Life Cycle Analysis of Leading Coagulants: Executive Summary

Format of this document

This is the Executive Summary of an LCA Study undertaken on behalf of INCOPA by Dr. Ing. Justyna Homa and Prof. h.c. Dipl. Ing. Erhard Hoffmann of the Karlsruhe Institute of Technology (KIT). The study was completed in April 2013 and revised in May 2014.

This document includes:

1. An introduction containing information about: the goal of the study and its boundaries; the data collection process; and the methodology used to interpret the data.
2. Summary of the LCA for all coagulants studied (Appendix A)
3. Individual summaries of the LCA data for different coagulants by type or active ingredient:
   - Polyaluminium chloride (PAC) (Appendix B)
   - Aluminium (Appendix C)
   - Iron (Appendix D)
   - Sodium aluminates (Appendix E)

The complete final report Carbon Footprint and LCA Study for different Coagulants Produced From INCOPA Member Companies can be obtained by emailing the INCOPA Sector Group Manager at info@incopa.org.

Life Cycle Analysis of Leading Coagulants: Executive Summary

Produced for INCOPA at the Karlsruhe Institute of Technology (KIT)
by Dr.-Ing. Justyna Homa and Prof. h.c. Dipl.-Ing. Erhard Hoffmann

Goal

The goal of this life cycle analysis (LCA) study was to quantify the environmental impacts associated with the production of coagulants and to identify their environmental load. The outcome of this cradle-to-gate study is the amount of carbon dioxide equivalents (kilograms of CO_2-equivalents) per mole of active ingredient (typically Fe^{3+} or Al^{3+}).

Scope

The study focussed on the cradle-to-gate emissions from coagulant production. Data was provided by nine different INCOPA members with production sites in six countries.

The system boundaries of this study included:

Cradle	Raw material extraction, processing and transport.
Production	Coagulant production including inputs such as electricity, heat, chemicals and additional fuels.
Gate	The scope of this LCA study ends at the point the coagulant exits the production site.

Conclusions

The mean carbon footprint value for all investigated coagulants is 0.106 kg CO_2-eq/mole Fe^{3+} or Al^{3+}. This finding fits well with the values calculated in previous or similar LCA studies. The value is extremely low. By contrast, producing one kilogram of beef results in around 30 kg of CO_2-eq emissions .

The considerable difference between the minimum and maximum carbon footprint values (range = 0.013 to 0.219 kg CO_2-eq/mole Fe^{3+} or Al^{3+}) is a consequence of the different raw materials which are used to produce each type of coagulant. Some raw materials have relatively high CO_2-eq emissions during their production or their transport to the coagulant production site.

As expected, the use of recycled materials or by-products from other production processes decreases the environmental impact of coagulant production. This highlights the effect of transport-related emissions on coagulant production as recycled materials and by-products are often onsite or come from nearby production facilities.

Methodology

This chapter describes the data collection and treatment that was carried out as part of the LCA. More detailed information about the methodology can be found in the complete final report.

Data Collection

Questionnaires were used to collect LCA data from INCOPA's members. The data collected covered both inputs to the coagulant production process, and outflows resulting from the production process. Information collected included:

- Quantities of raw materials and chemicals or intermediary products (including water) used during processing or manufacture.
- Quantities of purchased energy and purchased fuels which are consumed during processing or manufacturing of the product.
- Distances and modes of transport used to convey raw materials, intermediary products, and purchased fuels to the production site.
- Outflows from the production process including: emissions to air, water and ground; waste produced; and recyclable material.

Data Treatment

All data was entered into the SimaPro (System for Integrated Environmental Assessment of Products) software. SimaPro is a highly professional tool for collecting, managing and storing LCA data. It enables us to analyse and monitor the environmental impact of products and services. SimaPro comes with the full Ecoinvent dataset which contains data covering more than 4,000 processes.

Average European values (RER) or global values (GLO) from the Ecoinvent dataset were used for materials, energy and transport. Emissions from other inputs such as transport and electricity are already included.

Material consumption

Source values were assumed for materials consumed in the process of making coagulants. Table 1 shows the list of assumed values.

Water consumption

Raw river water and channel cooling water are equal to 0 kg CO_2-eq/kg. The energy needed to filter, screen and pump water is included under electricity. The following Ecoinvent values have been used for other sources of water:

- 'Drinking water, water purification treatment, production mix, at plant, from surface water/ RER'
- 'De-ionised water, reverse osmosis, production mix, at plant, from groundwater/RER'
- 'Process water, ion exchange, production mix, at plant, from surface water/RER'
- 'Water, decarbonised, at plant/RER'.

Energy use

The Ecoinvent value 'Electricity, medium voltage, production UCTE, at grid/UCTE S' has been used for electricity. (UCTE is the Union for the Co-ordination of Transmission of Electricity – a European group of electricity producers.) Other energy sources used in this inventory are:

- 'Steam, for chemical processes, at plant/RER'
- 'Natural gas, at long-distance pipeline/RER'
- 'Compressed air, average installation, >30kW, 6 bar gauge, at supply network/RER'
- 'Compressed air, average installation, <30kW, 10 bar gauge, at supply network/RER'
- 'Diesel, at refinery/RER'.

Transport

As the scope of this LCA study is cradle-to-gate, transport emissions are only calculated for inputs (raw materials) to the coagulant-making process. The contribution of transport has been calculated using average values. The values were calculated from actual transport data submitted by INCOPA members as part of a study.

The transport values used in this report are based on average transport distances and standard modes of transport. Transportation of raw materials and coagulants is carried out mainly by truck. However, some materials are sent by barge or ship. For this inventory, the following values have been used:

- Truck
- Barge/RER
- Transoceanic freight ship/OCE.

