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APPENDICES

Appendix A Characterization Data

Table A1 Results of the impact assessment from cultivation stage of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	N	P_2O_5	K_2O	Diesel	Glyphosate	Paraquate
abiotic depletion	kg Sb eq	1.3497	0.5424	0.0012	0.2040	0.4353	0.1255	0.0412
global warming	kg CO2 eq	247.5546	193.7883	0.1649	26.0907	11.4272	12.0978	3.9856
ozone layer depletion	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	11.9604	0.7116	0.0039	0.2402	3.0580	5.6702	2.2766
fresh water aquatic ecotox..	kg 1,4-DB eq	1.7192	0.0012	0.0000	0.0027	0.4846	0.9260	0.3048
marine aquatic ecotox.	kg 1,4-DB eq	11703.7452	0.0088	0.0000	0.0034	1738.9111	7620.9116	2343.9102
terrestrial ecotox.	kg 1,4-DB eq	0.3229	0.0001	0.0000	0.0003	0.0344	0.2146	0.0734
photochemical oxidation	kg C2H4	0.0206	0.0111	0.0001	0.0015	0.0037	0.0030	0.0012
acidification	kg SO2 eq	0.7568	0.5850	0.0026	0.0355	0.0373	0.0698	0.0266
eutrophication	kg PO4eq	0.1130	0.0960	0.0002	0.0059	0.0057	0.0038	0.0014

Table A2 Results of the impact assessment from extraction stage of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	FFB	Water	Diesel	Electricity
abiotic depletion	kg Sb eq	0.8060	0.7474	0.0000	0.0290	0.0296
global warming	kg CO2 eq	223.7034	219.9948	0.0001	0.6038	3.1048
ozone layer depletion	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	1.3929	0.9554	0.0001	0.4252	0.0122
fresh water aquatic ecotox.	kg 1,4-DB eq	0.0462	0.0039	0.0000	0.0422	0.0001
marine aquatic ecotoxicity	kg 1,4-DB eq	391.2628	0.0123	0.0391	390.7789	0.4325
terrestrial ecotoxicity	kg 1,4-DB eq	0.0031	0.0004	0.0000	0.0026	0.0001
photochemical oxidation	kg C2H4	0.0133	0.0127	0.0000	0.0004	0.0002
acidification	kg SO2 eq	0.6389	0.6229	0.0000	0.0073	0.0088
eutrophication	kg PO4--- eq	0.1037	0.1020	0.0000	0.0007	0.0010

Table A3 Results of the impact assessment from refining stage of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	CPO	Phosphoric acid,	Bentonite	Diesel	Electricity
abiotic depletion	kg Sb eq	5.0225	0.8147	0.0049	0.0050	1.1675	3.0304
global warming	kg CO2 eq	575.2180	224.6351	0.7695	0.7748	30.6472	318.3913
ozone layer depletion	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	12.6152	1.5966	0.9909	0.5745	8.2013	1.2520
fresh water aquatic ecotox.	kg 1,4-DB eq	2.7820	0.0525	1.3447	0.0798	1.2997	0.0054
marine aquatic ecotoxicity	kg 1,4-DB eq	8350.8548	437.0730	2709.7701	495.9977	4663.6589	44.3550
terrestrial ecotoxicity	kg 1,4-DB eq	0.1252	0.0049	0.0058	0.0153	0.0924	0.0068
photochemical oxidation	kg C2H4	0.0466	0.0141	0.0009	0.0005	0.0100	0.0211
acidification	kg SO2 eq	1.6789	0.6467	0.0208	0.0130	0.1000	0.8984
eutrophication	kg PO4--- eq	0.2293	0.1042	0.0101	0.0002	0.0154	0.0993

Table A4 Results of the impact assessment from microemulsion stage (Scenario I) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	Palm olein	Ethanol	Surfactant	Cosurfactant	Diesel	Electricity
abiotic depletion	kg Sb eq	22.1865	3.8126	3.9716	2.5629	5.0248	6.7685	0.0461
global warming	kg CO2 eq	1447.8506	538.5881	230.0274	179.3204	317.3953	177.6739	4.8456
ozone layer depletion	kg CFC-11 eq	0.0003	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
human toxicity	kg 1,4-DB eq	226.8797	4.3571	41.1856	71.9275	61.8441	47.5463	0.0191
fresh water aquatic ecotox.	kg 1,4-DB eq	37.0066	1.4551	7.4800	10.9188	9.6180	7.5346	0.0001
marine aquatic ecotoxicity	kg 1,4-DB eq	151905.3095	3624.5469	27347.6498	46322.8001	47572.5589	27037.0788	0.6750
terrestrial ecotoxicity	kg 1,4-DB eq	1.7973	0.0324	0.2317	0.5883	0.4093	0.5356	0.0001
photochemical oxidation	kg C2H4	0.4637	0.0362	0.2684	0.0439	0.0571	0.0577	0.0003
acidification	kg SO2 eq	4.4364	1.5614	0.6677	0.6767	0.9369	0.5800	0.0137
eutrophication	kg PO4--- eq	0.8042	0.2114	0.2615	0.0600	0.1804	0.0894	0.0015

Table A5 Results of the impact assessment from microemulsion stage (Scenario II) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	Palm olein	Bioethanol	Biodiesel(FAME)	Cosurfactant	Diesel	Electricity
abiotic depletion	kg Sb eq	18.8436	3.6923	1.8753	0.2944	6.0791	6.8563	0.0461
global warming	kg CO2 eq	1060.4748	521.5855	45.9425	-75.8684	383.9892	179.9805	4.8456
ozone layer depletion	kg CFC-11 eq	0.0003	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
human toxicity	kg 1,4-DB eq	447.5193	4.2195	282.0827	38.2145	74.8198	48.1636	0.0191
fresh water aquatic ecotox.	kg 1,4-DB eq	1242.0641	1.4092	1125.6629	95.7235	11.6360	7.6324	0.0001
marine aquatic ecotoxicity	kg 1,4-DB eq	216277.8041	3510.1238	118283.5424	9541.4403	57553.9360	27388.0865	0.6750
terrestrial ecotoxicity	kg 1,4-DB eq	536.3038	0.0313	493.9041	41.3306	0.4951	0.5425	0.0001
photochemical oxidation	kg C2H4	0.4106	0.0351	0.0521	0.1956	0.0691	0.0585	0.0003
acidification	kg SO2 eq	6.0974	1.5121	2.4318	0.4188	1.1335	0.5875	0.0137
eutrophication	kg PO4--- eq	2.3818	0.2048	1.6780	0.1887	0.2182	0.0905	0.0015

Table A6 Results of the impact assessment from microemulsion stage (Scenario III) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	Palm ole-in	Ethanol	Surfactant	Cosurfactant	Diesel	1-butanol	Electricity
abiotic depletion	kg Sb eq	23.9483	2.2513	3.6988	2.0735	5.4327	9.7592	0.6868	0.0461
global warming	kg CO2 eq	1324.8984	318.0316	214.2270	145.0778	343.1553	256.1808	43.3804	4.8456
ozone layer depletion	kg CFC-11 eq	0.0004	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000
human toxicity	kg 1,4-DB eq	243.0120	2.5728	38.3566	58.1924	66.8634	68.5551	8.4526	0.0191
fresh water aquatic ecotox.	kg 1,4-DB eq	39.2363	0.8592	6.9662	8.8338	10.3986	10.8639	1.3146	0.0001
marine aquatic ecotoxicity	kg 1,4-DB eq	162006.50	2140.26	25469.16	37477.11	51433.56	38983.67	6502.03	0.6750
terrestrial ecotoxicity	kg 1,4-DB eq	1.9816	0.0191	0.2157	0.4760	0.4425	0.7722	0.0559	0.0001
photochemical oxidation	kg C2H4	0.4600	0.0214	0.2500	0.0355	0.0617	0.0832	0.0078	0.0003
acidification	kg SO2 eq	4.0823	0.9220	0.6218	0.5475	1.0130	0.8363	0.1281	0.0137
eutrophication	kg PO4--- eq	0.7670	0.1248	0.2436	0.0485	0.1950	0.1289	0.0247	0.0015

Table A7 Results of the impact assessment from microemulsion stage (Scenario IV) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	CPO	Ethanol	Surfactant	Cosurfactant	Diesel	Electricity
abiotic depletion	kg Sb eq	18.4200	0.5887	4.0559	1.8128	4.7585	7.1579	0.0461
global warming	kg CO2 eq	1017.3912	162.3292	234.9120	126.8358	300.5706	187.8979	4.8456
ozone layer depletion	kg CFC-11 eq	0.0003	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
human toxicity	kg 1,4-DB eq	202.9565	1.1538	42.0602	50.8753	58.5658	50.2823	0.0191
fresh water aquatic ecotox.	kg 1,4-DB eq	32.4762	0.0379	7.6388	7.7230	9.1082	7.9682	0.0001
marine aquatic ecotoxicity	kg 1,4-DB eq	134653.3575	315.8444	27928.3799	32764.7572	45050.8043	28592.8967	0.6750
terrestrial ecotoxicity	kg 1,4-DB eq	1.6103	0.0035	0.2366	0.4161	0.3876	0.5664	0.0001
photochemical oxidation	kg C2H4	0.4308	0.0102	0.2741	0.0311	0.0541	0.0610	0.0003
acidification	kg SO2 eq	3.1421	0.4673	0.6819	0.4787	0.8873	0.6134	0.0137
eutrophication	kg PO4--- eq	0.6517	0.0753	0.2671	0.0424	0.1708	0.0945	0.0015

