REFERENCES

Abdel-Rahman, M.A., Tashiro, Y., and Sonomoto, K. (2011) Lactic acid production from lignocellulose-derived sugars using lactic acid bacteria: Overview and limits. Journal of Biotechnology 156(4), 286-301.

Andreanne, H. (2010) Lactic acid production from agribusiness waste starch fermentation with lactobacillus amylophilus and its cradle-to-gate life cycle assessment as a precursor to Poly-l-Lactide. M.S. Thesis, University of Montreal, Canada.

Bianchi, M. (2008) "Introduction to LCA." The European Commission's information hub on life cycle thinking based data, tools and services. 1 Oct 2008 < http:// lca.jrc.ec.europa.eu/lcainfohub/introduction.vm>

Bongsunun, S. (2013) "Forecasting result of major economic crop by whole kingdom year 2013" Division of Agricultural Forecasting. Mar 2013 <http://www2. oae.go.th/mis/Forecast/09_MAR2556/Thai/all/wh_01.pdf.>

Bridgwater, A.V. (1995) The technical and economic feasibility of biomass gasification for power generation. Fuel 74(5), 631-653.

Chavalparit, O., and Ongwandee, M. (2009) Clean technology for the tapioca starch industry in Thailand. Journal of Cleaner Production 17(2), 105-110.

Cherubini, F. (2010) The biorefinery concept: Using biomass instead of oil for producing energy and chemicals. Energy Conversion and Management 51(7), 1412-1421.

Cherubini, F., Bargigli, S., and Ulgiati, S. (2008) Life cycle assessment of urban waste management: Energy performances and environmental impacts. The case of Rome, Italy. Waste Management 28(12), 2552-2564.

Cherubini, F., and Jungmeier, G. (2010) LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass. The International Journal of Life Cycle Assessment 15(1), 53-66.

Cherubini, F., and Ulgiati, S. (2010) Crop residues as raw materials for biorefinery systems – A LCA case study. Applied Energy 87(1), 47-57.

Chinnawornrungsee, R., Malakul, P., and Mungcharoen, T. (2013) Life Cycle Energy and Environmental Analysis Study of a Model Biorefinery in Thailand. Chemical Engineering Transactions 32.

Clark, J.H., Luque, R., and Matharu, A.S. (2012) Green chemistry, biofuels, and biorefinery. Annual Review of Chemical and Biomolecular Engineering 3, 183-207.

Cok, B., Tsiropoulos, I., Roes, A.L., and Patel, M.K. (2013) Succinic acid production derived from carbohydrates: An energy and greenhouse gas assessment of a platform chemical toward a bio-based economy. Biofuels, Bioproducts and Biorefining: n/a-n/a.

Corma, A., Iborra, S., and Velty, A. (2007) Chemical routes for the transformation of biomass into chemicals. Chemical Reviews 107(6), 2411-2502.

Datta, R., Tsai, S.-P., Bonsignore, P., Moon, S.-H., and Frank, J.R. (1995). Technological and economic potential of poly(lactic acid) and lactic acid derivatives. FEMS Microbiology Reviews 16(2–3), 221-231.

DEDE. (2009) "Energy potential of agricultural residues in Thailand, 2009." Department of Alternative Energy Development and Efficiency, 31 Jul 2013 <http://www.dede.go.th/dede/index.php?option=com_content&view=article& id =130:2010-05-07-08-10-57&catid=58&Itemid=68>

Demirbas, M.F. (2009) Biorefineries for biofuel upgrading: A critical review. Applied Energy 86, Supplement 1(0): S151-S161.

Drift, B.v.d. (2008) Status of Biomass Gasification. Energy Research Centre of the Netherlands (ECN). B. v. d. Drift.

Energy Statistics (2012) Production / Imports / Exports and Consumption of Petroleum Products. Thailand Energy Statistics 2012.

Fukuda, H., Kondo, A., and Noda, H. (2001) Biodiesel fuel production by transesterification of oils. Journal of Bioscience and Bioengineering 92(5), 405-416.

Ghatak, H.R. (2011) Biorefineries from the perspective of sustainability: Feedstocks, products, and processes. Renewable and Sustainable Energy Reviews 15(8), 4042-4052.

Gheewala, S.H., Bonnet, S., Prueksakorn, K., and Nilsalab, P. (2011) Sustainability Assessment of a Biorefinery Complex in Thailand. Sustainability 3(3), 518-530.

Godson, D. (2012) "Asia Biogas Offers Tapioca Pulp (Garg) Bioenergy Technology." 10 Aug 2012 <http://www.asiabiogas.com/main /index.php/news-a-updates/item/88-10-aug-2012-asia-biogas-offers-tapioca-pulp-garg-bioenergy-technology.html.

Groot, W., and Borén, T. (2010) Life cycle assessment of the manufacture of lactide and PLA biopolymers from sugarcane in Thailand. The International Journal of Life Cycle Assessment 15(9), 970-984.

Huang, H.-J., Ramaswamy, S., Tschirner, U.W., and Ramarao, B.V. (2008) A review of separation technologies in current and future biorefineries. Separation and Purification Technology 62(1), 1-21.

iBizChannel. (2011) "PTTCH devoted stock aiming going on business in the second NatureWorks PLA plant." 14 Sep 2011 <http://www.manager.co.th/iBizChannel/ViewNews.aspx?NewsID=9540000116670>

Integrated Cassava Project. (2004) "Production of glucose syrup." Glucose Syrup. 31 Jul 2013 <http://www.cassavabiz.org/postharvest/gsyrup01.htm>

Jensen, A.A., Hoffman, L., Møller, B.T., Schmidt, A., Christiansen, K., Berendsen, S., Elkington, J., and Dijk, F.v. (1997) Life-cycle assessment (LCA) - a guide to approaches, experiences and information sources.

Jongskul, A. (2013) Agricultural Statistics of Thailand 2012. Office of Agricultural Economics. The Agricultural Cooperative Federation of Thailand, Ministry for Agricultural and Cooperatives. 402.

KAPI (2007) Recycling and Increasing Value of Waste from Ethanol Production. Kasetsart Agricultural and Agro-Industrial Product Improvement Institute. Final report: DEDE, Bangkok, Thailand.

Khongsiri, S. (2009) Life cycle assessment of cassava root and cassava starch. M.S. Thesis, Kasetsart University, Bangkok, Thailand. 144 pages.

