

Supplementary Materials: A Life Cycle Assessment of Silica Sand: Comparing the Beneficiation Processes

Anamarija Grbeš

Table S1. SIEVING, WASHING, SIZING OF THE RAW SILICA SAND

UNIT	INPUT	Unit	Amount	FROM
A-1	1. Raw silica sand	t/year	150,000.00	technosphere
	2. Diesel	t/year	13.6	technosphere
	3. Hydraulic oil	t/year	1	technosphere
	4. Motor oil	t/year	1	technosphere
	5. Grease	t/year	0.15	technosphere
	6. Tyres	t/year	0.219	technosphere
	OUTPUT	Unit	Amount	IN
	1. Raw silica sand	t/year	150,000.00	Proces 2
	2. Internal combustion motor-emission		x	nature (air)
	3. Hydrocarbons emission		x	nature (soil)
A-2	4. Noise		x	nature (air)
	5. Waste for treatment (Tyres)	t/year	0.219	technosphere
	INPUT	Unit	Amount	FROM
	1. Raw silica sand	t/year	150,000.00	process A-1
	2. Electricity	kWh/god	14,150.00	technosphere
	OUTPUT	Unit	Amount	IN
	1. Raw silica sand	t/year	150,000.00	process A-3
	INPUT	Unit	Amount	FROM
	1. Raw silica sand	t/year	150,000.00	process A-2
	2. Electricity	kWh/god	21,225.00	technosphere
A-3	OUTPUT	Unit	Amount	IN
	1. Raw silica sand	t/year	150,000.00	process A-4
	INPUT	Unit	Amount	FROM
	1. Raw silica sand	t/year	150,000.00	process A-3
	2. Electricity	kWh/god	31,413.00	technosphere
	OUTPUT	Unit	Amount	IN
	1. Passing P1 (95%)	t/year	142,500.00	process A-5
	2. Rejected O1 (5%)	t/year	7500.00	process A-8
	INPUT	Unit	Amount	FROM
	1. Passing P1 vibratory sieve	t/year	142,500.00	process A-4
A-4	2. Water	t/year	490,833.33	from nature
	3. Electricity	kWh	79,000.00	technosphere
	OUTPUT	Unit	Amount	IN
	1. Suspension S1	t/year	633,333.33	process A-6
	1.1. P1, suspended S1, 22%	t/year	142,500.00	
	1.2. Water in suspension S1	t/year	490,833.33	
	INPUT	Unit	Amount	FROM
	1. Suspension S1	t/year	633,333.33	process A-5
	1.1. P1, suspended S1, 22.5%	t/year	142,500.00	
	1.2. Water in suspension S1, 87.5%	t/year	490,833.33	
A-5	2. Electricity	kWh/god	9796.88	technosphere
	OUTPUT	Unit	Amount	IN
	1. Suspension S2	t/year	633,333.33	process A-7
	1.1. P1, suspended S1, 22%	t/year	142,500.00	
	1.2. Water in suspension S2	t/year	490,833.33	
	INPUT	Unit	Amount	FROM
	1. Suspension S2	t/year	633,333.33	process A-6
	1.1. P1, suspended S1, 22%	t/year	142,500.00	
	1.2. Water in suspension S2	t/year	490,833.33	
	INPUT	Unit	Amount	FROM
A-6	1. Suspension S2	t/year	633,333.33	process A-6
	1.1. P1, suspended S1, 22%	t/year	142,500.00	

A-8	1.2.	Water in suspension S2	t/year	490,833.33	
	2.	Electricity	kWh/god	10,555.90	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Rejected O2	t/year	18,750.00	process A-8
	1.1.	Minerals in O2, class +0.8mm (80%)	t/year	15,000.00	
	1.2.	Water in Rejected O2 (20%)	t/year	3750.00	
	2.	Suspension S3 (20% solids)	t/year	614,583.33	process A-9
	2.1.	Passing P2 (-0.8mm), suspended S3 (20%)	t/year	127,500.00	
	2.2.	Water in suspension S3 (80%)	t/year	487,083.33	
		INPUT	Unit	Amount	FROM
	1.	Rejected O1	t/year	7500.00	process A-4
	2.	Rejected O2 (+0.8mm)	t/year	18,750.00	process A-7
	2.1.	Minerals u O2	t/year	15,000.00	
	2.2.	Water in Rejected O2 (20%)	t/year	3750.00	
A-9	3.	Electricity	kWh/god	21,225.00	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Temporary disposed oversize	t/year	26,250.00	technosphere
	1.1.	Minerals O1+O2	t/year	22,500.00	
	1.2.	Water in Rejected O2	t/year	3750.00	
		INPUT	Unit	Amount	FROM
	1.	Suspension S3 (20% solids)	t/year	614,583.33	process A-7
	1.1.	Passing P2 (-0,8mm), suspended S3 (20%)	t/year	127,500.00	
	1.2.	Water in suspension S3 (80%)	t/year	487,083.33	
	2.	Electricity	kWh/god	70,750.00	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Suspension S4	t/year	460,297.62	process A-10
	1.1.	Class 0.1mm, suspended	t/year	19,500.00	
	1.2.	Water, suspended S4	t/year	440,797.62	
A-10	2.	Pulp S5 (70%solids 0.8/0.1 mm)	t/year	154,285.71	process A-11
	2.1.	Water, in pulp S5	t/year	46,285.71	
	2.2.	Minerals, class 0.8/0.1 in pulp (70%)	t/year	108,000.00	
		INPUT	Unit	Amount	FROM
	1.	Suspension S4	t/year	460,297.62	process A-9
	1.1.	Class 0.1mm, suspended	t/year	19,500.00	
	1.2.	Water, suspended S4	t/year	440,797.62	
		OUTPUT	Unit	Amount	IN
	1.	Class 0.1mm, sedimented	t/year	19,500.00	nature
	2.	Water	t/year	440,797.62	nature
		INPUT	Unit	Amount	FROM
	1.	Pulp S5 (70%solids 0.8/0.1 mm)	t/year	154,285.71	process A-9
	1.1.	Minerals, class 0.8/0.1 in pulp (70%)	t/year	108,000.00	
	1.2.	Water in pulp S5 (30%)	t/year	46,285.71	
A-11	2.	Electricity	kWh/god	84,900.00	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Pulp S5 (70%solids 0.8/0.1 mm), attrited	t/year	154,285.71	process A-12
	1.1.	Minerals, class 0.8/0.1 in pulp	t/year	107,430.00	
	1.2.	Minerals, class -0.1 mm (liberated)	t/year	570	
	1.3.	Water in pulp S5 (30%)	t/year	46,285.71	
		INPUT	Unit	Amount	FROM
	1.	Pulp S5 (70%solids 0.8/0.1 mm), attrited	t/year	154,285.71	process A-11
	1.1.	Minerals, class 0.8/0.1 in pulp	t/year	107,430.00	
	1.2.	Minerals, class -0.1 mm (liberated)	t/year	570	
	1.3.	Water in pulp S5 (30%)	t/year	46,285.71	
	2.	Water for sizing	t/year	114,000.00	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Overflow S6 (1.1% solids)	t/year	53,425.71	process A-13
A-12					

