HOCHSCHULE
HANNOVER
UNIVERSITY OF
APPLIED SCIENCES
AND ARTS
–
Fakultät II
Maschinenbau und
Bioverfahrenstechnik

IfBB
Institut für Biokunststoffe
und Bioverbundwerkstoffe

A life cycle assessment perspective: can carbon capture be utilized to manufacture platform chemicals and polymers to the close the carbon loop in a sustainable manner?

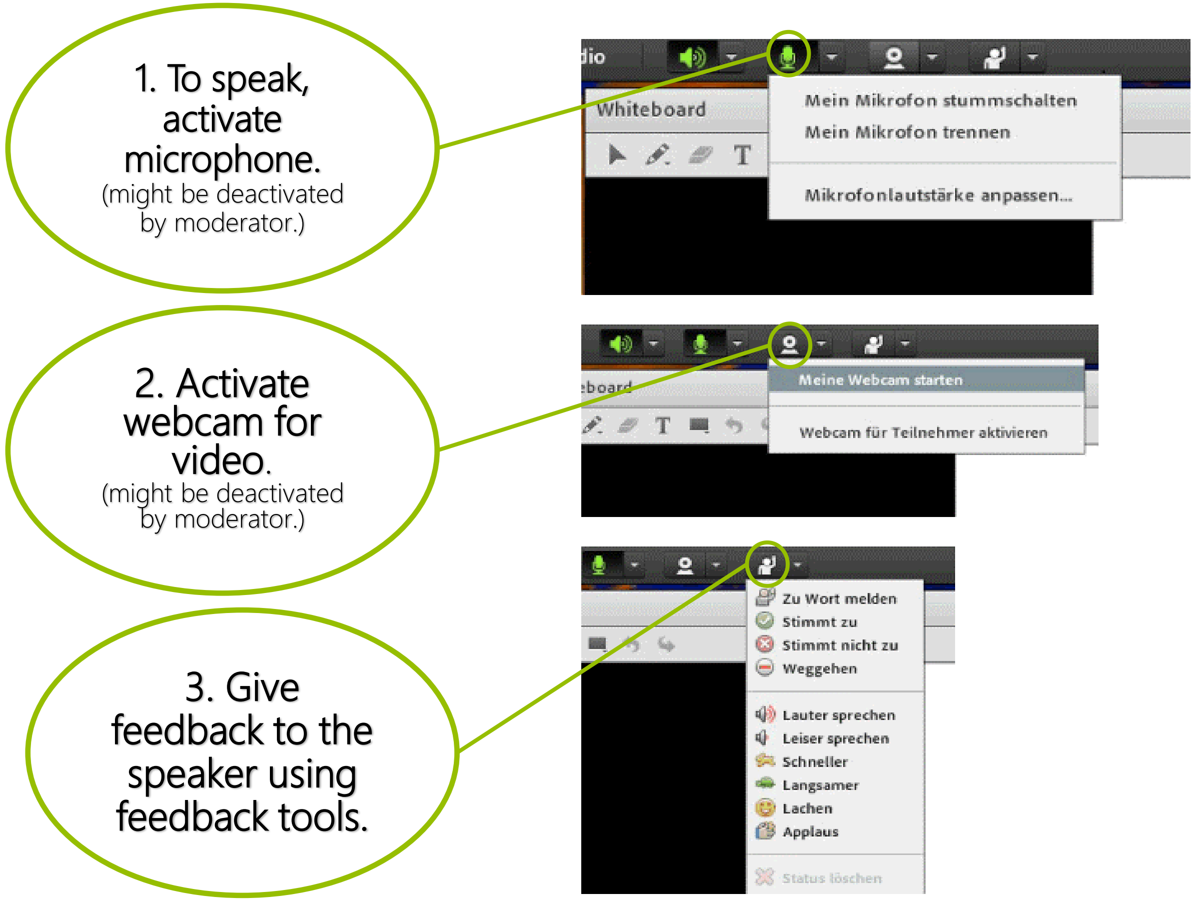
IfBB-Webinarreihe „Biowerkstoffe im Fokus“

Projektmitarbeiter: Vineet Shah
Moderation: Dr. Lisa Mundzeck

22.05.2025

Agenda

- **Duration approximately 30 Minutes**
- **Webinar will be recorded**
- **Questions during the presentation: Please use the “Chat“ module**
- **Questions will be addressed at the end of the presentation**



1. PROJECT INTRODUCTION: BIO4MATPRO
2. MOTIVATION UND GOALS
3. METHODOLOGY
4. PRELIMINARY RESULTS
5. OUTLOOK

Project Introduction:
Bio4MatPro - BL1-6 BioCO2Polymers

IfBB
Institut für Biokunststoffe und Bioverbundwerkstoffe

Project Title:	Development of a multi-enzyme-mediated CO2 conversion to DHA-based polymers
Acronym:	Bio4MatPro – BL1-6 Bio-CO2 Polymers
Duration:	01.09.2022 to 31.08.2025
Funding	SofortprogrammPLUS of the Federal Ministry of Education and Research (BMBF)
Sponsor:	Projektträger Jülich, Forschungszentrum Jülich GmbH (PtJ)
Funding code:	031B1144C

GEFÖRDERT VOM

SOFORT PROGRAMM PLUS

ptJ Projektträger Jülich Forschungszentrum Jülich

Bundesministerium für Bildung und Forschung

Project Introduction:
Project Partners and Goals

RWTH Aachen, Chair of Biotechnology (ABBt)
Prof. Dr. Ulrich Schwaneberg, Dr. Florian Bourdeaux, Vincent Emann
Project Coordination
Dihydroxyacetone Production using a Multienzymatic Cascade

Fraunhofer Institute for Applied Polymer Research (IAP)
Dr. Daniel Zehm, Dr. Antje Lieske, Anna Timofeeva
Polymerization of Dihydroxyacetone into homo- and copolymers

Hochschule Hannover, Institute for Bioplastics and Biocomposites (IfBB)
Prof. Dr. Ing. Andrea Siebert-Raths, Vineet Shah
Material Characterization and Ecological Hotspot Assessment

Nova-Institut GmbH
Dr. Achim Raschka, Narendar Raju Poranki
Economic Hotspot Assessment

Motivation and Goals
Ecological Hotspot Assessment

Goal: Identify the ecological hotspots of the value chain using the Life Cycle Assessment (LCA)

Four main processing steps of the value chain:

- Hydrogen Production
- Carbon Capture
- DHA (Dihydroxyacetone) Production
- Polymerization of DHA