To create corresponding values for different transport modes, a reference unit of one tonne kilometre (tkm) was applied. A tkm represents the transport of one tonne of goods by a certain means of transportation over one kilometre.

Table 1: Source values assumed for materials consumed in the process of making coagulants

Aluminium hydroxide:	The Ecoinvent value 'Aluminium hydroxide at plant/RER' has been applied.	
Chlorine:	Two Ecoinvent values have been used in the inventory: • 'Chlorine, gaseous, mercury cell, at plant/RER' or • 'Chlorine, gaseous, membrane cell, at plant/RER'.	
Hydrochloric acid:	20% synthetic, 80% by-product. Two Ecoinvent values have been used in the inventory: • 'Hydrochloric acid, 30% in H_2O, at plant/RER' or • 'Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER'.	
Iron oxide:	'Iron ore, 65% Fe, at beneficiation/GLO' has been applied.	
Sodium hydroxide:	'Sodium hydroxide, 50% in H_2O, membrane cell, at plant/RER' has been applied.	
Sulfuric acid:	45% virgin, and 55% by-product. The Ecoinvent value 'Sulfuric acid, liquid, at plant/RER' has been applied.	
Other materials:	In accordance with allocation rules, the CO_2-footprint of the following materials is considered to be equal to 0 kg CO_2-eq/kg. For these materials, only the transport emissions have been considered:	
	• Aluminium filter cake (recycled) • Caustic soda (recycled) • Copperas ($FeSO_4$ $7H_2O$) • Iron metal (recycled)	• Pickling acid (recycled) • Sodium aluminate (recycled) • Sulfuric acid (recycled).

Impact Assessment

To determine the environmental impact of coagulant production, the IPCC 2007 GWP 100a impact assessment methodology was used. Developed by the United Nations Intergovernmental Panel on Climate Change (IPCC), the methodology uses carbon dioxide (CO_2) as a reference greenhouse gas.

The IPCC 2007 GWP 100a impact assessment method provides a measurement of potential emissions to air over a period of 100 years. Emissions are expressed as a mass of carbon dioxide equivalents (CO_2-eq).

Results

The results of the LCA study can be found in the following appendices. To provide a visual representation of the results, tree diagrams have been prepared for each type of coagulant studied. An example is shown in Figure 1.

The top box represents the final product. The number in the bottom left corner indicates the total environmental load for this coagulant (expressed as kilograms of CO_2-equivalents per kilogram of product).

Each box in the bottom row represents a process. The thickness of the line indicates the amount of CO_2-equivalents each process contributes to the final product. The absolute values are shown in the bottom left corner while the percentage of the total emissions is indicated in the bottom right corner.

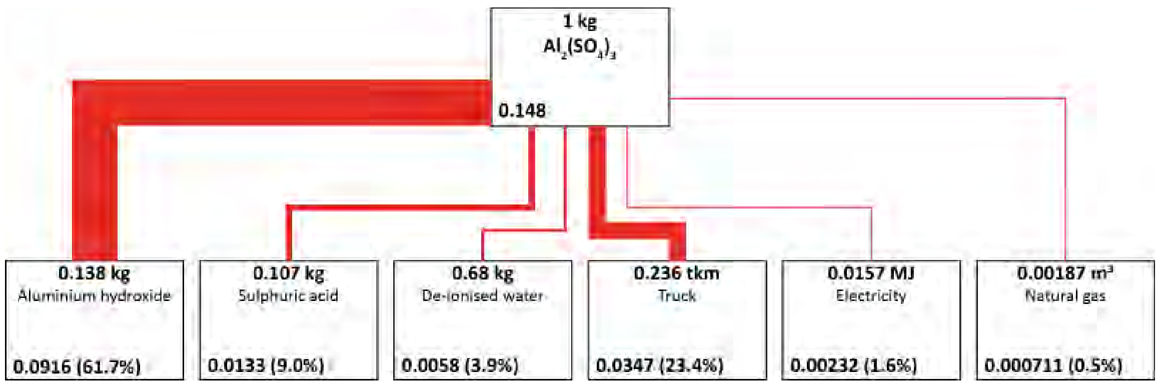

Figure 1: Tree diagram showing overview of process flows and emissions for $Al_2(SO_4)_3$

Appendix A:
Summary of LCA Results for all Coagulants

The range of carbon footprint values for all coagulants investigated are shown in Figure A-1. The values are expressed as kg CO_2-eq/kg product and per mole of Fe^{3+} or Al^{3+}.

The carbon footprint values vary from a minimum of 0.013 kg CO_2-eq/mole Fe^{3+} (0.029 kg CO_2-eq/kg product) up to a maximum of 0.219 kg CO_2-eq/mole Al^{3+} (0.773 kg CO_2-eq/kg product).

Mean carbon footprint

The mean carbon footprint for all coagulants is equal to 0.106 kg CO_2-eq/mole Fe^{3+} or Al^{3+}.

Impacts affecting environmental load

To identify which impacts affect the environmental load of coagulant production, the contributions of materials, water, energy and transport have been calculated for each coagulant. Figure A-2 shows the average impacts for materials, water, energy and transport.

In most cases, the environmental impact of raw materials extraction and chemicals manufacturing (materials) accounts for more than 60% of the total environmental impact. In the two production processes which utilise recycled materials or co-products, the impact of materials is small (average of 14.2%).

The average contribution of materials for all 11 coagulant production methods is 70.5%. This translates to 0.133 kg CO_2-eq/mole Fe^{3+} or Al^{3+}.