A-13	1.1.	Water	t/year	52,855.71	
	1.2.	Organics (0.38%)	t/year	2,174	
	1.3.	Minerals, class -0,1 mm	t/year	567,826	
	2.	Overflow S7 (50% solids)	t/year	214,860.00	process A-14
	2.1.	Water		107,430.00	
	2.2.	Minerals class 0.8/0.1 mm		107,430.00	
		INPUT	Unit	Amount	FROM
	1.	Suspension S6	t/year	53,425.71	process A-12
	1.1.	Class -0.1mm, suspended	t/year	570	
	1.2.	Water, suspended S6	t/year	52,855.71	
A-14		OUTPUT	Unit	Amount	IN
	1.	Class 0.1mm, sediment	t/year	570	nature
	2.	Water	t/year	52,855.71	nature
		INPUT	Unit	Amount	FROM
	1.	Overflow S7	t/year	214,860.00	process A-12
	1.1.	Water	t/year	107,430.00	
	1.2.	Minerals class 0.8/0.1 mm	t/year	107,430.00	
		OUTPUT	Unit	Amount	IN
	1.	Rejected O3 (80% solids)	t/year	134,287.50	process A-15
	1.1.	Water	t/year	26,857.50	
A-15	1.2.	Minerals class 0.8/0.1 mm	t/year	107,430.00	
	2.	Passing P3	t/year	80,572.50	process A-9
		INPUT	Unit	Amount	FROM
	1.	Rejected O3 (80% solids)	t/year	134,287.50	process A-14
	1.1.	Water	t/year	26,857.50	
	1.2.	Minerals class 0.8/0.1 mm	t/year	107,430.00	
	2.	Electricity	kWh/god	39,000.00	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Washed sand, w < 6%, class 0.8/0.1 mm	t/year	114,287.23	technosphere
	1.1.	Washed sand, solids, class 0.8/0.1 mm	t/year	107,430.00	
	1.2.	Water in washed sand (6%)	t/year	6857.23	
	2.	Water-drained 60%	t/year	12,000.16	nature (underground water)
	3.	Water loss (evaporation, soil retention)40%	t/year	8000.11	nature (air)

Table S2. ELECTROSTATIC CONCENTRATION.

UNIT		INPUT	Unit	Amount	FROM
B-1	1.	Washed sand, w<6%, class 0.8/0.1 mm	t/year	114,287.23	process A-15
	1.1.	Washed sand, solids, class 0.8/0.1 mm	t/year	107,430.00	
	1.2.	Water in washed sand (6%)	t/year	6857.23	
	2.	Electricity	kWh/year	76,200.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Washed sand, w < 6%, class 0.8/0.1 mm	t/year	114,287.23	process B-2
	1.1.	Washed sand, solids, class 0.8/0.1 mm	t/year	107,430.00	
	1.2.	Water in washed sand (6%)	t/year	6857.23	
		INPUT	Unit	Amount	FROM
	1.	Washed sand, w < 6%, class 0.8/0.1 mm	t/year	114,287.23	process B-1
B-2	1.1.	Washed sand, solids, class 0.8/0.1 mm	t/year	107,430.00	
	1.2.	Water in washed sand (6%)	t/year	6857.23	
	3.	Electricity	kWh/year	14,150.00	technosphere

	4.	Fuel oil	t/year	268,575	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Dried sand, solids, class 0.8/0.1 mm	t/year	107,430.00	process B-3
	2.	Water in washed sand (6%)	t/year	6857.23	process B-4
	3.	Dust	t/year	400	process B-4
		INPUT	Unit	Amount	FROM
	1.	Dried sand, solids, class 0.8/0.1 mm	t/year	107,430.00	process B-2
	2.	Solution HF (l), 70%–75%	t/year	45,121	technosphere
	2.1.	HF (l)	t/year	32,712	
	2.1.1.	Total fluorine	t/year	31,077	
	2.2.	Water in acid	t/year	12,408	
		OUTPUT	Unit	Amount	IN
	1.	Conditioned sand, solids class 0.8/0.1mm	t/year	107,048.48	process B-4
	1.1.	Dried sand, solids, class 0.8/0.1 mm	t/year	107,030.00	
B-3	1.2.	F, adsorbed on quartz grains in form of H ₂ SiF ₆	t/year	18,478	
	2.	Waste gases and fumes	t/year	12,825.74	process B-4
	2.1.	HF (g)	t/year	13,085	
	2.1.1.	Total fluorine	t/year	12,599	
	2.1.2.	H+ ioni	t/year	0.486	
	2.2.	Air	t/year	12,400.08	
	2.3.	Water fume	t/year	12,408	
	2.4.	Conditioned silica dust (flour)	t/year	400,168	
	2.4.1.	Silica flour	t/year	400	
	2.4.2.	F, adsorbed on quartz grains in form of H ₂ SiF ₆	t/year	0.168	
		INPUT	Unit	Amount	FROM
	1.	Waste gases and fumes	t/year	12,825.74	process B-3
	1.1.	HF (g)	t/year	13,085	
	1.1.1.	Total fluorine	t/year	12,599	
	1.1.2.	H+ ioni	t/year	0.486	
	1.2.	Air	t/year	12,400.08	
	1.3.	Water fume	t/year	12,408	
	1.4.	Conditioned silica dust (flour)	t/year	400,168	
	1.4.1.	Silica flour	t/year	400	
	1.4.2.	F, adsorbed on quartz grains in form of H ₂ SiF ₆	t/year	0.168	
B-4	2.	Electricity for air supply	kWh/year	32,670.00	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Waste gases and fumes	t/year	12,825.74	process B-5
	1.1.	HF (g)	t/year	13,085	
	1.1.1.	Total fluorine	t/year	12,599	
	1.1.2.	H+ ioni	t/year	0.486	
	1.3.	Air	t/year	12,400.08	
	1.4.	Water fume	t/year	12,408	
	2.	Conditioned silica dust (flour)	t/year	400,168	process B-12
	2.1.	Silica flour	t/year	400	
	2.2.	F, adsorbed on quartz grains in form of H ₂ SiF ₆	t/year	0.168	
B-5		INPUT	Unit	Amount	FROM

