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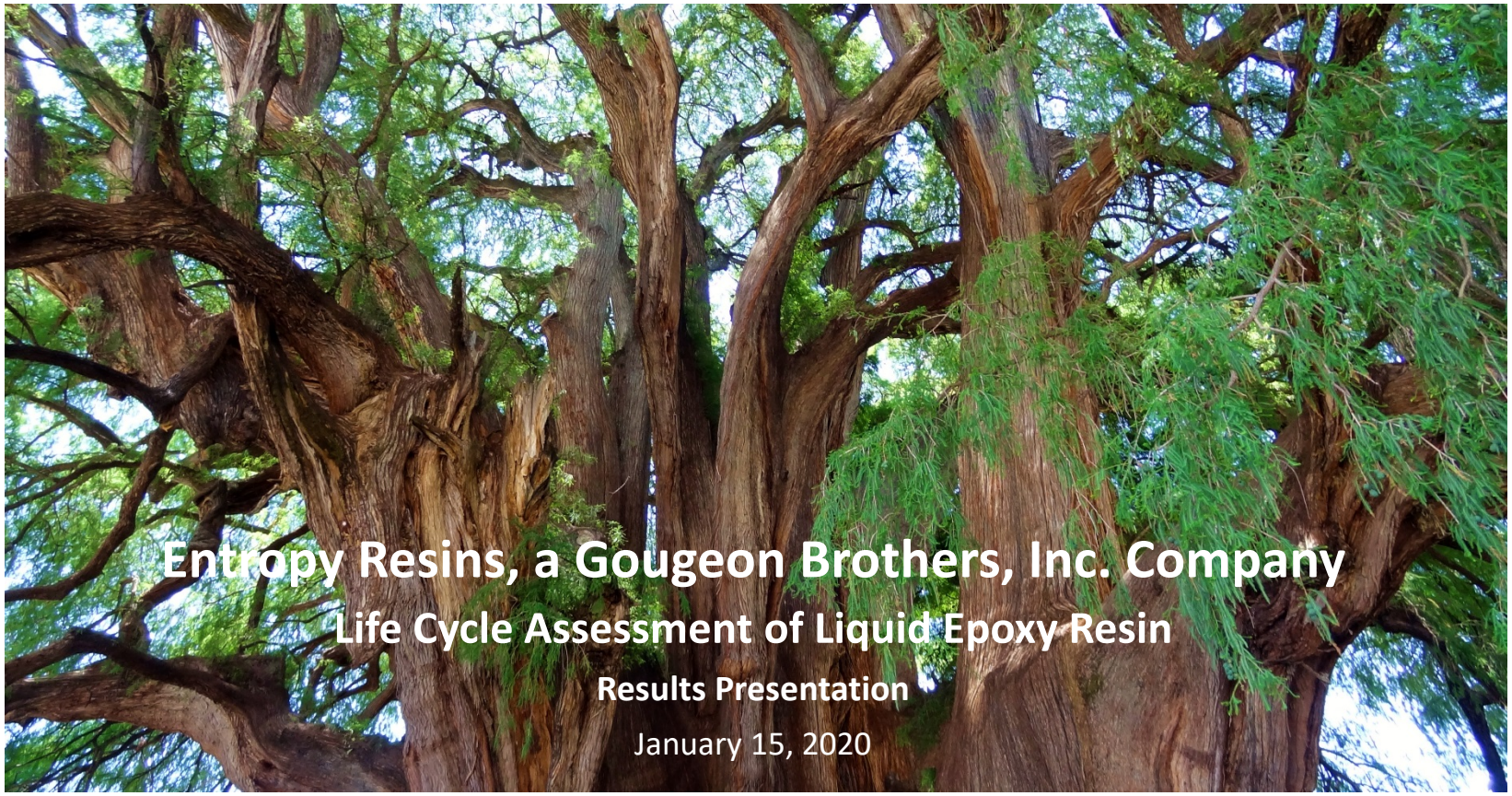

Entropy Resins, a Gougeon Brothers, Inc. Company

Life Cycle Assessment of Liquid Epoxy Resin

Results Presentation

January 15, 2020

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Long Trail Sustainability (LTS)

SKILLED CONSULTANCY

- Life cycle assessments
- Sustainable product development

QUALITY SOFTWARE TOOLS

- SimaPro LCA software
- DATASMART Life Cycle Inventory

RENOWNED LCA TRAINING

- Certificate programs
- Beginner to expert level courses

We provide the tools, knowledge and support that enable you to assess, reduce and effectively communicate the environmental impacts of your products.