Table A8 Results of the impact assessment from cultivation of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	N	P_2O_5	K_2O	Diesel	Glyphosate	Paraquate
Carcinogens	DALY	1.4E-06	5.6E-09	1.4E-11	2.3E-09	2.0E-07	8.8E-07	2.7E-07
Resp. organics	DALY	1.1E-07	1.8E-08	1.0E-10	7.6E-09	7.8E-08	6.3E-09	2.5E-09
Resp. inorganics	DALY	8.3E-05	5.9E-05	2.2E-07	8.5E-06	5.9E-06	7.5E-06	2.8E-06
Climate change	DALY	5.5E-05	4.3E-05	3.5E-08	5.5E-06	2.3E-06	2.5E-06	8.3E-07
Radiation	DALY	1.5E-07	0.0E+00	0.0E+00	0.0E+00	1.9E-08	1.1E-07	2.0E-08
Ozone layer	DALY	1.6E-08	0.0E+00	0.0E+00	0.0E+00	1.4E-08	1.6E-09	6.6E-10
Ecotoxicity	PAF*m2yr	7.5E+00	5.6E-05	2.7E-07	2.7E-05	9.2E-01	4.6E+00	1.9E+00
Acidification/ Eutrophication	PDF*m2yr	5.1E+00	4.4E+00	8.6E-03	2.7E-01	2.3E-01	1.7E-01	5.9E-02
Land use	PDF*m2yr	3.7E-01	0.0E+00	0.0E+00	0.0E+00	2.1E-01	1.2E-01	4.7E-02
Minerals	MJ surplus	4.3E-01	0.0E+00	0.0E+00	0.0E+00	5.6E-02	3.0E-01	6.8E-02
Fossil fuels	MJ surplus	3.5E+02	1.4E+02	2.9E-01	4.8E+01	1.3E+02	2.6E+01	1.0E+01

Table A9 Results of the impact assessment from extraction of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	FFB	Water	Diesel	Electricity
Carcinogens	DALY	4.6E-08	7.9E-09	1.4E-08	2.3E-08	1.5E-09
Resp. organics	DALY	2.8E-08	2.5E-08	3.6E-11	1.9E-09	8.2E-10
Resp. inorganics	DALY	6.9E-05	6.7E-05	4.4E-08	5.6E-07	1.4E-06
Climate change	DALY	5.0E-05	4.9E-05	1.3E-08	1.1E-07	9.5E-07
Radiation	DALY	1.6E-09	0.0E+00	2.6E-10	1.4E-09	0.0E+00
Ozone layer	DALY	5.3E-10	0.0E+00	7.4E-12	5.2E-10	3.2E-14
Ecotoxicity	PAF*m2yr	1.5E-01	8.3E-05	5.5E-02	8.5E-02	6.4E-03
Acidification/ Eutrophication	PDF*m2yr	4.8E+00	4.7E+00	7.8E-04	1.5E-02	6.8E-02
Land use	PDF*m2yr	4.1E-02	0.0E+00	1.1E-03	3.8E-02	1.7E-03
Minerals	MJ surplus	2.5E-02	0.0E+00	1.5E-02	4.5E-03	5.1E-03
Fossil fuels	MJ surplus	2.0E+02	1.8E+02	4.8E-02	7.8E+00	7.1E+00

Table A10 Results of the impact assessment from refining of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	CPO	Phosphoric acid	Bentonite	Diesel	Electricity
Carcinogens	DALY	1.1E-05	7.9E-08	1.2E-06	3.4E-08	9.6E-06	8.1E-08
Resp. organics	DALY	3.7E-06	2.9E-08	3.5E-10	1.7E-09	3.7E-06	4.4E-08
Resp. inorganics	DALY	4.2E-04	6.9E-05	1.5E-06	6.6E-07	2.8E-04	7.5E-05
Climate change	DALY	2.1E-04	4.9E-05	1.2E-07	1.2E-07	1.1E-04	5.0E-05
Radiation	DALY	9.0E-07	1.8E-09	3.0E-09	9.8E-10	8.9E-07	0.0E+00
Ozone layer	DALY	6.7E-07	5.9E-10	5.5E-11	8.2E-10	6.7E-07	1.7E-12
Ecotoxicity	PAF*m2yr	4.5E+01	3.7E-01	2.9E-01	3.4E-01	4.3E+01	3.4E-01
Acidification/ Eutrophication	PDF*m2yr	1.9E+01	4.7E+00	2.7E-02	1.6E-02	1.1E+01	3.6E+00
Land use	PDF*m2yr	1.0E+01	9.7E-02	1.4E-01	2.4E-02	1.0E+01	8.9E-02
Minerals	MJ surplus	3.0E+00	3.9E-02	5.5E-02	1.8E-03	2.6E+00	2.7E-01
Fossil fuels	MJ surplus	6.8E+03	2.0E+02	7.7E-01	1.0E+00	6.2E+03	3.7E+02

Table A11 Results of the impact assessment from microemulsion stage (Scenario I) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	Palm olein	Ethanol	Surfactant	cosurfactant	Diesel	Electricity
Carcinogens	DALY	2.4E-05	1.8E-06	5.4E-06	7.6E-06	6.3E-06	3.2E-06	1.6E-09
Resp. organics	DALY	3.3E-06	8.9E-08	8.6E-07	7.2E-07	4.1E-07	1.2E-06	8.8E-10
Resp. inorganics	DALY	5.5E-04	1.7E-04	8.5E-05	8.8E-05	1.1E-04	9.1E-05	1.5E-06
Climate change	DALY	3.0E-04	1.2E-04	4.8E-05	3.7E-05	6.6E-05	3.6E-05	1.0E-06
Radiation	DALY	1.4E-06	6.9E-09	2.0E-07	5.3E-07	4.1E-07	2.9E-07	0.0E+00
Ozone layer	DALY	2.7E-07	1.7E-09	7.1E-09	8.0E-09	3.3E-08	2.2E-07	3.4E-14
Ecotoxicity	PAF*m2yr	1.4E+02	1.6E+00	2.5E+01	3.7E+01	6.5E+01	1.4E+01	6.8E-03
Acidification/ Eutrophication	PDF*m2yr	2.2E+01	9.5E+00	2.6E+00	2.5E+00	3.4E+00	3.5E+00	7.3E-02
Land use	PDF*m2yr	8.2E+00	4.2E-01	9.3E-01	1.2E+00	2.3E+00	3.3E+00	1.8E-03
Minerals	MJ surplus	2.3E+01	4.7E-01	5.9E+00	8.8E+00	7.2E+00	8.7E-01	5.5E-03
Fossil fuels	MJ surplus	6.0E+03	6.9E+02	1.1E+03	6.8E+02	1.4E+03	2.0E+03	7.6E+00

Table A12 Results of the impact assessment from microemulsion stage (Scenario II) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	Palm olein	Bioethanol	Biodiesel (FAME)	Cosurfactant	Diesel	Electricity
Carcinogens	DALY	0.0013	0.0000	0.0013	0.0000	0.0000	0.0000	0.0000
Resp. organics	DALY	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Resp. inorganics	DALY	0.0009	0.0002	0.0003	0.0002	0.0001	0.0001	0.0000
Climate change	DALY	0.0002	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Radiation	DALY	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ozone layer	DALY	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ecotoxicity	PAF*m2yr	1140.8217	1.5871	1049.5753	-3.3083	78.4930	14.4678	0.0068
Acidification/ Eutrophication	PDF*m2yr	37.9321	9.2315	17.9451	3.0385	4.0532	3.5905	0.0732
Land use	PDF*m2yr	3914.9887	0.4064	3738.0555	170.4313	2.7690	3.3248	0.0018
Minerals	MJ surplus	27.6984	0.4530	15.9763	1.6192	8.7603	0.8841	0.0055
Fossil fuels	MJ surplus	4981.3868	669.5512	454.0335	73.1566	1702.5856	2074.4920	7.5678

