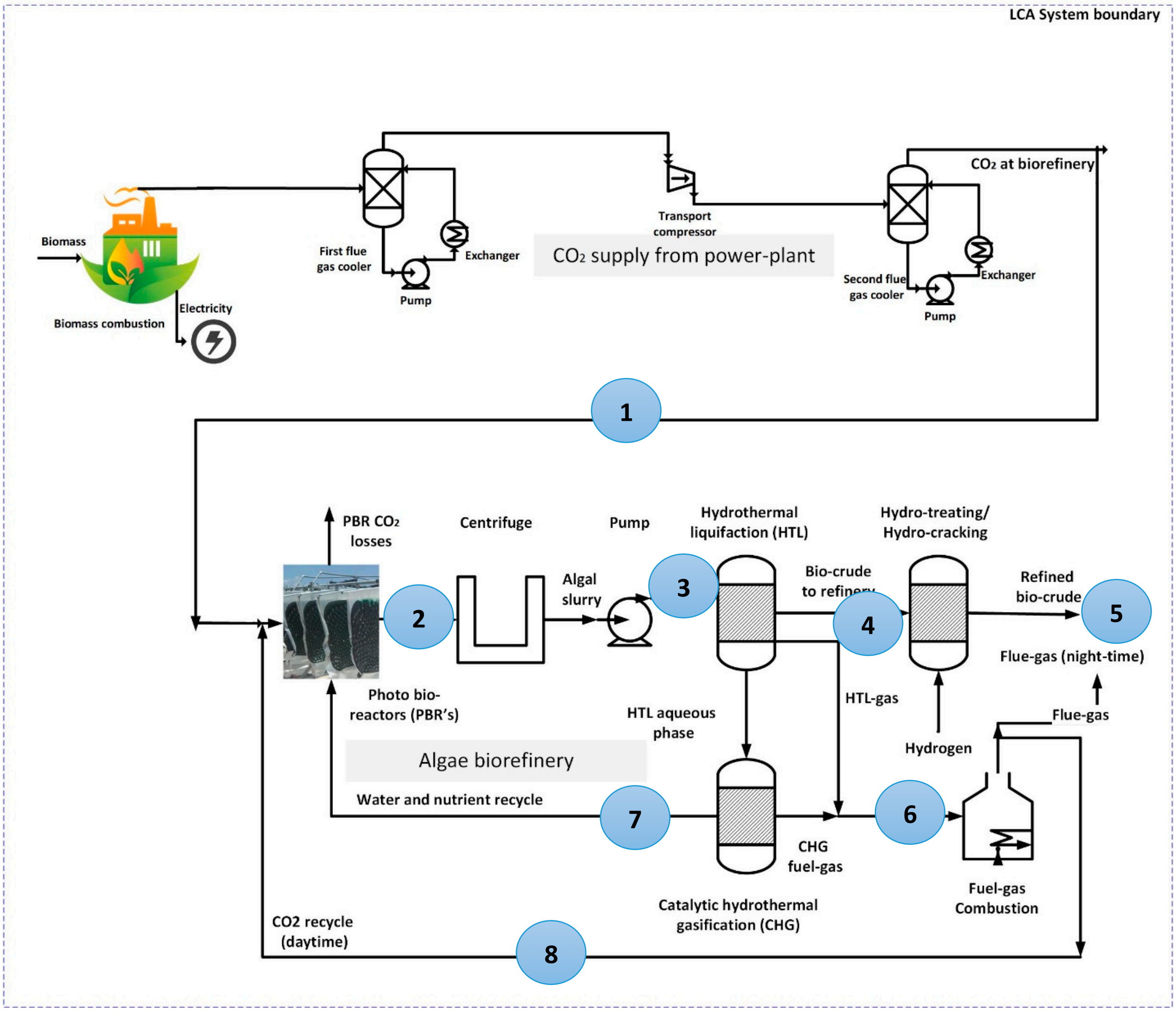

Figure S4: CO_2 from a biomass combustion plant

Electricity export from the biomass combustion unit

Day-time: 9.73 MWh/h

Night-time: 15.23 MWh/h

Biomass intake: 22000 kg/h

Table S4: Mass balance: CO_2 from a biomass combustion plant

	Units	1	2	3	4	5	6	7	8
Temperature	C	30.00	30.00	30.00	60.00	30.00	60.00	60.00	30.00
Pressure	bar	2.00	1.00	1.00	2.00	1.00	3.45	1.00	2.00
Mass Vapor Fraction		1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Mass Flows	kg/hr	151505.88	100709.57	50354.79	4099.48	3067.76	2334.79	82977.35	4984.05
Mass Fractions									
N2		0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O2		0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2		0.25	0.00	0.00	0.00	0.00	0.41	0.00	1.00
H2O		0.01	0.79	0.79	0.05	0.00	0.05	0.83	0.00
NH3		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
CH4		0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00
C2H6		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3H8		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-C4H10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-PENTAN		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEXANE		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C5H9NS		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
TOLUENE		0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00
RYRO3ETM		0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00

PHENO4M		0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
AMIPHENO		0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
INDOLE		0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
2-PYTENE		0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
C15OLEF		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
MC12AMID		0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16AMIDE		0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
C18AMIDE		0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16:0FA		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
C18:1FA		0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
C13H18		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
HEVOIL1		0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
HEVOIL2		0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
MPYRRD		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2MPENTA		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
CC5-METH		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2MHEXAN		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEPTANE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC6-METH		0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
PIPERDIN		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3MHEPTA		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
OCTANE		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHCYC6		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHBENZ		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
O-XYLENE		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C9H20		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
CC6-PRO		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C3BENZ		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00

4MNONAN	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C10H22	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C4BENZ	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C11H24	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C10H12	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C12H26	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
1234NA	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
CC6-HEX	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
14DMNAPH	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C13H28	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C7BENZ	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C8BENZ	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
TETMC16	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
C22H42O4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C14H30	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C15H32	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C16H34	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
C17H36	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C18H38	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C19H40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20H42	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
C22H46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24H50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C28H58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C30H62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH4HS	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2*NH4CO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALGAE	0.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00

Scenario 5: CO_2 from a biomass gasification plant

The biomass fuel can be used efficiently by employing the gasification process (Figure 5), which is a thermo-chemical conversion process. The biomass feedstock can be gasifier in an entrained flow gasifier which would yield a syngas having 11 % H_2 and 16 % CO (by volume). This energy-rich syngas can be used to operate a 45 MW gas turbine. A heat recovery steam generator (HRSG) utilizes the hot exhaust from the gas turbine and produces high-pressure steam at 10 bar and 500 °C. This steam is expanded in a 14 MW steam turbine. Furthermore, the flue gases are used for drying the biomass.