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SimaPro Global Partner Network

- LTS is the North American distributors of SimaPro LCA software
- Global partner network

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SimaPro

Partner Network

Transparency, Quality & Accuracy

Our commitments

We commit to TRANSPARENCY, QUALITY and ACCURACY.

We commit to science-based results. We won't engage in facts distortion.

We will use our experience and knowledge to inform our customers and to facilitate sustainable development and practices.

We will take every opportunity to maximise our positive impact.

We will engage with everyone who wants to take responsibility for a transition towards a more sustainable future.

Life Cycle Assessment

A scientific method for analysis of the environmental impacts associated with the life cycle of a product or service throughout the entire life cycle, from cradle-to-grave.

- Analyze energy, material and water inputs and waste and emission outputs

- **Cradle-to-grave** – Includes raw material extraction, manufacturing, distribution, use and disposal.

Image source: Solidworks Sustainability

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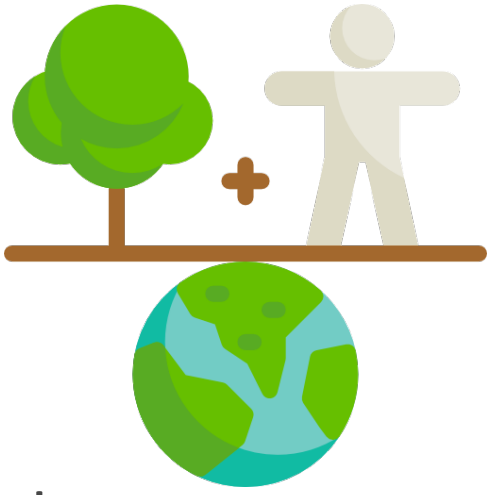
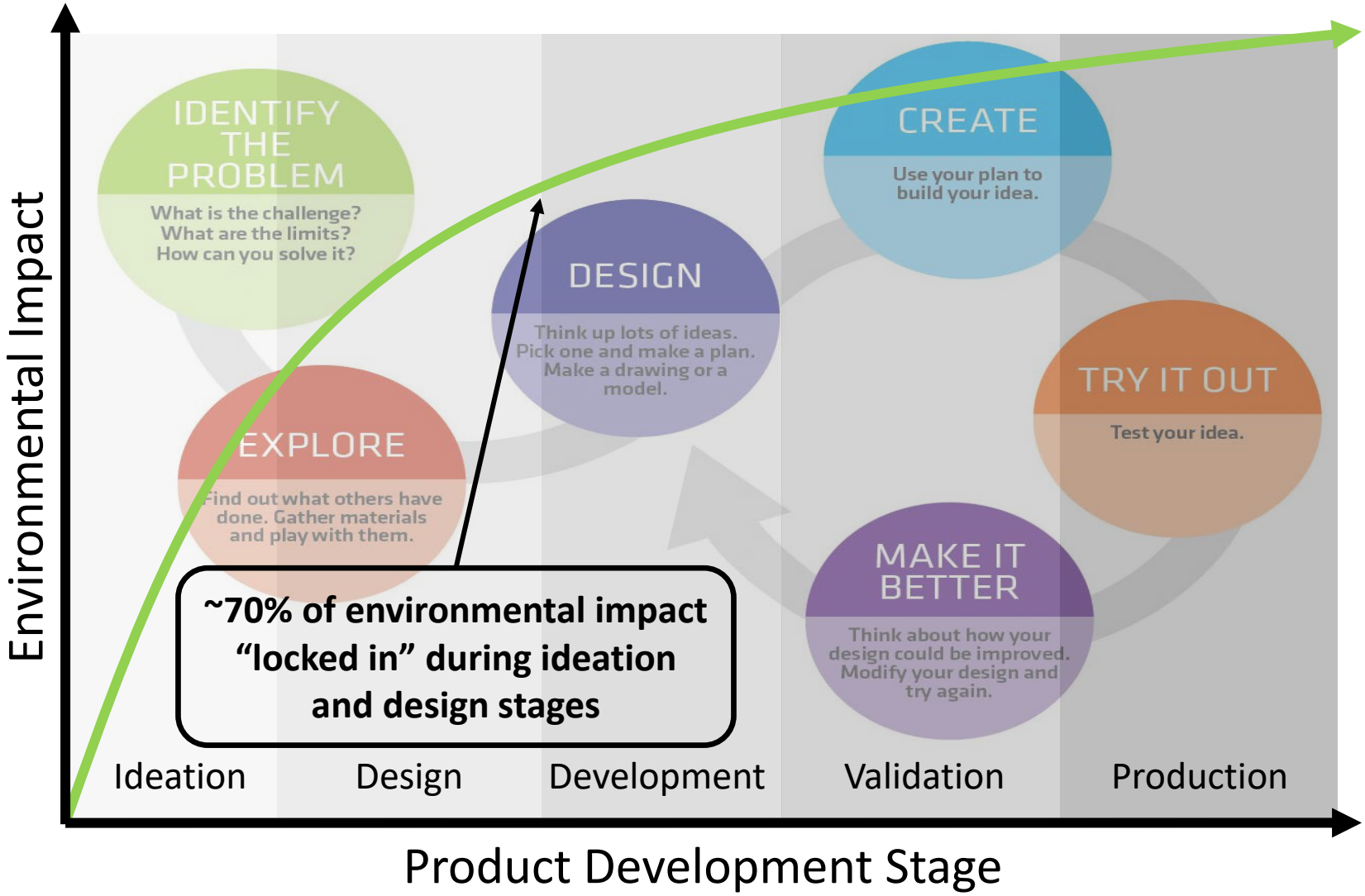
Business Case for LCA

