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Decarbonizing structural alloys in consumer electronics: Case studies at Apple

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Aluminum value-chain modeling.

Typical value-chain to produce an aluminum part is outlined in Figure S-1. Life-cycle inventory information was collected from a combination of primary data as well as literature sources including International Aluminum Institute (IAI) [1] and modeled using LCA for experts by Sphera. For material emissions, the results are normalized for 1 kg of aluminum billet. For heat emissions, the results are normalized for the material processed at each step. Finally, the results are aggregated [Table S-1] for a typical part to provide the contribution analysis for electricity, heat, and process chemicals. The results are aggregated to protect confidentiality of supplier data.

Figure S-1. Typical aluminum value chain to produce an aluminum part

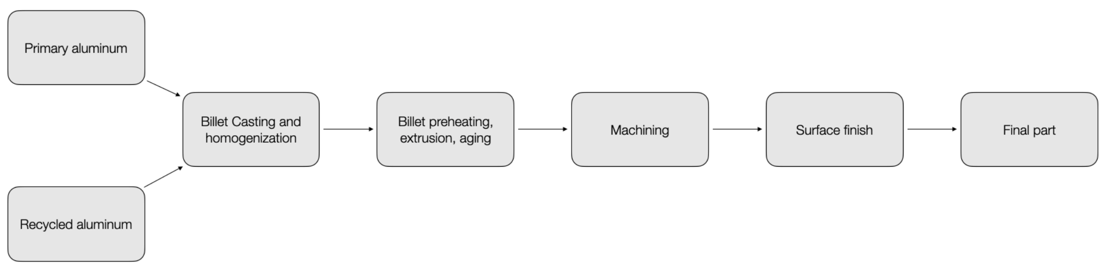

Table S-1. Lifecycle contribution analysis for a generic aluminum part GWP

Contribution	Details	GWP Contribution for an aluminum part(%)
Electricity		83%
Fuel	Natural gas Fuel oil Diesel Gasoline	11.5%
Process chemical	Sodium hydroxide Nitric acid Sulphuric acid Oxalic acid Phosphoric acid Hydrocarbon lubricant	2.8%
Other (upstream transport and aggregated data)	Aggregated models	2.5%

Titanium value-chain modeling

Typical value-chain to produce a titanium ingot is outlined in Figure S-2. Life-cycle inventory information was collected from a combination of primary data as well as literature sources (titanium sponge [2], vanadium GWP [3]) and modeled using LCA for experts by Sphera. The results [Table S-2] are normalized for 1 kg of titanium and are estimated for multiple scenarios, including titanium smelted using the average Chinese grid as well as hydroelectricity. The results are aggregated to protect confidentiality of supplier data.

Figure S-2. Typical cradle-to-gate/gate-to-gate value chain to produce a titanium ingot

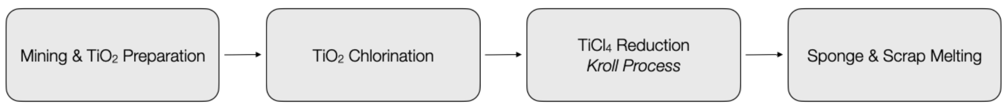

Table S-2. LCA results for titanium ingot output

	Primary Ti 6-4		**Recycled Ti 6-4**	
	Average Chinese Grid (kg CO2e/kg)	**Hydroelectricity** (kg CO2e/kg)	**Average Chinese Grid** (kg CO2e/kg)	**Hydroelectricity** (kg CO2e/kg)
Direct Emissions	2.5	2.5		
Pitch	0.56	0.56		
Petroleum coke	2.3	2.3		
Graphite electrode	0.075	0.075		
Sodium hydroxide	4.7	4.7		
Chlorine	1.7	1.7		
Sulfuric acid	0.017	0.017		
Magnesium	1.2	1.2		
Electricity (sponge +EBeam melting)	21.9	1.4	3.1	0.2
Vanadium	1.3	1.3		
Aluminum	0.93	0.28		
Raw material transport	0.074	0.074		
Total	37.3	16.1	3.1	0.2

Stainless-steel value-chain modeling

Typical value-chain to produce stainless-steel ingot is outlined in Figure S-3. Life-cycle inventory information was collected from a combination of primary data as well as literature [3-6] and modeled using LCA for experts by Sphera. The results [Table S-3] are normalized for 1 kg of stainless-steel ingot. The results are estimated for multiple scenarios including nickel sourced from different sources including FeNi, class-I nickel, and nickel pig iron. The results are aggregated to protect confidentiality of supplier data.

Figure S-3. Typical cradle-to-gate/gate-to-gate value chain to produce a stainless-steel ingot

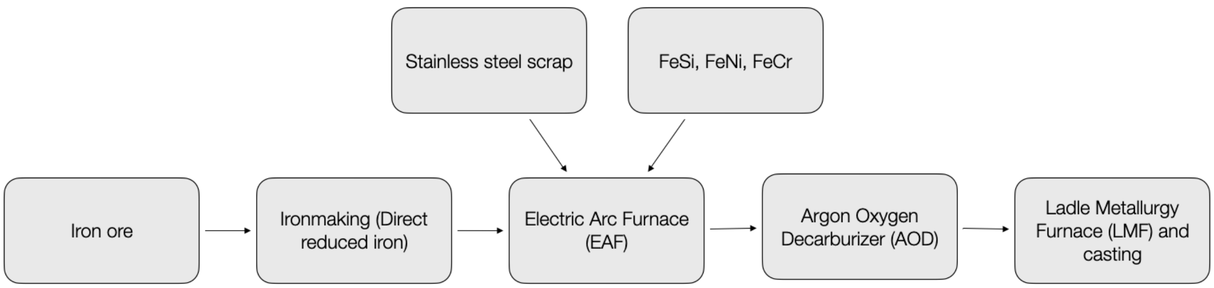

Table S-3. LCA results for stainless steel ingot output

	Stainless Steel 316L	
	Primary (kg CO2e/kg)	**80% RC** (kg CO2e/kg)
Electricity	1.4	1.00
FeCr	2.9	0.58
FeMn	0.084	0.016
FeMo	0.38	0.076
FeNi	5.7	1.1
FeSi	0.075	0.015
AOD	0.058	0.058
Argon	0.0049	0.0049
Coke	0.0066	0.0066
Lime	0.045	0.045
Nitrogen	0.068	0.068
Oxygen	0.0080	0.0080
Natural gas	0.72	0.34
Light fuel oil	0.021	0.003
Total	11.4	3.3

References

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