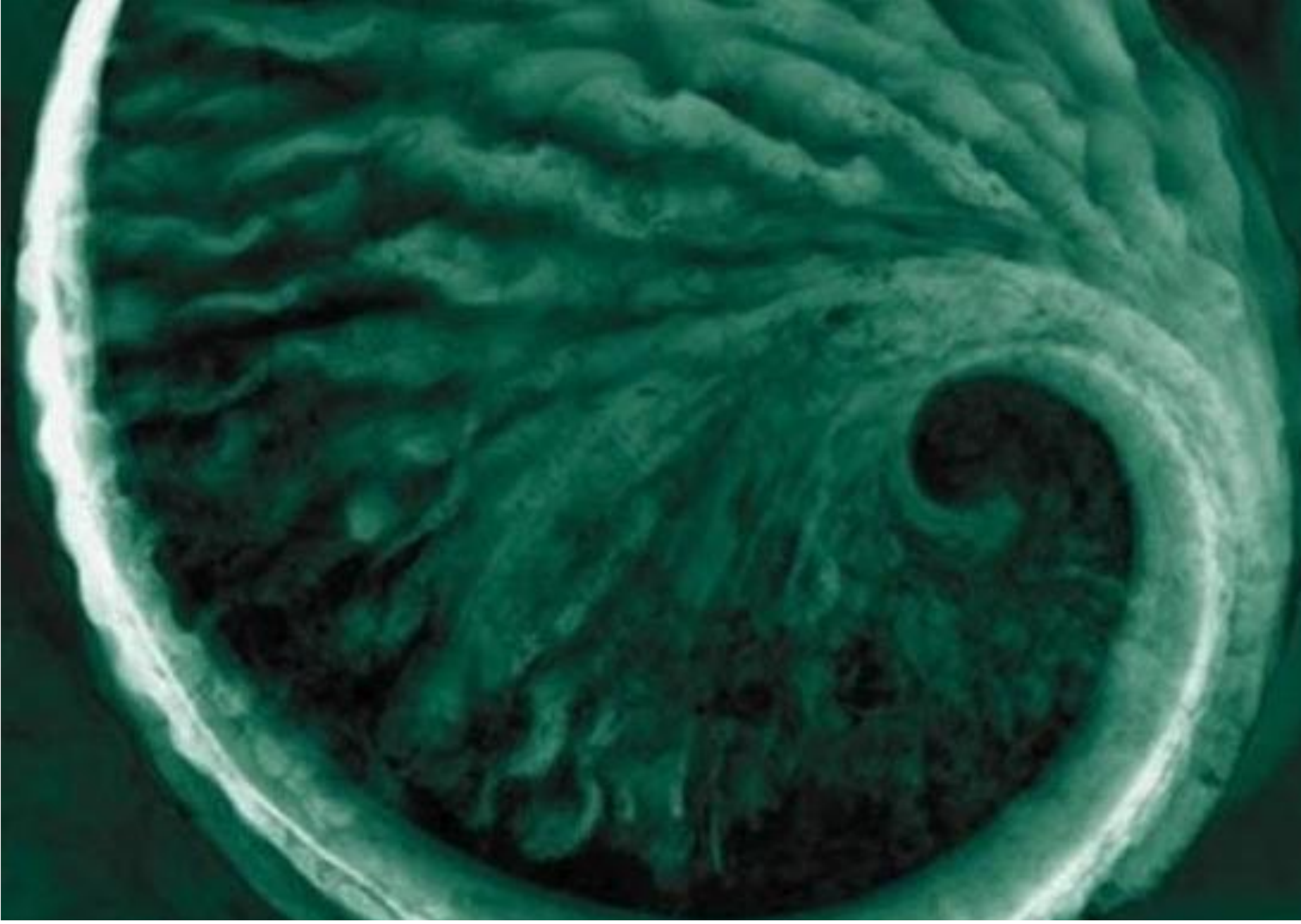

Cradle to Gate Life Cycle Assessment of Caprolactone

Draft Report

11 November 2022

Project No.: 0629134

EXECUTIVE SUMMARY

The goal of this study was to perform a cradle to gate life cycle assessment (LCA) of three polymer products derived from caprolactone, as manufactured by Ingevity. Caprolactone is a cyclic ester, a member of the lactone family, with the formula $(CH_2)_5CO_2$. Its monomer is used in the production of highly specialised polymers that have applications in various economic sectors, eg suture material in surgery, speciality polyurethanes and additive for resins. Three of these polymer groups are the focus of study for this LCA: caprolactone polyols; thermoplastics; and lactide copolymers.