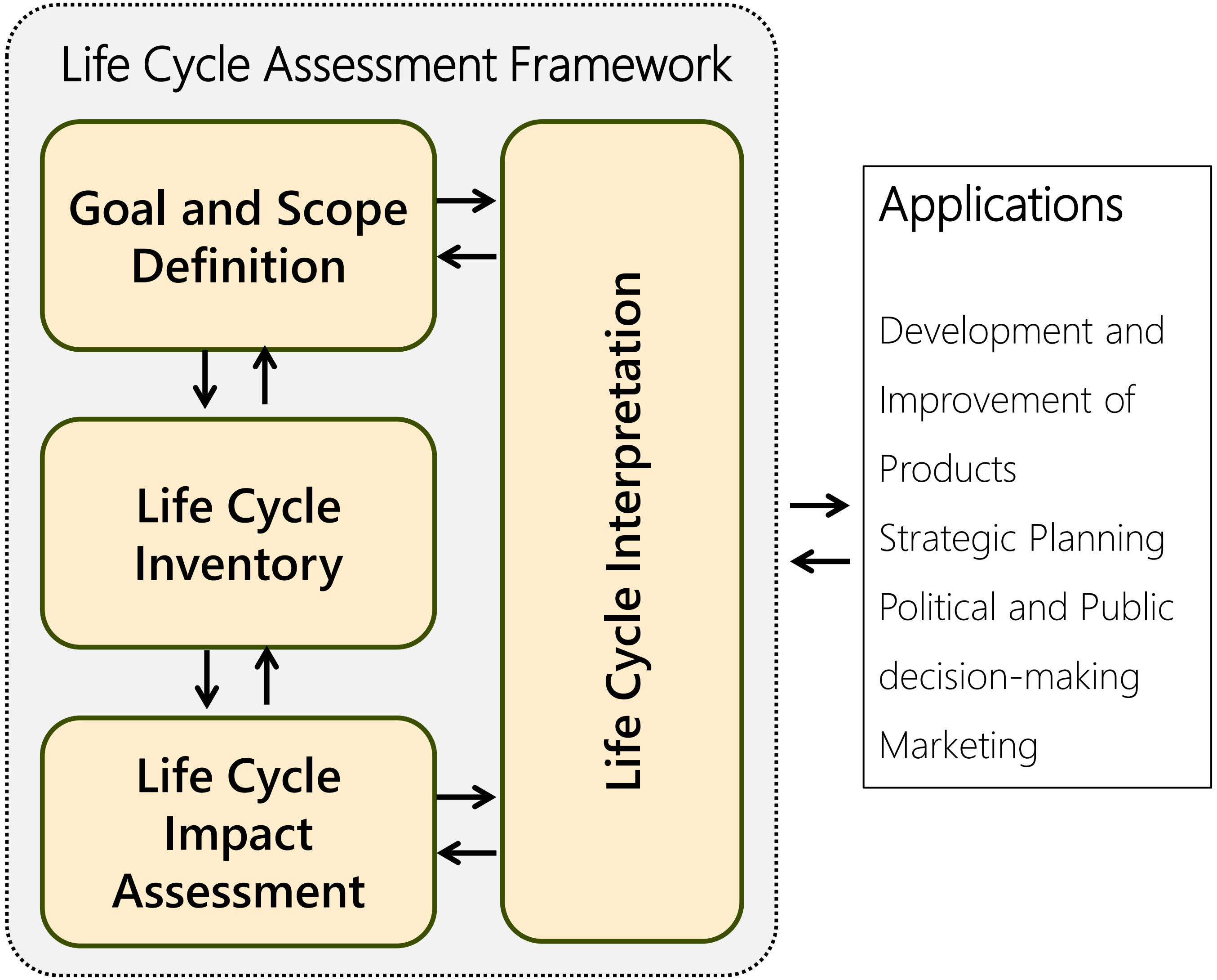
Upscaling of the processing steps from lab to commercial scale

Prospective LCA of the value chain to identify best-case future scenario

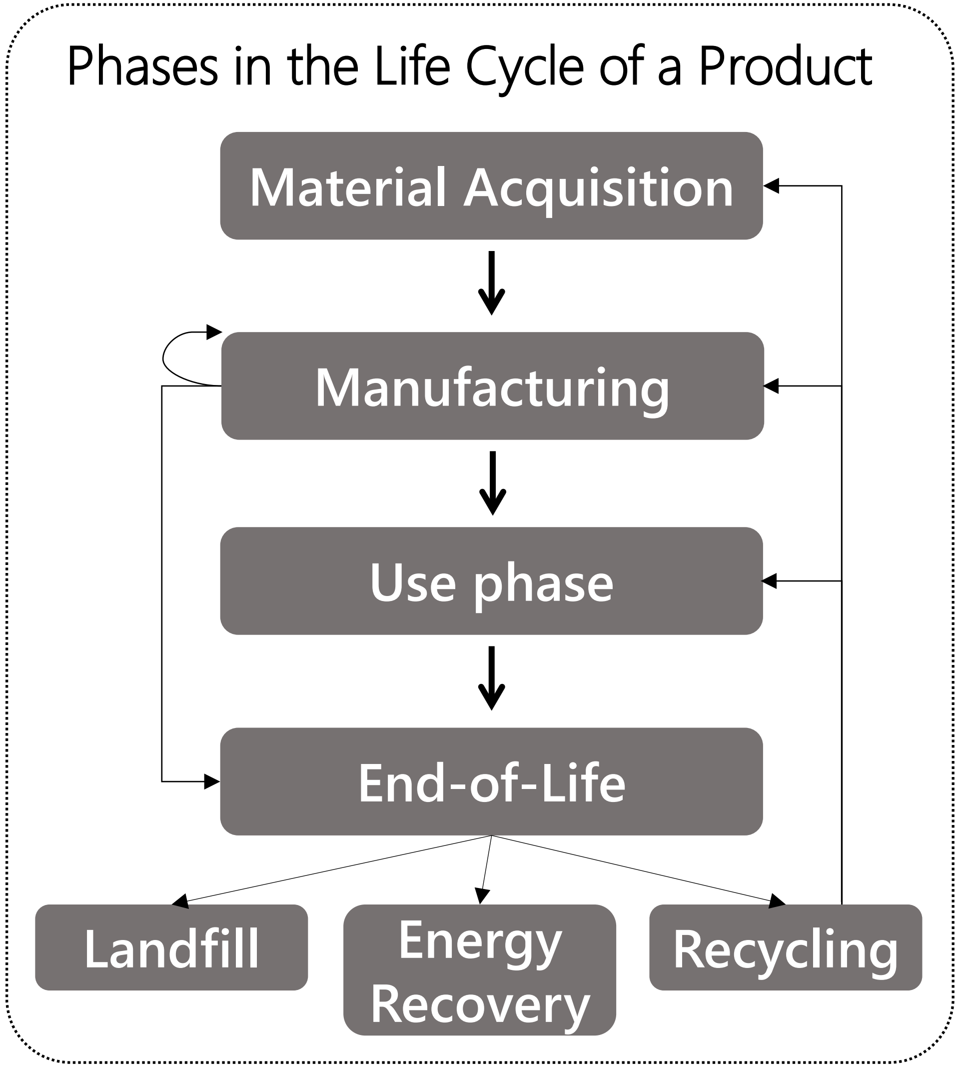
Evaluation of a scenario for the value chain in the Rhine mining area

Methodology
Life Cycle Assessment (LCA): Introduction

IfBB
Institut für Biokunststoffe und Bioverbundwerkstoffe



Source: DIN EN ISO 14040/44; Modified



Source: IfBB

Methodology
Goal and Scope of the LCA

- Functional Unit: 1 kg Polymer manufactured using DHA
- Additional Functions: utilization of captured carbon
- Lab-scale processes only used as reference for scale up