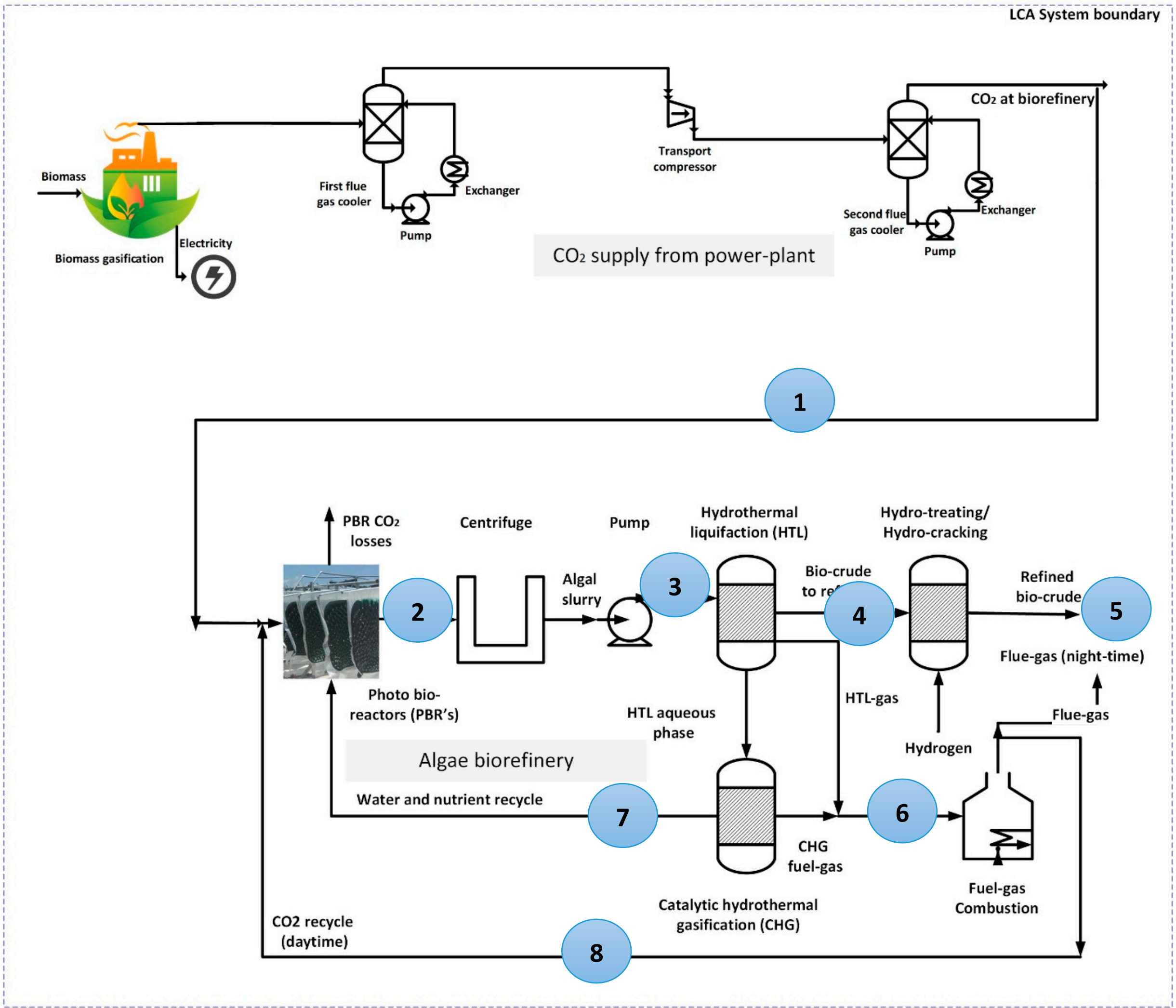

Figure S5: CO_2 from a biomass gasification plant

Electricity export from the biomass combustion unit

Day-time: 20.32 MWh/h

Night-time: 25.82 MWh/h

Biomass intake: 22000 kg/h

Table S5: Mass balance: CO_2 from a biomass gasification plant

	Units	1	2	3	4	5	6	7	8
Temperature	C	30.00	30.00	30.00	60.00	30.00	60.00	60.00	30.00
Pressure	bar	2.00	1.00	1.00	2.00	1.01	3.45	1.00	2.00
Mass Vapor Fraction		1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Mass Flows	kg/hr	323706.00	100709.57	50354.79	4099.48	3067.76	2334.79	82977.35	4984.05
Mass Fractions									
N2		0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O2		0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2		0.12	0.00	0.00	0.00	0.00	0.41	0.00	1.00
H2O		0.01	0.79	0.79	0.05	0.00	0.05	0.83	0.00
NH3		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
CH4		0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00
C2H6		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3H8		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-C4H10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-PENTAN		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEXANE		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C5H9NS		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
TOLUENE		0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00
RYRO3ETM		0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
PHENO4M		0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
AMIPHENO		0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
INDOLE		0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00

2-PYTENE	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
C15OLEF	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
MC12AMID	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16AMIDE	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
C18AMIDE	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16:0FA	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
C18:1FA	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
C13H18	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
HEVOIL1	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
HEVOIL2	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
MPYRRD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2MPENTA	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
CC5-METH	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2MHEXAN	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEPTANE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC6-METH	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
PIPERDIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3MHEPTA	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
OCTANE	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHCYC6	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHBENZ	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
O-XYLENE	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C9H20	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
CC6-PRO	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C3BENZ	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
4MNONAN	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C10H22	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C4BENZ	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00