	1.	Waste gases and fumes	t/year	12,825.74	process B-4
	1.1.	HF (g)	t/year	13,085	
	1.1.1.	Total fluorine	t/year	12,599	
	1.1.2.	H+ ioni	t/year	0.486	
	1.3.	Air	t/year	12,400.08	
	1.4.	Water fume	t/year	12,408	
	2.	Water (minimal)	t/year	3149.68	technosphere
	3.	Electricity	kWh/year	32,452.20	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Water onečišćena fluorom	t/year	3175.05	process B-6
	1.1.	Water	t/year	3162.09	process B-6
	1.2.	Total fluorine	t/year	12,473	process B-6
	1.3.	H+ ioni	t/year	0.486	process B-6
	2.	Cleaned air	t/year	12,400.21	nature (Air)
	1.1.	Air	t/year	12,400.08	nature (Air)
	1.4.	Fluor <1%	t/year	0.126	nature (Air)
		INPUT	Unit	Amount	FROM
	1.	Water with stripped fluorine	t/year	3175.05	process B-5
	1.1.	Water	t/year	3162.09	
	1.2.	Total fluorine	t/year	12,473	
	1.3.	H+ ioni	t/year	0.486	
	2.	Lime	t/year	21,921	technosphere
	2.1.	Ca ²⁺ in lime	t/year	11,849	
	2.2.	OH ⁻ in lime	t/year	10,072	
B-6	2.3.	H+ required for neutralisation	t/year	0.629	
	3.	Balance H+/OH ⁻	t/year	-0.143	calculation
	4.	HCl for neutralisation	t/year	2,578	technosphere
	4.1.	H+ ions	t/year	0.143	
	4.2.	Cl ⁻ ions	t/year	2,435	
		OUTPUT	Unit	Amount	IN
	1.	CaF ₂ suspension	t/year	3199.55	process B-6
	1.1.	CaF ₂ suspended	t/year	24,322	
	1.2.	Water in suspension	t/year	3172.79	
	1.3.	Cl ⁻ ions	t/year	2,435	
		INPUT	Unit	Amount	FROM
	1.	CaF ₂ suspension	t/year	3199.55	process B-8
	1.1.	CaF ₂ suspended	t/year	24,322	
	1.2.	Water in suspension	t/year	3172.79	
	1.3.	Cl ⁻ ions	t/year	2,435	
B-7	2.	Electricity	kWh/year	7,322	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Filter cake (inert CaF ₂)	t/year	26,757	process B-12
	1.1.	CaF ₂ in filtercake	t/year	24,322	
	1.2.	Water in filtercake	t/year	2,435	
	2.	Water	t/year	3170.36	technosphere
		INPUT	Unit	Amount	FROM
	1.	Conditioned sand, solids class 0.8/0.1mm	t/year	107,048.48	process B-3
B-8	1.1.	Dried sand, solids, class 0.8/0.1 mm	t/year	107,030.00	
	1.1.1.	Quartz (silica), 87%	t/year	93,116.10	
	1.1.2.	Feldspar, 13%	t/year	13,913.90	
	1.2.	F, adsorbed on quartz grains in form of	t/year	18,478	