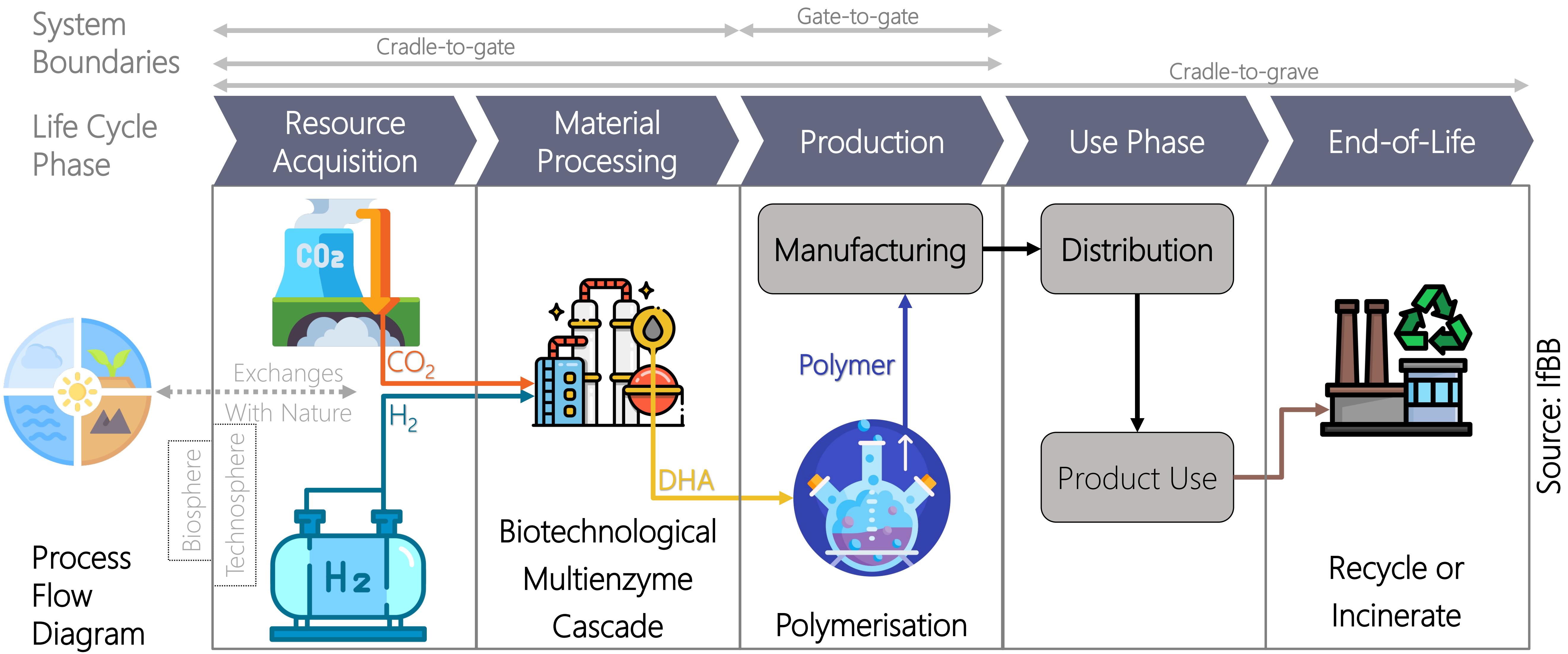
- System Boundaries: Cradle-to-gate + End-of-life
- Manufacturing, Distribution, and Use-phase not analysed

- Compliance: ISO 14040 / 14044 + EU-JRC PEF
- LCA methodology: Attributional + Prospective

- Impact assessment method: Environmental Footprints 3.1
- Life Cycle Inventory modelling: Sphera LCA for Experts
- Background Inventory: Sphera + Ecoinvent

Source: IfBB

Methodology
Scope: Process Flow Diagram & Boundaries

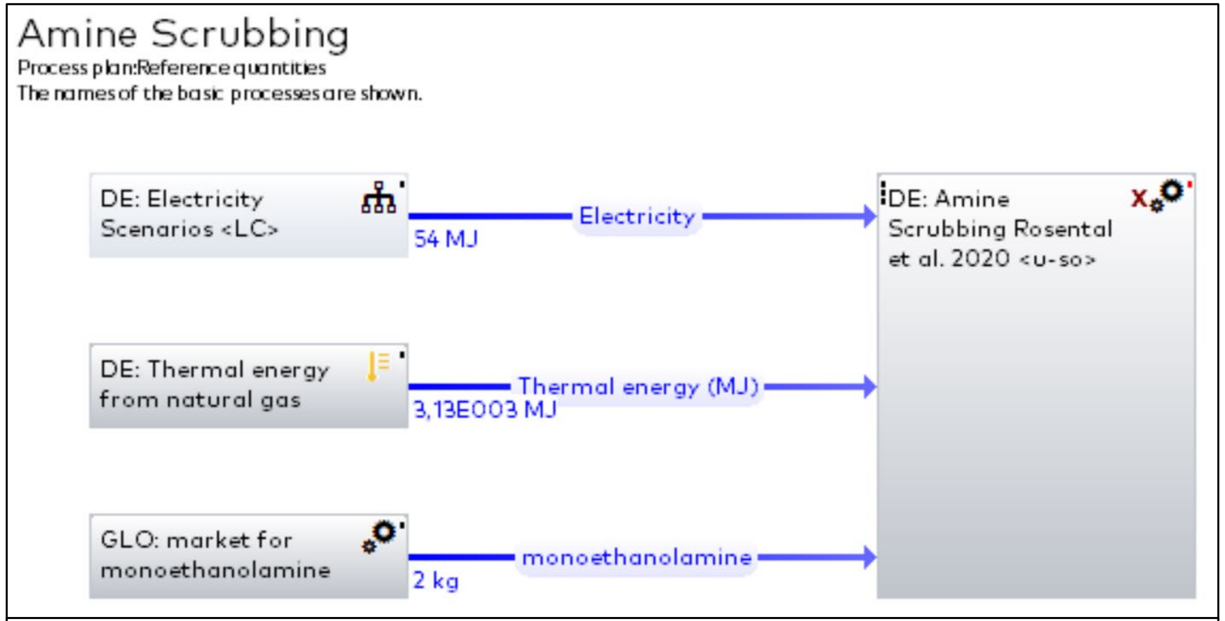


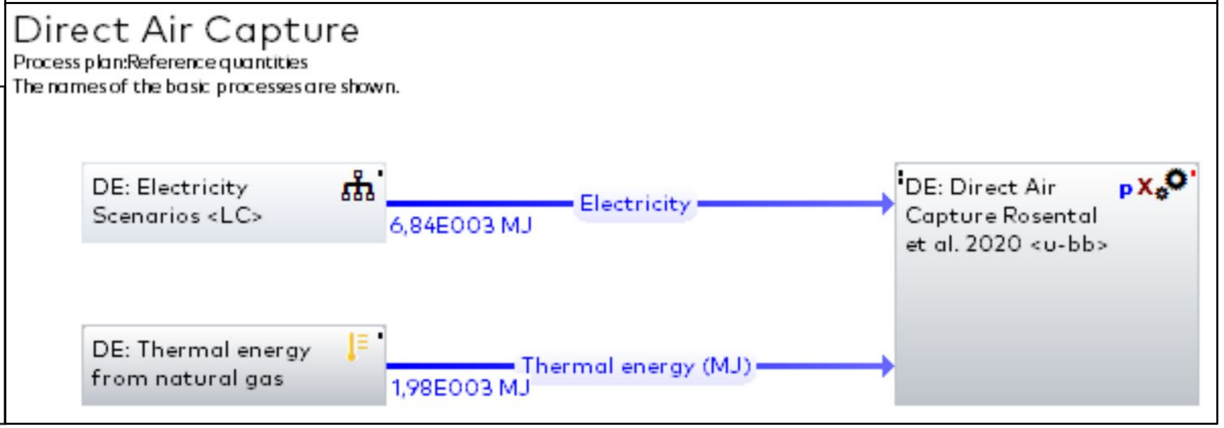
Methodology | Life Cycle Inventory
1 Ton CO_2 Capture | 1 kg Hydrogen

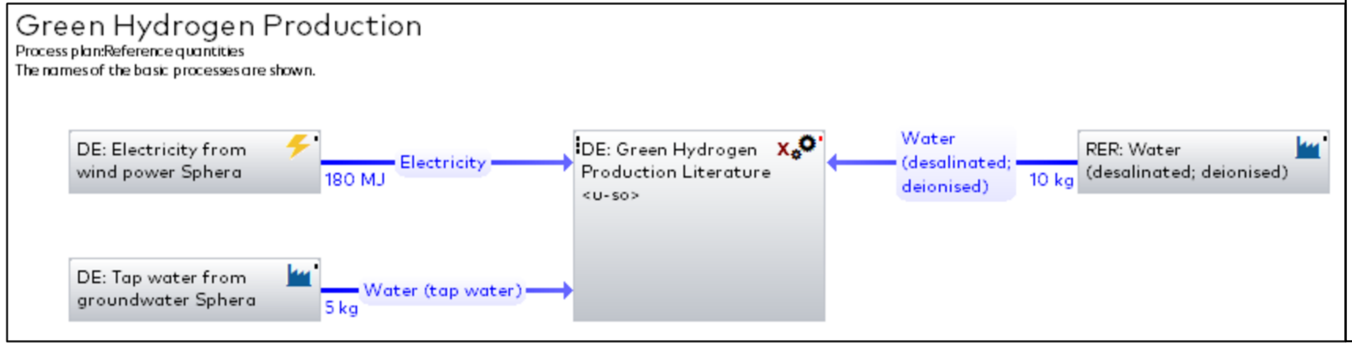
IfBB
Institut für Biokunststoffe
und Bioverbundwerkstoffe