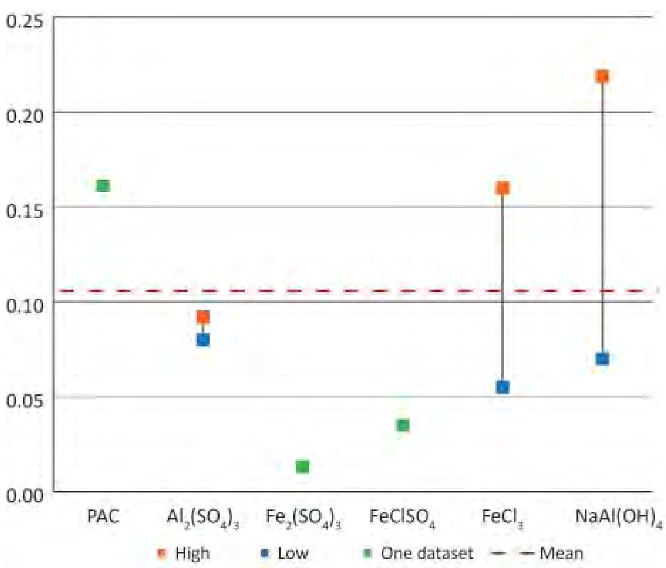

Figure A-1: Range of carbon footprint values for coagulants investigated (kg CO_2-eq/mole Fe^{3+} or Al^{3+})

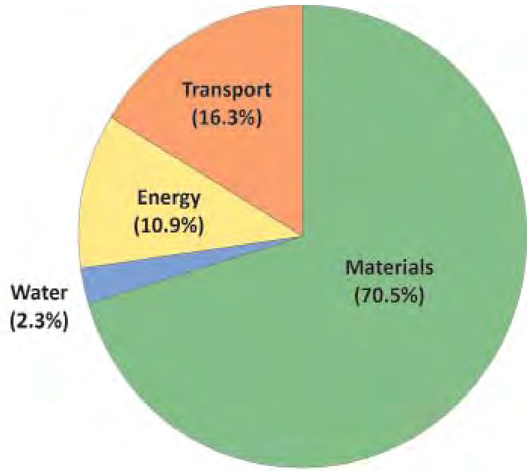

Figure A-2: Contribution of impacts on the carbon footprint of different coagulants

The average contribution of energy to the production processes is 10.9% (0.010 kg CO_2-eq/mole Fe^{3+} or Al^{3+}).

The average transport contribution is 16.3% (0.009 kg CO_2-eq/mole Fe^{3+} or Al^{3+}).

Conclusions

The mean carbon footprint value for all investigated coagulants is 0.106 kg CO_2-eq/mole Fe^{3+} or Al^{3+}. This finding fits well with the values calculated in previous or similar LCA studies. The value is extremely low. By contrast, producing one kilogram of beef results in around 30 kg of CO_2-eq emissions .

The considerable difference between the minimum and maximum carbon footprint values (range = 0.013 to 0.219 kg CO_2-eq/mole Fe^{3+} or Al^{3+}) is a consequence of the different raw materials which are used to produce each type of coagulant. Some raw materials have relatively high CO_2-eq emissions during their production or their transport to the coagulant production site.

As expected, the use of recycled materials or by-products from other production processes decreases the environmental impact of coagulant production. This highlights the effect of transport-related emissions on coagulant production as recycled materials and by-products are often onsite or come from nearby production facilities.

Appendix B:
LCA Results for Polyaluminum Chloride (PAC)

For the PAC process, the carbon footprint is 0.161 kg CO_2-eq/mole Al^{3+} (see Table B-1).

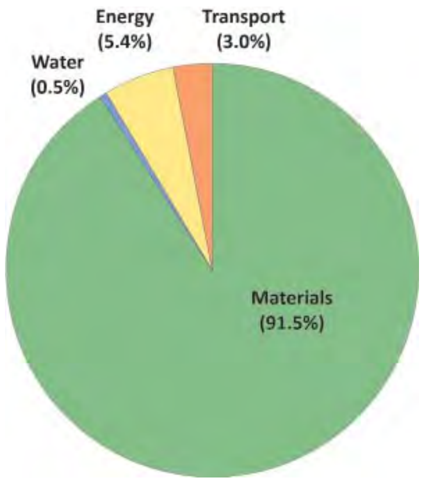

Figure B-1: Contribution of impacts on the carbon footprint of PAC coagulants

Table B-1: Carbon footprint of PAC coagulants investigated

Product	Carbon footprint (kg CO_2-eq/kg product)	Active ingredient content (g Fe^{3+} or Al^{3+}/kg)	Carbon footprint (kg CO_2-eq/mole Fe^{3+} or Al^{3+})
PAC	0.537	90	0.161

Table B-2: Contribution of impacts to the carbon footprint of PAC coagulants (kg CO_2-eq/kg product)