King, D., Inderwildi, O.R., and Williams, A. (2010) "The Future of Industrial Biorefineries." 2010 World Economic Forum. 3 May 2012

<http://www3.weforum.org/docs/WEF_FutureIndustrialBiorefineries_Report_2010.pdf>

Kosugi, A., Kondo, A., Ueda, M., Murata, Y., Vaithanomsat, P., Thanapase, W., Arai, T., and Mori, Y. (2009) Production of ethanol from cassava pulp via fermentation with a surface-engineered yeast strain displaying glucoamylase. Renewable Energy 34(5), 1354-1358.

Leung, C.C.J., Cheung, A.S.Y., Zhang, A.Y.-Z., Lam, K.F., and Lin, C.S.K. (2012) Utilisation of waste bread for fermentative succinic acid production. Biochemical Engineering Journal 65(0), 10-15.

Li, Q., Wang, D., Wu, Y., Li, W., Zhang, Y., Xing, J., and Su, Z. (2010) One step recovery of succinic acid from fermentation broths by crystallization. Separation and Purification Technology 72(3), 294-300.

Lin, S.K.C., Du, C., Blaga, A.C., Camarut, M., Webb, C., Stevens, C.V., and Soetaert, W. (2010) Novel resin-based vacuum distillation-crystallisation method for recovery of succinic acid crystals from fermentation broths. Green Chemistry 12(4), 666-671.

MacLeod, D. (2013) "International Sugar Statistics." 2 Aug 2013 <http://www.illovosugar.co.za/World_of_sugar/Sugar_Statistics/International.aspx>

Mangnimit, S., Malakul, P., and Gani, R. (2013) Sustainable Process Design of Biofuels : Bioethanol Production from Cassava rhizome. Paper presented at Proceedings of the 6th International Conference on Process Systems Engineering (PSE ASIA), 25 - 27 Jun 2013, Kuala Lumpur, Malaysia.

Mens, C.B., and Werf, H.v.d. (2007) "Life cycle assessment of farming systems." Encyclopedia of Earth. 10 Jul 2007 <http://www.eoearth.org/article/Life_cycle_assessment_of_farming_systems>

MTEC (2010) Sugar Production by Using Sugarcane. Bangkok, Thailand : MTEC (Unpublished)

Nguyen, T., and Gheewala, S. (2008) Life cycle assessment of fuel ethanol from cassava in Thailand. The International Journal of Life Cycle Assessment 13(2), 147-154.

NIA. (2008) "Companies which are doing business with biopolymers in Thailand." National roadmap for the development of bioplastics industry. 1 Mar 2008 < http://www.nia.or.th/bioplastics/download/bioplast_road map.pdf>

NIA. (2013) "National Roadmap for Development of Bioplastics Industry (2008-2012)." Progress in Implementation of Thailand's National Bioplastics Roadmap. 28 Jan 2013 <http://www.nesdb.go.th/Portals/0/news/ppt/13/PPT_0354280113.pdf>

Octave, S., and Thomas, D. (2009) Biorefinery: Toward an industrial metabolism. Biochimie 91(6), 659-664.

Olsson, L., and Hahn-Hägerdal, B. (1996) Fermentation of lignocellulosic hydrolysates for ethanol production. Enzyme and Microbial Technology 18(5), 312-331.

Ometto, A.R., Hauschild, M.Z., and Roma, W.N.L. (2009) Life cycle assessment of fuel ethanol from sugarcane in Brazil. The International Journal of Life Cycle Assessment 14(3), 236-247.

Panichnumsin, P., Nopharatana, A., Ahring, B., and Chaiprasert, P. (2010) Production of methane by co-digestion of cassava pulp with various concentrations of pig manure. Biomass and Bioenergy 34(8), 1117-1124.

Rajgor, G. (2004) Waste to Energy. reFOCUS, 26-28.

Rattanachomsri, U., Tanapongpipat, S., Eurwilaichitr, L., and Champreda, V. (2009) Simultaneous non-thermal saccharification of cassava pulp by multi-enzyme activity and ethanol fermentation by Candida tropicalis. Journal of Bioscience and Bioengineering 107(5), 488-493.

Saengchan, K. (2012) Japan support Thailand to produce "Ethanol" from cassava pulp. Thailand Tapioca Starch Newsletter, 1-4.

SETAC (1993) Guidelines for Life-Cycle Assessment: A Code of Practice. Brussels.

Silalertruksa, T., and Gheewala, S.H. (2010) Security of feedstocks supply for future bio-ethanol production in Thailand. Energy Policy 38(11), 7476-7486.

Silalertruksa, T., and Gheewala, S.H. (2011) Long-Term Bioethanol System and Its Implications on GHG Emissions: A Case Study of Thailand. Environmental Science & Technology 45(11), 4920-4928.

Song, H., and Lee, S.Y. (2006) Production of succinic acid by bacterial fermentation. Enzyme and Microbial Technology 39(3), 352-361.

Sutabutr, T. (2010, Mar 2010) "Current ethanol plants in Thailand." Department of Alternative Energy Development and Efficiency. Mar 2010 <http://www.dede.go.th/dede/fileadmin/usr/bers/gasohol_documents/gasohol_2010/032010_up_data_factory.pdf?ml=2&mlt=system&tmpl=component>

Sutabutr, T. (2012) "Ethanol Plants and Gasohol Update in February 2012." Department of Alternative Energy Development and Efficiency. 12 Feb 2012 <http://www.dede.go.th/dede/index.php?option=com_content&view=article&id=6869%3Aetahnol-plants-june-2011&catid=150%3Ainformationseng&lang=en#>

Thouphan, R. (2011) PTT synergies MCC. Technology Promotion Association (Thailand-Japan), 38, 83-85.

Tossanaitada, W., and Tia, W. (2009) Cogeneration Efficiency Enhancement in Sugar Mills. Paper presented at The 10th Annual Conference of Thai Society of Agricultural Engineering Innovation In Agricultural, Food and Renewable Energy Productions for Mankind, 1-3 Apr 2009, Surananee University, Nakhon Ratchasima, Thailand.

Tsiropoulos, I., Cok, B., and Patel, M.K. (2013) Energy and greenhouse gas assessment of European glucose production from corn – a multiple allocation approach for a key ingredient of the bio-based economy. Journal of Cleaner Production 43(0), 182-190.

Van De Graaf, M.J., Vallianpoer, F., Fiey, G., Delattre, L., and Schulten, E.A.M. (2012) Process for the crystallization of succinic acid, Google Patents.

Vink, E.T.H., Davies, S., and Kolstad, J.J. (2010) The eco-profile for current Ingeo® polylactide production. Industrial Biotechnology 6(4), 212-224.

Vink, E.T.H., Glassner, D.A., Kolstad, J.J., Wooley, R.J., and O'Connor, R.P. (2007) The eco-profiles for current and near-future NatureWorks® polylactide (PLA) production. Industrial Biotechnology 3(1), 58-81.