Image source: IfBB

- Carbon capture LCI follows the recommendations of the EU-JRC (Ramirez et al. 2022)
- Two carbon capture inventories have been modelled using Rosental et al. 2020
  - Amine Scrubbing (using Monoethanolamine)
  - Direct Air Capture (Climeworks)
- Hydrogen production modelled using (Alessandro, et al., 2024)

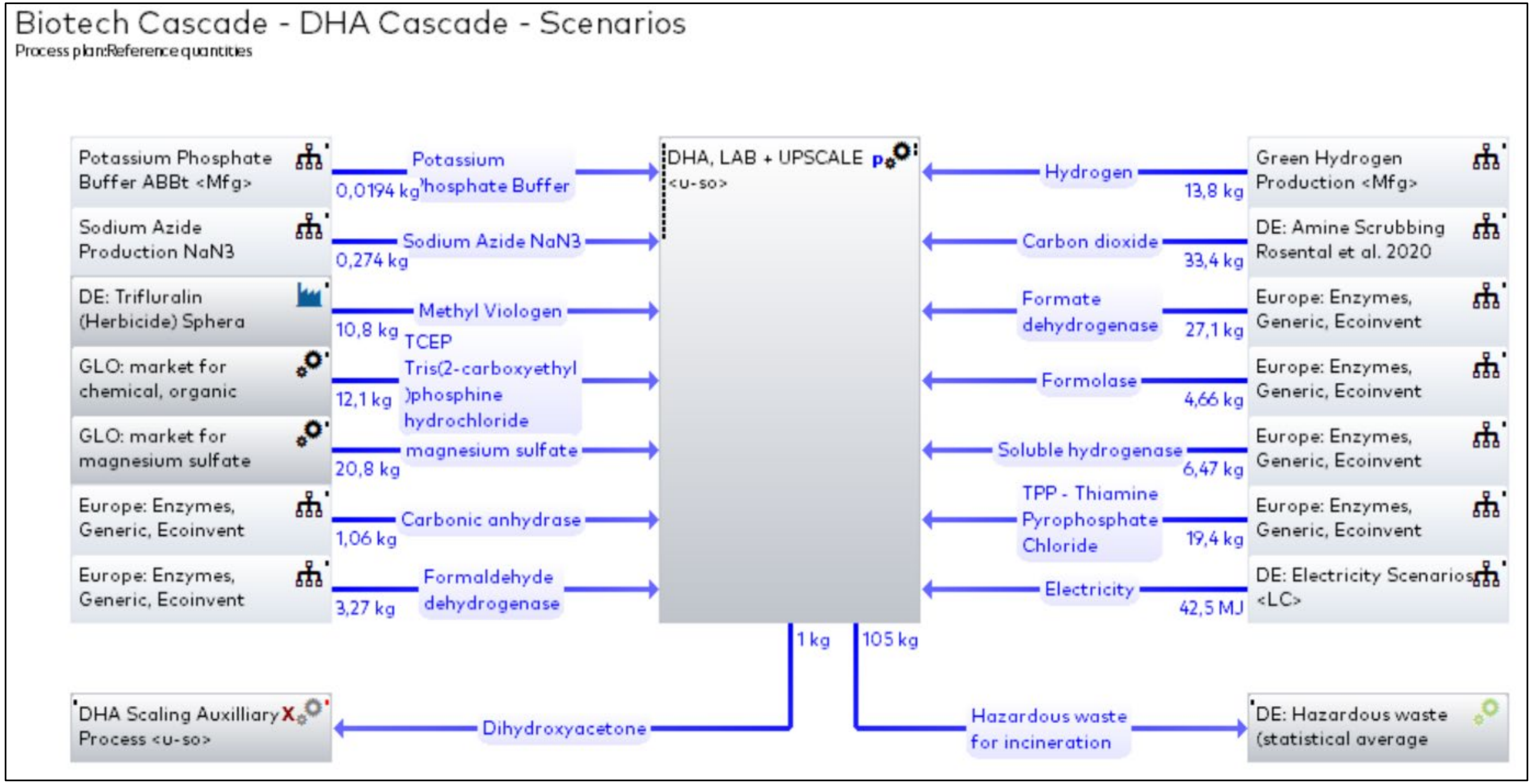






Methodology | Life Cycle Inventory
Lab-Scale Multi Enzymatic Cascade: 1 kg DHA

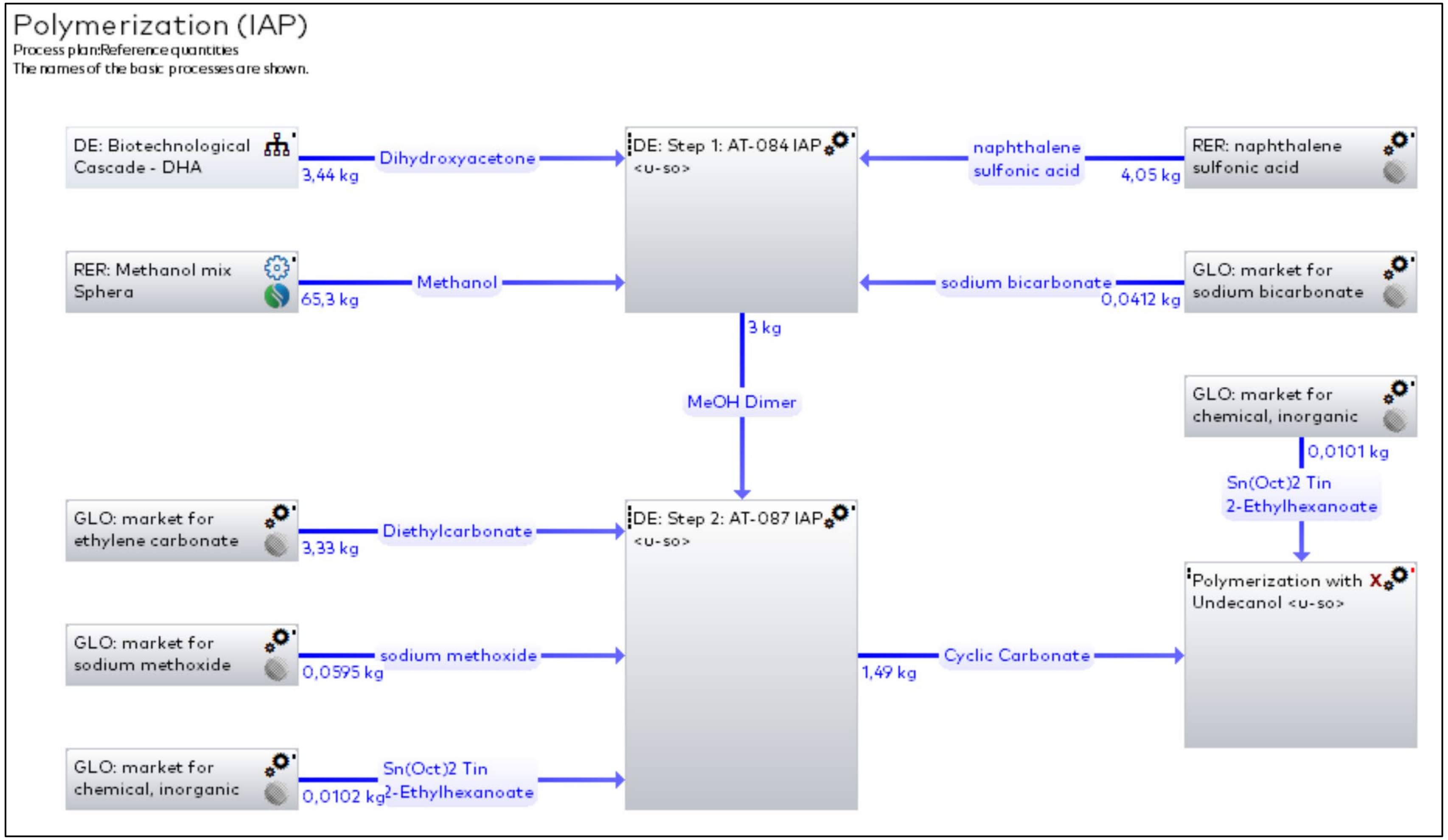
- Lab-scale experimental data from project partners
- Mass flow analysis complete
- Energy flow analysis incomplete
- Inventory data for enzymes and some chemicals – substituted by generic datasets



