Universiteit Utrecht

Faculty of Geosciences
Copernicus Institute of Sustainable Development

biobased performance materials

Environmental assessment of high-impact polylactic acid

Martijn Broeren (m.l.m.broeren@uu.nl), Li Shen, Ernst Worrell

INTRODUCTION AND OBJECTIVES

Polylactid acid (PLA) is one of the most significant fully biobased polymer which utilizes a novel chemical structure, as opposed to 'drop-in' biobased polymers. However, it is a relatively brittle plastic, which limits its application areas. Therefore, ongoing research is developing *high-impact PLA* (HIPLA) through compounding with additives or copolymerisation, aiming to improve PLA's impact resistance while maintaining its high modulus. However, adding additives or copolymers could lead to higher environmental impacts.

The aim of this study is to understand the trade-offs between the improved mechanical properties of HIPLA and its increased environmental impacts. An early-stage life cycle assessment (LCA) is conducted to assess the environmental performance of two HIPLA grades.

METHOD

The LCA studies the greenhouse gas (GHG) emissions and non-renewable energy use (NREU) associated with producing 1 kg of HIPLA (cradle-to-gate).

Two types of HIPLA are investigated:

- Type A: thermoplastic vulcanizates produced by compounding PLA with (6-15%) biobased fatty acid derivatives and a crosslinker;
- Type B: thermoplastic elastomers made by copolymerising lactides with (2-6%) biobased fatty acid derivatives.

HIPLA grades with different ratios of the input materials were produced and tested. Table 1 indicates the compositions considered in the LCA. The mechanical properties of Type A HIPLA were determined with and without annealing. The lab data on the HIPLA compositions, production process and mechanical properties are complemented with (confidential) industry data and publicly available data (Vink et al., 2010; Groot and Borén, 2010; Frischknecht et al., 2005).

An uncertainty analysis is carried out to assess the variability in the LCA's environmental indicators. The uncertainty analysis captures different production systems for PLA (e.g. feedstocks), as well as different estimates for the impact of producing the vegetable oil used to make fatty acid derivatives.