- Identify operational efficiencies
- Enhance brand value
- Optimize supply chain
- Create external communication
- Develop better policies
- Improve designs and develop new products



LCA in Product Development



Sources:
Lewis et al., 2001. Design + Environment, A Global Guide to Designing Greener Goods. Greenleaf, Melbourne.
https://theworks.org/educators-and-groups/elementary-engineering-resources/engineering-design-process/

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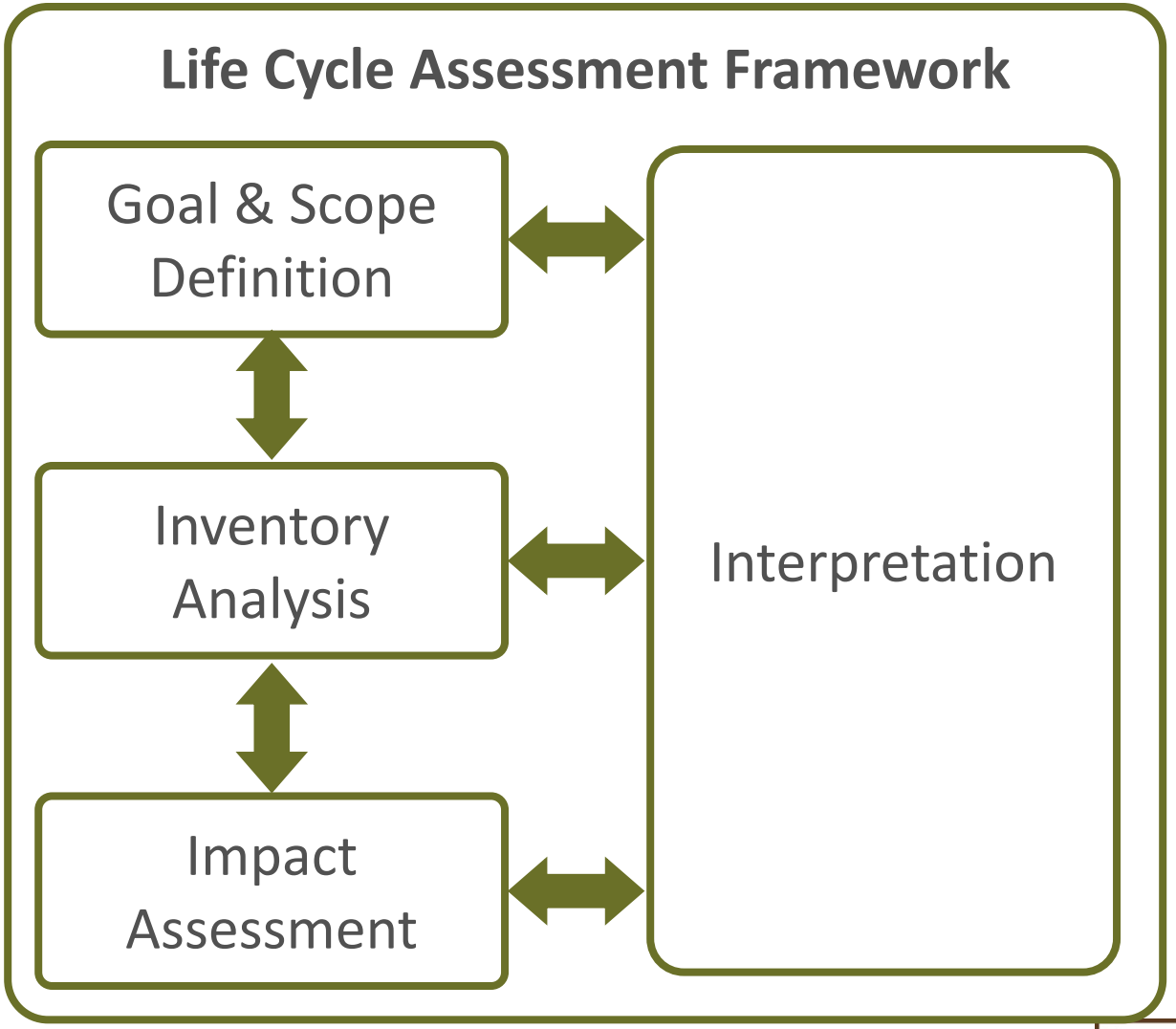
The Steps of an LCA