Table A13 Results of the impact assessment from microemulsion stage (Scenario III) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	Palm olein	Ethanol	Surfactant	cosurfactant	Diesel	1-butanol	Electricity
Carcinogens	DALY	2.4E-05	1.1E-06	5.0E-06	6.1E-06	6.8E-06	4.6E-06	8.6E-07	1.6E-09
Resp. organics	DALY	3.7E-06	5.3E-08	8.0E-07	5.8E-07	4.4E-07	1.7E-06	5.6E-08	8.8E-10
Resp. inorganics	DALY	5.2E-04	1.0E-04	7.9E-05	7.1E-05	1.2E-04	1.3E-04	1.5E-05	1.5E-06
Climate change	DALY	2.8E-04	6.8E-05	4.4E-05	3.0E-05	7.1E-05	5.2E-05	9.0E-06	1.0E-06
Radiation	DALY	1.5E-06	4.1E-09	1.9E-07	4.3E-07	4.4E-07	4.2E-07	5.6E-08	0.0E+00
Ozone layer	DALY	3.7E-07	1.0E-09	6.6E-09	6.4E-09	3.6E-08	3.2E-07	4.5E-09	3.4E-14
Ecotoxicity	PAF*m2yr	1.5E+02	9.7E-01	2.4E+01	3.0E+01	7.0E+01	2.1E+01	8.9E+00	6.8E-03
Acidification/ Eutrophication	PDF*m2yr	1.9E+01	5.6E+00	2.4E+00	2.0E+00	3.6E+00	5.1E+00	4.6E-01	7.3E-02
Land use	PDF*m2yr	9.6E+00	2.5E-01	8.6E-01	1.0E+00	2.5E+00	4.7E+00	3.1E-01	1.8E-03
Minerals	MJ surplus	2.3E+01	2.8E-01	5.5E+00	7.1E+00	7.8E+00	1.3E+00	9.9E-01	5.5E-03
Fossil fuels	MJ surplus	6.7E+03	4.1E+02	1.0E+03	5.5E+02	1.5E+03	3.0E+03	1.9E+02	7.6E+00

Table A14 Results of the impact assessment from microemulsion stage (Scenario IV) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	CPO	Ethanol	Surfactant	Cosurfactant	Diesel	Electricity
Carcinogens	DALY	2.0E-05	5.8E-08	5.5E-06	5.3E-06	6.0E-06	3.4E-06	1.6E-09
Resp. organics	DALY	3.1E-06	2.1E-08	8.8E-07	5.1E-07	3.9E-07	1.3E-06	8.8E-10
Resp. inorganics	DALY	4.0E-04	5.0E-05	8.7E-05	6.2E-05	1.0E-04	9.6E-05	1.5E-06
Climate change	DALY	2.1E-04	3.6E-05	4.9E-05	2.6E-05	6.2E-05	3.8E-05	1.0E-06
Radiation	DALY	1.3E-06	1.3E-09	2.1E-07	3.8E-07	3.9E-07	3.1E-07	0.0E+00
Ozone layer	DALY	2.8E-07	4.3E-10	7.2E-09	5.6E-09	3.1E-08	2.3E-07	3.4E-14
Ecotoxicity	PAF*m2yr	1.3E+02	2.7E-01	2.6E+01	2.6E+01	6.1E+01	1.5E+01	6.8E-03
Acidification/ Eutrophication	PDF*m2yr	1.5E+01	3.4E+00	2.6E+00	1.8E+00	3.2E+00	3.7E+00	7.3E-02
Land use	PDF*m2yr	7.5E+00	7.1E-02	9.5E-01	8.7E-01	2.2E+00	3.5E+00	1.8E-03
Minerals	MJ surplus	2.0E+01	2.9E-02	6.0E+00	6.2E+00	6.9E+00	9.2E-01	5.5E-03
Fossil fuels	MJ surplus	5.3E+03	1.4E+02	1.1E+03	4.8E+02	1.3E+03	2.2E+03	7.6E+00

Appendix B Normalization Data

Table B1 Results of the impact assessment from cultivation stage of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	N	P_2O_5	K_2O	Diesel	Glyphosate	Paraquate
abiotic depletion		8.5E-12	3.2E-10	6.9E-13	1.2E-10	2.5E-10	7.3E-11	2.4E-11
global warming (GWP100)		5.6E-12	7.7E-10	6.5E-13	1.0E-10	4.5E-11	4.8E-11	1.6E-11
ozone layer depletion (ODP)		1.4E-14	0.0E+00	0.0E+00	0.0E+00	1.4E-11	1.5E-12	6.4E-13
human toxicity		2.0E-13	3.8E-12	2.1E-14	1.3E-12	1.6E-11	3.0E-11	1.2E-11
fresh water aquatic ecotox.		8.3E-13	1.5E-13	4.9E-15	3.5E-13	6.4E-11	1.2E-10	4.1E-11
marine aquatic ecotoxicity		1.5E-11	2.8E-15	5.5E-18	1.1E-15	5.5E-10	2.4E-09	7.4E-10
terrestrial ecotoxicity		1.2E-12	1.4E-13	4.6E-15	3.3E-13	3.8E-11	2.3E-10	8.0E-11
photochemical oxidation		2.0E-13	6.1E-11	5.0E-13	8.0E-12	2.0E-11	1.7E-11	6.4E-12
acidification		2.3E-12	8.7E-10	3.9E-12	5.3E-11	5.6E-11	1.0E-10	4.0E-11
eutrophication		8.5E-13	1.9E-10	3.1E-13	1.2E-11	1.1E-11	7.7E-12	2.8E-12

Table B2 Results of the impact assessment from extraction stage of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	FFB	Water	Diesel	Electricity
abiotic depletion		5.16E-12	4.72E-12	1.76E-15	1.62E-13	2.72E-13
global warming (GWP100)		5.11E-12	4.99E-12	1.37E-15	1.21E-14	1.03E-13
ozone layer depletion (ODP)		4.43E-16	0	6.15E-18	4.36E-16	2.66E-20
human toxicity		2.41E-14	1.59E-14	1.57E-15	6.29E-15	2.97E-16
fresh water aquatic ecotox.		3.4E-14	1.86E-15	1.41E-14	1.81E-14	3.69E-17
marine aquatic ecotoxicity		5.06E-13	1.62E-17	4.9E-14	4.57E-13	8.31E-16
terrestrial ecotoxicity		1.23E-14	1.63E-15	1.69E-15	8.64E-15	3.66E-16
photochemical oxidation		1.28E-13	1.22E-13	9.98E-17	3.54E-15	2.87E-15
acidification		1.98E-12	1.92E-12	4.73E-16	1.99E-14	3.94E-14
eutrophication		7.83E-13	7.68E-13	1.94E-16	4.7E-15	1.06E-14

Table B3 Results of the impact assessment from refining stage of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	CPO	Phosphoric acid	Bentonite	Diesel	Electricity
abiotic depletion		1.49E-10	5.09E-12	2.39E-14	2.36E-14	1.3E-10	1.44E-11
global warming		2.28E-11	5.04E-12	1.35E-14	1.32E-14	1.22E-11	5.44E-12
ozone layer depletion		5.57E-13	4.93E-16	4.57E-17	6.82E-16	5.56E-13	1.41E-18
human toxicity		2.47E-12	2.64E-14	1.28E-14	7.18E-15	2.41E-12	1.57E-14
fresh water aquatic ecotox.		1.16E-11	2.51E-14	5.02E-13	2.88E-14	1.1E-11	1.95E-15
marine aquatic ecotoxicity		1.12E-10	5.71E-13	2.77E-12	4.9E-13	1.08E-10	4.41E-14
terrestrial ecotoxicity		6.26E-12	1.83E-14	1.71E-14	4.33E-14	6.16E-12	1.94E-14
photochemical oxidation		1.98E-12	1.34E-13	6.49E-15	3.85E-15	1.68E-12	1.52E-13
acidification		9.58E-12	1.98E-12	4.97E-14	3.02E-14	5.44E-12	2.09E-12
eutrophication		3.44E-12	7.76E-13	5.87E-14	1.4E-15	2.04E-12	5.63E-13

Table B4 Results of the impact assessment from microemulsion stage (Scenerio I) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	Palm olein	Ethanol	Surfactant	Cosurfactant	Diesel	Electricity
abiotic depletion		1.38E-10	2.491E-11	2.50284E-11	1.476E-11	2.8822E-11	4.4E-11	2.891E-13
global warming (GWP100)		3.24E-11	1.264E-11	5.20663E-12	3.708E-12	6.5391E-12	4.2E-12	1.091E-13
ozone layer depletion (ODP)		2.28E-13	1.503E-15	5.85816E-15	6.036E-15	2.4889E-14	1.9E-13	2.825E-20
human toxicity		3.61E-12	7.523E-14	6.85824E-13	1.094E-12	9.3736E-13	8.2E-13	3.156E-16
fresh water aquatic ecotox.		1.71E-11	7.267E-13	3.60245E-12	4.805E-12	4.2162E-12	3.8E-12	3.918E-17
marine aquatic ecotoxicity		1.91E-10	4.947E-12	3.59953E-11	5.571E-11	5.6993E-11	3.7E-11	8.839E-16
terrestrial ecotoxicity		6.54E-12	1.268E-13	8.75467E-13	2.031E-12	1.4078E-12	2.1E-12	3.887E-16
photochemical oxidation		4.38E-12	3.591E-13	2.56675E-12	3.835E-13	4.9701E-13	5.7E-13	3.052E-15
acidification		1.35E-11	4.988E-12	2.05729E-12	1.905E-12	2.6276E-12	1.9E-12	4.191E-14
eutrophication		5.96E-12	1.646E-12	1.96359E-12	4.113E-13	1.2328E-12	7E-13	1.129E-14

