Comparative Life Cycle Assessment of Cellulose-based Masks and Plastic-based Masks

Yong-Chul Jang* and Howon Lee

UNCRD 12th 3R and Circular Economy Forum

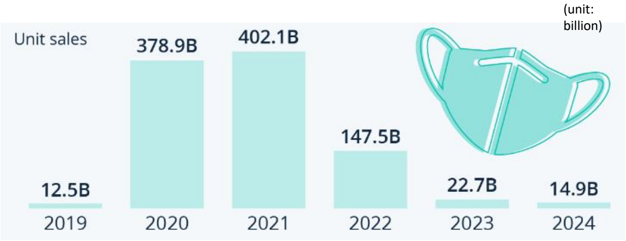
March 4 2025

Chungnam National University

1. Research Background

1-1. Introduction

- After COVID-19 pandemic, there is a rapid increased consumption of single-use masks (12 billions in 2019 vs. 402 billion in 2021)
- Single-use masks are almost all made of Polypropylene(PP).
- During life cycle stage of the masks, several environmental issues are related to resource depletion, greenhouse gas emission, microplastic in the environment upon improper disposal
- Bio-based masks, biodegradable masks can be viable options to the alternative to PP masks



[Fig] Recent global sales of face-masks

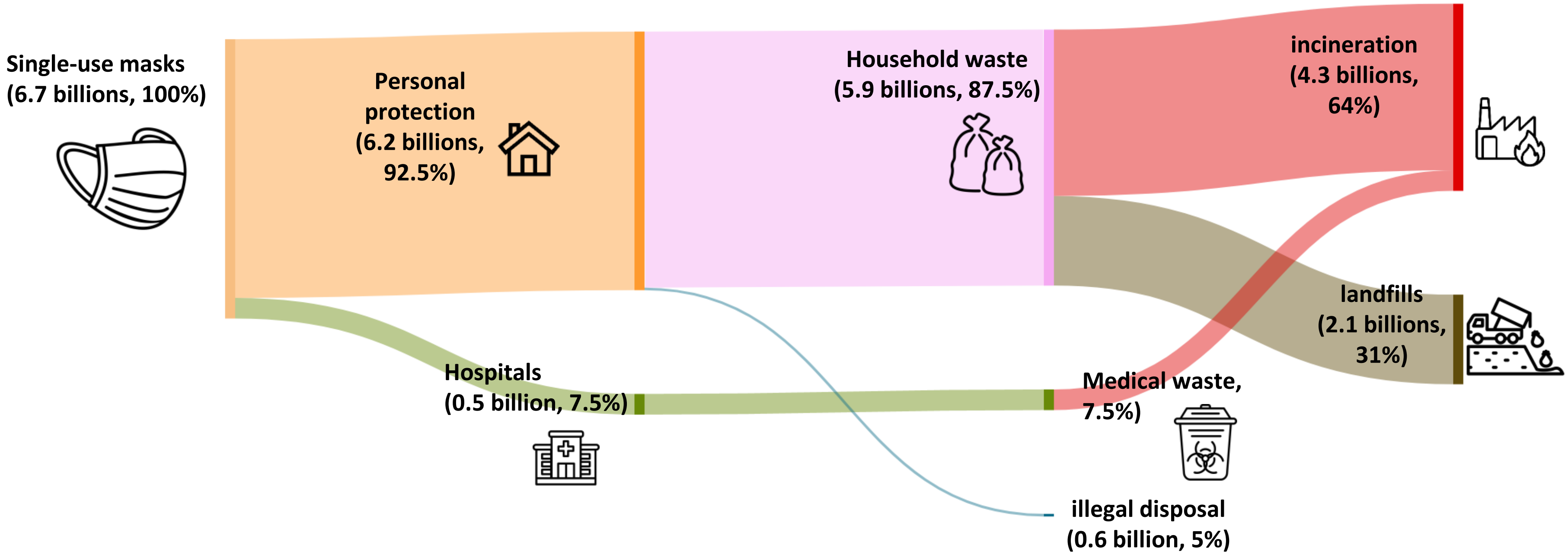
(ref: Statista, https://www.statista.com/chart/29100/global-face-mask-sales/)

[Fig] Cellulose fiber

(ref: Korea textile news)

1. Research Background

- **In 2020, 6.7 billions of single-use face masks were consumed in Korea and treated by incineration (64%) and landfilling (31%).**



[Fig] Material flow of plastic-based single use face masks in Korea (2020)