Witayapairot, W. (2010) Environmental impact evaluation of sugar production from cane using life cycle assessment. M.S. Thesis, Suranaree University of Technology, Nakhon Ratchasima, Thailand.

APPENDICES

Appendix A Life Cycle Inventory (LCI)

Table A1 Results of the inventory analysis of sugarcane cultivation in Thailand (MTEC, 2012)

Inventory of sugarcane cultivation					
Input			**Output**		
Type	**Amount**	**Unit**	**Type**	**Amount**	**Unit**
Chemical			**Product**		
Fertilizer (N)	1.78E-03	kg	Sugarcane	1	kg
Fertilizer (P)	8.29E-04	kg			
Fertilizer (K)	7.39E-04	kg	**Co-product**		
Paraquat	1.29E-05	kg	Cane trash - 0% burning	0.199	kg
Atrazine	4.50E-05	kg			
Ametryne	3.21E-05	kg	**Air emissions**		
2,4-D	1.29E-05	kg	Carbon monoxide	8.84E-07	kg
			Nitrogen oxide	1.04E-06	kg
Fuel/Electricity			PM10	1.72E-07	kg
Diesel	1.21E-03	kg	sulfur dioxide	3.38E-07	kg
			Methane	4.31E-09	kg
			Nitrogen dioxide	1.92E-08	kg
			Carbon dioxide	3.96E-03	kg

Table A2 Results of the inventory analysis of sugarcane ethanol conversion (Ometto et al., 2010)

Inventory of sugarcane ethanol conversion					
Input			**Output**		
Type	**Quantity**	**Unit**	**Type**	**Quantity**	**Unit**
Raw material			**Product**		
Sugarcane	14.706	kg	Ethanol (96%)	1	kg
Water	118.613	kg			
			Co-product		
Chemical			Vinasse	20.625	kg
Sulfuric acid	1.13E-02	kg	Bagasse	4.265	kg
Fuel/Electricity			**Water emissions**		
Steam	2.75	kg	Sulfuric acid	1.13E-02	kg
Electricity	0.344	kWh			

Table A3 Results of the inventory analysis of ethanol dehydration

Inventory of ethanol dehydration					
Input			Output		
Type	Quantity	Unit	Type	Quantity	Unit
Raw material			**Product**		
Ethanol (96%)	1.04	kg	Ethanol (99.5%)	1	kg
Make up cooling water	2.79	kg			
			Air emission		
			Water	4.12E-02	kg
Fuel/Electricity					
Electricity	1.10E-02	kWh			

Table A4 Results of the inventory analysis of sugar milling in Thailand (MTEC, 2012)

Inventory of sugar milling					
Input			Output		
Type	Amount	Unit	Type	Amount	Unit
Raw material			**Product**		
Sugarcane plant	1000	kg	Raw sugar	109.57	kg
Energy			**Co-product**		
Steam	450	kg	Molasses	36.28	kg
Electricity	17.37	kWh	Bagasse	290	kg
Chemical					
Lime	2.11	kg			
Sodium chloride	0.78	kg			
Hydrochloric acid	4.50E-04	kg			
SiO_2	2.31E-03	kg			
Biocide	3.66E-03	kg			
Aluminium sulfate	3.73E-03	kg			
Caustic soda flake	1.16E-03	kg			
Flocculants	0.0386	kg			
Miscellaneous	5.72E-03	kg			

Table A5 Results of the inventory analysis of molasses ethanol conversion (KAPI, 2008)

Inventory of molasses ethanol conversion					
Input			**Output**		
Type	**Quantity**	**Unit**	**Type**	**Quantity**	**Unit**
Raw material			**Product**		
Molasses	4500	kg	Ethanol	1000	kg
Water	15.838	m^3			
			Co-product		
Fuel/Electricity			Biogas recovery	208.75	m^3
Stream	3112.5	kg	Yeast residue	11.088	kg
Electricity	362.5	kWh			

Table A6 Results of the inventory analysis of cassava cultivation (Khongsiri, 2009).

Inventory of cassava cultivation					
Input			**Output**		
Type	**Quantity**	**Unit**	**Type**	**Quantity**	**Unit**
Raw material			**Products**		
Cassava stems	345	piece	Cassava root	1000	kg
Cassava peel	1076	kg	Cassava residue	555.048	kg
Chicken manure	2580	kg	Cassava stems	872	piece
N-fertilizer	1.249	kg			
P-fertilizer	0.7	kg	**Air emissions**		
K-fertilizer	1.336	kg	Carbon dioxide	8.315	kg
Alachlor	0.096	kg	Nitrogen oxide	0.171	kg
Paraquat	0.15	kg	Sulfur dioxide	0.011	kg
Glyphosate	0.292	kg	Nitrous oxide	0.044	kg
Zinc	0.086	kg	Ammonia	0.264	kg
			Volatile organic compound	0.058	kg
Fuel					
Diesel	2.475	kg			

Table A7 Results of the inventory analysis of cassava chips production (Silalertruksa and Gheewala, 2011)

Inventory of cassava chips production					
Input			Output		
Type	Quantity	Unit	Type	Quantity	Unit
Raw material			**Product**		
Cassava roots	2100	kg	Cassava chips	1000	kg
			Rhizome	11.59	kg
Fuel/Electricity			Sand	8.26	kg
Diesel	11.0552	kg			
			Air emissions		
			Carbon monoxide	0.00804882	kg
			Nitrogen oxide	0.0094692	kg
			PM10	0.00156242	kg
			sulfur dioxide	0.00307749	kg
			Methane	3.9297E-05	kg
			Nitrogen dioxide	0.00017518	kg
			Carbon dioxide	36.077652	kg

Table A8 Results of the inventory analysis of cassava ethanol conversion (KAPI, 2008)

Inventory of cassava ethanol conversion					
Input			Output		
Type	Quantity	Unit	Type	Quantity	Unit
Raw material			**Product**		
Cassava chips	3083.75	kg	Ethanol	1000	kg
Water	10.9375	m^3			
			Co-product		
Fuel/Electricity			Biogas recovery	100	m^3
Electricity	262.5	kWh	DDGS production	250	kg
Steam	3375	kg	Yeast residue	11.0875	kg
			Carbon dioxide	916.67	kg

Table A9 Results of the inventory analysis of one ton of cassava starch with biogas production line (MTEC, 2012)