Table B5 Results of the impact assessment from microemulsion stage (Scenerio II) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	Palm olein	Bioethanol	Biodiesel(FAME)	Cosurfactant	Diesel	Electricity
abiotic depletion		1.2E-10	2.3E-11	1.2E-11	1.9E-12	3.8E-11	4.3E-11	2.9E-13
global warming (GWP100)		2.4E-11	1.2E-11	1.0E-12	-1.7E-12	8.7E-12	4.1E-12	1.1E-13
ozone layer depletion (ODP)		2.5E-13	1.4E-15	2.5E-14	3.4E-15	3.3E-14	1.9E-13	2.8E-20
human toxicity		7.5E-12	7.0E-14	4.7E-12	6.4E-13	1.2E-12	8.0E-13	3.2E-16
fresh water aquatic ecotox.		6.0E-10	6.8E-13	5.4E-10	4.6E-11	5.6E-12	3.7E-12	3.9E-17
marine aquatic ecotoxicity		2.9E-10	4.6E-12	1.6E-10	1.3E-11	7.6E-11	3.6E-11	8.9E-16
terrestrial ecotoxicity		2.0E-09	1.2E-13	1.9E-09	1.6E-10	1.9E-12	2.1E-12	3.9E-16
photochemical oxidation		3.9E-12	3.4E-13	5.0E-13	1.9E-12	6.6E-13	5.6E-13	3.1E-15
acidification		1.9E-11	4.7E-12	7.5E-12	1.3E-12	3.5E-12	1.8E-12	4.2E-14
eutrophication		1.8E-11	1.5E-12	1.3E-11	1.4E-12	1.6E-12	6.8E-13	1.1E-14

Table B6 Results of the impact assessment from microemulsion stage (Scenerio III) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	Palm olein	Ethanol	Surfactant	Cosurfactant	Diesel	1-butanol	Electricity
abiotic depletion		1.51E-10	1.423E-11	2.33764E-11	1.31E-11	3.4334E-11	6.2E-11	4.34E-12	2.91E-13
global warming (GWP100)		3.01E-11	7.219E-12	4.86295E-12	3.293E-12	7.7896E-12	5.8E-12	9.847E-13	1.1E-13
ozone layer depletion (ODP)		3.09E-13	8.581E-16	5.47147E-15	5.36E-15	2.9649E-14	2.6E-13	3.748E-15	2.85E-20
human toxicity		4.06E-12	4.297E-14	6.40555E-13	9.718E-13	1.1166E-12	1.1E-12	1.412E-13	3.18E-16
fresh water aquatic ecotox.		1.9E-11	4.15E-13	3.36466E-12	4.267E-12	5.0225E-12	5.2E-12	6.349E-13	3.95E-17
marine aquatic ecotoxicity		2.14E-10	2.825E-12	3.36193E-11	4.947E-11	6.7892E-11	5.1E-11	8.583E-12	8.91E-16
terrestrial ecotoxicity		7.51E-12	7.243E-14	8.1768E-13	1.804E-12	1.677E-12	2.9E-12	2.12E-13	3.92E-16
photochemical oxidation		4.41E-12	2.051E-13	2.39733E-12	3.406E-13	5.9206E-13	8E-13	7.485E-14	3.08E-15
acidification		1.26E-11	2.849E-12	1.9215E-12	1.692E-12	3.13E-12	2.6E-12	3.957E-13	4.22E-14
eutrophication		5.78E-12	9.401E-13	1.83398E-12	3.653E-13	1.4686E-12	9.7E-13	1.857E-13	1.14E-14

Table B7 Results of the impact assessment from microemulsion stage (Scenerio IV) of 1 ton of microemulsion biofuel production by using CML 2 baseline 2000 V2.03/ the Netherlands, 1997

Impact category	Unit	Total	CPO	Ethanol	Surfactant	Cosurfactant	Diesel	Electricity
abiotic depletion		1.2E-10	3.7E-12	2.6E-11	1.1E-11	3.0E-11	4.5E-11	2.9E-13
global warming (GWP100)		2.3E-11	3.7E-12	5.3E-12	2.9E-12	6.8E-12	4.3E-12	1.1E-13
ozone layer depletion (ODP)		2.3E-13	3.6E-16	6.0E-15	4.7E-15	2.6E-14	1.9E-13	2.8E-20
human toxicity		3.4E-12	1.9E-14	7.0E-13	8.5E-13	9.8E-13	8.4E-13	3.2E-16
fresh water aquatic ecotox.		1.6E-11	1.8E-14	3.7E-12	3.7E-12	4.4E-12	3.8E-12	3.9E-17
marine aquatic ecotoxicity		1.8E-10	4.2E-13	3.7E-11	4.3E-11	5.9E-11	3.8E-11	8.9E-16
terrestrial ecotoxicity		6.1E-12	1.3E-14	9.0E-13	1.6E-12	1.5E-12	2.1E-12	3.9E-16
photochemical oxidation		4.1E-12	9.8E-14	2.6E-12	3.0E-13	5.2E-13	5.9E-13	3.1E-15
acidification		9.7E-12	1.4E-12	2.1E-12	1.5E-12	2.7E-12	1.9E-12	4.2E-14
eutrophication		4.9E-12	5.7E-13	2.0E-12	3.2E-13	1.3E-12	7.1E-13	1.1E-14

Table B8 Results of the impact assessment from cultivation of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	N	P_2O_5	K_2O	Diesel	Glyphosate	Paraquate
Carcinogens		8.9E-05	3.7E-07	9.0E-10	1.5E-07	1.3E-05	5.8E-05	1.8E-05
Resp. organics		7.3E-06	1.2E-06	6.8E-09	5.0E-07	5.1E-06	4.1E-07	1.7E-07
Resp. inorganics		5.4E-03	3.8E-03	1.5E-05	5.5E-04	3.8E-04	4.9E-04	1.8E-04
Climate change		3.6E-03	2.8E-03	2.2E-06	3.6E-04	1.5E-04	1.6E-04	5.4E-05
Radiation		9.9E-06	0.0E+00	0.0E+00	0.0E+00	1.2E-06	7.3E-06	1.3E-06
Ozone layer		1.1E-06	0.0E+00	0.0E+00	0.0E+00	9.2E-07	1.0E-07	4.3E-08
Ecotoxicity		1.5E-04	1.1E-09	5.2E-12	5.2E-10	1.8E-05	9.0E-05	3.7E-05
Acidification/ Eutrophication		1.0E-03	8.6E-04	1.7E-06	5.3E-05	4.4E-05	3.3E-05	1.2E-05
Land use		7.3E-05	0.0E+00	0.0E+00	0.0E+00	4.1E-05	2.3E-05	9.2E-06
Minerals		5.1E-05	0.0E+00	0.0E+00	0.0E+00	6.7E-06	3.6E-05	8.1E-06
Fossil fuels		4.2E-02	1.6E-02	3.4E-05	5.7E-03	1.6E-02	3.2E-03	1.2E-03

Table B9 Results of the impact assessment from extraction of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	FFB	Water	Diesel	Electricity
Carcinogens		3.0E-06	5.2E-07	9.1E-07	1.5E-06	9.9E-08
Resp. organics		1.8E-06	1.7E-06	2.3E-09	1.3E-07	5.3E-08
Resp. inorganics		4.5E-03	4.4E-03	2.8E-06	3.6E-05	9.2E-05
Climate change		3.2E-03	3.2E-03	8.2E-07	7.2E-06	6.2E-05
Radiation		1.1E-07	0.0E+00	1.7E-08	8.9E-08	0.0E+00
Ozone layer		3.5E-08	0.0E+00	4.8E-10	3.4E-08	2.1E-12
Ecotoxicity		2.9E-06	1.6E-09	1.1E-06	1.7E-06	1.2E-07
Acidification/ Eutrophication		9.3E-04	9.1E-04	1.5E-07	3.0E-06	1.3E-05
Land use		8.0E-06	0.0E+00	2.1E-07	7.5E-06	3.3E-07
Minerals		3.0E-06	0.0E+00	1.8E-06	5.3E-07	6.1E-07
Fossil fuels		2.4E-02	2.2E-02	5.7E-06	9.2E-04	8.4E-04

Table B10 Results of the impact assessment from refining of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	CPO	Phosphoric acid	Bentonite	Diesel	Electricity
Carcinogens		0.0007	0.0000	0.0001	0.0000	0.0006	0.0000
Resp. organics		0.0002	0.0000	0.0000	0.0000	0.0002	0.0000
Resp. inorganics		0.0275	0.0045	0.0001	0.0000	0.0180	0.0049
Climate change		0.0137	0.0032	0.0000	0.0000	0.0072	0.0033
Radiation		0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Ozone layer		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ecotoxicity		0.0009	0.0000	0.0000	0.0000	0.0008	0.0000
Acidification/ Eutrophication		0.0037	0.0009	0.0000	0.0000	0.0021	0.0007
Land use		0.0020	0.0000	0.0000	0.0000	0.0019	0.0000
Minerals		0.0004	0.0000	0.0000	0.0000	0.0003	0.0000
Fossil fuels		0.8078	0.0235	0.0001	0.0001	0.7395	0.0446