RESULTS AND DISCUSSION

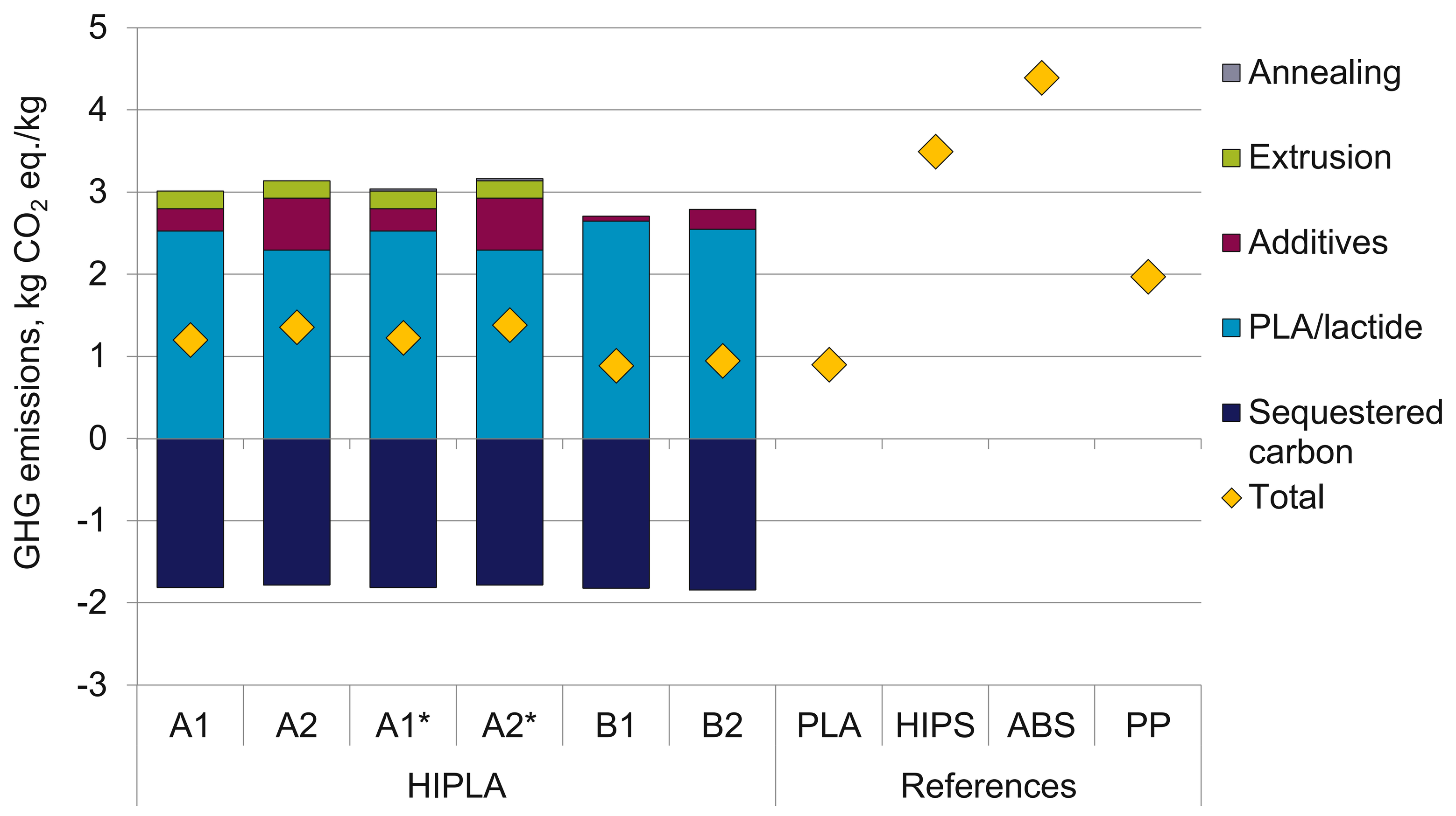

FIGURE 1: Breakdown of cradle-to-gate HIPLA GHG emissions. HIPLA A1 and B1 correspond to low additive amounts (6% and 2%, respectively), and A2 and B2 correspond to high amounts (15% and 6%). A1* and A2* are the annealed versions of HIPLA A1 and A2, respectively.
The GHG emissions of HIPLA Type A are up to 50% higher than pure PLA (biogenic carbon deducted), but still 60% lower than e.g. high-impact polystyrene (HIPS). HIPLA Type B emissions are only 5% higher than PLA due to lower amount of fatty acid derivatives (Table 1).