		H2SiF6			
	2.	Electricity	kWh/year	39,251.11	technosphere
		OUTPUT	Unit	Amount	IN
	1.	Silica sand concentrate, solids class 0.8/0.1mm	t/year	93,940.59	process B-9
	1.1.	Silica, 98%	t/year	92,045.89	
	1.2.	Feldspar, 2%	t/year	1878.49	
	1.3.	F, adsorbiran na zrna u obliku H2SiF6	t/year	16,218	
	2.	Feldspar concentrate, solids class 0.8/0.1mm	t/year	13,091.67	process B-10
	2.1.	Feldspar, 90%	t/year	11,780.47	
	2.2.	Silica, 10%	t/year	1308.94	
	2.3.	F, adsorbiran na zrna u obliku H2SiF6	t/year	2.26	
		INPUT	Unit	Amount	FROM
	1.	Silica sand concentrate, solids class 0.8/0.1mm	t/year	93,940.59	process B-8
	1.1.	Silica, 98%	t/year	92,045.89	
	1.2.	Feldspar, 2%	t/year	1878.49	
	1.3.	F, adsorbed on quartz grains in form of H2SiF6	t/year	16,218	
	2.	Air for dedusting	t/year	51,000.00	process B-8
	3.	Electricity	kWh/year	21,960.00	technosphere
B-9	3.1.	Electricity (magnetic separator)	kWh/year	6960.00	
	3.2.	Electricity (elevator)	kWh/year	15,000.00	
		OUTPUT	Unit	Amount	IN
	1.	Silica sand concentrate, solids class 0.8/0.1mm	t/year	93,845.71	technosphere
	1.1.	Silica, 98%	t/year	91,952.92	
	1.2.	Feldspar, 2%	t/year	1876.59	
	1.3.	F, adsorbed on quartz grains in form of H2SiF6	t/year	16,202	
	2.	Dust	t/year	0.939	process B-12
	3.	Magnetics concentrate	t/year	93,941	process B-11
		INPUT	Unit	Amount	FROM
	1.	Feldspar concentrate, solids class 0.8/0.1mm	t/year	13,091.67	process B-8
	1.1.	Feldspar, 90%	t/year	11,780.47	
	1.2.	Silica, 10%	t/year	1308.94	
	1.3.	F, adsorbed on quartz grains in form of H2SiF6	t/year	2.26	
	2.	Electricity	kWh/year	18,000.00	technosphere
	2.1.	Electricity (magnetski separator)	kWh/year	3000.00	
B-10	2.2.	Electricity (elevator)	kWh/year	15,000.00	
		OUTPUT	Unit	Amount	IN
	1.	Feldspar concentrate, solids class 0.8/0.1mm	t/year	13,078.45	technosphere
	1.1.	Feldspar, 90%	t/year	11,768.57	
	1.2.	Silica, 10%	t/year	1307.62	
	1.3.	F, adsorbed on quartz grains in form of H2SiF6	t/year	2,258	
	2.	Dust	t/year	0.131	process B-12
	3.	Magnetics concentrate	t/year	11.78	process B-11
		INPUT	Unit	Amount	FROM
	1.	Magnetics concentrate	t/year	93,941	process B-9
B-11	2.	Magnetics concentrate	t/year	11.78	process B-10
	3.	Electricity	kWh/year	15,000.00	technosphere
		OUTPUT	Unit	Amount	IN

	1.	Magnetični produkt	t/year	105,721	technosphere
		INPUT	Unit	Amount	FROM
	1.	Dust	t/year	401,107	from process B-11
	2.	Filter cake (inert CaF ₂)	t/year	26,757	
	2.1.	CaF ₂	t/year	24,322	
	2.2.	Water	t/year	2,435	
B-12	4.	Diesel	t/year	0.6	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Intert mineral material disposed nature	t/year	454,621	nature
	1.1.	Dust	t/year	401,107	
	1.2.	Filter cake (inert CaF ₂)	t/year	26,757	
	1.3.	CaF ₂	t/year	24,322	
	1.4.	Water	t/year	2,435	

Table S3. FLOTATION.

UNIT		INPUT	Unit	Amount	FROM
	1.	Washed sand, w < 6%, class 0.8/0.1 mm	t/year	114,287.23	from process A-15
	1.1.	Washed sand, solids, class 0.8/0.1 mm	t/year	107,430.00	
	1.2.	Water in washed sand (6%)	t/year	6857.23	
	2.	Water	t/year	64,762.77	from technosphere
	3.	H ₂ SO ₄ , 98%	t/year	3,581	from technosphere
	3.1.	H ₂ SO ₄ , 100%	t/year	3,509	
C-1	3.2.	H ₂ O, 100%	t/year	0.072	
	4.	Electricity	kWh/year	66,000.00	from technosphere
	4.1.	Electricity-pumpa	kWh/year	44,000.00	
	4.2.	Electricity-agitator	kWh/year	22,000.00	
		OUTPUT	Unit	Amount	IN
	1.	Conditioned pulp	t/year	179,053.58	process C-2
	1.1.	Sand	t/year	107,430.00	
	1.2.	Water	t/year	71,620.07	
	1.3.	Acid	t/year	3,509	
		INPUT	Unit	Amount	FROM
	1.	Conditioned pulp	t/year	179,053.58	from process C-1
	1.1.	Sand	t/year	107,430.00	
	1.2.	Water	t/year	71,620.07	
	1.3.	Acid	t/year	3,509	
	2.	Water	t/year	250,669.93	from technosphere
C-2	3.	Tallow amine	t/year	40,286	from technosphere
	4.	Fuel oil	t/year	28.2	from technosphere
	5.	Electricity	kWh/year	22,000.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Overflow-1	t/year	21,547.99	process C-10
	1.1.	Sand	t/year	5371.50	
	1.2.	Water	t/year	16,114.50	
	1.3.	Acid	t/year	0.351	

	1.4.	Tallow amine	t/year	36,258	
	1.5.	Fuel oil	t/year	25,38	
	2.	Underflow-1	t/year	408,244.01	process C-3
	2.1.	Sand	t/year	102,058.50	
	2.2.	Water	t/year	306,175.50	
	2.3.	Acid	t/year	3,334	
	2.4.	Tallow amine	t/year	4,029	
	2.5.	Fuel oil	t/year	2.82	
	3.	Electricity	kWh/year	22,000.00	from technosphere
		INPUT	Unit	Amount	FROM
	1.	Underflow-1	t/year	408,244.01	from process C-2
	1.1.	Sand	t/year	102,058.50	
	1.2.	Water with flotation reagents	t/year	306,185.68	
	1.2.1.	Water	t/year	306,175.50	
	1.2.2.	Acid	t/year	3,334	
	1.2.3.	Tallow amine	t/year	4,029	
	1.2.4.	Fuel oil	t/year	2.82	
		OUTPUT	Unit	Amount	IN
C-3	1.	Thickened Underflow-1	t/year	170,097.50	process C-4
	1.1.	Sand	t/year	102,058.50	
	1.2.	Water, with flotation reagents	t/year	68,039.00	
	1.2.1.	Water	t/year	68,036.74	
	1.2.2.	Acid	t/year	0.741	
	1.2.3.	Tallow amine	t/year	0.895	
	1.2.4.	Fuel oil	t/year	0.627	
	2.	Water with flotation reagents	t/year	238,136.50	technosphere*
	2.1.	Water	t/year	238,138.76	
	2.2.	Acid	t/year	2,593	
	2.3.	Tallow amine	t/year	3,133	
	2.4.	Fuel oil	t/year	2,193	
		INPUT	Unit	Amount	FROM
	1.	Thickened Underflow-1	t/year	170,097.50	from process C-3
	1.1.	Sand	t/year	102,058.50	
	1.2.	Water, with flotation reagents	t/year	68,039.00	
	1.3.	Water	t/year	68,036.74	
	1.4.	Acid	t/year	0.741	
	1.5.	Tallow amine	t/year	0.895	
	1.6.	Fuel oil	t/year	2,193	
	2.	H2SO4, 98%	t/year	2,646	from technosphere
C-4	2.1.	H2SO4, 100%	t/year	2,593	
	2.2.	H2O, 100%	t/year	0.053	
	3.	Electricity	kWh/year	22,000.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Thickened Underflow-1	t/year	170,099.52	process C-5
	1.1.	Sand	t/year	102,058.50	
	1.2.	Water, with flotation reagents	t/year	68,041.02	
	1.2.1.	Water	t/year	68,036.79	
	1.2.2.	Acid	t/year	3,334	
	1.2.3.	Tallow amine	t/year	0.895	
	1.2.4.	Fuel oil	t/year	2,193	
		INPUT	Unit	Amount	FROM
C-5	1.	Thickened Underflow-1	t/year	170,099.52	from process C-4

