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Confidential

Streamlined Cradle-To-Grave Life Cycle Assessment of Cardia Biohybrid™ Products

Cardia Biohybrid™ Products

Cardia Biohybrid™ resin products are compatibilised blends of thermoplastic starch made from renewable, sustainable raw materials such as corn and tapioca starch, with traditional plastics such as polyethylene or polypropylene. The environmental performance described below concerns the Cardia Biohybrid™ BL-F resin, a high starch polymer content masterbatch with 66% renewable content. Cardia Biohybrid™ BL-F has been tailored to intimately blend with polyethylene and polypropylene, and is suitable for a broad range of packaging applications, including flexible film, injection moulding, blow moulding and extrusion applications.

Life Cycle Assessment

The streamlined cradle-to-grave Life Cycle Assessment (LCA), commissioned by Cardia Bioplastics, was performed by the Centre for Design at RMIT University, Melbourne, Australia. LCA is a scientific method of quantifying potential environmental impacts of products or services over their lifetime. The LCA methodology used in this study followed the set of ISO 14040 LCA standards.

Goal, scope, environmental indicators of LCA

The goal of the streamlined LCA study was to quantify and compare the potential environmental impacts of Cardia Biohybrid™ BL-F with low density polyethylene (LDPE) in flexible film and with polypropylene (PP) in injection moulding applications, over the full life cycle (cradle to grave). Development grade Cardia Biohybrid™ X-BL-F masterbatch (66% renewable content) was also included in the study. The plastics processing and end-of-life scenarios were considered for European, North American (USA) and Australian regional scenarios. Cardia Bioplastics commissioned the streamlined LCA in order to communicate independent, credible and transparent environmental information to certain of Cardia's internal stakeholders and customers. A diagram illustrating the key processes included in the LCA is presented in Figure 1.

The system boundaries of the study included all relevant material and energy flows to and from the environment associated with the life cycle stages. The system boundary included

- All processes for extraction and production of raw materials;
- Fertilizer production and emissions during farming;
- Transport and conversion of the materials into products;
- The packaging and distribution of the products to the point of use; and
- The end of life waste management of the materials.

The postconsumer waste management scenarios modelled in this streamlined LCA are landfill and incineration with energy recovery (heat and electricity). The landfill and incineration scenarios reflect current practices that take place in Europe, USA and Australia. Capital equipment, infrastructure,

filling and use processes were not included. The functional unit for the streamlined assessment was 1 kg of finished product.

