

Supplementary materials

Apple pomace integrated biorefinery for biofuels production: A techno-economic and environmental sustainability analysis

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Table SM1. Workers per shift for representative unit operations (Ulrich and Vasudevan, 2004)

Unit operation	Workers/shift
Vessels and towers	0.2
Heat exchangers	0.05
Agitators	0.2
Compressors/Pumps	0.1
Centrifugal Separator	0.05
Evaporators	0.3
Crystallizer	0.4
Dryers	1
Distillation Column	0.5
Chemical reactors	1

Table SM2. Cost of utilities provided by off-sites for a plant.

Utility	Specific type	Cost	Reference
Steam (latent heat only)	LPS: 6 bar - 160°C	9.45 \$/t	Turton et al., (2018)
Water	Cooling water	0.0157 \$/t	Turton et al., (2018)
Electricity	220 V	0.08 \$/kWh	CNE (2021)
Diesel		0.65 \$/kg	Enap Chile (2021)

Table SM3. Cost of raw materials

Raw material	Cost	Reference
Activated carbon	1.5 \$/t	Alibaba (2023)
Nutrient	595 \$/t	Chemanalyst (2022)
Process water	0.435 \$/t	Turton et al., (2018)
Sodium bicarbonate	300 \$/t	Chemanalyst (2022)
Polymer	0.68 \$/kg	Madeinchina (2023)

Table SM4. Cost of waste treatment

Waste treatment	Cost	Reference
Solid waste	14 \$/t	Senado Chile (2023)

Table SM5. Life Cycle Inventory for bioethanol production based on 1 t of bioethanol.

Pre-treatment section			
Input	Value	Output	Value
Pomace (t)	18.4		
Electricity (kWh)	380.0		
Fermentation section			
Input	Value	Output	Value
Nutrients (kg)	7.0	CO ₂ (t)	1.1
Water (t)	21.0		
Air (t)	1,918.9		
Cooling water (t)	192.1		
Electricity (kWh)	1,850.7		
Purification section			
Input	Value	Output	Value
Cooling water (t)	1,633.2		
Steam (t)	9.4		
Electricity (kWh)	2.9		
Steam generation section			
Input	Value	Output	Value
Water (kg)	448.7	CO ₂ (kg)	248.2
		Ash (kg)	119.9
Vinasse treatment section (biogas production)			
Input	Value	Output	Value
Water (t)	7.1	Fertilizer sludge (m ³)	16.3
Sodium bicarbonate (g)	33.5	<i>Emissions to air</i>	
Polymer (kg)	2.1	CO ₂ (kg)	99.6
Electricity (kWh)	23.7	NH ₃ (g)	119.3
		N ₂ O (g)	1.1
		CH ₄ (g)	69.6
		<i>Emissions to water</i>	
		COD (g)	13.9
		Total N (g)	3.1
		Total P (mg)	3.5
		Total solids (mg)	28.3

Table SM6. Inventory data for lagooning treatment of 1 t of vinasse

Inputs from the Technosphere			Outputs to the Technosphere		
Materials			Products		
Sodium bicarbonate	2.14	kg	Fertirrigation	3.17	t
			Subproducts		
Energy			Sludge fertiliser	7.67	kg
Pump	0.01	kWh	Outputs to the nature		
			Emissions from pre-treatment		
			CO ₂	0.28	kg
			Emissions from air lagoons		
			CO ₂	0.01	kg
			CH ₄	4.96	kg

Table SM7. Inventory data for composting treatment of 1 t vinasse

Inputs from the Technosphere			Outputs to the Technosphere		
Materials			Products		
Water	464.64	kg	Compost	0.45	Tonnes
Diesel from Wheel loader	21.09	g	Outputs to the nature		
Sodium bicarbonate	2.94	g	Emissions to air from conditioning		
Energy			CO ₂	0.26	kg
Electricity	602.16	kWh	Emissions to air from composting		
			CO	0.16	kg
			CH ₄	1.68	kg
			N ₂ O	0.42	kg
			CO ₂	1.35	t
			NH ₃	0.42	kg
			Emissions to air from loader		
			CO	0.17	g
			CH ₄	0.01	g
			NO _x	0.81	g
			CO ₂	0.08	
			VOC	0.04	g
			PM	0.02	g

Waste		
Wastewater treatment		
Leachate	0.01	m ³

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