1. Research Objective

1-2. Objectives

① Conduct LCA study on cellulose-based masks and plastic-based masks

② Evaluate environmental impacts of cellulose-based masks and plastic-based masks by life cycle

③ Assess carbon footprints of cellulose-based masks and plastic-based masks

2. Methodology

2-1. Goal and Definition

- Goal: evaluate environmental impacts of cellulose-based masks and pp-based masks
- Functional unit: 1 ton KF-94 face single-use masks
- System boundary: Cradle to Grave
- LCA software: SimaPro v.9.4.0.2
- Impact assessment method: IMPACT 2002+
- Mid-point approach: 15 impact categories

[Table] Impact 2002+ method and impact category

category	unit
Carcinogens	kg C_2H_3Cl eq
Non-carcinogens	kg C_2H_3Cl eq
Respiratory inorganics	kg PM2.5 eq
Ionizing radiation	Bq C-14 eq
Ozone layer depletion	kg CFC-11 eq
Respiratory organics	kg C_2H_4 eq
Aquatic ecotoxicity	kg TEG water
Terrestrial ecotoxicity	kg TEG soil
Terrestrial acid/nutri	kg SO_2 eq
Land occupation	m^2org.arable
Aquatic acidification	kg SO_2 eq
Aquatic eutrophication	kg PO_4 P-lim
Global warming	kg CO_2 eq
Non-renewable energy	MJ primary
Mineral extraction	MJ surplus

2. Methodology

2-2. Database and assumptions

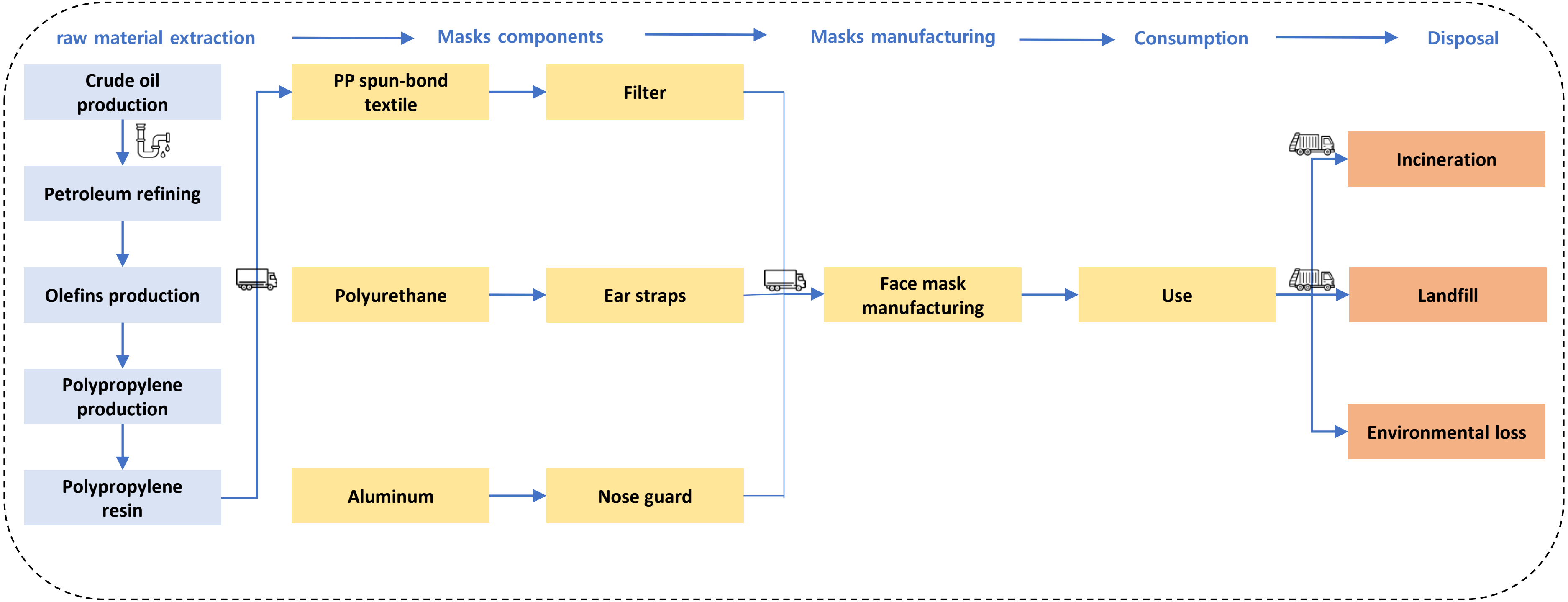
- Data collection: field survey, literature and report
- Unit process data: Ecoinvent 3.8, USLCI Database
  (if LCI Database is unavailable, similar process data were used)
- Packaging data for masks are excluded