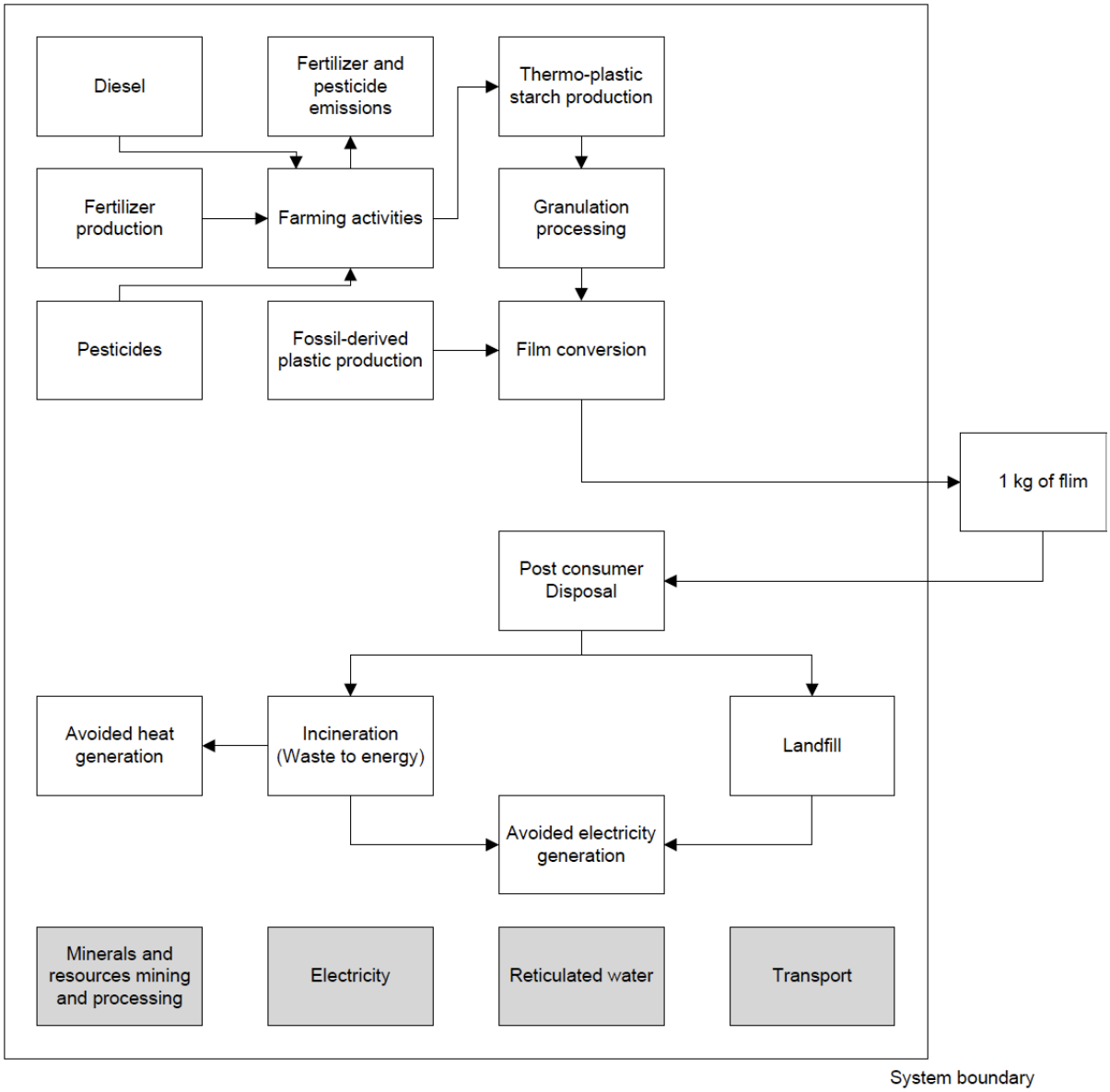

Figure 1. Diagram illustrating key processes considered in LCA

The streamlined LCA study investigated the potential environmental impacts relating to the following environmental and process indicators: global warming potential, cumulative energy demand, minerals depletion and fossil fuel depletion. A definition of these indicators is included in Table1.

Indicators	Unit	Description
Global warming potential	kg CO_2 eq	Climate change effects resulting from the emission of carbon dioxide (CO_2), methane or other global warming gases into the atmosphere – this indicator is represented in CO_2 equivalents.
Cumulative energy demand LHV	MJ LHV	All energy use including fossil, renewable, electrical and fossil feedstock (energy incorporated into materials such as plastic).
Depletion of fossil fuels	MJ Surplus	The additional energy required to extract fossil fuel resources due to depletion of reserves, leaving lower quality reserves behind.

Table 1. Characterisation of environmental and process indicators assessed in LCA study

Results

In summary, the streamlined Cradle-To-Grave Life Cycle Assessment confirms the beneficial environmental profile of Cardia Biohybrid™ Products when replacing commodity polyolefin plastics typically used for flexible film (LDPE) and injection moulding applications (PP).

The streamlined LCA results for global warming potential, cumulative energy demand and fossil fuel depletion categories for a Europe and USA waste management scenario are summarised in Table 2 and 3.

Impact category	Units	LDPE		Biohybrid™ BL-F		% reduction BL-F vs LDPE		Developmental Biohybrid™ X-BL-F		% reduction X-BLF vs LDPE	
Region		USA	Europe	USA	Europe	USA	Europe	USA	Europe	USA	Europe
Global Warming	kg CO_2 eq	2.6	2.9	1.8	1.8	31%	38%	1.4	1.5	46%	48%
Cumulative Energy Demand	MJ LHV	78.3	78.7	47.5	49.1	39%	38%	62.1	63.6	21%	19%
Fossil fuel depletion	MJ Surplus	6.2	5.3	3.2	2.9	47%	45%	2.8	2.7	55%	49%

Table 2. Summary and comparison of streamlined cradle-to-grave LCA results for polyethylene (LDPE), Cardia Biohybrid™ BL-F and developmental grade Cardia Biohybrid™ X-BL-F in a European and USA waste management scenario

Impact category	Units	PP		Biohybrid™ BL-F		% reduction BL-F vs PP		Developmental Biohybrid™ X-BL-F		% reduction X-BL-F vs PP	
Region		USA	Europe	USA	Europe	USA	Europe	USA	Europe	USA	Europe
Global Warming	kg CO2 eq	3.5	3.7	1.8	1.8	49%	51%	1.4	1.5	60%	59%
Cumulative Energy Demand	MJ LHV	74.1	74.8	47.5	49.1	36%	34%	62.1	63.6	16%	15%
Fossil fuel depletion	MJ Surplus	6.4	6.4	3.2	2.9	49%	55%	2.8	2.7	56%	58%

Table 3. Summary and comparison of streamlined cradle-to-grave LCA results for polypropylene (PP), Cardia Biohybrid™ BL-F and developmental grade Cardia Biohybrid™ X-BL-F in a European and USA waste management scenario

Figures 2 and 3 illustrate the environmental benefit of Cardia Biohybrid™ resins replacing traditional polyolefin resins in a European waste management scenario. The LCA results of polyethylene (LDPE) and polypropylene (PP) are compared to Cardia Biohybrid™ BL-F and Cardia Biohybrid™ X-BL-F.