Table B11 Results of the impact assessment from microemulsion stage (Scenario I) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	Palm olein	Ethanol	Surfactant	Cosurfactant	Diesel	Electricity
Carcinogens		0.0016	0.0001	0.0004	0.0005	0.0004	0.0002	0.0000
Resp. organics		0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
Resp. inorganics		0.0355	0.0111	0.0055	0.0057	0.0072	0.0059	0.0001
Climate change		0.0198	0.0075	0.0031	0.0024	0.0043	0.0024	0.0001
Radiation		0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ozone layer		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ecotoxicity		0.0028	0.0000	0.0005	0.0007	0.0013	0.0003	0.0000
Acidification/ Eutrophication		0.0042	0.0019	0.0005	0.0005	0.0007	0.0007	0.0000
Land use		0.0016	0.0001	0.0002	0.0002	0.0004	0.0006	0.0000
Minerals		0.0028	0.0001	0.0007	0.0010	0.0009	0.0001	0.0000
Fossil fuels		0.7086	0.0823	0.1333	0.0810	0.1675	0.2437	0.0009

Table B12 Results of the impact assessment from microemulsion stage (Scenario II) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	Palm olein	Bioethanol	Biodiesel (FAME)	Cosurfactant	Diesel	Electricity
Carcinogens		0.0838	0.0001	0.0824	0.0005	0.0005	0.0002	0.0000
Resp. organics		0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Resp. inorganics		0.0559	0.0108	0.0196	0.0108	0.0087	0.0060	0.0001
Climate change		0.0148	0.0073	0.0009	-0.0010	0.0052	0.0024	0.0001
Radiation		0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Ozone layer		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ecotoxicity		0.0222	0.0000	0.0205	-0.0001	0.0015	0.0003	0.0000
Acidification/ Eutrophication		0.0074	0.0018	0.0035	0.0006	0.0008	0.0007	0.0000
Land use		0.7634	0.0001	0.7289	0.0332	0.0005	0.0006	0.0000
Minerals		0.0033	0.0001	0.0019	0.0002	0.0010	0.0001	0.0000
Fossil fuels		0.5928	0.0797	0.0540	0.0087	0.2026	0.2469	0.0009

Table B13 Results of the impact assessment from microemulsion stage (Scenario III) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	Palm olein	Ethanol	Surfactant	Cosurfactant	Diesel	1-butanol	Electricity
Carcinogens		0.0016	0.0001	0.0003	0.0004	0.0004	0.0003	0.0001	0.0000
Resp. organics		0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Resp. inorganics		0.0337	0.0066	0.0052	0.0046	0.0077	0.0085	0.0010	0.0001
Climate change		0.0180	0.0045	0.0029	0.0020	0.0046	0.0034	0.0006	0.0001
Radiation		0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ozone layer		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ecotoxicity		0.0030	0.0000	0.0005	0.0006	0.0014	0.0004	0.0002	0.0000
Acidification/ Eutrophication		0.0038	0.0011	0.0005	0.0004	0.0007	0.0010	0.0001	0.0000
Land use		0.0019	0.0000	0.0002	0.0002	0.0005	0.0009	0.0001	0.0000
Minerals		0.0027	0.0000	0.0007	0.0008	0.0009	0.0001	0.0001	0.0000
Fossil fuels		0.7944	0.0486	0.1241	0.0655	0.1811	0.3514	0.0229	0.0009

Table B14 Results of the impact assessment from microemulsion stage (Scenario IV) of 1 ton of microemulsion biofuel production by using Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A

Impact category	Unit	Total	CPO	Ethanol	Surfactant	Cosurfactant	Diesel	Electricity
Carcinogens		0.0013	0.0000	0.0004	0.0003	0.0004	0.0002	0.0000
Resp. organics		0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
Resp. inorganics		0.0261	0.0033	0.0056	0.0040	0.0068	0.0063	0.0001
Climate change		0.0139	0.0023	0.0032	0.0017	0.0041	0.0025	0.0001
Radiation		0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ozone layer		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ecotoxicity		0.0025	0.0000	0.0005	0.0005	0.0012	0.0003	0.0000
Acidification/ Eutrophication		0.0029	0.0007	0.0005	0.0003	0.0006	0.0007	0.0000
Land use		0.0015	0.0000	0.0002	0.0002	0.0004	0.0007	0.0000
Minerals		0.0024	0.0000	0.0007	0.0007	0.0008	0.0001	0.0000
Fossil fuels		0.6277	0.0172	0.1361	0.0573	0.1586	0.2577	0.0009

Appendix C Inventory Data

Table C Life cycle inventory for the production of 1 ton of ME biofuel

Life Cycle Biofuel Production	SI	SII	SIII	SIV	Reference
Input					
(a) Oil palm plantation					
N-fertilizer(kg)	21.26	20.62	12.54	21.89	Fertilizer N (Pleanjai, 2009)
P2O5(kg)	0.14	0.13	0.08	0.14	Fertilizer P_2O_5 (Pleanjai, 2009)
K2O-fertilizer(kg)	39.34	38.16	23.21	40.52	Fertilizer K_2O (Pleanjai, 2009)
Glyphosate(kg)	0.75	0.73	0.44	0.77	Glyphosate, at regional storehouse/ RER S (Pleanjai, 2009)
Paraquat(kg)	0.27	0.26	0.16	0.28	Bipyridylium-compound, at regional storehouse/RER S (Pleanjai, 2009)
Diesel used (for FFB transport) (kg)	18.12	18.12	18.12	18.12	Diesel, low sulphur, at refinery/ CH S (Pleanjai, 2009)
(b)Crude palm oil production					

Life Cycle Biofuel Production	SI	SII	SIII	SIV	Reference
FFB(kg)	2726.13	2644.35	1608.4	2808	(Pleanjai, 2009)
Electricity(kWh)	6.96	6.77	4.12	7.19	Electricity Thailand Base 2007 (Kaewmai, 2012)
Water for boiler (kg)	2269.93	2201.83	1339.26	2338	Water, completely softened, at plant/RER S (Kaewmai, 2012)
Diesel for starting turbine (kg)	1.08	1.05	0.64	1.11	Diesel, low-sulphur, at refinery/RER S (Kaewmai, 2012)
(c) Crude palm oil refining					
CPO (kg)	444.36	431.03	262.17	457.69	(Pleanjai, 2009)
Water (kg)	52.58	51	31	54.16	Water, completely softened, at plant/RER S (Arpornpong, 2013)
Phosphoric acid (kg)	0.41	0.39	0.24	0.42	Phosphoric acid, industrial grade, 85% in H2O, at plant/RER S (Arpornpong, 2013)
Bentonite (kg)	4.14	4.02	2.44	4.26	Bentonite ETH S (Arpornpong, 2013)
Electricity (kwh)	369.1	357.45	217.95	-	Electricity Thailand Base 2007 (Arpornpong, 2013)
Diesel used (kg) (for transport)	864.87	864.87	864.87	864.87	Diesel, low-sulphur, at refinery/CH S (Pleanjai, 2009)

Life Cycle Biofuel Production	**SI**	**SII**	**SIII**	**SIV**	**Reference**
(d) ME biofuel production					
Refined palm oil (kg)	315.5	305.54*	186.3**	-	Palm olein (Arpornpong, 2013)
RBDPO (kg)	-	-	-	324.68	Crude palm oil (Manaphati, 2015)
Ethanol (kg)	184.6	-	171.92**	188.52*	Ethanol from ethylene, at plant/RER S (Arpornpong, 2013)
Bioethanol(kg)	-	189.76	-	-	Ethanol, 95% in H2O, from rye, at distillery/RER S (Manaphati, 2015)
Surfactant (kg)	75.2	-	60.84**	53.19*	Ethoxylated alcohols (AE7), petrochemical, at plant/RER S (Arpornpong, 2013)
Biodiesel(FAME)(kg)	-	47.11	-	-	Palm methyl ester, production MY, at service station/CH S (Manaphati, 2015)
Cosurfactant (kg)	139.6	168.89*	150.93**	132.2*	1-butanol, propylene hydroformylation, at plant/RER S (Arpornpong *et al.*, 2014)
1-butanol(kg)	-	-	19.08	-	1-butanol, propylene hydroformylation, at plant/RER S (Apichatyothin,2015)
Diesel (kg)	285	288.7*	410.93**	301.4*	Diesel, low-sulphur, at refinery/CH S (Arpornpong, 2013)

Life Cycle Biofuel Production	SI	SII	SIII	SIV	Reference
Electricity for mixing (kWh)	7.46	7.46	7.46	7.46	Electricity Thailand Base 2007 (Arpornpong, 2013)
Output					
(a)Oil palm plantation					
FFB (kg)	2726.13	2644.35	1608.4	2808	(Arpornpong, 2013)
(b)Crude palm oil production					
Product					
CPO(kg)	444.36	431.03	262.17	457.69	(Arpornpong, 2013)
Coproduct					
Palm kernel (kg)	142.08	137.82	83.83	146.34	(Arpornpong, 2013)
Solid waste					
Decanter cake (kg)	93.24	90.44	55.01	96.04	(Kaewmai, 2012)
Shell (kg)	159.84	155.04	94.31	164.64	(Kaewmai, 2012)

Life Cycle Biofuel Production	SI	SII	SIII	SIV	Reference
Fiber (kg)	168.72	163.66	99.54	173.78	(Kaewmai, 2012)
Empty bunches (kg)	581.64	564.19	343.17	599.09	(Kaewmai, 2012)
Liquid waste					
Palm oil mill effluent (m3)	1.52	1.47	0.89	0.68	(Kaewmai, 2012)
(c) Crude palm oil refining					
Palm olein(kg)	315.5	305.54	186.3	324.68	(Papong *et al.*, 2009)
Palm stearin(kg)	128.86	124.99	76.03	132.73	(Papong *et al.*, 2009)
(d) ME biofuel production					
ME biofuel (kg)	1000	1000	1000	1000	(Arpornpong, 2013)

* (Manaphati, 2015)

** (Apichatyothin, 2015)

Appendix D Inventory Data Calculation

Cultivation

Scenario I (Input data)

Reference: Pleanjai, S. and Gheewala, S.H. (2009) Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, 86(1), 209–214.