Source: IfBB

Methodology | Life Cycle Inventory
Lab-Scale Polymerization: 1 kg Polymer

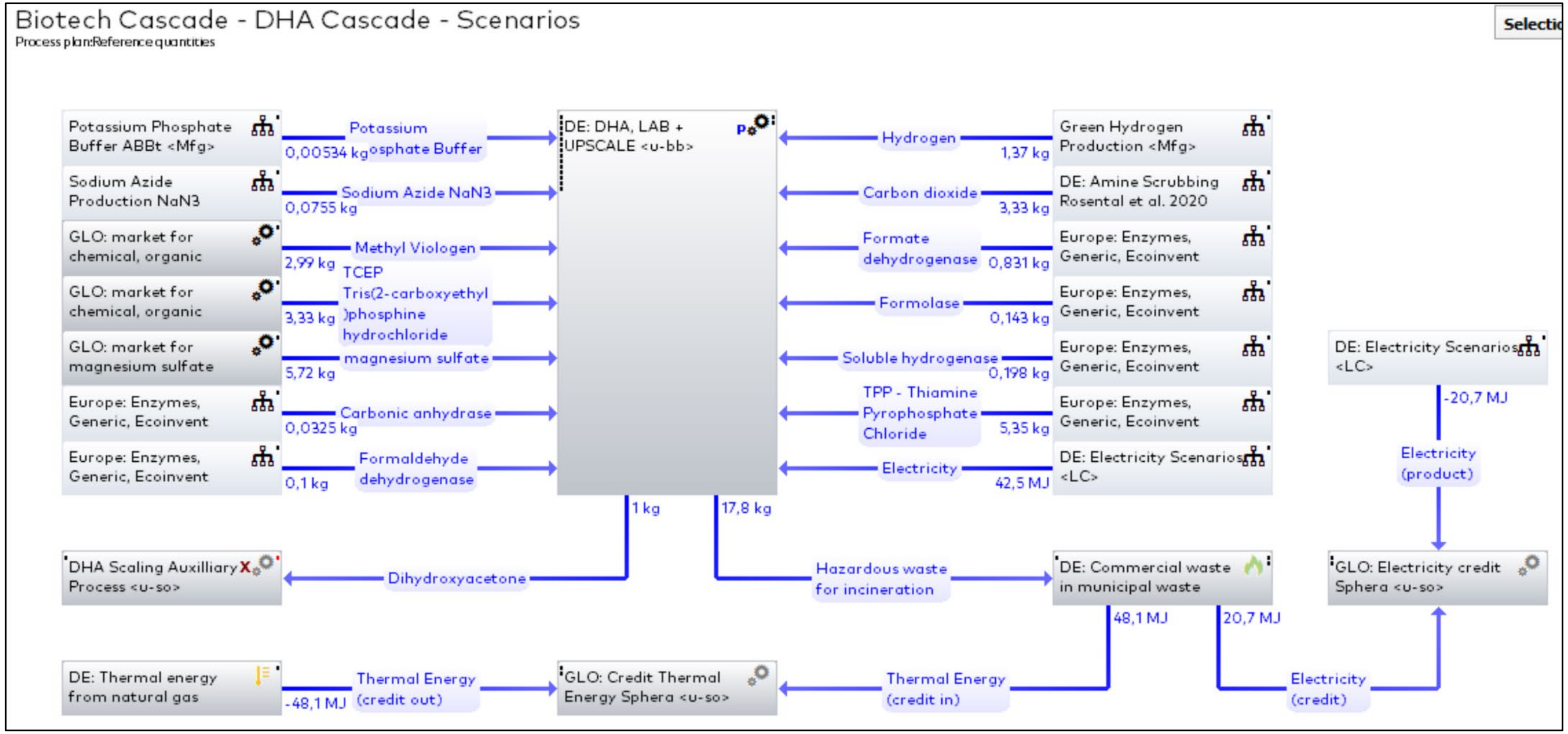
- Inventory model based on lab-scale experimental data from project partners
- Mass flow analysis partly complete
- Energy flow analysis incomplete
- Background inventory data for some organic chemicals still incomplete; currently substituted by generic dataset for organic chemicals



Source: IfBB

Methodology | Life Cycle Inventory
Upscaled DHA Production: 1 kg DHA

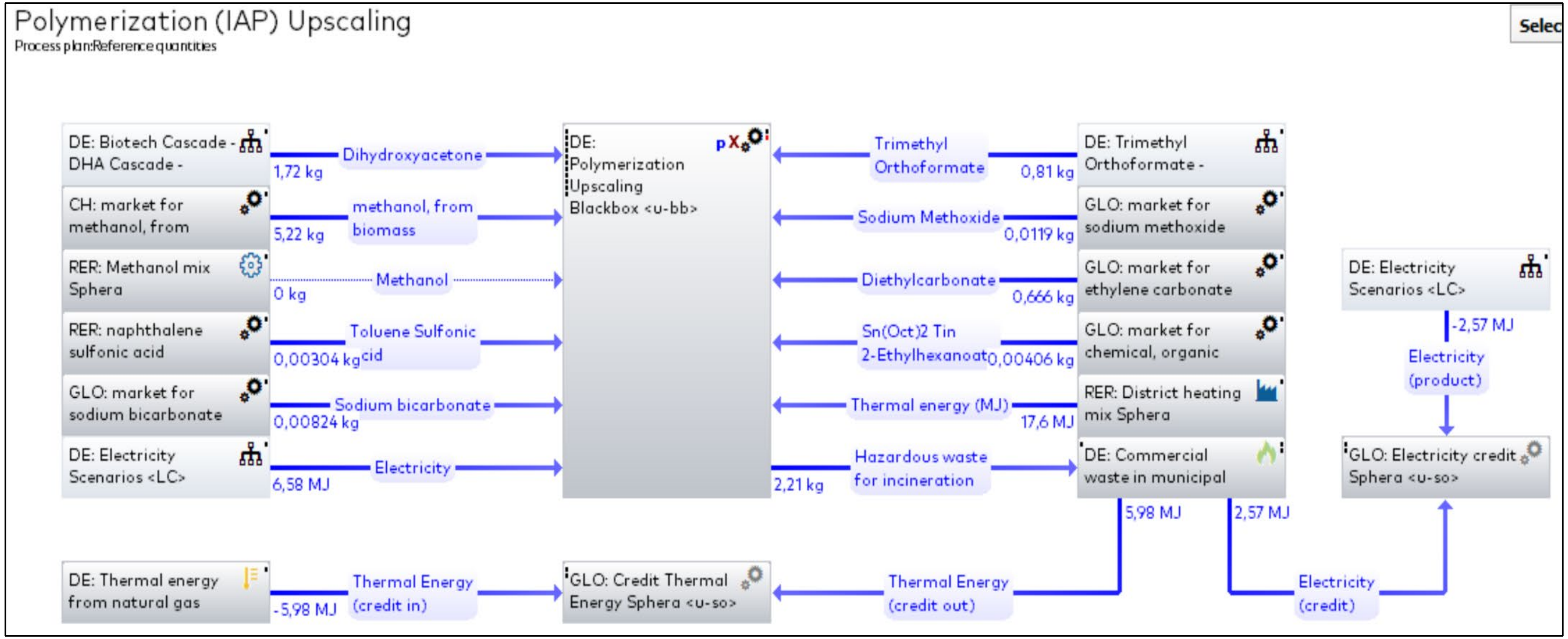
- Scale up by comparing production efficiencies of biorefineries 20 years apart
- 11% reduction in reactants
- 57% reduction in energy consumption
- 73% reduction in consumption of catalysts and enzymes