Inventory of cassava starch with biogas production line					
Input			Output		
Item	Quantity	Unit	Item	Quantity	Unit
Raw material			**Product**		
cassava root	4,500	kg	Cassava starch	1000	kg
Sulfur	0.554	kg			
Water	12.665	m^3	**By products**		
		-	Cassava peel	248.6	kg
Fuel/Electricity			Rhizome	24.836	kg
Electricity	201.775	kWh	Cassava residue	460.47	kg
Fuel oil	1.189	kg	Sand	17.71	kg
			Biogas	79.492	m^3
			Air emissions		
			Carbon monoxide	0.0007569	kg
			Nitrogen oxide	0.0025735	kg
			PM10	0.0002927	kg
			sulfur dioxide	0.0075691	kg
			Methane	0.0001564	kg
			Nitrogen dioxide	1.716E-05	kg
			Carbon dioxide	3.9561028	kg
			Water emissions		
			Waste water	19.628	m^3
			BOD	0.927	kg
			COD	4.17	kg
			Suspended solids	3.326	kg
			TDS	65.661	kg
			Oil & grease	0.216	kg

Table A10 Results of the inventory analysis of cassava sugar production (MTEC, 2012)

Inventory of sugar from cassava sugar production					
Input			**Output**		
Item	**Quantity**	**Unit**	**Item**	**Quantity**	**Unit**
Raw material			**Product**		
cassava starch	1050	kg	Sugar(D-glucose)	1000	kg
Sulfuric acid (100%)	1.207	kg			
Sodium hydroxide	0.756	kg	**Air emissions**		
Water	27	m^3	Carbon monoxide	0.003979	kg
			Nitrogen oxide	0.0135286	kg
Fuel/Electricity			PM10	0.0015385	kg
Fuel oil	6.250457	kg	sulfur dioxide	0.0397899	kg
Electricity	144	kWh	Methane	0.0008223	kg
			Nitrogen dioxide	9.019E-05	kg
			Carbon dioxide	20.796847	kg
			Water emissions		
			Waste water	6.89	m^3

Table A11 Results of the inventory analysis of BSA production (Cok et al., 2013)

Inventory of biosuccinic acid production					
Input			**Output**		
Type	**Amount**	**Unit**	**Type**	**Amount**	**Unit**
Raw material			**Product**		
Sugar	1.1172	kg	Succinic acid	1	kg
Process water	31	kg			
HCl 30%	0.0752	kg	**Co-product**		
$Ca(OH)_2$	0.0528	kg	Biogas	0.0416	m^3
Fuel/Electricity			**Soil emissions**		
Total steam	3.114	kg	Waste sludge	0.001	kg
Electricity	1.672	kWh			

Table A12 Results of the inventory analysis of LA production (Andreanne, 2010)

Inventory of lactic acid from sugar					
Input			Output		
Type	Amount	Unit	Type	Amount	Unit
Raw material			**Product**		
Dextrose	1.11	kg	Lactic acid (88% wt)	1	kg
Tap water (15°C)	11.11	kg			
CSL	1.08	kg	**Co-product**		
Calcium hydroxide	0.37	kg	Gypsum (pure, dry, weight)	0.67	kg
Cooling water	391.7	kg			
Sulphuric acid	0.49	kg	**Waste**		
			Sludge	0.12	kg
Fuel/Electricity					
Saturated steam	4.86	kg	**Water emissions**		
(121°C, 1.1 bar)			Wastewater	11	kg
Electricity	0.0015	kWh			

Table A13 Results of the inventory analysis of cassava rhizome ethanol conversion (Mangnimit et al., 2013)

Inventory of cassava rhizome ethanol conversion					
Input			Output		
Type	Quantity	Unit	Type	Quantity	Unit
Raw material			**Products**		
Cassava Rhizome	3.166	kg	Ethanol 99.5% wt.	1	kg
Sulfuric acid	0.052	kg			
Water	3.6071	kg	**Co-products**		
Lime	0.0361	kg	Gypsum	0.0664	kg
Make up cooling water	16.1276	kg			
Ammonia	0.0007	kg	**Air emissions**		
			Water	0.5713	kg
Electricity/Heat			Furfural	0.02384	kg
Steam	4.4635	kg	Ethanol	0.0627	kg
Electricity	0.2071	kW	Carbon dioxide	1.0302	kg
			Oxygen	0.00182	kg
			Acetic acid	0.00003	kg
			Water emissions		
			Treated water	3.6223	kg
			Sulfuric acid	0.0042	kg
			Acetic acid	0.0035	kg
			Furfural	0.0249	kg
			Ethanol	0.0173	kg
			Waste		
			Bio waste	0.3243	kg

Table A14 Results of the inventory analysis of electrical energy cogeneration (Witayapairot, 2010)

Inventory of electricity from bagasse					
Input			**Output**		
Type	**Amount**	**Unit**	**Type**	**Amount**	**Unit**
Raw material			**Product**		
Bagasse	3.5	kg	Electricity	1.0	kWh
Water	1.624	kg	Steam	10.286	kg
Fuel/Electricity			**Air emissions**		
Diesel	0.0483	kg	Carbon dioxide	0.1730	kg
			Carbon monoxide	0.0062	kg
			Nitrogenoxide	0.0015	kg
			Sulfur dioxide	0.0007	kg
			Methane	0.0000	kg
			SPM	0.0001	kg
			TSP	0.0000	kg
			Hydrocarbon	0.0000	kg
			Water emissions		
			Blowdown water	0.2410	kg
			Soil emissions		
			Ash	0.1050	kg

Table A15 Results of the inventory analysis of cassava pulp biogas production (Godson, 2012)

Inventory of biogas production from cassava pulp					
Input			**Output**		
Type	**Amount**	**Unit**	**Type**	**Amount**	**Unit**
Raw material			**Product**		
Cassava pulp	1000	kg	Biogas	64.5	m^3

Table A16 Results of the inventory analysis of electricity from biogas (Chinnawornrungsee et al., 2013)

Inventory of electricity from biogas					
Input			Output		
Type	Amount	Unit	Type	Amount	Unit
Raw material			**Product**		
Biogas	1	m^3	Electricity from biogas	1.2	kWh
			Air emissions		
			Carbon monoxide	0.0001	kg
			Nitrogen oxide	0.0005	kg
			PM10	0.0008	kg
			PM2.5	0.0008	kg
			Sulfur dioxide	0.0001	kg

Table A17 Results of the inventory data of feedstocks transportation for 1 ton-kilometer (tkm) (1 km for no load) for 10-wheel truck at full load 16 tons (MTEC, 2012)