N fertilizer=7.79 kg/ton FFB

1000kg of FFB→7.79kg N

2726.13kg of FFB→21.26kg N#

P_2O_5 fertilizer= 0.05kg/ton FFB

1000kg of FFB→0.05kg P2O5

2726.13kg of FFB→0.14 kg P2O5#

K_2O fertilizer=14.41kg/ton FFB

1000kg of FFB→14.41kg K2O

2726.13 kg of FFB→39.34kg K2O#

Glyphosate=0.28kg/ton FFB

1000kg of FFB→0.28kg Glyphosate

2726.13kg of FFB→0.75 kg Glyphosate#

Paraquate =0.1kg/ton FFB

1000kg of FFB→0.1kg paraquate

2726.13kg of FFB→0.27kg paraquate#

Diesel density=0.85kg/L

Fuel comsumption=1.6km/L of diesel

1.6km→1L of diesel

34km→21.25L

1L→0.85kg

21.25L→18kg#

Scenario I (output data)

FFB 1 ton=0.163ton CPO

163kg CPO→1000kg FFB

444.36kg CPO→2726.13kg FFB#

Scenario II (input data)

Reference:Pleanjai, S., H, S., & Gheewala. (2009). Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, S209–S214.

N fertilizer=7.79 kg/ton FFB

1000kg of FFB→7.79kg N

2644.35kg of FFB→20.62kg N#

P_2O_5 fertilizer= 0.05kg/ton FFB

1000kg of FFB→0.05kg P2O5

2644.35kg of FFB→0.13 kg P2O5#

K_2O fertilizer=14.41kg/ton FFB

1000kg of FFB→14.41kg K2O

2644.35kg of FFB→38.16kg K2O#

Glyphosate=0.28kg/ton FFB

1000kg of FFB→0.28kg Glyphosate

2644.35kg of FFB→0.73kg Glyphosate#

Paraquate =0.1kg/ton FFB

1000kg of FFB→0.1kg paraquate

2644.35kg of FFB→0.26kg paraquate#

Diesel density=0.85kg/L

Fuel comsumption=1.6km/L of diesel

1.6km→1L of diesel

34km→ · 21.25L

1L→0.85kg

21.25L→18kg#

Scenario II (output data)

FFB 1 ton=0.163ton CPO

163kg CPO→1000kg FFB

431.03 kg CPO→2644.35kg FFB#

Scenario III (input data)

Reference: Pleanjai, S. and Gheewala, S.H. (2009) Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, 86(1), 209–214.

N fertilizer=7.79 kg/ton FFB

1000kg of FFB→7.79kg N

1608.4 kg of FFB→12.54kg N#

P_2O_5 fertilizer= 0.05kg/ton FFB

1000kg of FFB→0.05kg P2O5

1608.4 kg of FFB→0.08kg P2O5#

K_2O fertilizer=14.41kg/ton FFB

1000kg of FFB→14.41kg K2O

1608.4 kg of FFB→23.21kg K2O#

Glyphosate=0.28kg/ton FFB

1000kg of FFB→0.28kg Glyphosate

1608.4 kg of FFB→0.44kg Glyphosate#

Paraquate =0.1kg/ton FFB

1000kg of FFB→0.1kg paraquate

1608.4 kg of FFB→ 0.16kg paraquate#

Diesel density=0.85kg/L

Fuel comsumption=1.6km/L of diesel

1.6km→1L of diesel

34km→ 21.25L

1L→0.85kg

21.25L→18kg#

Scenario III (output data)

FFB 1 ton=0.163ton CPO

163kg CPO→1000kg FFB

262.17 kg CPO→1608.4 kg FFB#

Scenario IV (input data)

Reference: Pleanjai, S. and Gheewala, S.H. (2009) Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, 86(1), 209–214.

N fertilizer=7.79 kg/ton FFB

1000kg of FFB→7.79kg N

2808 kg of FFB→21.89 kg N#

P_2O_5 fertilizer= 0.05kg/ton FFB

1000kg of FFB→0.05kg P2O5

2808kg of FFB→0.14 kg P2O5#

K_2O fertilizer=14.41kg/ton FFB

1000kg of FFB→14.41kg K2O

2808kg of FFB→40.52kg K2O#

Glyphosate=0.28kg/ton FFB

1000kg of FFB→0.28kg Glyphosate

2808kg of FFB→0.77kg Glyphosate#

Paraquate =0.1kg/ton FFB

1000kg of FFB→0.1kg paraquate

2808kg of FFB→ 0.28kg paraquate#

Diesel density=0.85kg/L

Fuel comsumption=1.6km/L of diesel

1.6km→1L of diesel

34km→ 21.25L

1L→0.85kg

21.25L→18kg#

Scenario IV (output data)

FFB 1 ton=0.163ton CPO

163kg CPO→1000kg FFB

457.69 kg CPO→2808 kg FFB#

Extraction

Scenario I (input data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11, 141–151.

FFB =0.163ton CPO/ 1 ton of FFB

163kg CPO→1000kg FFB

444.36kg CPO→2726.13kg FFB#

Water=5.11m3 H2O/1 ton of CPO

444.36kg CPO→2.27m3 H2O

water density=999.97kg/m3

1m3 H2O→999.97kg H2O

2.27m3 H2O→2269.93kg H2O#

Diesel=2.85L/ 1 ton of CPO

1000kg CPO→2.85L

444.36kg CPO→1.27L

Diesel1L→0.85kg diesel

1.27L→ 1.08kg diesel#

Electricity=15.67kWh/1 ton CPO

1000kg CPO→15.67kWh

444.36kg CPO→6.96kWh#

Scenario I (output data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11, 141–151.

CPO=163kg CPO/ton of FFB

1000 kg FFB→163kg CPO

2726.13kg FFB→444.36kg CPO#

PK(Palm Kernel)=320 kg PK/ 1 ton CPO

1000kg CPO→320 kg PK

444.36kg CPO→142 kg PK#

DC (Decanter cake)=210kg DC/1 ton CPO

1000kg CPO→210 kg DC

444.36kg CPO→93kg DC#

Shell= 360kg shell/ 1 ton of CPO

1000kg CPO→360kg Shell

444.36kg CPO→160 kg Shell#

Fiber=380kg fiber/ 1 ton CPO

1000kg CPO→380kg Fiber

444.36kg CPO→168kg Fiber#

EB(Empty Bunches)=1310kgEB/1 ton CPO

1000kg CPO→1310 kg EB

444.36kg CPO→ 581kg EB#

POME (Palm Oil Mill Effluent)= 3.43 m3POME/ 1 ton CPO

1000kg CPO→ 3.43 m3 POME

444.36kg CPO→1.52 m3 POME#

Scenario II (input data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11, 141–151.

FFB =0.163ton CPO/ 1 ton of FFB

163kg CPO→1000kg FFB

431.03kg CPO→2644.35kg FFB#

Water=5.11m3 H2O/1 ton of CPO

1000kg CPO→5.11m3 H2O

431.03kg CPO→2.2m3 H2O

water density=999.97kg/m3

1m3 H2O→999.97kg H2O

2.2m3 H2O→2201kg H2O#

Diesel=2.85L/ 1 ton of CPO

1000kg CPO→2.85L

431.03kg CPO→1.23L

Diesel1L→0.85kg diesel

1.23L→ 1.05kg diesel#

Electricity=15.67kWh/1 ton CPO

1000kg CPO→15.67kWh

431.03kg CPO→6.77kWh#

Scenario II (output data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11; 141–151.

CPO=163kg CPO/ton of FFB

1000 kg FFB→163kg CPO

2644.35kg FFB→431.03kg CPO#

PK (Palm Kernel)=320 kg PK/ 1 ton CPO

1000kg CPO→320 kg PK

431.03kg CPO→137 kg PK#

DC (Decanter cake)=210kg DC/1 ton CPO

1000kg CPO→210 kg DC

431.03kg CPO→90kg DC#

Shell= 360kg shell/ 1 ton of CPO

1000kg CPO→360kg Shell

431.03kg CPO→155 kg Shell#

Fiber=380kg fiber/ 1 ton CPO

1000kg CPO→380kg Fiber

431.03kg CPO→163kg Fiber#

EB (Empty Bunches)=1310kgEB/1 ton CPO

·1000kg CPO→1310 kg EB

431.03kg CPO→ 564kg EB#

POME (Palm Oil Mill Effluent)= 3.43 m3POME/ 1 ton CPO

1000kg CPO→ 3.43 m3 POME

431.03kg CPO→1.47 m3 POME#

Scenario III (input data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11, 141–151.