[Table] Data acquisition related to single-use face masks life cycle in this study

Life cycle	Contents	References
Pre-production stages	Pre-production stages of plastic-based single-use masks	Franklin Associates report , 2021
	Pre-production stages of cellulose-based single-use masks	Chen , 2009 Krexner et al., 2022 Corcelli et al. , 2022
Production stages	Production stages of plastic-based and cellulose-based single-use masks	Turkmen, 2021
Transportation stages	Transportation means of plastic-based and cellulose-based single-use masks	Turkmen, 2021
Disposal stages	Status of waste generation and disposal	Korea Ministry of Environment: 2022 Status of waste generation and disposal Anti-Corruption and Civil Rights Commission of Korea: Single-use face masks waste disposal plan

2. Methodology

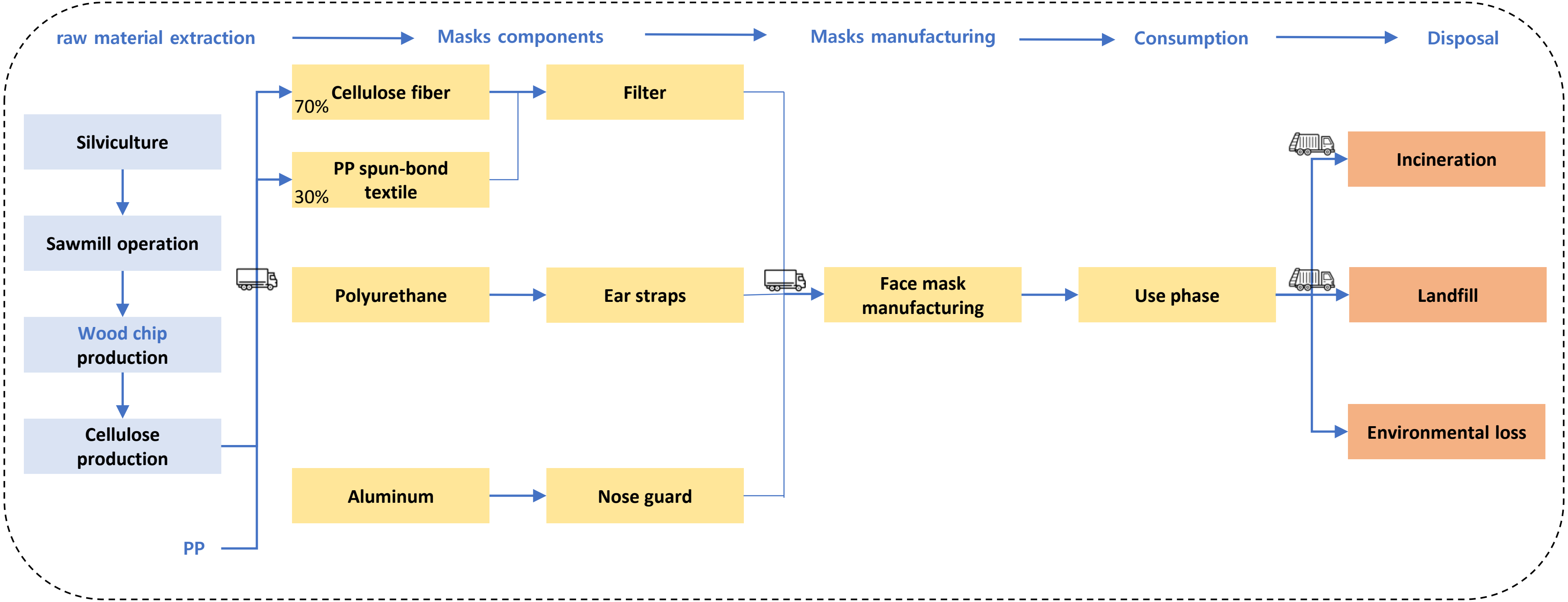
2-3. System boundary for plastic-based masks