C11H24		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C10H12		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C12H26		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
1234NA		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
CC6-HEX		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
14DMNAPH		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C13H28		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C7BENZ		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C8BENZ		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
TETMC16		0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
C22H42O4		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C14H30		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C15H32		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C16H34		0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
C17H36		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C18H38		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C19H40		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20H42		0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
C22H46		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24H50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C28H58		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C30H62		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH4HS		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2*NH4CO3		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALGAE		0.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00

Scenario 6: CO_2 from DAC

Industrial-scale quantities of CO_2 can be captured directly from the atmosphere utilizing Direct Air Capture (DAC) systems. This is different from the above-discussed scenarios, where the CO_2 is routed from the flue gas of power plants. A number of DAC technologies have been proposed differing mainly in their CO2 capture and recovery mechanisms [7][8]. The present study focuses on a process developed by Carbon Engineering (CE) [9]. The mass and energy balance for this particular DAC process have been reported by Keith et al. [9]. A chemical absorbent composed of potassium hydroxide is used to filter air and captures approximately 80% of the 400 ppm carbon dioxide in the air. The CO_2-depleted air is released back to the atmosphere. Two connected chemical loops are used to concentrate the captured CO_2 (Figure 4). While the first loop utilizes an aqueous solution of potassium hydroxide and potassium carbonate, the second loop uses calcium hydroxide and calcium carbonate. The calcium carbonate is eventually calcined to release concentrated CO_2. A 10 MW natural gas-based combined heat and power (CHP) unit provides the process steam requirements and the electricity for CO_2 compression, air contactors, and the biorefinery. The calciner would also require a 3 t/h supply of natural gas to meet its heating requirement. It should be noted that the DAC process extracts a significant portion of CO_2 from flue gases generated in the CHP and the calciner, apart from the majority of CO_2 coming from the atmosphere. Herein, DAC and the algal biorefinery processes have been integrated such that the CHP plant provides for the electricity requirement of both processes. At night-time the DAC plant is shut down, while the CHP plant continues to operate sending electricity to the grid.