FFB =0.163ton CPO/ 1 ton of FFB

163kg CPO→1000kg FFB

262.17kg CPO→1608.4kg FFB#

Water=5.11m3 H2O/1 ton of CPO

1000kg CPO→5.11m3 H2O

262.17kg CPO→1.34m3 H2O

water density=999.97kg/m3

1m3 H2O→999.97kg H2O

1.34 m3 H2O→1339kg H2O#

Diesel=2.85L/ 1 ton of CPO

1000kg CPO→2.85L

262.17kg CPO→0.7L

Diesel1L→0.85kg diesel

0.7L→ 0.6kg diesel#

Electricity=15.67kWh/1 ton CPO

1000kg CPO→15.67kWh

262.17kg CPO→4.12kWh#

Scenario III (output data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11. 141–151.

CPO=163kg CPO/ton of FFB

1000 kg FFB→163kg CPO

1608.4kg FFB→262.17kg CPO#

PK (Palm Kernel)=320 kg PK/ 1 ton CPO

1000kg CPO→320 kg PK

262.17kg CPO→83 kg PK#

DC (Decanter cake)=210kg DC/1 ton CPO

1000kg CPO→210 kg DC

262.17kg CPO→55kg DC#

Shell= 360kg shell/ 1 ton of CPO

1000kg CPO→360kg Shell

262.17kg CPO→94 kg Shell#

Fiber=380kg fiber/ 1 ton CPO

1000kg CPO→380kg Fiber

262.17kg CPO→99kg Fiber#

EB (Empty Bunches)=1310kgEB/1 ton CPO

1000kg CPO→1310 kg EB

262.17kg CPO→ 343kg EB#

POME (Palm Oil Mill Effluent)= 3.43 m3POME/ 1 ton CPO

1000kg CPO→ 3.43 m3 POME

262.17kg CPO→0.89 m3 POME#

Scenario IV (input data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11, 141–151.

FFB =0.163ton CPO/ 1 ton of FFB

163kg CPO→1000kg FFB

457.69kg CPO→2808kg FFB#

Water=5.11m3 H2O/1 ton of CPO

1000kg CPO→5.11m3 H2O

457.69kg CPO→2.34m3 H2O

Water density=999.97kg/m3

1m3 H2O→999.97kg H2O

2.34 m3 H2O→2338 kg H2O#

Diesel=2.85L/ 1 ton of CPO

1000kg CPO→2.85L

457.69kg CPO→1.3L

Diesel1L→0.85kg diesel

1.3L→ 1.1kg diesel#

Electricity=15.67kWh/1 ton CPO

1000kg CPO→15.67kWh

457.69kg CPO→7.19kWh#

Scenario IV (output data)

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11, 141–151.

CPO=163kg CPO/ton of FFB

1000 kg FFB→163kg CPO

2808kg FFB→457.69kg CPO#

PK(Palm Kernel)=320 kg PK/ 1 ton CPO

1000kg CPO→320 kg PK

457.69kg CPO→146 kg PK#

DC (Decanter cake)=210kg DC/1 ton CPO

1000kg CPO→210 kg DC

457.69kg CPO→96kg DC#

Shell= 360kg shell/ 1 ton of CPO

1000kg CPO→360kg Shell

457.69kg CPO→164kg Shell#

Fiber=380kg fiber/ 1 ton CPO

1000kg CPO→380kg Fiber

457.69kg CPO→173kg Fiber#

EB (Empty Bunches)=1310kgEB/1 ton CPO

1000kg CPO→1310 kg EB

457.69kg CPO→ 599kg EB#

POME (Palm Oil Mill Effluent)= 3.43 m3POME/ 1 ton CPO

1000kg CPO→ 3.43 m3 POME

457.69kg CPO→0.68 m3 POME#

Refining

Scenario I (Input data)

Reference: Pleanjai, S. and Gheewala, S.H. (2009) Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, 86(1), 209–214.

CPO=163kg/ton of FFB

1000 kg FFB→163kg CPO

2726.13kg FFB→444.36kg CPO#

Reference: Arpornpong, N., Charoensaeng, A., Sabatini, D.A., and Khaodhiar, S. (2013) Alternative renewable biofuel from palm oil-diesel based reverse micelle microemulsions:Environmental impact assessment. Ph.D. Dissertation, International Program in Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand.

Water=167kg H_2O/1 ton RPO (Refined Palm Oil)

1000kg RPO→167 kg H2O

315kg RPO→52.6 kg H2O#

PA (Phosphoric acid)=1.31kg PA/ 1 ton RPO

1000kg RPO→1.31 kg PA

315kg RPO→0.41 kg PA#

Bentonite=13.12kg bentonite/ 1 ton RPO

1000kg RPO→13.12 kg bentonite

315kg RPO→4.14 kg bentonite#

Electricity=1169 kWh electricity/ 1 ton RPO

1000kg RPO→1169 kWh electricity

315kg RPO→369.1 kWh electricity#

Scenario I (output data)

Reference: Papong, S., and Malakul, P. (2009) Life cycle energy efficiency and potentials of biodiesel production from palm. Energy Policy, 38(1), 226–233.

PO (Palm Olein) =0.71kg PO/kg CPO

1kg CPO→0.71kg PO

444.36kg CPO→315.5 kg PO#

PS (Palm Stearin)=0.29kg PS/kg CPO

1kg CPO→0.29 kg PS

444.36kg CPO→128.8 kg PS#

Scenario II (Input data)

Reference: Pleanjai, S. and Gheewala, S.H. (2009) Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, 86(1), 209–214.

CPO=163kg/ton of FFB

1000 kg FFB→163kg CPO

2644.35kg FFB→431.03kg CPO#

Reference: Arpornpong, N., Charoensaeng, A., Sabatini, D.A., and Khaodhiar, S. (2013) Alternative renewable biofuel from palm oil-diesel based reverse micelle microemulsions:Environmental impact assessment. Ph.D. Dissertation, International Program in Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand.

Water=167kg H2O/1 ton RPO (Refined Palm Oil)

1000kg RPO→167 kg H2O

305kg RPO→51 kg H2O#

PA(Phosphoric acid)=1.31kg PA/ 1 ton RPO

1000kg RPO→1.31 kg PA

305kg RPO→0.39 kg PA#

Bentonite=13.12kg bentonite/ 1 ton RPO

1000kg RPO→13.12 kg bentonite

305kg RPO→4.02 kg bentonite#

Electricity=1169 kWh electricity/ 1 ton RPO

1000kg RPO→1169 kWh electricity

305kg RPO→357.4 kWh electricity#

Scenario II (output data)

Reference: Papong, S., and Malakul, P. (2009) Life cycle energy efficiency and potentials of biodiesel production from palm. Energy Policy, 38(1), 226–233.

PO (Palm Olein)=0.71kg PO/kg CPO

1kg CPO→0.71kg PO

431kg CPO→305 kg PO#

PS (Palm Stearin)=0.29kg PS/kg CPO

1kg CPO→0.29 kg PS

431kg CPO→124 kg PS#

Scenario III (Input data)

Reference: Pleanjai, S. and Gheewala, S.H. (2009) Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, 86(1), 209–214.

CPO=163kg/ton of FFB

1000 kg FFB→163kg CPO

1608kg FFB→262kg CPO#

Reference: Arpornpong, N., Charoensaeng, A., Sabatini, D.A., and Khaodhiar, S. (2013) Alternative renewable biofuel from palm oil-diesel based reverse micelle microemulsions:Environmental impact assessment. Ph.D. Dissertation, International Program in Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand.

Water=167kg H2O/1 ton RPO(Refined Palm Oil)

1000kg RPO→167 kg H2O

186kg RPO→31 kg H2O#

PA (Phosphoric acid)=1.31kg PA/ 1 ton RPO

1000kg RPO→1.31 kg PA

186kg RPO→0.24 kg PA#

Bentonite=13.12kg bentonite/ 1 ton RPO

1000kg RPO→13.12 kg bentonite

186kg RPO→2.44 kg bentonite#

Electricity=1169 kWh electricity/ 1 ton RPO

1000kg RPO→1169 kWh electricity

186kg RPO→217.9 kWh electricity#

Scenario III (output data)

Reference: Papong, S., and Malakul, P. (2009) Life cycle energy efficiency and potentials of biodiesel production from palm. Energy Policy, 38(1), 226–233.

PO (Palm Olein)=0.71kg PO/kg CPO

1kg CPO→0.71kg PO

262kg CPO→186 kg PO#

PS (Palm Stearin)=0.29kg PS/kg CPO

1kg CPO→0.29 kg PS

262kg CPO→76 kg PS#

Scenario IV (Input data)

Reference: Pleanjai, S. and Gheewala, S.H. (2009) Full chain energy analysis of biodiesel production from palm oil in Thailand. Applied Energy, 86(1), 209–214.