Product	Materials	Energy	Transport	Water
PAC	0.491	0.02924	0.01627	0.00025

Production process of PAC coagulants

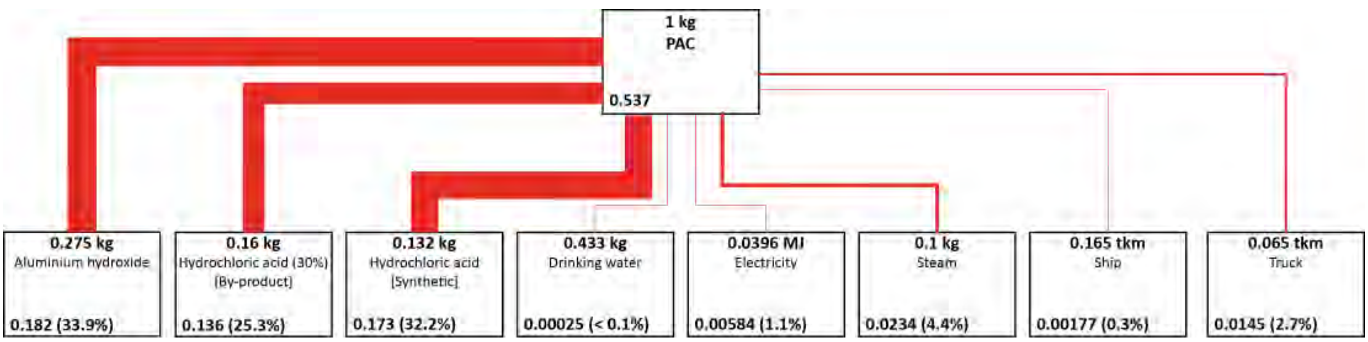

Figure B-2: Overview of the PAC production process tree

Appendix C:
LCA Results for Aluminium Sulfate Coagulants

For the two aluminium sulfate processes, the carbon footprint ranges from 0.088 to 0.092 kg CO_2-eq/mole Al^{3+} (see Table C-1).

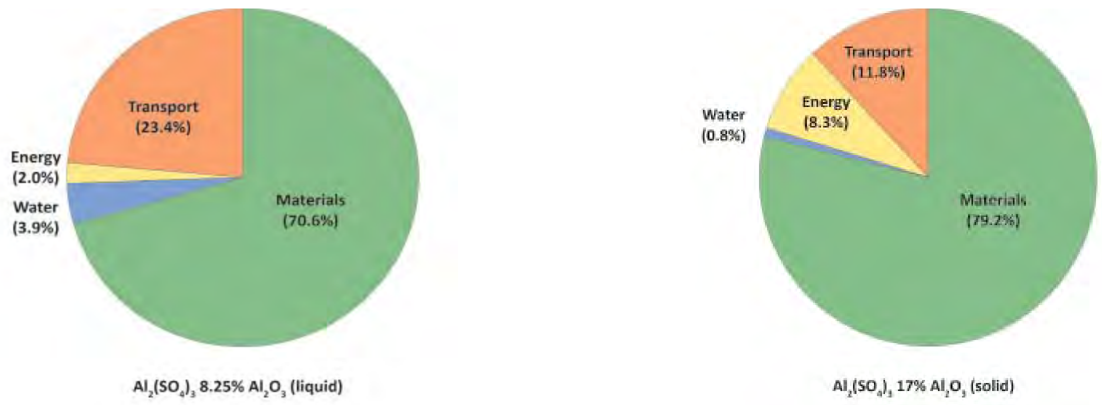

Figure C-1: Contribution of impacts on the carbon footprint of aluminium sulfate coagulants

Table C-1: Carbon footprint of aluminium sulfate coagulants investigated

Product	Carbon footprint (kg CO_2-eq/kg product)	Active ingredient content (g Al^{3+}/kg)	Carbon footprint (kg CO_2-eq/mole Al^{3+})
$Al_2(SO_4)_3$ 8.25% Al_2O_3 (liquid)	0.148	43.6	0.092
$Al_2(SO_4)_3$ 17% Al_2O_3 (solid)	0.295	90.8	0.088

Table C-2: Contribution of impacts to the carbon footprint of aluminium sulfate coagulants (kg CO_2-eq/kg product)

Product	Materials	Energy	Transport	Water
$Al_2(SO_4)_3$ 8.25% Al_2O_3 (liquid)	0.1049	0.0030	0.0347	0.0058
$Al_2(SO_4)_3$ 17% Al_2O_3 (solid)	0.2329	0.0243	0.0347	0.0024

Production process of aluminium sulfate coagulants

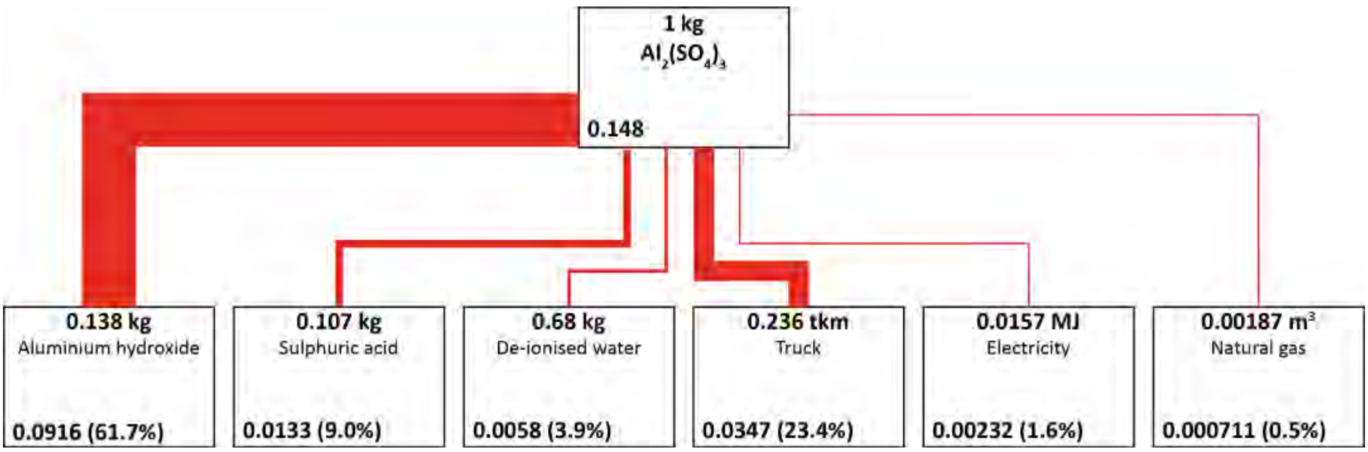

Figure C-2: Overview of the $Al_2(SO_4)_3$ 8.25% Al_2O_3 (liquid) production process tree