Source: IfBB

Methodology | Life Cycle Inventory
Upscaled Polymerization: 1 kg Polymer

- Energy requirements obtained from PLA Production Vink, et al., 2015
- Conservative estimates for material flow efficiencies from Piccinno, et al., 2016
- Bio-methanol as solvent
- Thermal treatment of wastes with credit



Source: IfBB

Methodology
Prospective LCA: SIMPL Approach

- Prospective LCA: Systematic scenario-based LCA of technological development in the future

- SIMPL Approach (Langkau et. al. 2023): Scenario-based inventory modelling for prospective LCA

- Scenario Field: Possible future scenarios for carbon capture and utilization by manufacturing polymer materials

- Key Factor are non-inventory parameters that influence the scenario field.
  e.g., maturation of carbon capture technology, enzyme production, development of energy mixes, etc.

- Explorative Scenarios defined using PESTEL Framework for the year 2050 (Burt et al. 2006)
  PESTEL - Political, Economic, Social, Technological, Environmental, Legal factors)

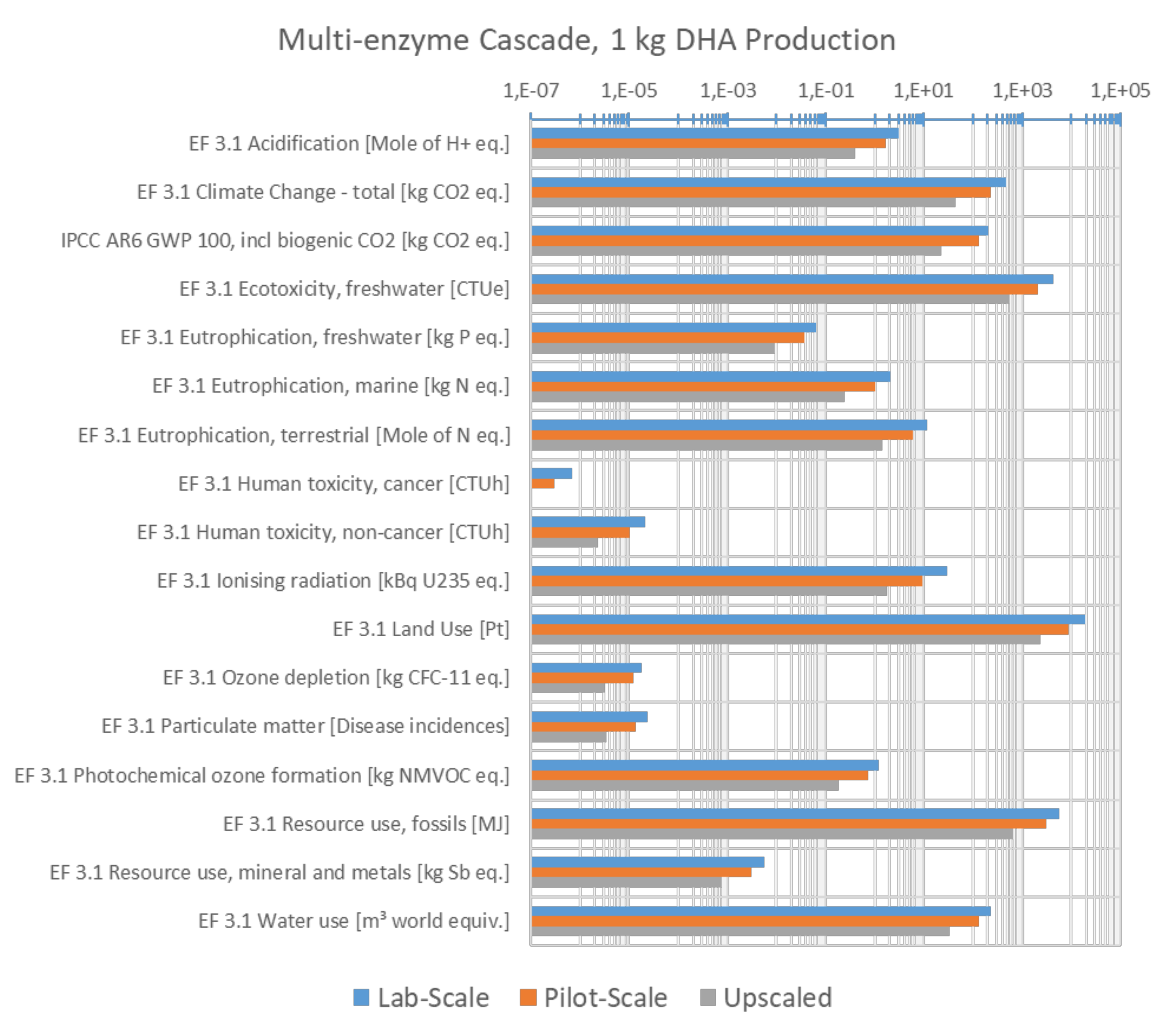
- Normative Scenario: Utilization of carbon captured in the rhine mining area through the production of novel polymer using DHA produced in a biotechnological reactor