	1.1.	Sand	t/year	102,058.50	
	1.2.	Water, with flotation reagents	t/year	68,041.02	
	1.2.1.	Water	t/year	68,036.79	
	1.2.2.	Acid	t/year	3,334	
	1.2.3.	Tallow amine	t/year	0.895	
	1.2.4.	Fuel oil	t/year	2,193	
	2.	Water	t/year	238,134.48	from technosphere
	3.	Anionic collector Aero 855	t/year	26.79	from technosphere
	4.	Electricity	kWh/year	22,000.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Overflow-2	t/year	40,847.73	PROCESS C-11
	1.1.	Sand	t/year	10,205.85	
	1.2.	Water, with flotation reagents	t/year	30,641.88	
	1.2.1.	Water	t/year	30,617.13	
	1.2.2.	Acid	t/year	0.333	
	1.2.3.	Tallow aminee	t/year	0.09	
	1.2.4.	Anionic collector Aero 855	t/year	24,111	
	1.2.5.	Fuel oil	t/year	0.219	
	2.	Underflow-2	t/year	642,975.66	process C-6
	2.1.	Sand	t/year	91,852.65	
	2.2.	Water, with flotation reagents	t/year	275,560.41	
	2.2.1.	Water	t/year	275,554.14	
	2.2.2.	Acid	t/year	3	
	2.2.3.	Tallow amine	t/year	0.806	
	2.2.4.	Anionic collector Aero 855	t/year	2,679	
	2.2.5.	Fuel oil	t/year	1,974	
		INPUT	Unit	Amount	FROM
	1.	Underflow-2	t/year	642,975.66	from process C-5
	1.1.	Sand	t/year	91,852.65	
	1.2.	Water, with flotation reagents	t/year	275,560.41	
	1.2.1.	Water	t/year	275,554.14	
	1.2.2.	Acid	t/year	3	
	1.2.3.	Tallow amine	t/year	0.806	
	1.2.4.	Anionic collector Aero 855	t/year	2,679	
	1.2.5.	Fuel oil	t/year	1,974	
		OUTPUT	Unit	Amount	IN
	1.	Thickened Underflow-2	t/year	153,087.75	process C-7
C-6	1.1.	Sand	t/year	91,852.65	
	1.2.	Water, with flotation reagents	t/year	61,235.10	
	1.3.	Water	t/year	61,233.71	
	1.4.	Acid	t/year	0.667	
	1.5.	Tallow amine	t/year	0.179	
	1.6.	Anionic collector Aero 855	t/year	0.595	
	1.7.	Fuel oil	t/year	0.439	
	2.	Water with flotation reagents	t/year	214,325.31	technosphere*
	2.1.	Water	t/year	214,320.44	
	2.2.	Acid	t/year	2,334	
	2.3.	Tallow amine	t/year	0.627	
	2.4.	Anionic collector Aero 855	t/year	2,084	
	2.5.	Fuel oil	t/year	1,535	
		INPUT	Unit	Amount	FROM
C-7	1.	Thickened Underflow-2	t/year	153,087.75	from process C-6
	1.1.	Sand	t/year	91,852.65	

	1.2.	Water, with flotation reagents	t/year	61,235.10	
	1.3.	Water	t/year	61,233.71	
	1.4.	Acid	t/year	0.667	
	1.5.	Tallow amine	t/year	0.179	
	1.6.	Anionic collector Aero 855	t/year	0.595	
	1.7.	Fuel oil	t/year	0.439	
	2.	H2SO4, 98%	t/year	2,381	from technosphere
	2.1.	H2SO4, 100%	t/year	2,334	
	2.2.	H2O, 100%	t/year	0.048	
	3.	Electricity	kWh/year	22,000.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Thickened Underflow-2	t/year	153,090.62	process C-8
	1.1.	Sand	t/year	91,852.65	
	1.2.	Water, with flotation reagents	t/year	61,237.97	
	1.2.1.	Water	t/year	61,233.76	
	1.2.2.	Acid	t/year	3	
	1.2.3.	Tallow amine	t/year	0.179	
	1.2.4.	Anionic collector Aero 855	t/year	0.595	
	1.2.5.	Fuel oil	t/year	0.439	
		INPUT	Unit	Amount	FROM
	1.	Thickened Underflow-2	t/year	153,090.62	from process C-7
	1.1.	Sand	t/year	91,852.65	
	1.2.	Water, with flotation reagents	t/year	61,237.97	
	1.2.1.	Water	t/year	61,233.76	
	1.2.2.	Acid	t/year	3	
	1.2.3.	Tallow amine	t/year	0.179	
	1.2.4.	Anionic collector Aero 855	t/year	0.595	
	1.2.5.	Fuel oil	t/year	0.439	
	2.	Water	t/year	214,319.98	from technosphere
	3.	HF,70%	t/year	75.45	from technosphere
	3.1.	HF,100%	t/year	52,815	
	3.2.	H2O	t/year	22,635	
	4.	Fuel oil	t/year	23,673	from technosphere
C-8	5.	Electricity	kWh/year	22,000.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Overflow-3	t/year	73,505.85	PROCESS C-12
	1.1.	Sand	t/year	18,370.53	
	1.2.	Water, with flotation reagents	t/year	55,135.32	
	1.2.1.	Water	t/year	55,115.27	
	1.2.2.	Acid	t/year	0.6	
	1.2.3.	Tallow amine	t/year	0.036	
	1.2.4.	Anionic collector Aero 855	t/year	0.119	
	1.2.5.	Fuel oil	t/year	19,289	
	2.	Underflow	t/year	293,951.06	process C-9
	2.1.	Sand	t/year	73,482.12	
	2.2.	Water, with flotation reagents	t/year	220,468.94	
	2.2.1.	Water	t/year	220,461,10	
	2.2.2.	Acid	t/year	2.4	
	2.2.3.	Tallow amine	t/year	0.143	
	2.2.4.	Anionic collector Aero 855	t/year	0.476	
	2.2.5.	Fuel oil	t/year	4,822	