Type	Type of load				
	Unit	No load	50% load	75% load	Full load
Input					
Diesel	kg	0.1775	0.0273	0.0194	0.0150
Output					
Carbon dioxide	g	519.97	86.42	61.41	47.37
Carbon monoxide	g	1.7813	0.2961	0.2104	0.1623
Nitrogen oxides	g	5.3549	0.89	0.6324	0.4879
Particulate matter	g	0.4014	0.0667	0.0474	0.0366
Hydrocarbons	g	0.465	0.0773	0.0549	0.0424
Methane	g	0.0112	0.0019	0.0013	0.001
Benzene	g	8.84E-03	1.47E-03	1.04E-03	8.05E-04
Toluene	g	3.72E-03	6.18E-04	4.39E-04	3.39E-04
Xylene	g	3.72E-03	6.18E-04	4.39E-04	3.39E-04
Non – methane volatile organic compounds	g	0.9586	0.1475	0.1048	0.0809
Sulfur oxides	g	0.1209	0.0186	0.0132	0.0102
Nitrous Oxide	g	0.0218	0.0033	0.0024	0.0018
Cadmium	g	1.73E-06	2.66E-07	1.89E-07	1.46E-07
Copper	g	2.94E-04	4.52E-05	3.21E-05	2.48E-05
Chromium	g	8.64E-06	1.33E-06	9.45E-07	7.29E-07
Nickel	g	1.21E-05	1.86E-06	1.32E-06	1.02E-06
Selenium	g	1.73E-06	2.66E-07	1.89E-07	1.46E-07
Zinc	g	1.73E-04	2.66E-05	1.89E-05	1.46E-05
Lead	g	1.90E-08	2.92E-09	2.08E-09	1.60E-09
Mercury	g	3.46E-09	5.32E-10	3.78E-10	2.91E-10

Appendix B Life Cycle Impact Assessment (LCIA)

Table B1 Results of the impact assessment 1 kg sugarcane based ethanol by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	-0.0173	0.0013	0.0009	0.0000	-0.0194
global warming (GWP100)	kg CO2 eq	-1.8065	0.3062	0.1343	0.0000	-2.2471
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	-0.5024	0.0061	0.0061	0.0000	-0.5146
fresh water aquatic ecotox.	kg 1,4-DB eq	-0.0334	0.0007	0.0000	0.0000	-0.0342
marine aquatic ecotoxicity	kg 1,4-DB eq	-287.6359	4.3913	0.0877	0.0000	-292.1149
terrestrial ecotoxicity	kg 1,4-DB eq	-0.0095	0.0001	0.0000	0.0000	-0.0096
photochemical oxidation	kg C2H4	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2 eq	-0.0017	0.0012	0.0008	0.0000	-0.0037
eutrophication	kg PO4--- eq	0.0001	0.0001	0.0002	0.0000	-0.0002

Table B2 Results of the impact assessment 1 kg sugarcane based ethanol by using Eco-indicator 95 V2.03 / Europe e

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	-1.7872	0.2896	0.1337	0.0000	-2.2104
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	-0.0011	0.0013	0.0011	0.0000	-0.0034
eutrophication	kg PO4	0.0001	0.0001	0.0002	0.0000	-0.0002
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	-0.0024	0.0005	0.0001	0.0000	-0.0030
summer smog	kg C2H4	0.0000	0.0000	0.0002	0.0000	-0.0003
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	-32.9927	2.6567	1.8380	0.0000	-37.4874
solid waste	kg	-0.0001	0.0001	0.0002	1.0000	-0.0004

Table B3 Results of the impact assessment 1 kg molasses based ethanol by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	-0.0102	0.0014	0.0009	-0.0187	0.0062
global warming (GWP100)	kg CO2 eq	-0.7075	0.3243	0.1421	-1.9371	0.7633
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	-0.2019	0.0065	0.0065	-0.4017	0.1868
fresh water aquatic ecotox.	kg 1,4-DB eq	-0.0138	0.0007	0.0000	-0.0281	0.0136
marine aquatic ecotoxicity	kg 1,4-DB eq	-131.7483	4.6497	0.0927	-266.6218	130.1312
terrestrial ecotoxicity	kg 1,4-DB eq	-0.0042	0.0001	0.0000	-0.0082	0.0039
photochemical oxidation	kg C2H4	0.0002	0.0000	0.0000	0.0000	0.0001
acidification	kg SO2 eq	0.0006	0.0013	0.0009	-0.0035	0.0020
eutrophication	kg PO4--- eq	0.0418	0.0002	0.0002	-0.0002	0.0416

Table B4 Results of the impact assessment 1 kg molasses based ethanol by using Eco-indicator 95 V2.03 / Europe e

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	-0.7190	0.3066	0.1414	-1.9137	0.7467
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	0.0012	0.0014	0.0011	-0.0032	0.0019
eutrophication	kg PO4	0.0418	0.0001	0.0002	-0.0002	0.0416
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	-0.0004	0.0006	0.0001	-0.0028	0.0017
summer smog	kg C2H4	0.0001	0.0000	0.0002	-0.0003	0.0001
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	-17.7479	2.8130	1.9441	-35.2854	12.7804
solid waste	kg	-0.0005	0.0001	0.0002	-0.0009	0.0001

Table B5 Results of the impact assessment 1 kg sugarcane based BSA by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	0.0078	0.0008	0.0005	-0.0101	0.0166
global warming (GWP100)	kg CO2 eq	1.1173	0.1781	0.0778	-1.0441	1.9055
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	0.0410	0.0036	0.0036	-0.2165	0.2504
fresh water aquatic ecotox.	kg 1,4-DB eq	0.0094	0.0004	0.0000	-0.0152	0.0241
marine aquatic ecotoxicity	kg 1,4-DB eq	52.8513	2.5544	0.0508	-143.7080	193.9541
terrestrial ecotoxicity	kg 1,4-DB eq	0.0011	0.0001	0.0000	-0.0044	0.0054
photochemical oxidation	kg C2H4	0.0002	0.0000	0.0000	0.0000	0.0002
acidification	kg SO2 eq	0.0045	0.0007	0.0005	-0.0019	0.0052
eutrophication	kg PO4--- eq	0.0006	0.0001	0.0001	-0.0001	0.0005

Table B6 Results of the impact assessment 1 kg sugarcane based BSA by using Eco-indicator 95 V2.03 / Europe e

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	1.0984	0.1685	0.0774	-1.0315	1.8841
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	0.0050	0.0007	0.0006	-0.0017	0.0053
eutrophication	kg PO4	0.0006	0.0001	0.0001	-0.0001	0.0005
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	0.0023	0.0003	0.0001	-0.0015	0.0034
summer smog	kg C2H4	0.0002	0.0000	0.0001	-0.0001	0.0002
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	12.6821	1.5454	1.0640	-19.0187	29.0913
solid waste	kg	0.0020	0.0000	0.0001	-0.0005	0.0023