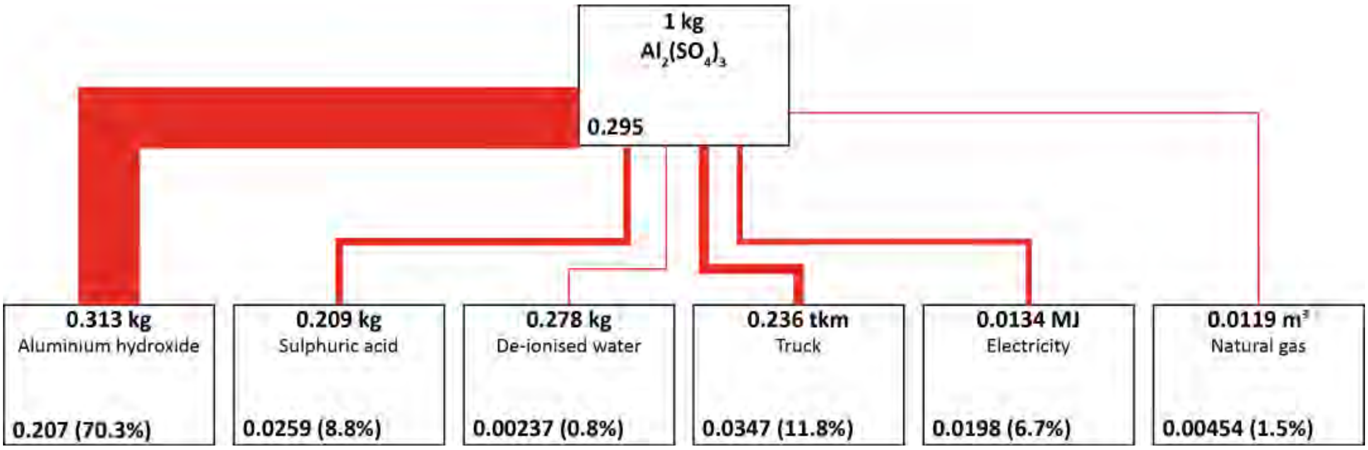

Figure C-3: Overview of the $Al_2(SO_4)_3$ 17% Al_2O_3 (solid) production process tree

Appendix D:
LCA Results for Iron-based Coagulants

The products are:

- $Fe_2(SO_4)_3$ – one process route
- $FeClSO_4$ – one process route
- $FeCl_3$ – two process routes.

For the four iron-based coagulant production processes, the carbon footprint ranges from 0.013 to 0.160 kg CO_2-eq/mole Fe^{3+} (see Table D-1).