These products are all manufactured at Ingevity's site in Warrington, United Kingdom. The functional units and reference flows for these products are: (i) 1000 kg of caprolactone monomer; (ii) 1000 kg of caprolactone polyols polymer; (iii) 1000 kg of caprolactone thermoplastics polymer; and (iv) 1000 kg of caprolactone-lactide copolymer.

The target audience for the study includes Ingevity's staff, its clients and other stakeholders. Consequently, the results of the assessment will support internal and external communication in relation to the environmental performance of Ingevity's caprolactone-based polymer products. The study was conducted according to the requirements of ISO 14040, 14044, and 14067 (ISO, 2006a; ISO, 2006b; ISO, 2018). A third-party critical review was undertaken by LCA expert Michael Levy, from First Environment, Inc (USA).

The environmental performance of the four products, assessed through 13 environmental impact categories, can be seen in Table E.1 (below). For climate change (fossil), the results range between 5.3 and 5.6 MT CO_2 eq/MT. Climate change (CO_2 uptake) shows relatively higher negative results for caprolactone-lactide co-polymer, due to the carbon uptake from maize during crop production (maize is a raw material used in lactide production) but consequently it also has higher burdens for climate change (land transformation) and climate change (biogenic).

Table E.1 Life cycle impact assessment results (FU = 1,000 kg product)

Impact category	Unit	Monomer	Polyol	Thermoplastic	Co-polymer
Climate change, fossil	kg CO_2 eq	5,360	5,650	5,530	5,280
Climate change, biogenic	kg CO_2 eq	276	292	294	310
Climate change, land transformation	kg CO_2 eq	1.29	1.76	1.56	4.73
Climate change, CO_2 uptake	kg CO_2 eq	-256	-261	-271	-553
Human toxicity, cancer	CTU_h	8.05E-06	8.63E-06	7.69E-06	7.25E-06
Human toxicity, non-cancer	CTU_h	2.78E-05	3.24E-05	2.88E-05	3.28E-05
Resource use, energy carriers	MJ	114,000	117,000	116,000	107,000
Resource use, minerals and metals	kg Sb eq	1.71E-03	3.93E-03	1.99E-03	5.49E-03
Acidification	mol H^+ eq	22.1	23.4	22.8	22.9
Water consumption	m^3 depriv.	1,480	1,880	2,250	1,920

Impact category	Unit	Monomer	Polyol	Thermoplastic	Co-polymer
Energy consumption (non-renewable)	MJ	122,282	126,432	125,392	115,585
Energy consumption (renewable)	MJ	3,765	5,020	4,928	8,050
On-site waste generation	kg	106	98.9	109	90.5

Production of the monomer is the main hotspot for the three polymer product groups, while the main hotspots identified in the production of monomer itself is cyclohexanone used in the manufacturing process. Hydrogen peroxide makes a lower, but significant, contribution to the total burdens. Energy use (mainly steam and natural gas) also makes a significant contribution to the total burdens and would have been higher were it not for the use of green electricity on-site. The initiators make a lower, but still noticeable contribution, especially for polyol and thermoplastics, while packaging is rather more relevant for the polyols.

Based on these results, it is observed that cyclohexanone is the main hotspot. Further investigation regarding alternative sources of cyclohexanone (geographically and technologically) may be worth exploring to examine options to reduce the footprint of the caprolactone product groups assessed. Moreover, expanding renewable sources of other energy inputs (green tariffs) would also deliver environmental benefits, eg changing from natural gas to a biomass source to make steam.

For the sake of completeness, the quality of the study could be improved by expanding data collection to fill the data gaps mentioned throughout this report, eg tracing transport distance for nitrogen or seeking the environmental profile of certain raw materials from suppliers (eg for catalysts and initiators).