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Entropy Resins' Project

NOTE: Confidential information has been removed from this version of the report.

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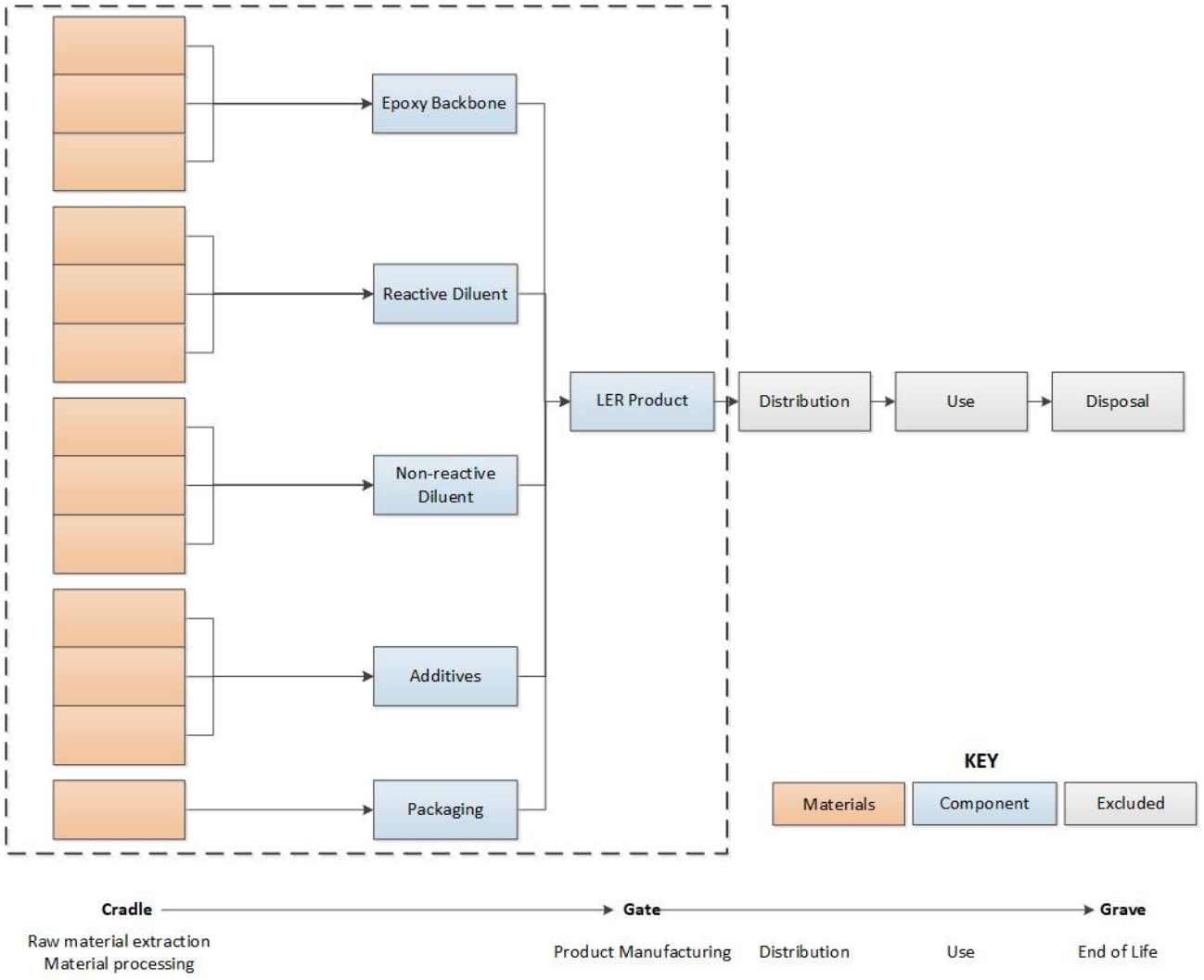
Goal and Scope

What is the goal of the study? What does the study entail?