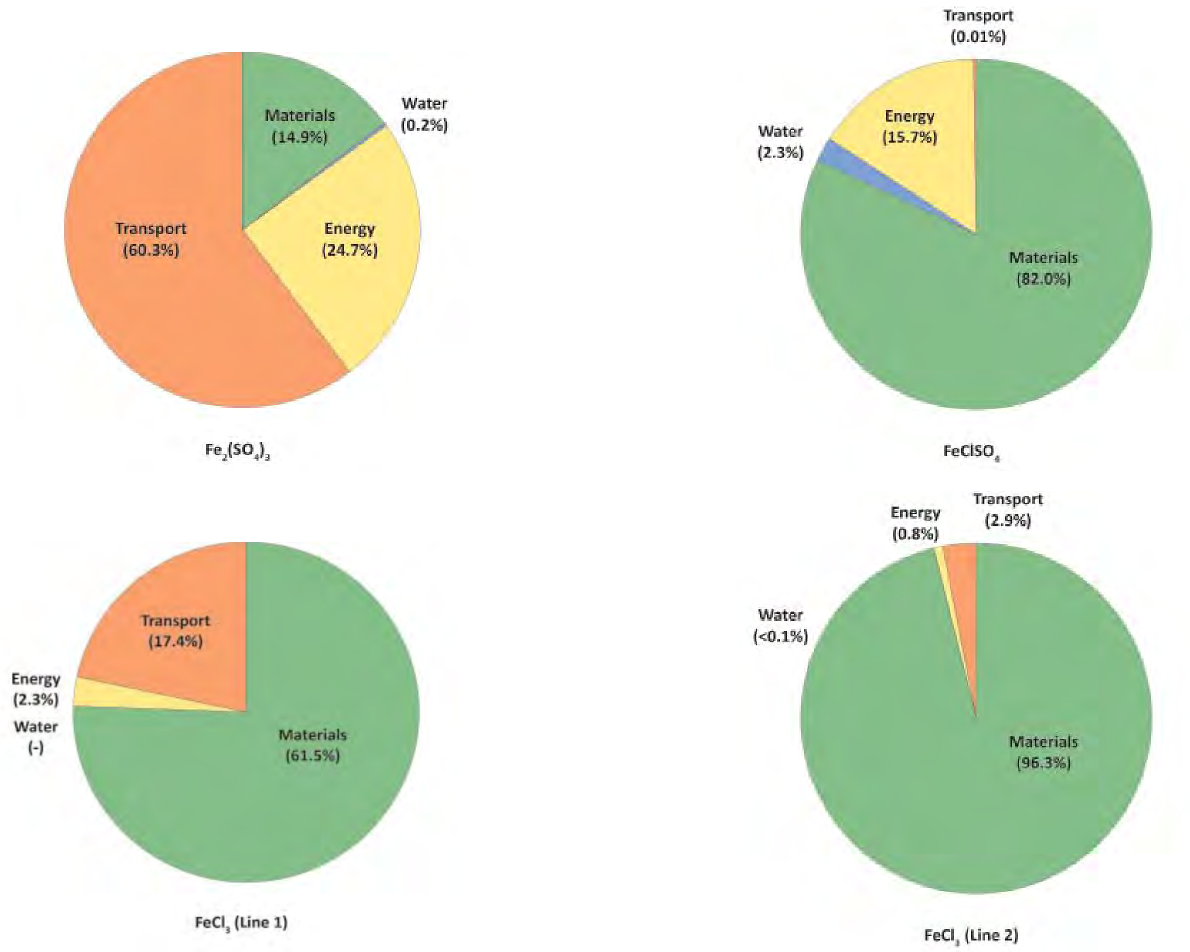

Figure D-1: Contribution of impacts on the carbon footprint of iron-based coagulants

Table D-1: Carbon footprint of iron-based coagulants investigated

Product	Carbon footprint (kg CO_2-eq/kg product)	Active ingredient content (g Fe^{3+}/kg)	Carbon footprint (kg CO_2-eq/mole Fe^{3+})
$Fe_2(SO_4)_3$	0.029	130	0.013
$FeClSO_4$	0.076	123	0.035
$FeCl_3$ (pickling acids)	0.135	138	0.055
$FeCl_3$ (iron oxide)	0.395	138	0.160

Table D-2: Contribution of impacts to the carbon footprint of iron-based coagulants (kg CO_2-eq/kg product)

Product	Materials	Energy	Transport	Water
$Fe_2(SO_4)_3$	0.0044	0.0073	0.0177	5.0 x 10^{-5}
$FeClSO_4$	0.0626	0.0120	7.7 x 10^{-6}	0.0018
$FeCl_3$ (pickling acids)	0.0829	0.0300	0.0234	-
$FeCl_3$ (iron oxide)	0.38015	0.00302	0.0115	0.000243