		INPUT	Unit	Amount	FROM
	1.	Underflow-3	t/year	293,951.06	from process C-8
	1.1.	Sand	t/year	73,482.12	
	1.2.	Water, with flotation reagents	t/year	220,468.94	
	1.2.1.	Water	t/year	220,461.10	
	1.2.2.	Acid	t/year	2.4	
	1.2.3.	Tallow amine	t/year	0.143	
	1.2.4.	Anionic collector Aero 855	t/year	0.476	
	1.2.5.	Fuel oil	t/year	4,822	
		OUTPUT	Unit	Amount	IN
	1.	Thickened Underflow-3	t/year	122,470.20	process C-13
C-9	1.1.	Sand	t/year	73,482.12	
	1.2.	Water, with flotation reagents	t/year	48,988.08	
	1.2.1.	Water	t/year	48,986.34	
	1.2.2.	Acid	t/year	0.533	
	1.2.3.	Tallow amine	t/year	0.032	
	1.2.4.	Anionic collector Aero 855	t/year	0.106	
	1.2.5.	Fuel oil	t/year	1,072	
	2.	Water with flotation reagents	t/year	171,480.86	process C-12
	2.1.	Water	t/year	171,474.76	
	2.2.	Acid	t/year	1,867	
	2.3.	Tallow amine	t/year	0.111	
	2.4.	Anionic collector Aero 855	t/year	0.37	
	2.5.	Fuel oil	t/year	3,751	
		INPUT	Unit	Amount	FROM
	1.	Overflow-1	t/year	21,547.99	from process C-2
	1.1.	Sand	t/year	5371.50	
	1.2.	Water with flotation reagents	t/year	16,176.49	
	1.2.1.	Water	t/year	16,114.50	
	1.2.2.	Acid	t/year	0.351	
	1.2.3.	Tallow amine	t/year	36,258	
	1.2.4.	Fuel oil	t/year	25.38	
		OUTPUT	Unit	Amount	IN
	1.	Thickened Overflow-1	t/year	8952.50	process C-14
C-10	1.1.	Sand	t/year	5371.50	
	1.2.	Water, with flotation reagents	t/year	3581.00	
	1.2.1.	Water	t/year	3567.28	
	1.2.2.	Acid	t/year	0.078	
	1.2.3.	Tallow amine	t/year	8,026	
	1.2.4.	Fuel oil	t/year	5,618	
	2.	Water with flotation reagents	t/year	12,595.49	process C-15
	2.1.	Water	t/year	12,547.22	
	2.2.	Acid	t/year	0.273	
	2.3.	Tallow amine	t/year	28,231	
	2.5.	Fuel oil	t/year	19,762	
		INPUT	Unit	Amount	FROM
	1.	Overflow-2	t/year	40,847.73	from process C-5
	1.1.	Sand	t/year	10,205.85	
	1.2.	Water, with flotation reagents	t/year	30,641.88	
C-11	1.2.1.	Water	t/year	30,617.13	
	1.2.2.	Acid	t/year	0.333	
	1.2.3.	Tallow amine	t/year	0.09	
	1.2.4.	Anionic collector Aero 855	t/year	24,111	
	1.2.5.	Fuel oil	t/year	0.219	
		OUTPUT	Unit	Amount	IN