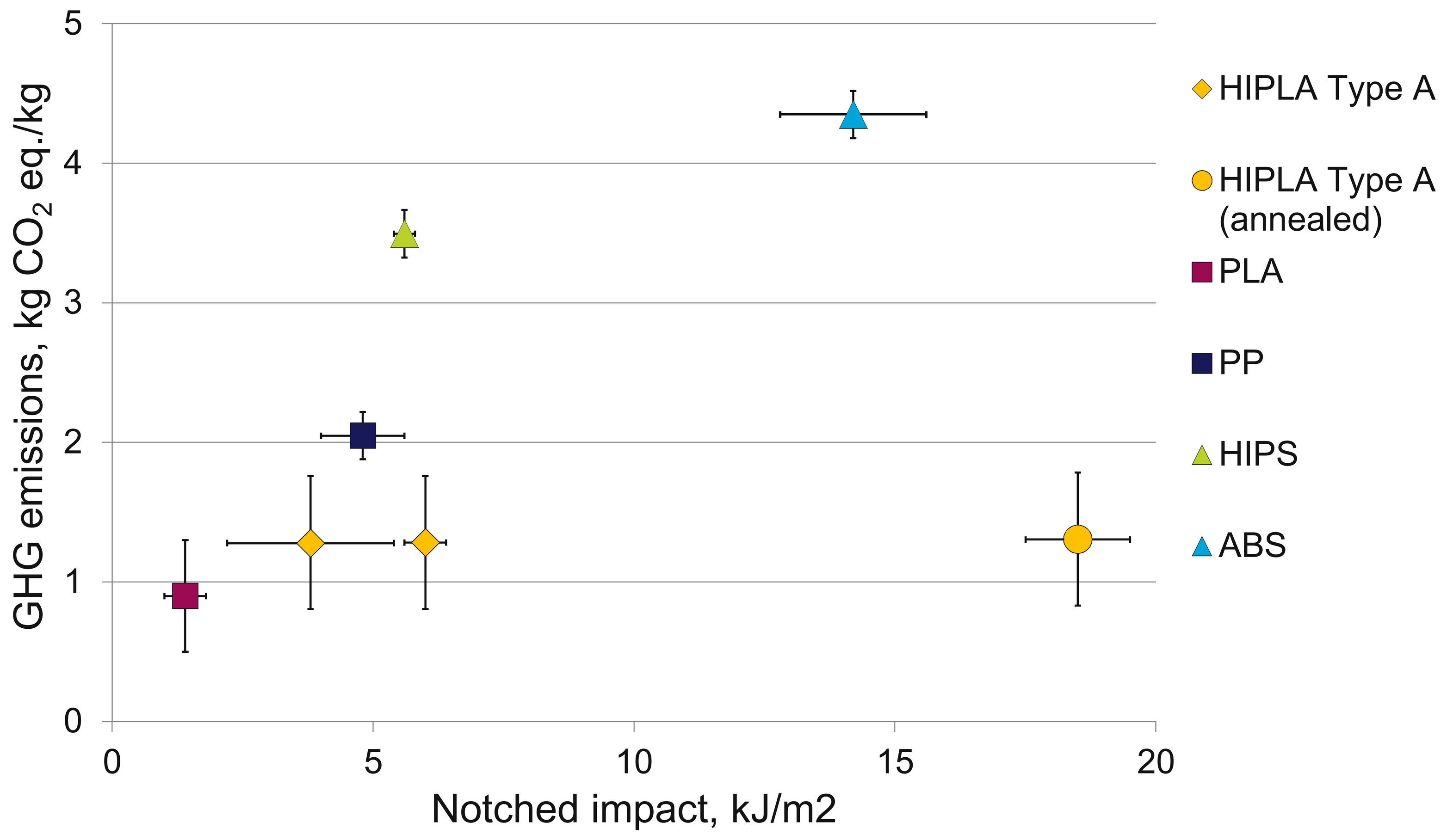

FIGURE 2: Cradle-to-gate GHG emissions (biogenic carbon deducted) and impact resistance of HIPLA. Error bars indicate LCA uncertainty analysis (y-axis) and 95% confidence intervals (x-axis). HIPLA more than doubles notched impact resistance over PLA; can meet or exceed HIPS impact performance at lower GHG emissions.