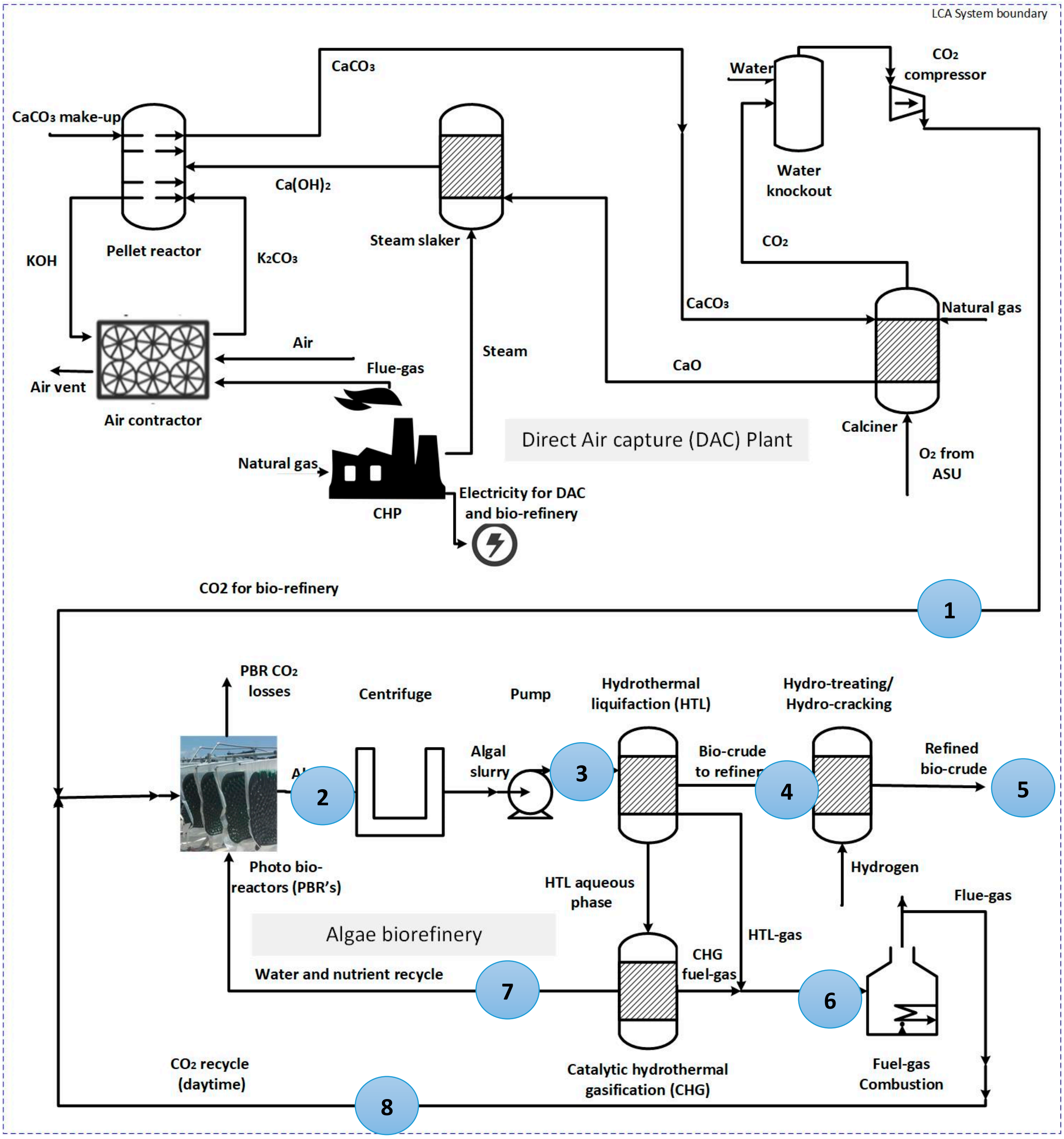

Figure S6: CO_2 from DAC

Electricity export from the CHP unit

Day-time: 3.73 MW

Night-time: 8.12 MW

Steam to steam-slaker: 8.56 MW

Natural gas to CHP: 1860 kg/hr

Natural gas to calciner: 3050 kg/hr

Table S6: Mass balance: CO_2 from DAC

	Units	1	2	3	4	5	6	7	8
Temperature	C	40.00	30.00	30.00	60.00	30.00	60.00	60.00	30.00
Pressure	bar	2.00	1.00	1.00	2.00	1.01	3.45	1.00	2.00
Mass Vapor Fraction		1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Mass Flows	kg/hr	39525.36	101921.10	50960.55	4150.98	3104.13	2368.48	83952.87	5049.47
Mass Fractions									
N2		0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O2		0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2		0.97	0.00	0.00	0.00	0.00	0.41	0.00	1.00
H2O		0.00	0.79	0.79	0.05	0.00	0.05	0.83	0.00
NH3		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
CH4		0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00
C2H6		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C3H8		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-C4H10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-PENTAN		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEXANE		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C5H9NS		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
TOLUENE		0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00
RYRO3ETM		0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
PHENO4M		0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
AMIPHENO		0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
INDOLE		0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00

2-PYTENE		0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
C15OLEF		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
MC12AMID		0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16AMIDE		0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
C18AMIDE		0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
C16:0FA		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
C18:1FA		0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
C13H18		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
HEVOIL1		0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
HEVOIL2		0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
2MPENTA		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
CC5-METH		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2MHEXAN		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
HEPTANE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC6-METH		0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
PIPERDIN		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3MHEPTA		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
OCTANE		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHCYC6		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
ETHBENZ		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
O-XYLENE		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C9H20		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
CC6-PRO		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C3BENZ		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
4MNONAN		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C10H22		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C4BENZ		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C11H24		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00

C10H12		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C12H26		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
1234NA		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
CC6-HEX		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
14DMNAPH		0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
C13H28		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C7BENZ		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C8BENZ		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
TETMC16		0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
C22H42O4		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C14H30		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C15H32		0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
C16H34		0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
C17H36		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C18H38		0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
C19H40		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20H42		0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
C22H46		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24H50		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C28H58		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C30H62		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH4HS		0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
2*NH4CO3		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALGAE		0.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00

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