	1.	Thickened Overflow-2	t/year	17,009.75	process C-14
	1.1.	Sand	t/year	10,205.85	
	1.2.	Water, with flotation reagents	t/year	6803.90	
	1.2.1.	Water	t/year	6798.40	
	1.2.2.	Acid	t/year	0.074	
	1.2.3.	Tallow amine	t/year	0.02	
	1.2.4.	Anionic collector Aero 855	t/year	5,354	
	1.2.5.	Fuel oil	t/year	0.049	
	2.	Water, with flotation reagents	t/year	23,837.98	process C-15
	2.1.	Water	t/year	23,818.72	
	2.2.	Acid	t/year	0.259	
	2.3.	Tallow amine	t/year	0.07	
	2.4.	Anionic collector Aero 855	t/year	18,758	
	2.5.	Fuel oil	t/year	0.171	
		INPUT	Unit	Amount	FROM
	1.	Overflow-3	t/year	73,505.85	from process C-8
	1.1.	Sand	t/year	18,370.53	
	1.2.	Water, with flotation reagents	t/year	55,135.32	
	1.2.1.	Water	t/year	55,115.27	
	1.2.2.	Acid	t/year	0.6	
	1.2.3.	Tallow amine	t/year	0.036	
	1.2.4.	Anionic collector Aero 855	t/year	0.119	
	1.2.5.	Fuel oil	t/year	19,289	
		OUTPUT	Unit	Amount	IN
C-12	1.	Thickened Overflow-3	t/year	30,617.55	process C-14
	1.1.	Sand	t/year	18,370.53	
	1.2.	Water, with flotation reagents	t/year	12,247.02	
	1.2.1.	Water	t/year	12,242.57	
	1.2.2.	Acid	t/year	0.133	
	1.2.3.	Tallow amine	t/year	0.008	
	1.2.4.	Anionic collector Aero 855	t/year	0.026	
	1.2.5.	Fuel oil	t/year	4,285	
	2.	Water, with flotation reagents	t/year	42,888.30	process C-15
	2.1.	Water	t/year	42,872.71	
	2.2.	Acid	t/year	0.467	
	2.3.	Tallow amine	t/year	0.028	
	2.4.	Anionic collector Aero 855	t/year	0.093	
	2.5.	Fuel oil	t/year	15,004	
		INPUT	Unit	Amount	FROM
C-13	1.	Thickened Underflow-3	t/year	122,470.20	from process C-8
	1.1.	Sand	t/year	73,482.12	
	1.2.	Water, with flotation reagents	t/year	48,988.08	
	1.2.1.	Water	t/year	48,986.34	
	1.2.2.	Acid	t/year	0.533	
	1.2.3.	Tallow amine	t/year	0.032	
	1.2.4.	Anionic collector Aero 855	t/year	0.106	
	1.2.5.	Fuel oil	t/year	1,072	
		OUTPUT	Unit	Amount	IN
	1.	Glass grade silica sand, w < 10%	t/year	81,646.80	technosphere
	1.1.	Sand	t/year	73,482.12	
	1.2.	Water, with flotation reagents	t/year	8164.68	
	1.2.1.	Water	t/year	4898.63	
	1.2.2.	Acid	t/year	0.053	
	1.2.3.	Tallow amine	t/year	0.003	
	1.2.4.	Anionic collector Aero 855	t/year	0.011	
	1.2.5.	Fuel oil	t/year	0.107	

C-14	2.	Water, with flotation reagents	t/year	44,089.27	process C-15
	2.1.	Water	t/year	44,087.70	
	2.2.	Acid	t/year	0.48	
	2.3.	Tallow amine	t/year	0.029	
	2.4.	Anionic collector Aero 855	t/year	0.095	
	2.5.	Fuel oil	t/year	0.964	
		INPUT	Unit	Amount	FROM
	1.	Thickened Overflow-1	t/year	8952.50	from process C-10
	1.1.	Sand	t/year	5371.50	
	1.2.	Water, with flotation reagents	t/year	3581.00	
	1.2.1.	Water	t/year	3567.28	
	1.2.2.	Acid	t/year	0.078	
	1.2.3.	Tallow amine	t/year	8,026	
	1.2.4.	Fuel oil	t/year	5,618	
	2.	Thickened Overflow-2	t/year	17,009.75	from process C-11
	2.1.	Sand	t/year	10,205.85	
	2.2.	Water, with flotation reagents	t/year	6803.90	
	2.2.1.	Water	t/year	6798.40	
	2.2.2.	Acid	t/year	0.074	
	2.2.3.	Tallow amine	t/year	0.02	
	2.2.4.	Anionic collector Aero 855	t/year	5,354	
	2.2.5.	Fuel oil	t/year	0.049	
	3.	Thickened Overflow-3	t/year	30,617.55	from process C-12
	3.1.	Sand	t/year	18,370.53	
	3.2.	Water, with flotation reagents	t/year	12,247.02	
	3.2.1.	Water	t/year	12,242.57	
	3.2.2.	Acid	t/year	0.133	
	3.2.3.	Tallow amine	t/year	0.008	
	3.2.4.	Anionic collector Aero 855	t/year	0,026	
	3.2.5.	Fuel oil	t/year	4,285	
		OUTPUT	Unit	Amount	IN
	1.	Muscovite concentrate, w < 10%	t/year	6087.70	technosphere
	1.1.	Sand	t/year	5371.50	
	1.2.	Water, with flotation reagents	t/year	358.1	
	1.2.1.	Water	t/year	356,728	
	1.2.2.	Acid	t/year	0.008	
	1.2.3.	Tallow amine	t/year	0.803	
	1.2.4.	Fuel oil	t/year	0.562	
	2.	Heavy minerals concentrate, w < 10%	t/year	11,566.63	technosphere
	2.1.	Sand	t/year	10,205.85	
	2.2.	Water, with flotation reagents	t/year	680.39	
	2.2.1.	Water	t/year	679.84	
	2.2.2.	Acid	t/year	0.007	
	2.2.3.	Tallow amine	t/year	0.002	
	2.2.4.	Anionic collector Aero 855	t/year	0.535	
	2.2.5.	Fuel oil	t/year	0.005	
	3.	Feldspar concentrate, w < 10%	t/year	20,819.93	technosphere
	3.1.	Sand	t/year	18,370.53	
	3.2.	Water, with flotation reagents	t/year	1224.70	
	3.2.1.	Water	t/year	1224.26	
	3.2.2.	Acid	t/year	0.013	
	3.2.3.	Tallow amine	t/year	0.001	
	3.2.4.	Anionic collector Aero 855	t/year	0.003	
	3.2.5.	Fuel oil	t/year	0.428	
	4.	Water with flotation reagents	t/year	20,368.73	process C-15