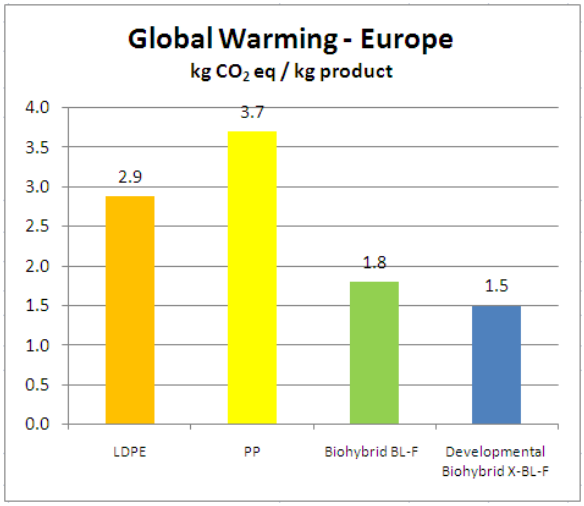

Figure 2. LCA results for global warming potential

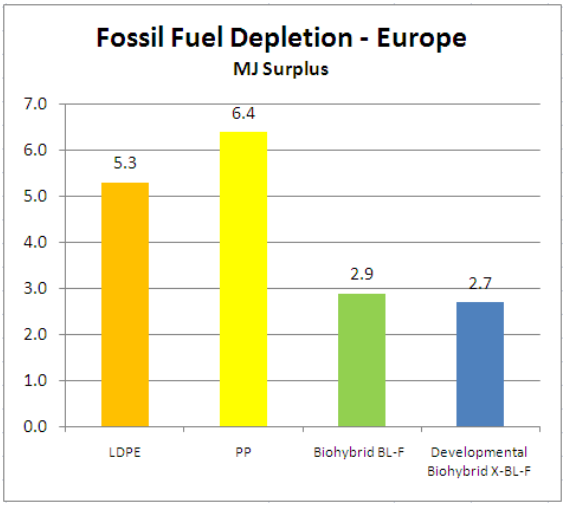

Figure 3. LCA results for fossil fuel depletion

In the European scenario Cardia Biohybrid™ BL-F resin lowers the contribution to global warming by up to 51% for polyethylene and up to 59% for polypropylene.

Fossil fuel depletion can be reduced by more than 49% by replacing polyethylene with Cardia Biohybrid™ BL-F resin products in a PE application. The reduction versus PP exceeds 58%.

In common applications of polyethylene films and polypropylene injection moulding products Cardia Biohybrid™ resins are typically used in a blend with the traditional polyolefins. Table 4 and 5 summarise and compare the environmental impact of the current Cardia Biohybrid™ BL-F and the development grade Cardia Biohybrid™ X-BL-F when blended in a 50% ratio.

Impact category	Units	LDPE		Blend of 50% Biohybrid™ BL-F and 50% LDPE		% reduction vs LDPE		Blend of 50% Developmental Biohybrid™ X-BL-F and 50% LDPE		% reduction vs LDPE	
Region		USA	Europe	USA	Europe	USA	Europe	USA	Europe	USA	Europe
Global Warming	kg CO_2 eq	2.6	2.9	2.2	2.3	15%	19%	2.0	2.1	22%	25%
Cumulative Energy Demand	MJ LHV	78.3	78.7	63.0	64.2	20%	18%	70.3	71.5	10%	9%
Fossil fuel depletion	MJ Surplus	6.2	5.3	4.6	4.3	25%	20%	4.5	4.1	28%	22%

Table 4. Summary and comparison of streamlined cradle-to-grave LCA results for polyethylene (LDPE) and typical blends of LDPE with 50% Cardia Biohybrid™ BL-F and Cardia Biohybrid™ X-BL-F in a European and USA waste management scenario

Impact category	Units	PP		Blend of 50% Biohybrid™ BL-F and 50% PP		% reduction vs PP		Blend of 50% Developmental Biohybrid™ X-BL-F and 50% PP		% reduction vs PP	
Region		USA	Europe	USA	Europe	USA	Europe	USA	Europe	USA	Europe
Global Warming	kg CO_2 eq	3.5	3.7	3.0	2.9	16%	22%	2.8	2.7	22%	27%
Cumulative Energy Demand	MJ LHV	74.1	74.8	60.9	62.4	18%	17%	68.2	69.7	8%	7%
Fossil fuel depletion	MJ Surplus	6.4	6.4	5.5	5.1	15%	21%	5.4	5.0	17%	23%

Table 5. Summary and comparison of streamlined cradle-to-grave LCA results for polypropylene and blends of polypropylene with 50% of Cardia Biohybrid™ BL-F and Cardia Biohybrid™ X-BL-F in a European and USA waste management scenario

With regard to global warming potential in a European waste management scenario, Cardia Biohybrid™ BL-F offers an improvement of 19% versus LDPE in a typical flexible film application using 50% Cardia Biohybrid™ BL-F resin. The improvement versus PP is 22% in a typical injection moulding application using 50% Biohybrid™ BL-F. Cardia Biohybrid™ X-BL-F will further enhance this improvement to 25% vs LDPE and 27% vs PP.