Goal & Scope

- **Goal**
  - To understand the cradle-to-gate environmental impacts of the bio-based liquid epoxy resin (LER) formulation produced by Entropy Resins for the America's market, as well as compare bio-based LER formulation to the same formulation using industry average petrochemical based components.
- **Intended applications**
  - Informing Entropy Resins' marketing activities, external communication and informing product sustainability strategies.
- **Target audience**
  - Entropy Resins customers.
- **Functional unit**
  - 1 kg of LER packaged for distribution to customers.

System Boundaries



Excluded Processes:

- Infrastructure; Human activities; R&D; Services.

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Life Cycle Inventory

What data were used? What assumptions were made?

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Life Cycle Inventory

- **Primary data**
  - Collected primary data from Entropy Resins on bio-based product formulation and transportation distances and modes for raw materials, manufacturing inputs and outputs (e.g. energy consumption, water use, direct air emissions, waste), packaging and production volumes for the six month period between November 2018 and April 2019.
- **Secondary data** (Used ecoinvent 3.5[1])
  - LCI data for raw materials, manufacturing, energy production and transport.

[1] See www.ecoinvent.ch for more information about ecoinvent.

- **Assumptions**
  - The formulation is the same between the bio-based LER product and the industry average petrochemical based LER product.

Impact Assessment Method: LTS 2019 Method

Impact Category	Unit	Method	Description
Human Health	Disability Adjusted Life Years (DALY)	ReCiPe 2016 Endpoint (H) v1.03	Includes human health impacts from Climate Change, Human Toxicity, Photochemical Oxidant Formation, Particulate Matter Formation, Ionizing Radiation and Ozone Depletion
Ecosystems	Species * yr	ReCiPe 2016 Endpoint (H) v1.03	Includes ecosystem impacts from Climate Change, Terrestrial Acidification, Freshwater Eutrophication, Ecotoxicity, Agricultural Land Occupation, Urban Land Occupation and Natural Land Transformation
Resources	$/kg	ReCiPe 2016 Endpoint (H) v1.03	Includes resource impacts from Fossil Depletion and Metal Depletion
Climate Change	kg CO_2 eq.	IPCC 2013 GWP 100a v1.03	Combines the effect of the periods of time that the various greenhouse gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation
Cumulative Energy Demand	MJ	CED v1.11	Includes non-renewable and renewable energy sources
Water Use	m3	ReCiPe 2016 Midpoint (H) v1.03	Measures the amount of fresh water consumed

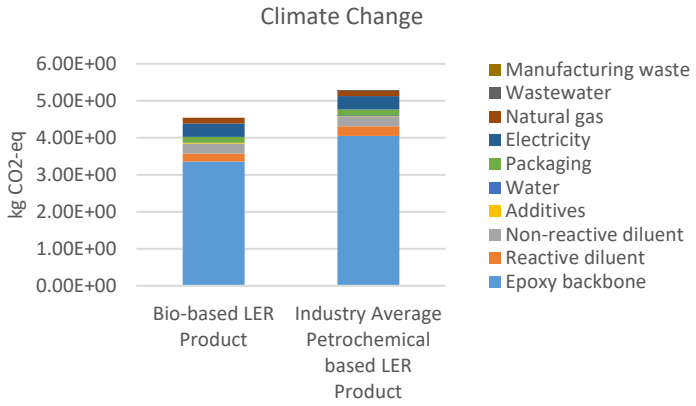
Comparative Analysis

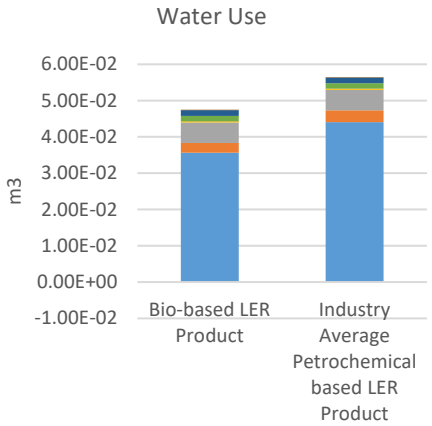
How does the bio-based compare to the industry average petrochemical based LER product?