	4.1.	Water	t/year	20,347.42	
	4.2.	Acid	t/year	0.257	
	4.3.	Tallow amine	t/year	7,249	
	4.4.	Fuel oil	t/year	8,957	
	4.5.	Anionic collector Aero 855	t/year	4,842	
		INPUT	Unit	Amount	FROM
	1.	Water with flotation reagents	t/year	12,595.49	from process 10
		Water	t/year	12,547.22	
		Acid	t/year	0.273	
		Tallow amine	t/year	28,231	
		Fuel oil	t/year	19,762	
	2.	Water, with flotation reagents	t/year	23,837.98	from process 11
		Water	t/year	23,818.72	
		Acid	t/year	0.259	
		Tallow amine	t/year	0.07	
		Anionic collector Aero 855	t/year	18,758	
		Fuel oil	t/year	0.171	
	3.	Water, with flotation reagents	t/year	42,888.30	from process 12
		Water	t/year	42,872.71	
		Acid	t/year	0.467	
		Tallow amine	t/year	0.028	
		Anionic collector Aero 855	t/year	0.093	
		Fuel oil	t/year	15,004	
c-15	4.	Water, with flotation reagents	t/year	44,089.27	from process 13
		Water	t/year	44,087.70	
		Acid	t/year	0.48	
		Tallow amine	t/year	0.029	
		Anionic collector Aero 855	t/year	0.095	
		Fuel oil	t/year	0.964	
	5.	Water with flotation reagents	t/year	20,368.73	from process 14
		Water	t/year	20,347.42	
		Acid	t/year	0.257	
		Tallow amine	t/year	7,249	
		Fuel oil	t/year	8,957	
		Anionic collector Aero 855	t/year	4,842	
		OUTPUT	Unit	Amount	IN
	1.	Acidic water	t/year	143,779.77	technosphere*
	1.1.	Water	t/year	143,673.78	
	1.2.	Acid	t/year	1,736	
	2.	Hydrocarbons	t/year	104,252	technosphere*
	2.1.	Tallow amine	t/year	35,606	
	2.2.	Fuel oil	t/year	44,858	
	2.3.	Anionic collector Aero 855	t/year	23,788	

Table S4. GRAVITY CONCENTRATION.

UNIT		INPUT	Unit	Amount	FROM
D-1	1.	Sized attrited sand	t/year	134,287.50	from process A-14
	1.1.	Sand 0.8/0.1 mm	t/year	107,430.00	
	1.2.	Water	t/year	26,857.50	
	2.	Water	t/year	223,812.50	FROM prirode
	3.	Electricity	kWh/year	15,400.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Heavy minerals (10%)	t/year	35,810.00	process D-3
	1.1.	Sand 0.8/0.1 mm	t/year	10,743.00	
	1.2.	Water	t/year	25,067.00	
	2.	Silica and light minerals (90%)	t/year	322,290.00	process D-2
	2.1.	Sand 0.8/0.1 mm	t/year	96,687.00	
	2.2.	Water	t/year	225,603.00	
		INPUT	Unit	Amount	FROM
	1.	Silica and light minerals	t/year	322,290.00	from process D-1
D-2	1.1.	Sand 0.8/0.1 mm	t/year	96,687.00	
	1.2.	Water	t/year	225,603.00	
	2.	Electricity	kWh/year	15,400.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Glass grade silica sand (85%)	t/year	273,946.50	process D-3
	1.1.	Sand 0.8/0.1 mm	t/year	82,183.95	
	1.2.	Water	t/year	191,762.55	
	2.	Feldspar (15%)	t/year	48,343.50	process D-3
	2.1.	Sand 0.8/0.1 mm	t/year	14,503.05	
	2.2.	Water	t/year	33,840.45	
		INPUT	Unit	Amount	FROM
	1.	Heavy minerals	t/year	35,810.00	from process D-1
	1.1.	Sand 0.8/0.1 mm	t/year	10,743.00	
	1.2.	Water	t/year	25,067.00	
D-3	2.	Glass grade silica sand	t/year	273,946.50	from process D-2
	2.1.	Sand 0.8/0.1 mm	t/year	82,183.95	
	2.2.	Water	t/year	191,762.55	
	3.	Feldspar (15%)	t/year	48,343.50	from process D-2
	3.1.	Sand 0.8/0.1 mm	t/year	14,503.05	
	3.2.	Water	t/year	33,840.45	
	4.	Electricity (x3)	kWh/year	30,200.00	from technosphere
		OUTPUT	Unit	Amount	IN
	1.	Heavy minerals	t/year	17,905.00	process D-4
	1.1.	Sand 0.8/0.1 mm	t/year	10,743.00	
	1.2.	Water	t/year	7162.00	
	2.	Glass grade silica sand	t/year	91,315.50	process D-4
	2.1.	Sand 0.8/0.1 mm	t/year	82,183.95	
	2.2.	Water	t/year	9131.55	
	3.	Feldspar (15%)	t/year	16,114.50	process D-4
	3.1.	Sand 0.8/0.1 mm	t/year	14,503.05	
	3.2.	Water	t/year	1611.45	
	4.	Water	t/year	232,765.00	nature
		INPUT	Unit	Amount	FROM
	1.	Heavy minerals	t/year	17,905.00	from process D-3
D-4	1.1.	Sand 0.8/0.1 mm	t/year	10,743.00	
	1.2.	Water	t/year	7162,00	
	2.	Glass grade silica sand	t/year	91,315.50	from process D-3
	2.1.	Sand 0.8/0.1 mm	t/year	82,183.95	

2.2.	Water	t/year	9131.55	
3.	Feldspar (15%)	t/year	16,114.50	from process D-3
3.1.	Sand 0.8/0.1 mm	t/year	14,503.05	
3.2.	Water	t/year	1611.45	
4.	Electricity for conveyor belt	kWh/year	20,000.00	from technosphere
	OUTPUT	Unit	Amount	IN
1.	Heavy minerals	t/year	11,459.20	technosphere
1.1.	Sand 0.8/0.1 mm	t/year	10,743.00	
1.2.	Water	t/year	716.2	
2.	Glass grade silica sand	t/year	83,097.11	technosphere
2.1.	Sand 0.8/0.1 mm	t/year	82,183.95	
2.2.	Water	t/year	913,155	
3.	Feldspar (15%)	t/year	14,664.20	technosphere
3.1.	Sand 0.8/0.1 mm	t/year	14,503.05	
3.2.	Water	t/year	161,145	
4.	Water	t/year	16,114.50	nature