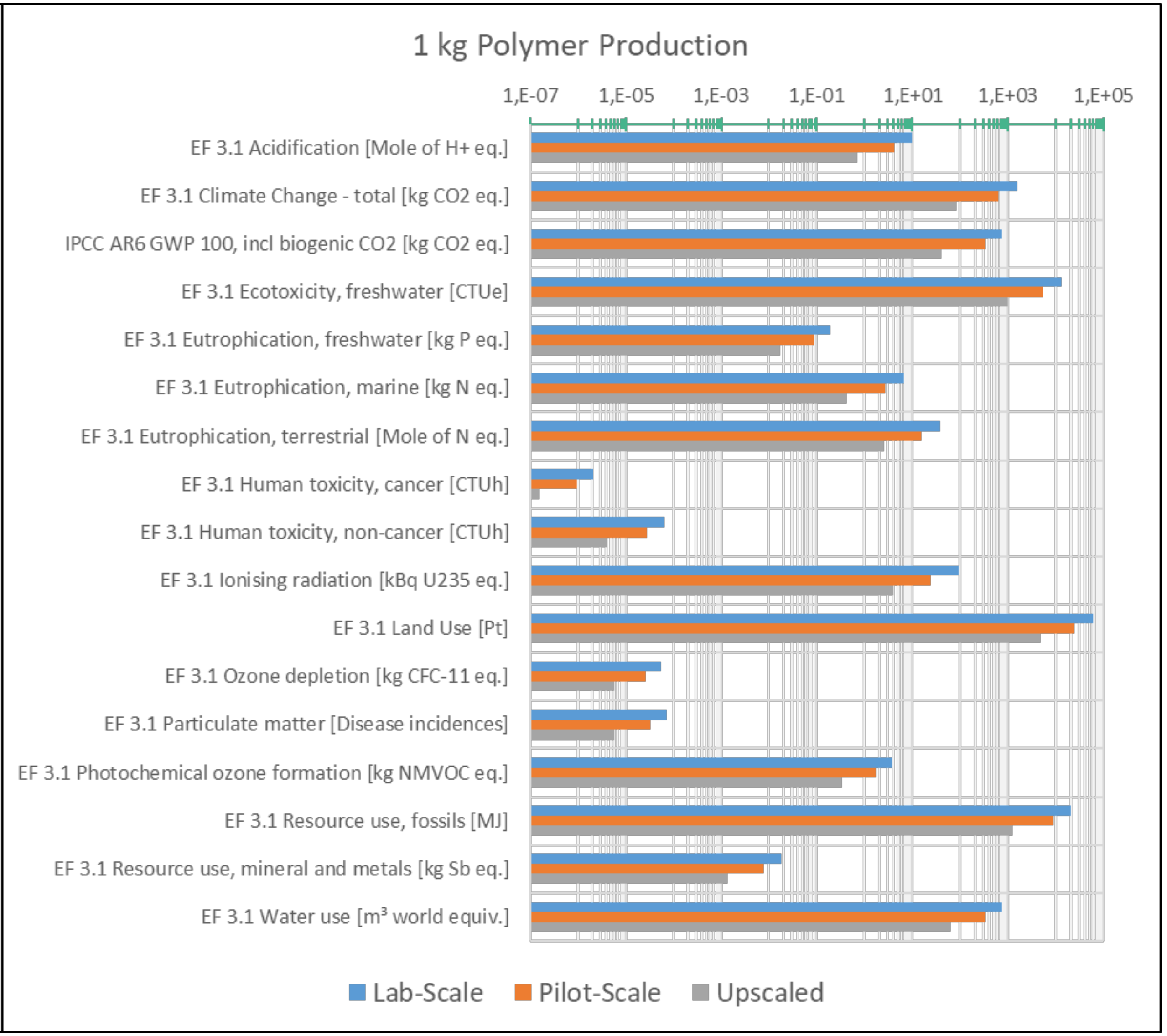
Methodology
Scenarios: SIMPL + PESTEL Framework

- Key factor analysis performed using weighting
- Consistency check performed using causal loop diagram and cross consistency assessment
- Key factors to be assessed: Political Subsidies, Energy Supply, Research Funding, Climate + Emissions Policy
- Key inventory parameters identified based on sensitivity analyses of existing inventory models:
  Electricity Supply, Material Acquisition, Carbon Capture
- Cornerstone (best & worst case) scenarios developed by combining key factors and key inventory parameters
- Normative scenario inventory modelling based on upscaling and cornerstone explorative scenarios

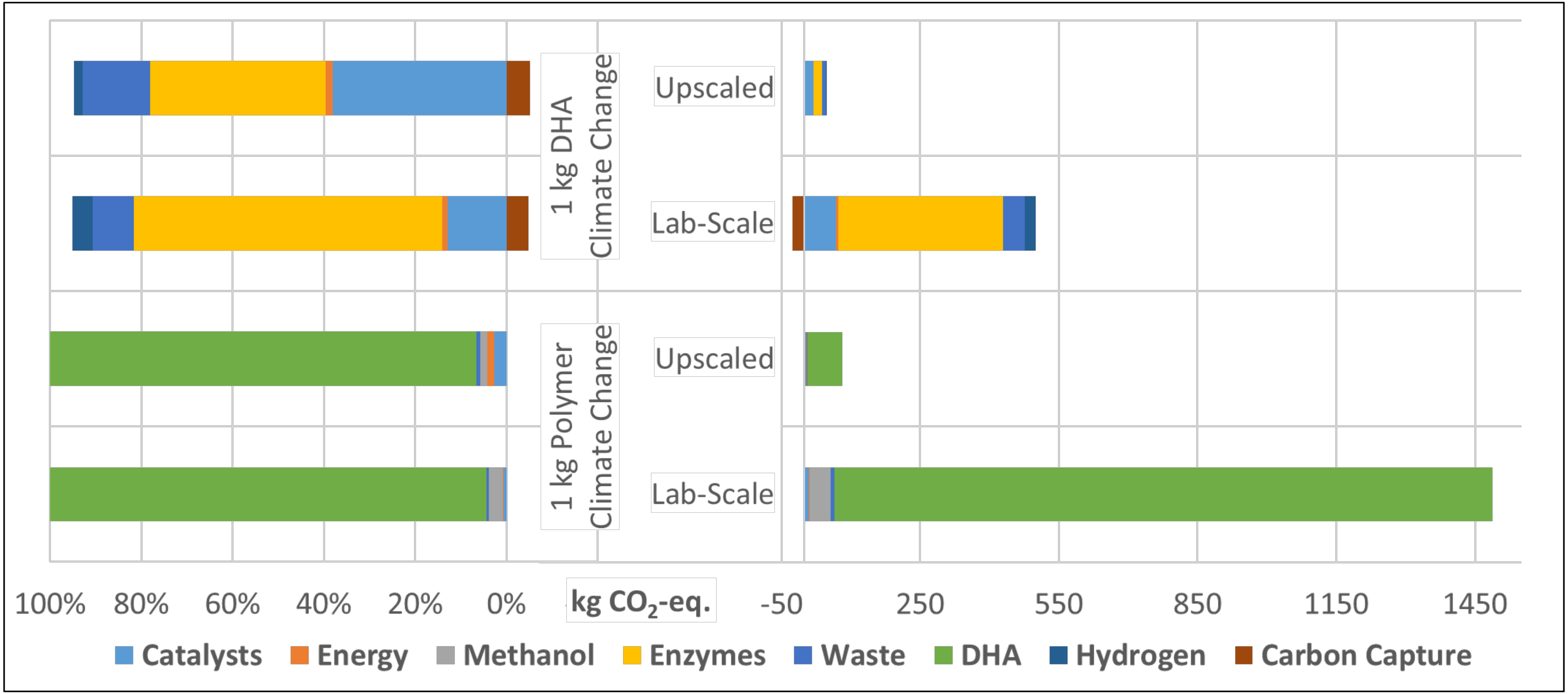
Results | Life Cycle Impact Assessment
Comparison of Lab-Scale and Upscaled Processes