Production process of iron-based coagulants

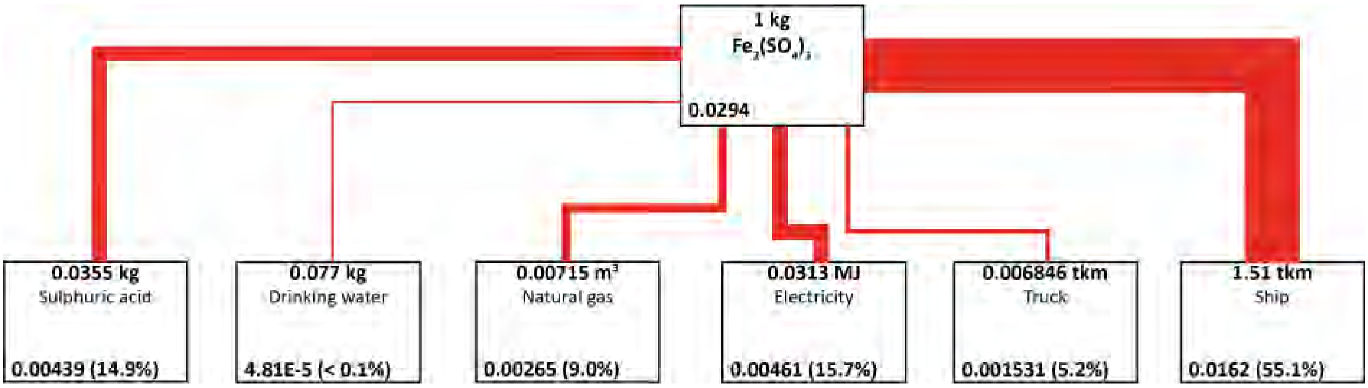

Figure D-2: Overview of the $Fe_2(SO_4)_3$ production process tree

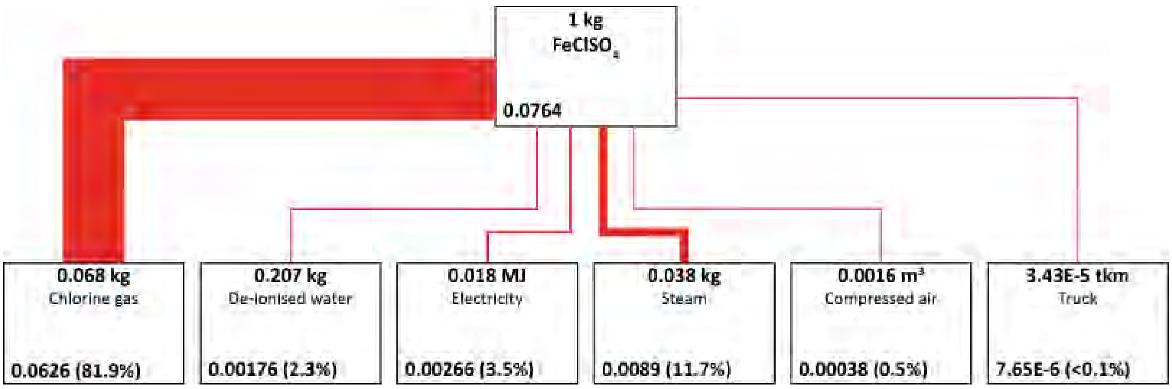

Figure D-3: Overview of the $FeClSO_4$ production process tree

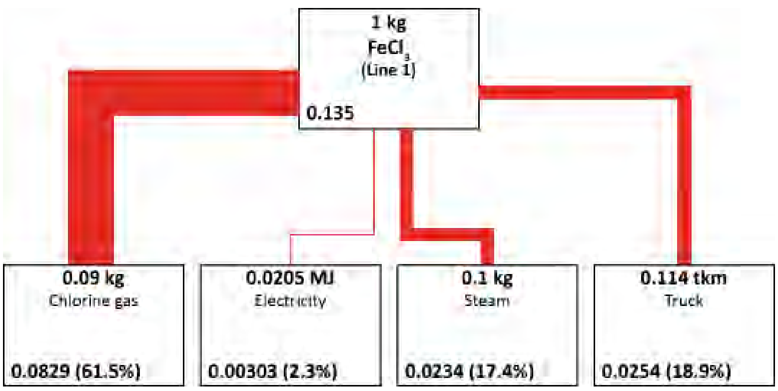

Figure D-4: Overview of the $FeCl_3$ (pickling acids) production process tree

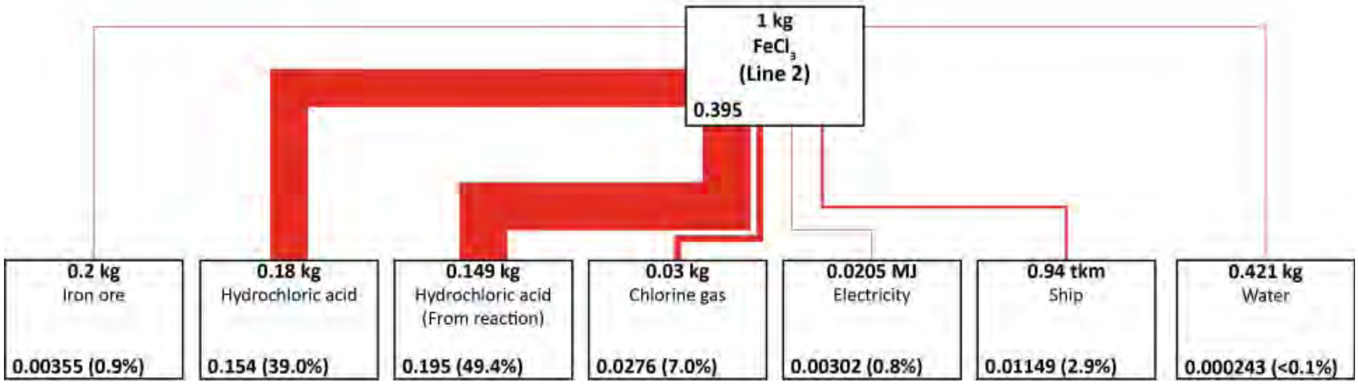

Figure D-5: Overview of the $FeCl_3$ (iron oxide) production process tree

Appendix E:
LCA Results for Sodium Aluminate Coagulants

For the sodium aluminate coagulant production processes, the carbon footprint ranges from 0.07 to 0.219 kg CO_2-eq/mole Al^{3+} (see Table E-1).

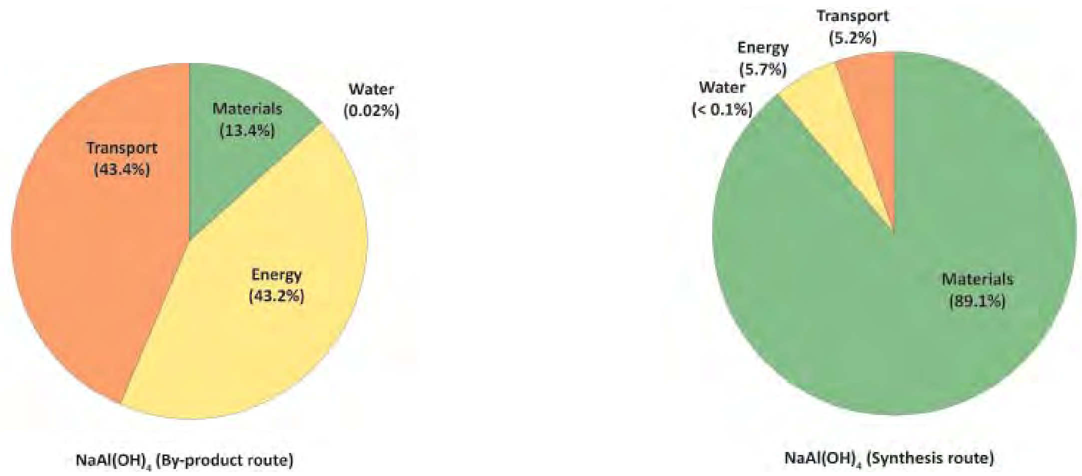

Figure E-1: Contribution of impacts on the carbon footprint of sodium aluminate coagulants

Table E-1: Carbon footprint of sodium aluminate coagulants investigated

Product	Carbon footprint (kg CO_2-eq/kg product)	Active ingredient content (g Al^{3+}/kg)	Carbon footprint (kg CO_2-eq/mole Al^{3+})
$NaAl(OH)_4$ (by-product route)	0.168	100.7	0.070
$NaAl(OH)_4$ (synthesis route)	0.773	95.4	0.219

Table E-2: Contribution of impacts to the carbon footprint of sodium aluminate coagulants (kg CO_2-eq/kg product)

Product	Materials	Energy	Transport	Water
$NaAl(OH)_4$ (by-product route)	0.0225	0.0728	0.0730	3.8×10^{-5}
$NaAl(OH)_4$ (synthesis route)	0.6880	0.0440	0.0405	1.6×10^{-6}