[Fig] System boundary for plastic-based masks during LCA study

2. Methodology

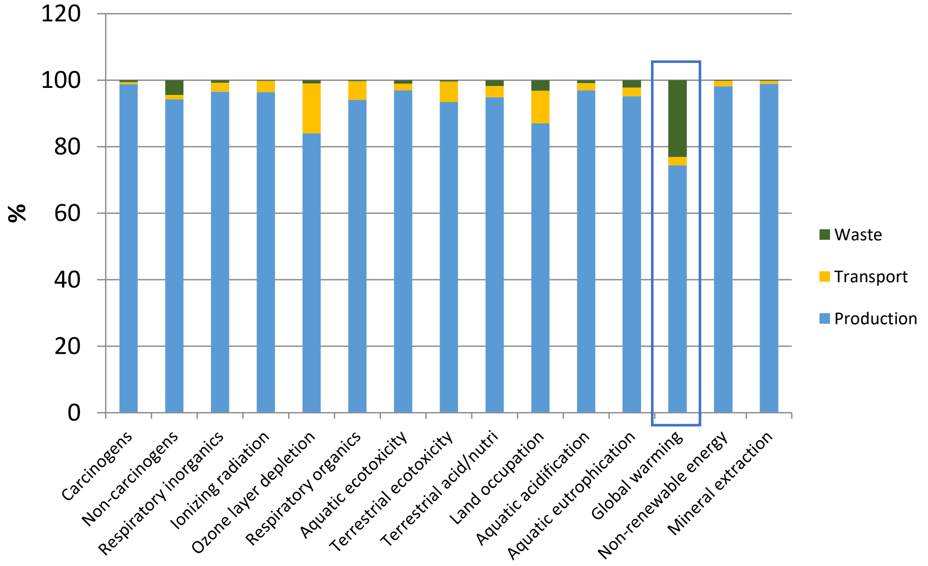
2-4. System boundary for cellulose-based masks



[Fig] System boundary for cellulose-based masks during LCA study

3. Results and Discussion

3-1. Impact assessment of plastic-based masks by LCA(1 ton)



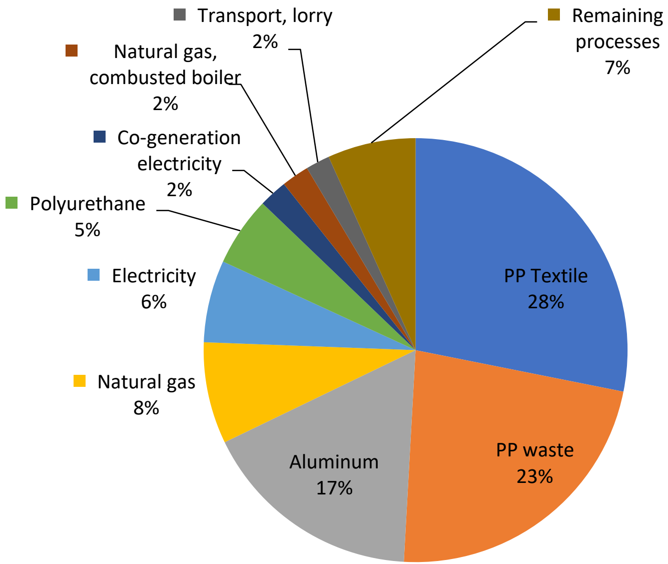
- Production stage is a dominant factor contributing all the impacts
- Global warming impact: 7.18 ton CO_2 eq, Ozone depletion 2.02E-04 kg CFC-11 eq, mineral extraction 248 MJ surplus
- Global warming impact category: Production stage 5.34 ton CO_2 eq(74.5%), disposal stage 1.65 ton CO_2 eq(23%), and transportation 0.18 ton CO_2 eq(2.5%),

[Table] Impact assessment results of plastic-based masks (mid-point)

Impact category	Unit	Total	Production	Transport	Disposal
Global warming	kg CO_2 eq	7.18E+03	5.34E+03	1.82E+02	1.65E+03
	%	100	74.5	2.5	23.0
Carcinogens	kg C_2H_3Cl eq	2.16E+02	2.13E+02	1.32E+00	1.17E+00
	%	100	98.9	0.7	0.4
Mineral extraction	MJ surplus	2.48E+02	2.45E+02	2.29E+00	3.72E-01
	%	100	98.9	0.9	0.2

3. Results and Discussion

3-2. Contribution analysis of unit processes of plastic-based masks to global warming impact