Table B7 Results of the impact assessment 1 kg cassava based BSA by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	0.0192	0.0006	0.0003	0.0017	0.0166
global warming (GWP100)	kg CO2 eq	2.2341	0.0942	0.0463	0.1881	1.9055
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	0.2660	0.0118	0.0021	0.0017	0.2504
fresh water aquatic ecotox.	kg 1,4-DB eq	0.0259	0.0016	0.0000	0.0002	0.0241
marine aquatic ecotoxicity	kg 1,4-DB eq	207.2379	12.0116	0.0302	1.2420	193.9541
terrestrial ecotoxicity	kg 1,4-DB eq	0.0058	0.0004	0.0000	0.0000	0.0054
photochemical oxidation	kg C2H4	0.0002	0.0000	0.0000	0.0000	0.0002
acidification	kg SO2 eq	0.0081	0.0020	0.0003	0.0006	0.0052
eutrophication	kg PO4--- eq	0.0011	0.0004	0.0001	0.0002	0.0005

Table B8 Results of the impact assessment 1 kg cassava based BSA by using Eco-indicator 95 V2.03 / Europe e

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	2.2087	0.0907	0.0461	0.1878	1.8841
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	0.0086	0.0023	0.0004	0.0006	0.0053
eutrophication	kg PO4	0.0011	0.0004	0.0001	0.0002	0.0005
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	0.0043	0.0002	0.0000	0.0006	0.0034
summer smog	kg C2H4	0.0004	0.0001	0.0001	0.0000	0.0002
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	33.6406	1.2716	0.6334	2.6443	29.0913
solid waste	kg	0.0031	0.0003	0.0001	0.0004	0.0023

Table B9 Results of the impact assessment 1 kg sugarcane based LA by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	0.0002	0.0007	0.0005	-0.0101	0.0091
global warming (GWP100)	kg CO2 eq	0.1951	0.1761	0.0772	-1.0441	0.9859
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	0.1525	0.0035	0 0035	-0.2165	0.3619
fresh water aquatic ecotox.	kg 1,4-DB eq	0.0343	0.0004	0.0000	-0.0152	0.0491
marine aquatic ecotoxicity	kg 1,4-DB eq	147.5945	2.5257	0.0504	-143.7080	288.7264
terrestrial ecotoxicity	kg 1,4-DB eq	0.0013	0.0001	0.0000	-0.0044	0.0056
photochemical oxidation	kg C2H4	0.0008	0.0000	0.0000	0.0000	0.0008
acidification	kg SO2 eq	0.0085	0.0007	0.0005	-0.0019	0.0092
eutrophication	kg PO4--- eq	0.0026	0.0001	0.0001	-0.0001	0.0025

Table B10 Results of the impact assessment 1 kg sugarcane based LA by using Eco-indicator 95 V2.03 / Europe e

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	0.1551	0.1666	0.0769	-1.0315	0.9432
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	0.0079	0.0007	0.0006	-0.0017	0.0083
eutrophication	kg PO4	0.0026	0.0001	0.0001	-0.0001	0.0025
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	0.0060	0.0003	0.0001	-0.0015	0.0071
summer smog	kg C2H4	0.0005	0.0000	0.0001	-0.0001	0.0005
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	10.5948	1.5280	1.0568	-19.0187	27.0286
solid waste	kg	0.0902	0.0000	0.0001	-0.0005	0.0905

Table B11 Results of the impact assessment 1 kg cassava based LA by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	0.0116	0.0006	0.0003	0.0017	0.0091
global warming (GWP100)	kg CO2 eq	1.3095	0.0906	0.0449	0.1881	0.9859
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	0.3771	0.0114	0.0021	0.0017	0.3619
fresh water aquatic ecotox.	kg 1,4-DB eq	0.0507	0.0015	0.0000	0.0002	0.0491
marine aquatic ecotoxicity	kg 1,4-DB eq	301.5560	11.5583	0.0293	1.2420	288.7264
terrestrial ecotoxicity	kg 1,4-DB eq	0.0060	0.0004	0.0000	0.0000	0.0056
photochemical oxidation	kg C2H4	0.0008	0.0000	0.0000	0.0000	0.0008
acidification	kg SO2 eq	0.0120	0.0019	0.0003	0.0006	0.0092
eutrophication	kg PO4--- eq	0.0031	0.0004	0.0001	0.0002	0.0025

Table B12 Results of the impact assessment 1 kg cassava based LA by using Eco-indicator 95 V2.03 / Europe e

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	1.2630	0.0873	0.0447	0.1878	0.9432
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	0.0114	0.0022	0.0004	0.0006	0.0083
eutrophication	kg PO4	0.0031	0.0004	0.0001	0.0002	0.0025
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	0.0079	0.0002	0.0000	0.0006	0.0071
summer smog	kg C2H4	0.0007	0.0001	0.0001	0.0000	0.0005
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	31.5109	1.2236	0.6144	2.6443	27.0286
solid waste	kg	0.0912	0.0003	0.0001	0.0004	0.0905

Table B13 Results of the impact assessment 1 kg cassava based ethanol by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	0.0087	0.0007	0.0004	0.0008	0.0069
global warming (GWP100)	kg CO2 eq	2.0018	0.1155	0.0567	0.1215	1.7081
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	0.2191	0.0145	0.0026	0.0002	0.2018
fresh water aquatic ecotox.	kg 1,4-DB eq	0.0165	0.0019	0.0000	0.0000	0.0146
marine aquatic ecotoxicity	kg 1,4-DB eq	152.8416	14.7312	0.0370	0.0061	138.0673
terrestrial ecotoxicity	kg 1,4-DB eq	0.0046	0.0005	0.0000	0.0000	0.0042
photochemical oxidation	kg C2H4	0.0001	0.0000	0.0000	0.0000	0.0001
acidification	kg SO2 eq	0.0050	0.0024	0.0003	0.0001	0.0021
eutrophication	kg PO4--- eq	0.0122	0.0005	0.0001	0.0000	0.0117

Table B14 Results of the impact assessment 1 kg cassava based ethanol by using Eco-indicator 95 V2.03 / Europe e

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	1.9793	0.1113	0.0565	0.1214	1.6901
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	0.0054	0.0028	0.0004	0.0002	0.0020
eutrophication	kg PO4	0.0122	0.0004	0.0001	0.0000	0.0117
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	0.0021	0.0003	0.0000	0.0001	0.0017
summer smog	kg C2H4	0.0004	0.0001	0.0001	0.0000	0.0001
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	17.9253	1.5595	0.7764	1.5760	14.0134
solid waste	kg	0.0007	0.0004	0.0001	0.0002	0.0001

Table B15 Results of the impact assessment 1 kg cassava rhizome based ethanol by using CML 2 baseline 2000 V2.03 / World, 1990

Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
abiotic depletion	kg Sb eq	0.0097	0.0001	0.0002	0.0000	0.0095
global warming (GWP100)	kg CO2 eq	2.2031	0.0004	0.0279	0.0002	2.1650
ozone layer depletion (ODP)	kg CFC-11 eq	0.0000	0.0000	0.0000	0.0000	0.0000
human toxicity	kg 1,4-DB eq	0.2823	0.0000	0.0013	0.0000	0.2797
fresh water aquatic ecotox.	kg 1,4-DB eq	0.0218	0.0000	0.0000	0.0000	0.0216
marine aquatic ecotoxicity	kg 1,4-DB eq	188.6221	0.0453	0.0182	0.0003	187.3386
terrestrial ecotoxicity	kg 1,4-DB eq	0.0056	0.0000	0.0000	0.0000	0.0056
photochemical oxidation	kg C2H4	0.0243	0.0000	0.0000	0.0000	0.0242
acidification	kg SO2 eq	0.0040	0.0000	0.0002	0.0000	0.0036
eutrophication	kg PO4--- eq	0.0003	0.0000	0.0000	0.0000	0.0002

Table B16 Results of the impact assessment 1 kg cassava rhizome based ethanol by using Eco-indicator 95 V2.03 / Europe e

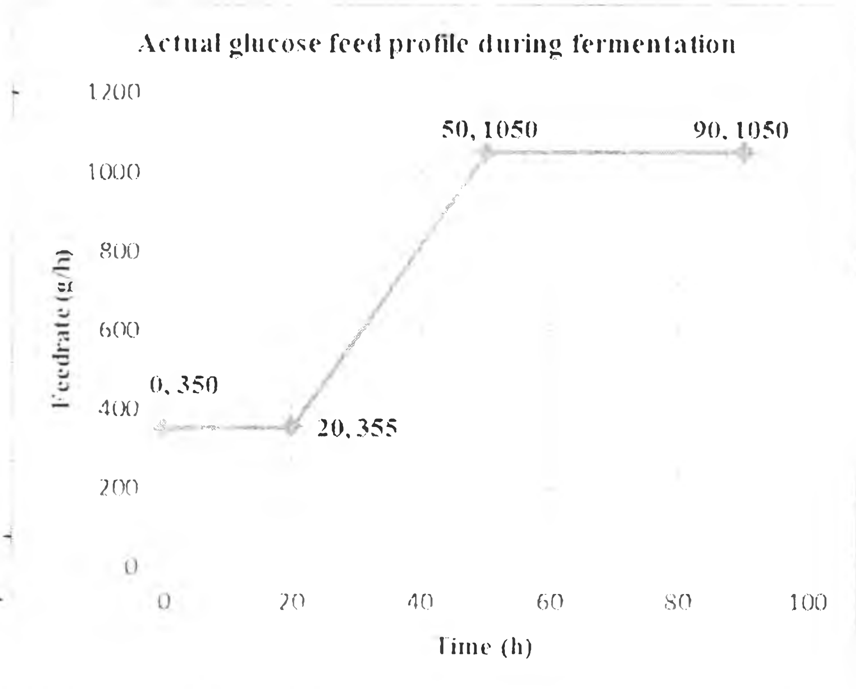
Impact category	Unit	Total	Stage 1	Stage 2	Stage 3	Stage 4
greenhouse	kg CO2	2.1778	0.0096	0.0278	0.0002	2.1403
ozone layer	kg CFC11	0.0000	0.0000	0.0000	0.0000	0.0000
acidification	kg SO2	0.0038	0.0000	0.0002	0.0000	0.0034
eutrophication	kg PO4	0.0003	0.0000	0.0000	0.0000	0.0002
heavy metals	kg Pb	0.0000	0.0000	0.0000	0.0000	0.0000
carcinogens	kg B(a)P	0.0000	0.0000	0.0000	0.0000	0.0000
winter smog	kg SPM	0.0027	0.0000	0.0000	0.0000	0.0027
summer smog	kg C2H4	0.0164	0.0000	0.0000	0.0000	0.0163
pesticides	kg act.subst	0.0000	0.0000	0.0000	0.0000	0.0000
energy resources	MJ LHV	19.7593	0.0048	0.3824	0.0023	19.2407
solid waste	kg	0.0002	0.0000	0.0000	0.0000	0.0002

Appendix C Calculations

Life cycle inventory of BSA from Cok et al. (2013) was not completely disclosed. Therefore, some of inputs such as sugar, lime ($Ca(OH)_2$), and hydrochloric acid (HCl) have to be calculated from the related existing data, i.e., patent US 20120238722A1.

The procedures of BSA production are briefly described as follow:

1) The medium of preculture and growth phase is prepared which has 20 g/L gatactose as the main component.
2) The 50%wt glucose is fed to produce BSA as shown in figure below.
3) Broth is maintained at pH 5 by using 6 N KOH.



Assumtions

1) Sugar and titrants from patent US 20120238722A1 in Example 3 is estimated as same value as in journal because it belongs to DSM and Roquette and this Example use yeast as microorganism.
2) Medium of preculture and growth phase is assumed as galactose 20 g/L because main component is galactose 20 g/L.

3) BSA concentration is still 34.5 g/L in case of pH = 3

4) $Ca(OH)_2$ can completely replace KOH.

Definitions

gal = galactose	gal20 = 20 g/L galactose	glu50 = 50%wt glucose
KOH6N = 6 N KOH	HCl30 = 30% HCl	

Constants

$\rho_{gal} = 1.723\ g/cm^3$	$\rho_{gal20} = 1.008\ g/cm^3$	$\rho_{glu50} = 1.21\ g/cm^3$
$\rho_{KOH6N} = 1.172\ g/cm^3$	$\rho_{HCl30} = 1.1493\ g/cm^3$ -	$M_{KOH} = 56.1$
$M_{Ca(OH)2} = 74.09$	$M_{HCl} = 36.46$	

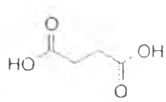
BSA data	$pK_{a1} = 4.2$	$K_{a1} = 10^{-4.2}$
	$pK_{a2} = 5.6$	$K_{a2} = 10^{-5.6}$

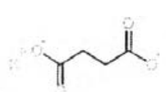
Start with medium	:	galactose 20 g/L	700 kg	$V_1 = 694.44$ L
Then, feed sugar	;	glucose 50%wt	70,125 g	$V_2 = 57.95$ L