Production process of sodium aluminate coagulants

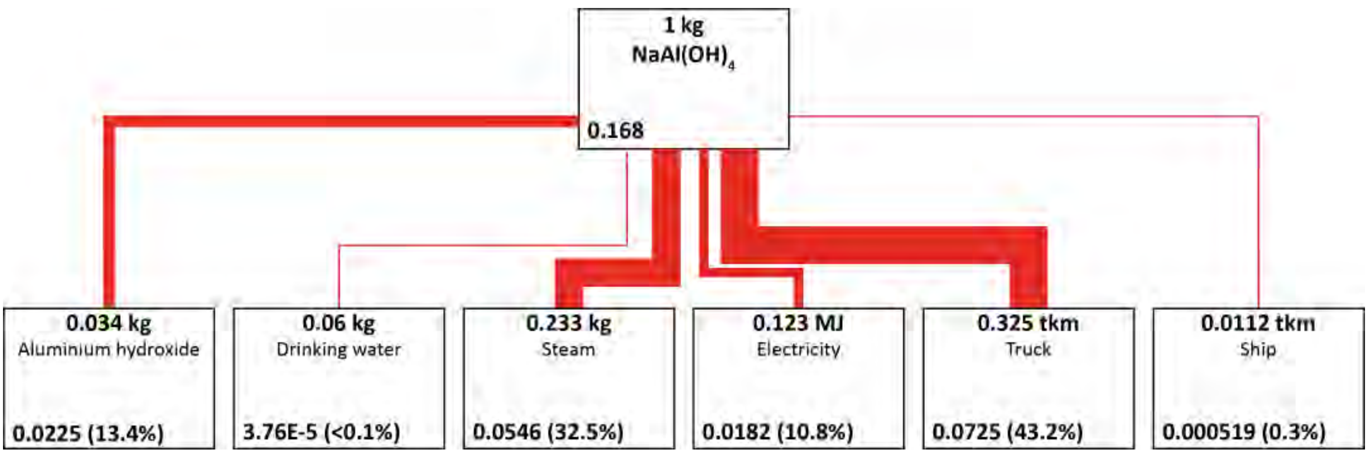

Figure E-2: Overview of the $NaAl(OH)_4$ (by-product route) production process tree

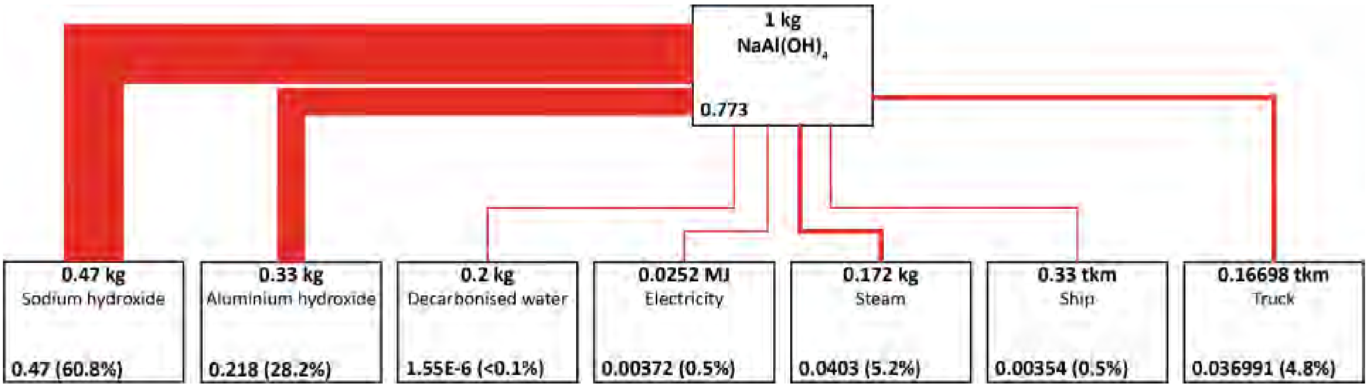

Figure E-3: Overview of the $NaAl(OH)_4$ (synthesis route) production process tree

Appendix F:
Abbreviations and Chemical Symbols

Abbreviations

The following abbreviations are used in this document:

CO_2-eq	carbon dioxide equivalent
GLO	Ecoinvest code indicating a global value
IPCC	Inter-governmental Panel on Climate Change
LCA	life cycle analysis
OCE	Ecoinvest code for oceanic ship
RER	Ecoinvest code indicating a European value
tkm	one tonne kilometre
UCTE	Union for the Co-ordination of Transmission of Electricity

Chemical Symbols

The following chemical symbols are used in this document:

Al	aluminium
$Al(OH)_3$	aluminium hydroxide
$Al_2(SO_4)_3$	aluminium sulfate
Al_2O_3	aluminium oxide
Al^{3+}	trivalent aluminium
AlOH	aluminium hydroxide
Cl_2	chlorine
CO_2	carbon dioxide
Fe	iron
$Fe_2(SO_4)_3$	iron (III) sulfate
Fe^{2+}	bivalent iron
Fe_2ClSO_4	ferro chloride sulfate
Fe^{3+}	trivalent iron

Fe_3O_4	iron oxide
$FeCl_3$	iron (III) chloride
$FeClSO_4$	ferro chloride sulfate
FeO	iron oxide
$FeSO_4\ 7H_2O$	copperas
Fe_xOy	iron oxide
H_2O	water
H_2SO_4	sulfuric acid
HCl	hydrochloric acid
HNO_3	nitric acid
$NaAl(OH)_4$	sodium tetrahydroxyaluminate
$NaNO_3$	sodium nitrate
NOx	nitrogen oxide
PAC	polyaluminium chloride

Editing and layout by Textcetra
www.textcetra.eu

incopa

Avenue E. van Nieuwenhuyse 4
B-1160 Brussels, Belgium
T: +32 2 676 7248 F: +32 2 676 7241
E: info@incopa.org www.incopa.org