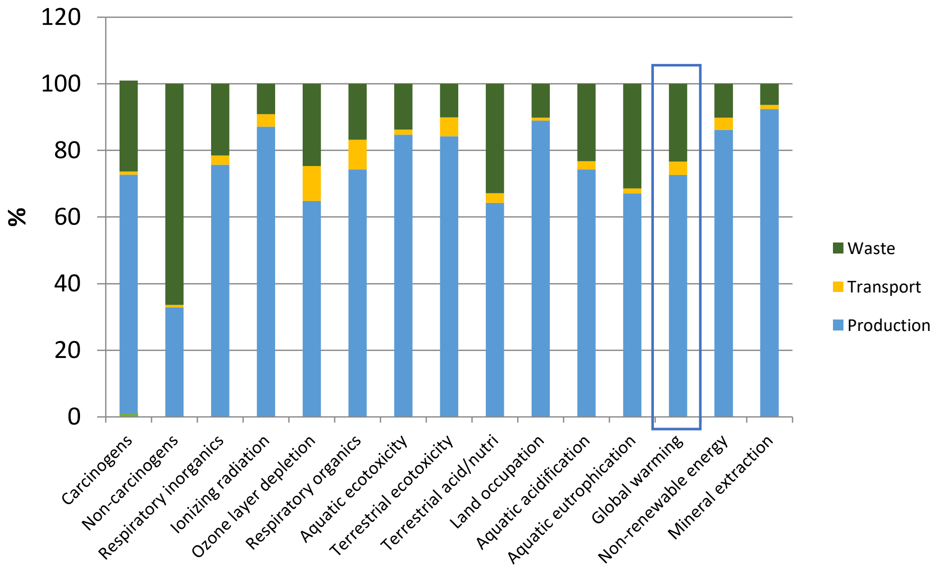


process	impact (kg CO_2 eq)
PP textile	2,020 (28%)
PP waste	1,633 (23%)
Aluminum	1,218 (17%)
Natural gas	556 (8%)
Electricity	450 (6%)
Polyurethane	381 (5%)
Others	13%

[Figure] Contribution analysis of unit processes of plastic-based masks to global warming impact

3. Results and Discussion

3-3. Impact assessment of cellulose-based masks by LCA(1 ton)



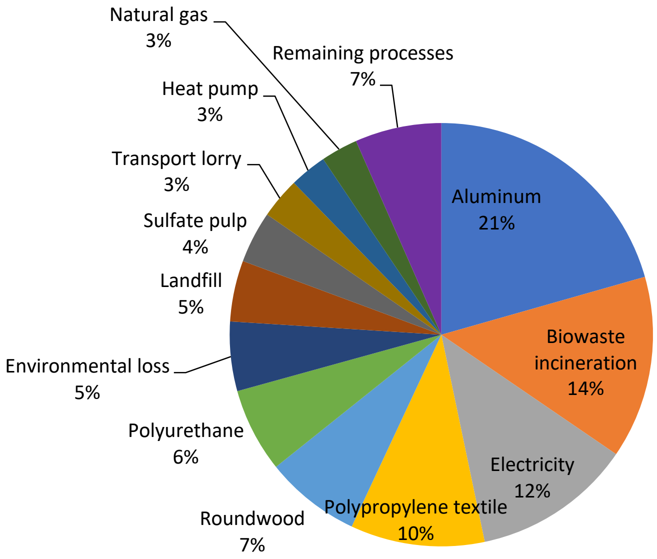
- Production stage is a dominant factor contributing all the impacts, while non-carcinogens category, disposal stage 393 kg C_2H_3Cl eq(67%)
- Global warming impact: 6.06 ton CO_2 eq, Ozone depletion 3.92E-04 kg CFC-11 eq, mineral extraction 263 MJ surplus
- Global warming impact category: Production stage 4.40 ton CO_2 eq(72.6%), transportation 0.24 ton CO_2 eq(4.1%), disposal stage 1.41 ton CO_2 eq(23.3%)로 나타남

[Table] Impact assessment results of cellulose-based masks (mid-point)

Impact category	Unit	Total	Production	Transport	Disposal
Global warming	kg CO_2 eq	6.06E+03	4.40E+03	2.46E+02	1.41E+03
	%	100	72.6	4.1	23.3
Carcinogens	kg C_2H_3Cl eq	1.93E+02	1.38E+02	4.25E+00	3.93E+02
	%	100	72.9	0.7	26.4
Mineral extraction	MJ surplus	2.63E+02	2.43E+02	3.29E+00	1.65E+01
	%	100	92.4	1.3	6.3

3. Results and Discussion

3-4. Contribution analysis of unit processes of plastic-based masks to global warming impact