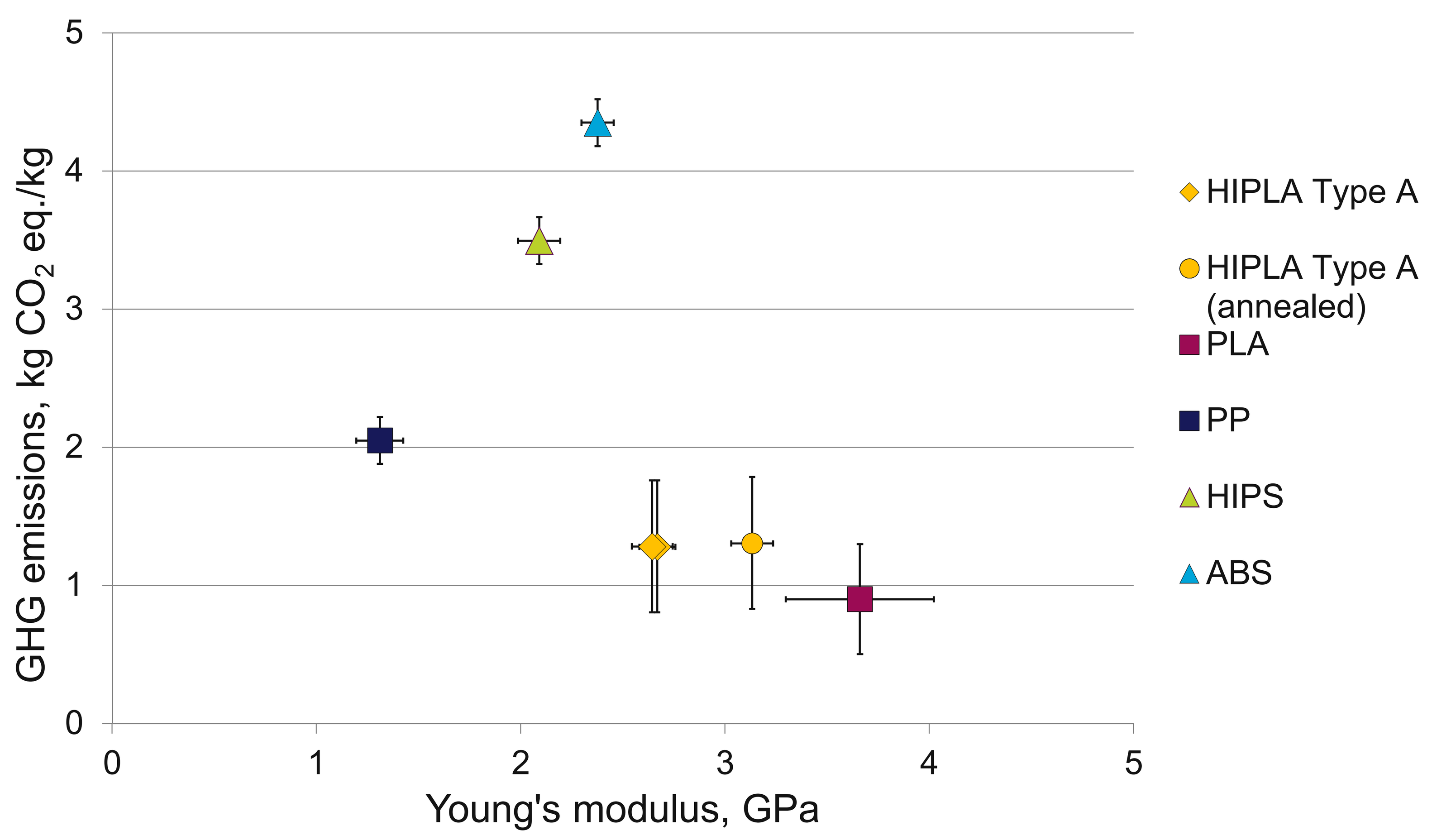

FIGURE 3: Cradle-to-gate GHG emissions (biogenic carbon deducted) and Young's modulus of HIPLA (error bars identical to Fig. 2). HIPLA is more flexible than pure PLA but retains relatively high modulus.

CONCLUSIONS

- GHG emissions for HIPLA production are higher than for PLA (Fig. 1), due to the additional materials and processing steps. The associated NREU is also up to 25% higher for Type A HIPLA compared to PLA, and up to 3% for Type B. The LCA's uncertainty analysis (y-axis error bars in Fig. 2 and 3) shows that different PLA production processes and vegetable oil feedstocks would not result in a different ranking of plastics.
- However, the composition modifications for Type A HIPLA result in greatly improved impact strength (Fig. 2) and elongation and break, and a largely maintained modulus (Fig. 3). These improvements may enable Type A HIPLA to compete with HIPS and ABS in applications where impact strength is important. Compared to these petrochemical plastics, Type A HIPLA can reduce greenhouse gases by 60-75%.
- Future research should focus on implementing HIPLA in real world applications to evaluate its performance in practice and account for differences in density compared to petrochemicals. Furthermore, additional LCA impact categories should be studied to illustrate potential trade-offs, e.g. related to toxicity.

This research was conducted within Biobased Performance Materials, subproject SUSTAIN, and financially supported by the Dutch Ministry of Economic Affairs.
www.biobasedperformancematerials.nl

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G. and Spielmann M., 2005, The ecoinvent database: Overview and methodological framework, Int. J. of LCA, vol. 10, 3–9.
Groot, W.J., T. Borén. 2010. Life cycle assessment of the manufacture of lactide and PLA biopolymers from sugarcane in Thailand. Int. J. of LCA, vol.15-9. 970-984.
Vink, E.T.H., S. Davies, J.J. Kolstad. 2010. The eco-profile of current Ingeo polylactide production. Industrial Biotechnology, vol. 6-4. 212-224