BSA concentration in final broth : [BSA] = 34.5 g/L

Maintain pH = 5 by 6 N KOH : 6 N KOH $\mathbf{V_3} = ?$

Total volume (1) : $V_{t1} = V_1 + V_2 + \mathbf{V_3} = 752.39 + \mathbf{V_3}$



+ 2KOH →  + $2H_2O$

pH < 7 buffer formula is applied

Remaining weak acid : $[a] = \dfrac{aC_aV_a - bC_bV_b}{aV_t} = \dfrac{2(0.29)V_{t1} - 1(6)V_3}{2V_{t1}}$

Generated salt : $[s] = \dfrac{bC_bV_b}{aV_t} = \dfrac{1(6)V_3}{2V_{t1}}$

Diprotic acid (BSA) : $[H^+]_1 = \dfrac{[a]}{[s]}K_{a1} = [\dfrac{2(0.29)V_{t1} - 6V_3}{6V_3}]\times 10^{-4.2}$

$[H^+]_2 = \dfrac{[a]_2}{[s]}K_{a2} = \dfrac{[H^+]_1}{[s]}K_{a2}$

Summation of $[H^+]$: $[H^+]_1 + [H^+]_2 = [H^+]_1 + \dfrac{[H^+]_1}{[s]}K_{a2} = [H^+]_1\{1 + \dfrac{K_{a2}}{[s]}\}$

Due to Reverdia fermentation at pH ≤ 3, pH 3 is therefore applied instead of pH 5;

$$10^{-3} = \{[\frac{2(0.29)V_{t1} - 6V_3}{6V_3}]\times 10^{-4.2}\}\times(1 + \frac{2\times 10^{-5.6}}{6V_3}V_{t1})$$

$36V_3^2\times10^{-3} = (0.58V_3 + 0.58\times752.39 - 6V_3)\times10^{-4\,2}[6V_3 + (2V_3 + 752.39\times2)\times10^{-5\,6}]$

$36V_3^2\times10^{1\,2} = (436.3862 - 5.42V_3)[6V_3 + 2\times10^{-5\,6}V_3 + 1504.78\times10^{-5\,6}]$

$0 = (603.08)V_3^2 - (2.618.2989)V_3 - 1.649$

$V_3 = 4.342$ L

So : $V_{t1} = 752.39 + V_3 = 756.732$ L

Then : BSA $= (34.5\ g/L)\times V_{t1} = 26.107$ kg

According to Li et al. (2010), yield of direct crystallization is 70%;

BSA = (26.107 kg)×0.70 = 18.2749 kg

So : Glucose = 35.06 kg

Then : KOH $= (6\ mol/L)(V_3)(M_{KOH}) = 1.4615$ kg

Find $Ca(OH)_2$ from equivalent OH^- ; $\frac{m_{KOH}}{M_{KOH}} = 2\times\frac{m_{Ca(OH)_2}}{M_{Ca(OH)_2}}$

Therefore KOH = 1.4615 kg equivalent to $Ca(OH)_2$ = 0.965 kg

To produce BSA 1 kg, use sugar $= \frac{35.06\ kgSugar}{18.27\ kgBSA}$ = ***1.918 kg***

$Ca(OH)_2 = \frac{0.965\ kgLime}{18.27\ kgBSA}$ = ***0.0528 kg***

From Cok et al. (2013) ; Total titrants $= Ca(OH)_2 + HCl_{30}$ = 0.128 kg

So : HCl_{30} = 0.128 - 0.0528 = ***0.0752 kg***

For direct crystallization, pH < 2 (Li et al., 2010, Lin et al., 2010)

Recheck whether pH of broth less than 2 if HCl_{30} = 0.0752 kg/kg BSA feed into fermenter;

$HCl_{30} = (\frac{0.0752\ kg}{1\ kg\ BSA})(18.275\ kg\ BSA) = 1.3743$ kg - $V_{HCl30} = 1.1958$ L

HCl $= (30\%)(1.3743\ kg) = (0.4123\ kg)/(\frac{36.46\ g}{mol}) = 11.308$ mol

Initial	[s] = 0.0172	11.308	0	0
Rxn	-0.0172	-0.0172×2	+0.0172	+0.0172
Final	0	11.2739	0.0172	0.0172

Total volume (2) : $V_{t2} = V_{t1} + V_{HCl30}$ = 757.928 L

Remaining strong acid: $[H^+] = \frac{11.2739\ mol}{V_{t2}}$ = 0.01487 mol/L

$[H^+]$ from new BSA : $[H^+]_1 = \sqrt{K_{a1}[a]} = \sqrt{K_{a1}(0.0172)}$ = 1.0418×10^{-3} mol/L

$[H^+]_2 = \sqrt{K_{a2}[H^+]_1}$ = 5.1154×10^{-5} mol/L

$[H^+]$ from old BSA: $[H^+]$ = 10^{-3} mol/L

$\sum[H^+] = 0.01487 + 1.0418\times10^{-3} + 5.1154\times10^{-5} + 10^{-3}$ = 0.0268 mol/L

$pH = -\log\sum[H^+] = 1.77 < 2$

Therefore HCl_{30} = 0.0752 kg/kg BSA can be stood. #

However, the amount of sugar used should be calculated from commercial scale (Cok et al., 2013) instead of pilot scale from patent.

Calculate CO_2 uptake of corn during cultivation fromVink et al. (2010) ;

Energy content of corn = 16.3 MJ/kg Corn

Nonrenewable energy use = 24.9658 MJ/kg PLA

So, corn use = 1.5316 kg Corn/kg PLA

The gross greenhouse gas take-up = -1.94 kg CO_2/kg PLA

Therefore, CO_2 uptake of corn = -1.2666 kg CO_2/kg Corn

Calculate sugar use from Cok et al. (2013) ;

The gross greenhouse gas take-up = -1.5 kg CO_2/kg BSA

So, corn use = 1.18427 kg Corn/kg BSA

From another DSM journal referred (Tsiropoulos et al., 2013)

Allocated corn use to produce sugar = 1.06 kg Corn/kg Sugar (dry solid)

Therefore, sugar use = 1.1172 kg Sugar/kg BSA #

CURRICULUM VITAE

Name: Mr. Vasin Kunakemakorn

Date of Birth: June 18, 1989

Nationality: Thai

University Education:

2008 – 2011 Bachelor Degree of Engineering (Petrochemical and Polymeric Materials), Faculty of Engineering, Silpakorn University, Nakhon Pathom, Thailand

Working Experience:

April-June 2011	Position:	Student Internship in section of Pipeline Business Planning at Chonburi Operations Center.
	Company name:	PTT Public Company Limited

Proceedings:

1. Kunakemakorn, V., Malakul, P. (2014, April 22) Eco-efficiency Evaluation of a Biorefinery Model for Biofuel and Biochemicals Production in Thailand Based on Life Cycle Assessment Approach. Proceedings of the 5th Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and the 20th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.