Unit process	Climate change Impacts ($kg\ CO_2\ eq$)
Aluminum	1,218 (21%)
Biowaste incineration	825 (14%)
Electricity	720 (12%)
PP textile	606 (10%)
Roundwood	432 (7%)
Polyurethane	380 (6%)
Others	1,830 (30%)

[Figure] Contribution analysis of unit processes of cellulose-based masks to global warming impact (kg CO2 eq)

4. Summary and Conclusion

Summary and implications

1) We evaluated the environmental impacts of two different single-use masks systems (plastic-based vs. cellulose-based)
2) In the global warming impact category, 1 ton cellulose-based masks resulted in 6.06 ton CO_2 eq, while pp-based masks contributed to 7.18 ton CO_2 eq
3) In many impact categories, the environmental impacts of cellulose-based masks were relatively lower than those of plastic-based masks.
4) Production stage is the major factor contributing to all the impacts by consuming energy, resources, and pollutants
5) Further study is warranted to examine life cycle cost analysis for these two systems

충남대학교
Chungnam National University

Thank you for you attention

Prof. Yong-Chul Jang
gogator@cnu.ac.kr
Chungnam National University

2. Methodology

2-5. Life cycle inventory data for plastic-based masks

[Table] Data Inventory for pre-manufacturing stage for plastic-based masks

Type		materials	value	unit
Input	Raw	Propylene	834.2	kg
	aux	Nitrogen	52.7	kg
	aux	electricity	246.8	kWh
	aux	Natural gas	28.0	m^3
	aux	water	2,468	kg
output	products	PP resin	822.7	kg
	Air emissions	CO_2, NMVOC, dusts	8.4	kg
	Water emission	BOD, COD, zinc	0.03	kg

[Table] Data Inventory for transportation stage for plastic-based masks

Type	method	distance
Raw material trans 1 (oil-raw supply)	Pipeline	30 km
Raw material trans 2 (raw supply-manufacture)	3.5-7.5 ton truck	50 km
Product trans (manufacture-sales)	3.5-7.5ton truck	200 km
Waste trans (collection-incineration)	MSW collection truck	20 km
Waste trans (collection-landfills)	MSW collection truck	20 km

[Table] Data Inventory for manufacturing stage for plastic-based masks

구분	Materials/substances	value	unit
Filter	PP resin textile, spun bond	822.7	kg
Ear straps	Polyurethane	83.3	kg
Nose guard	Aluminum	94.0	kg
assembly	electricity	534.2	kWh

[Table] Data Inventory for disposal stage for plastic-based masks

method	ratio
incineration	64%
landfills	31%
loss	5%

2. Methodology

2-6. Life cycle inventory data for cellulose-based masks

[Table] Data Inventory for pre-manufacturing stage for cellulose-based masks

type		material	value	unit
Silviculture	input	Forest	0.002	ha
		Electricity	0.1	kWh
		Diesel	3	kg
	output	CO_2, SO_2, NO_X	10.6	kg
		wood	12.1	m^3
Sawmill operation	input	wood	12.1	m^3
		electricity	39	MJ
		Steam	82	MJ
	output	CO_2, SO_2, NO_X	371	g
		Saw dust	5.4	m^3
Wood chip production	input	Saw dust	5.4	m^3
		Electricity	137	MJ
		Diesel	0.042	kg
	output	CO_2, SO_2, NO_X	482	g
		Wood chips	822.7	kg
Cellulose extraction	input	Wood chip	822.7	kg
		water	40,370	kg
		electricity	265.6	kWh
	output	cellulose	575.9	kg

[Table] Data Inventory for manufacturing stage for cellulose-based masks

Material	Type	value	unit
Filter	PP resin textile, spun bond	246.8	kg
	Cellulose fiber	575.9	
Ear straps	Polyurethane	83.3	kg
Nose guard	Aluminum	94.0	kg
assembly	electricity	534.2	kWh

[Table] Data Inventory for transportation stage for cellulose-based masks

type	methods	distance
Raw material transport 1 (forest-woods)	7.5-16 ton truck	50 km
Raw material transport 2 (woods-chips)	3.5-7.5 ton truck	50 km
Raw material transport 3 (wood chips-cellulose extract)	3.5-7.5 ton truck	50 km
Raw material transport 4 (cellulose-masks manufact)	3.5-7.5 ton truck	50 km
Product transport (masks manuf-sales)	3.5-7.5 ton truck	200 km
Waste trans (collection-incineration)	MSW collection truck	20 km
Waste trans (collection-landfills)	MSW collection truck	20 km