CPO=163kg/ton of FFB

1000 kg FFB→163kg CPO

2808kg FFB→457kg CPO#

Reference: Arpornpong, N., Charoensaeng, A., Sabatini, D.A., and Khaodhiar, S. (2013) Alternative renewable biofuel from palm oil-diesel based reverse micelle microemulsions:Environmental impact assessment. Ph.D. Dissertation, International Program in Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand.

Water=167kg H2O/1 ton RPO(Refined Palm Oil)

1000kg RPO→167 kg H2O

324kg RPO→54 kg H2O#

PA (Phosphoric acid)=1.31kg PA/ 1 ton RPO

1000kg RPO→1.31 kg PA

324kg RPO→0.42 kg PA#

Bentonite=13.12kg bentonite/ 1 ton RPO

1000kg RPO→13.12 kg bentonite

324kg RPO→4.26 kg bentonite#

Scenario IV (output data)

Reference: Papong, S., and Malakul, P. (2009) Life cycle energy efficiency and potentials of biodiesel production from palm. Energy Policy, 38(1), 226–233.

PO (Palm Olein)=0.71kg PO/kg CPO

1kg CPO→0.71kg PO

457kg CPO→324 kg PO#

PS (Palm Stearin)=0.29kg PS/kg CPO

1kg CPO→0.29 kg PS

457kg CPO→132 kg PS#

ME (Microemulsion) Biofuel Production

Scenario I (Input data)

Reference: Arpornpong, N., Charoensaeng, A., Sabatini, D.A., and Khaodhiar, S. (2013) Alternative renewable biofuel from palm oil-diesel based reverse micelle microemulsions:Environmental impact assessment. Ph.D. Dissertation, International Program in Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand.

PO (Plam olein)=315.5 kg PO/1 ton ME biofuel

Ethanol= 184.6kg Ethanol/ 1 ton ME biofuel

Surfactant= 75.2 kg Surfactant/ 1 ton ME biofuel

Cosurfactant= 139.6 kg cosurfactant/ 1 ton ME biofuel

Diesel=285 kg diesel/ 1 ton ME biofuel

Electricity= 7.46 kWh electricity/ 1 ton ME biofuel

Scenario I (Output data)

Microemulsion biofuel = 1 ton

Scenario II (Input data)

Reference: Manaphati, S. (2015). New hybrid biofuel using palm oil/ diesel ethanol based reverse micelle microemulsion. M.S. Thesis, The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

PO (Plam olein)=305.5 kg PO/1 ton ME biofuel

Bioethanol= 189 kg bioethanol/ 1 ton ME biofuel

Fatty Acid Methyl Ester (FAME) = 47 kg FAME/ 1 ton ME biofuel

Cosurfactant= 168 kg cosurfactant/ 1 ton ME biofuel

Diesel=288 kg diesel/ 1 ton ME biofuel

Electricity= 7.46 kWh electricity/ 1 ton ME biofuel

Scenario II (Output data)

Microemulsion biofuel = 1 ton

Scenario III (Input data)

Reference: Apichatyothin, W. (2015). Formultion of vegetable oil based microemulsion biofuel with butanol in palm oil/diesel blends. M.S. Thesis, The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

PO (Plam olein)=186 kg PO/1 ton ME biofuel

Ethanol= 171 kg ethanol/ 1 ton ME biofuel

Surfactant= 60 kg surfactant/ 1 ton ME biofuel

Cosurfactant= 150 kg cosurfactant/ 1 ton ME biofuel

1-butanol=19kg 1-butanol/ 1 ton ME biofuel

Diesel=410 kg diesel/ 1 ton ME biofuel

Electricity= 7.46 kWh electricity/ 1 ton ME biofuel

Scenario III (Output data)

Microemulsion biofuel = 1 ton

Scenario IV (Input data)

Reference: Manaphati, S. (2015). New hybrid biofuel using palm oil/ diesel ethanol based reverse micelle microemulsion. M.S. Thesis, The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok, Thailand.

RBDPO (Refined Bleached Deodorized Plam Oil)=324 kg RBDPO/1 ton ME biofuel

Ethanol= 188 kg Ethanol/ 1 ton ME biofuel

Surfactant= 53 kg Surfactant/ 1 ton ME biofuel

Cosurfactant= 132 kg cosurfactant/ 1 ton ME biofuel

Diesel=301 kg diesel/ 1 ton ME biofuel

Electricity= 7.46 kWh electricity/ 1 ton ME biofuel

Scenario IV (Output data)

Microemulsion biofuel = 1 ton

Biogas and Electricity Generation Calculation

Reference: Kaewmai, R., Kittikun, H.A., and Musikavong, C. (2012) Greenhouse gas emissions of palm oil mills in Thailand. International Journal of Greenhouse Gas Control, 11, 141–151.

Palm Oil Mill Effluent (POME) from Scenario (I) = 1.52m^3

COD= 76198 mg of COD/L of POME

1000L→1m3

1L →1x10-3 m3

1x10-3 m3→76198 mg of COD

1.52m^3 →115.82 kg of COD

1kg of COD →0.251kg of CH4

115.82 kg of COD→29.07 kg of CH4

0.656kg of CH4→1m3 of CH4

29.07 kg of CH4→44.31m3 of CH4#

1m3 of CH4→23 MJ of CH4

44.31m3 of CH4→1019.13 MJ of CH4#

1MJ of CH4 →0.2778 kwh

1019.13 MJ of CH4→283.32 kwh of electricity#

Emission factor=23kg of CO2eq/kg of CH4 (Ecoinvent database)

GHG emission=23 kg CO2 eq/kg of CH4 x 29.07 kg CH4= 669 kg of CO2 eq.#

Palm Oil Mill Effluent (POME) from Scenario (II) = 1.47m^3

COD= 76198 mg of COD/L of POME

1000L→1m3

1L →1x10-3 m3

1x10-3 m3→76198 mg of COD

$1.47m^3$ →112.01 kg of COD

1kg of COD →0.251kg of CH4

112.01 kg of COD→28 kg of CH4

0.656kg of CH4→1m3 of CH4

28 kg of CH4→42.68 m3 of CH4#

1m3 of CH4→23 MJ of CH4

42.68 m3 of CH4→981 MJ of CH4#

1MJ of CH4 →0.2778 kwh

981 MJ of CH4→272.7 kwh of electricity#

Emission factor=23kg of CO2eq/kg of CH4 (Ecoinvent database)

GHG emission=23 kg CO2 eq/kg of CH4 x 28 kg CH4= 644 kg of CO2 eq.#

Palm Oil Mill Effluent (POME) from Scenario (III) = 0.89 m^3

COD= 76198 mg of COD/L of POME

1000L→1m3

1L →1x10-3 m3

1x10-3 m3→76198 mg of COD

$1.52m^3$ →67.8 kg of COD

1kg of COD →0.251 kg of CH4

67.8 kg of COD→17.02 kg of CH4

0.656kg of CH4→1m3 of CH4

17.02 kg of CH4→25.29 m3 of CH4#

1m3 of CH4→23 MJ of CH4

25.29 m3 of CH4→596.85 MJ of CH4#

1MJ of CH4 →0.2778 kwh

596.85 MJ of CH4→165.9 kwh of electricity#

Emission factor=23kg of CO2eq/kg of CH4 (Ecoinvent database)

GHG emission=23 kg CO2 eq/kg of CH4 x 17.02 kg CH4= 391.46 kg of CO2 eq.#

Palm Oil Mill Effluent (POME) from Scenario (IV) = 0.68 m^3

COD= 76198 mg of COD/L of POME

1000L→1m3

1L →1x10-3 m3

1x10-3 m3→76198 mg of COD

0.68 m^3 →51.81 kg of COD

1kg of COD →0.251 kg of CH4

51.81 kg of COD→13 kg of CH4

0.656kg of CH4→1m3 of CH4

13 kg of CH4→19.82 m3 of CH4#

1m3 of CH4→23 MJ of CH4

19.82 m3 of CH4→455.86 MJ of CH4#

1MJ of CH4 →0.2778 kwh

455.86 MJ of CH4→126.73 kwh of electricity#

Emission factor=23kg of CO2eq/kg of CH4 (Ecoinvent database)

GHG emission=23 kg CO2 eq/kg of CH4 x 13 kg CH4= 299 kg of CO2 eq.#

CURRICULUM VITAE

Name: Ms. Chaw Su Hlaing

Date of Birth: Auguest 3, 1987

Nationality: Myanmar

University Education:

2003 – 2006 Bachelor Degree (Industiral Chemistry), 2008 - 2012 Master Degree (Industrial Chemistry) Dagon University, Yangon, Myanmar

Working Experience:

2012- 2013 Position: Research and Development Member

Company name: Myanmar Mayson Company Limited

Proceedings:

1. Suhlaing, C.; and Charoensaeng, A. (2015, April 21) Environmental life Cycle Assessment of Microemulsion Biofuel Production. Proceedings of the 6th Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and the 21th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.