IfBB Institut für Biokunststoffe und Bioverbundwerkstoffe



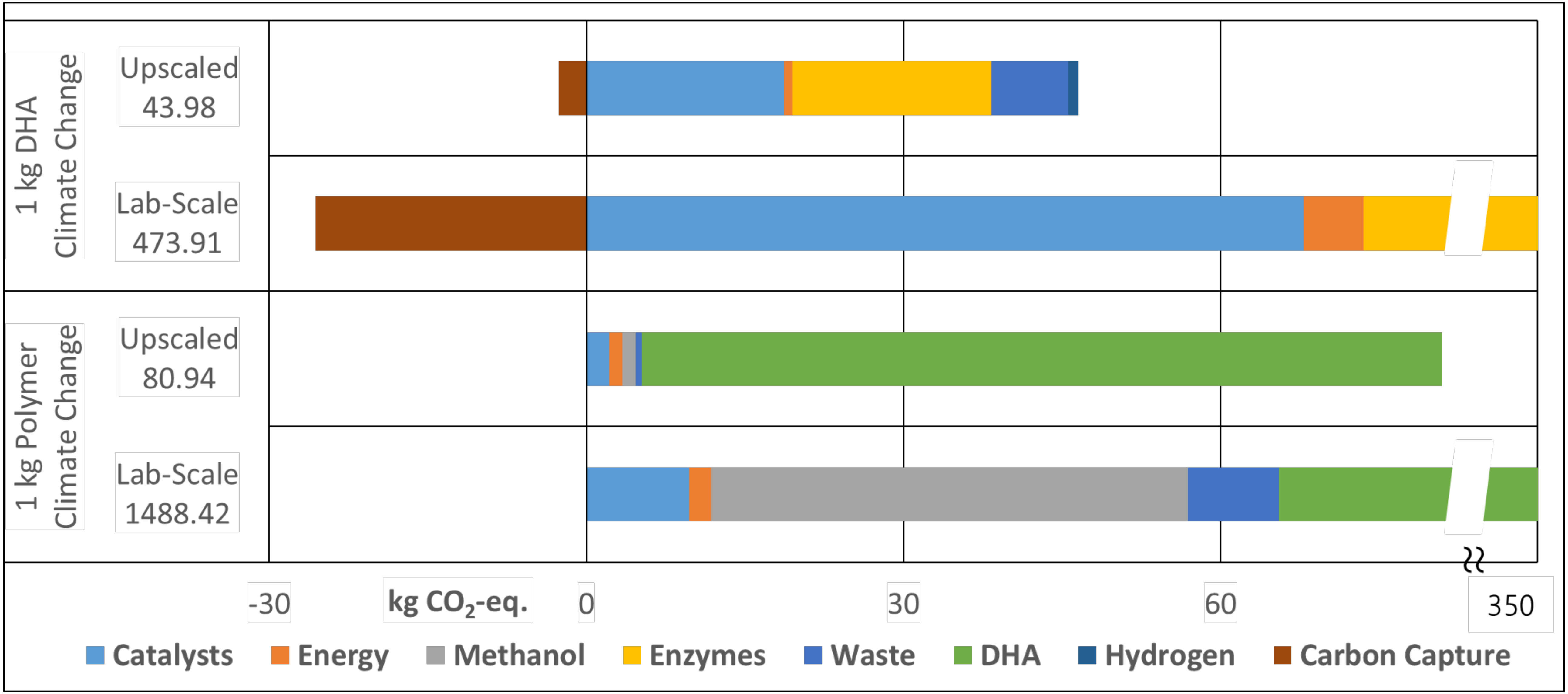


Results | Life Cycle Impact Assessment
Comparison of Lab-Scale and Upscaled Processes



Results | Life Cycle Impact Assessment
Comparison of Lab-Scale and Upscaled Processes

IfBB
Institut für Biokunststoffe und Bioverbundwerkstoffe



Outlook
Limitations and Next Steps

- Uncertainty in upscaling inventory data based on lab-scale inventory data
- Uncertainty in background inventory datasets for prospective LCA
- Explorative scenarios based on probabilistic outcomes do not necessarily reflect future
- Normative scenarios based on wished outcomes do not necessarily reflect probabilistic outcomes
- Characterization factors in impact assessment are based on current environmental outcomes and pathways
- Map upscaled inventory with Scenario Fields, calculate results for Explorative Scenarios
- Model Normative Scenario and calculate LCIA Results and Uncertainty Analyses

Outlook
Conclusions

- Upscaling from lab-scale to commercial scale drastically reduces potential impacts
- Including future energy mixes gives a better perspective of future potential impacts
- Inventory modelling of enzymes remains a challenge in terms of uncertainty assessment
- Upscaling of DHA multi-enzymatic cascade remains a challenge in terms of uncertainty assessment
- Prospective LCA results yields meaningful results in understanding the future impacts of value chains
- Interpretation of LCA results would be helpful in political decision-making process

Projektträger Jülich
Forschungszentrum Jülich

Bundesministerium für Bildung und Forschung

IfBB
Institut für Biokunststoffe und Bioverbundwerkstoffe

Thank you very much for your attention!

Contact:

Hochschule Hannover, University for Applied Sciences and Arts

IfBB – Institute for Bioplastics and Biocomposites

Heisterbergallee 10A

30453 Hannover

Vineet Shah, M. Eng.

Tel.: 0511 / 9296 – 7612

E-Mail: vineet-shailesh.shah@hs-hannover.de

www.ifbb-hannover.de

IfBB-Newsletter - subscribe now!

Nächstes Webinar: 12. Juni um 11 Uhr: Nachhaltiges Calciumcarbonat aus Eierschalen: Technologieentwicklung zur hochwertigen Reststoffnutzung

References

Deutsches Institut für Normung (2021): DIN EN ISO 14040, Umweltmanagement - Ökobilanz - Grundsätze und Rahmenbedingungen (ISO 14040:2006 + Amd 1:2020). = Environmental management - life cycle assessment - principles and framework (ISO 14040:2006 + Amd 1:2020). Deutsche Fassung EN ISO 14040:2006 + A1:2020. Berlin: Beuth Verlag GmbH (Deutsche Norm).

Deutsches Institut für Normung (2021): DIN EN ISO 14044, Umweltmanagement - Ökobilanz - Anforderungen und Anleitungen (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). = Environmental management - life cycle assessment - requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020). Deutsche Fassung EN ISO 14044:2006 + A1:2018 + A2:2020. Berlin: Beuth Verlag GmbH (Deutsche Norm).

Andrea Ramirez Ramirez; Aïcha El Khamlichi; Georg Markowz; Nils Rettenmaier; Martin Baitz; Gerfried Jungmeier; Tom Bradley (2022): LCA4CCU - Guidelines for Life Cycle Assessment of Carbon Capture and Utilisation. Report initiated and financially supported by the European Commission Directorate-General for Energy, 2020.

Rosental, Marian; Fröhlich, Thomas; Liebich, Axel (2020): Life Cycle Assessment of Carbon Capture and Utilization for the Production of Large Volume Organic Chemicals. In Front. Clim. 2, Article 586199. DOI: 10.3389/fclim.2020.586199.

Environmental life cycle assessment (LCA) comparison of hydrogen delivery options within Europe [Report] / auth. Alessandro ARRIGONI [et al.] / Joint Research Center ; European Comission. - Luxembourg : Publications Office of the European Union, 2024. - JRC137953.

From laboratory to industrial scale: a scale-up framework for chemical processes in life cycle assessment [Journal] / auth. Piccinno Fabiano [et al.] // Journal of Cleaner Production / ed. Almeida Cecília Maria, Moreira Maria Teresa and Wang Yutao. - [s.l.] : Science Direct, November 2016. - Vol. 135. - pp. 1085-1097.

A Life Cycle Assessment of Ethanol produced from Sugarcane Molasses [Report] : Master's Thesis / auth. Theka Edward / Chemical Engineering ; University of Cape Town. - Cape Town : University of Cape Town, 2002.

Life cycle assessment of safflower and sugar beet molasses-based biofuels [Journal] / auth. Isler-Kaya Asli and Karaosmanoglu Filiz // Renewable Energy. - [s.l.] : Elsevier, December 2022. - 1 : Vol. 201. - pp. 1127-1138.

Life Cycle Inventory and Impact Assessment Data for 2014 Ingeo™ Polylactide Production [Journal] / auth. Vink Erwin T. H. and Davies Steve // Industrial Biotechnology / ed. Gross Richard A.. - [s.l.] : Mary Ann Liebert Inc., June 11, 2015. - 3 : Vol. 11.

Langkau, Sabine; Steubing, Bernhard; Mutel, Christopher; Ajie, Maulana Permana; Erdmann, Lorenz; Voglhuber-Slavinsky, Ariane; Janssen, Matty (2023): A stepwise approach for Scenario-based Inventory Modelling for Prospective LCA (SIMPL). In Int J Life Cycle Assess 28 (9), pp. 1169–1193. DOI: 10.1007/s11367-023-02175-9.

George Burt; George Wright; Ron Bradfield; George Cairns; Kees Van Der Heijden (2006): The role of scenario planning in exploring the environment in view of the limitations of PEST and its derivatives.