Comparative Analysis

Bio-based compared to the industry average petrochemical based LER product

	Human Health (DALY)	Ecosystems (Species * yr)	Resources ($/kg)	Cumulative Energy Demand (MJ)	Climate Change (kg CO_2 eq.)	Water Use (m3)
Bio-based LER Product	1.09E-05	2.10E-08	6.04E-01	9.10E+01	4.54E+00	4.74E-02
Industry Average Petrochemical based LER Product	1.25E-05	2.42E-08	6.81E-01	1.03E+02	5.28E+00	5.64E-02
Percent Difference	-13%	-13%	-11%	-12%	-14%	-16%





- The bio-based LER product has between 11% - 16% fewer environmental impacts than the industry average petrochemical based LER product, which come from the epoxy backbone.
- The bio-based LER product uses a bio-based ECH material, while the industry average petrochemical LER product uses a petroleum based ECH material.

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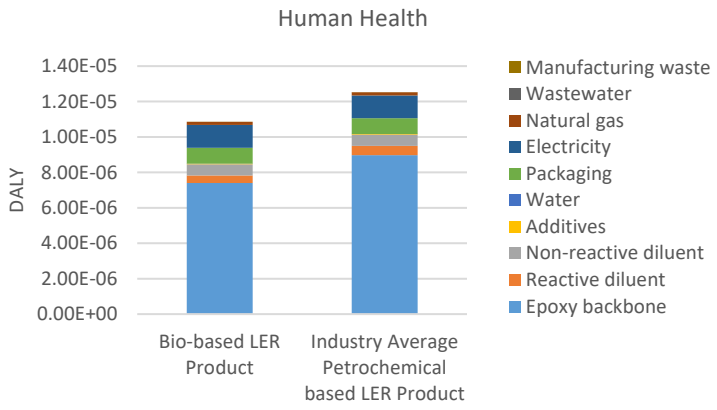
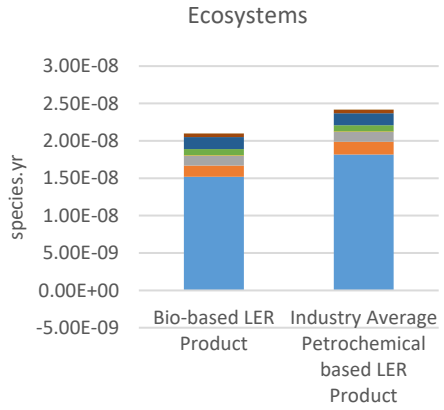
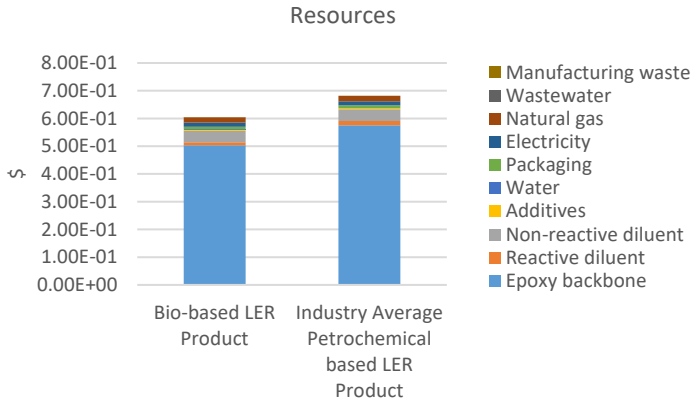
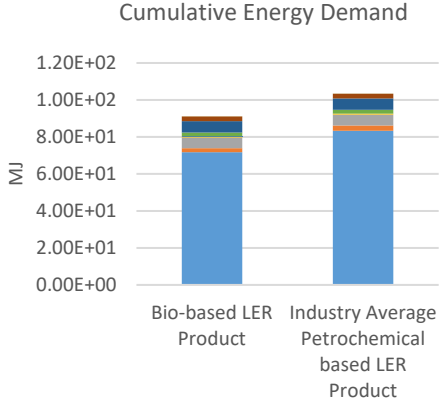
Comparative Analysis

Bio-based compared to the industry average petrochemical based LER product









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Contribution Analysis: Bio-based LER Product

What are the environmental hotspots?

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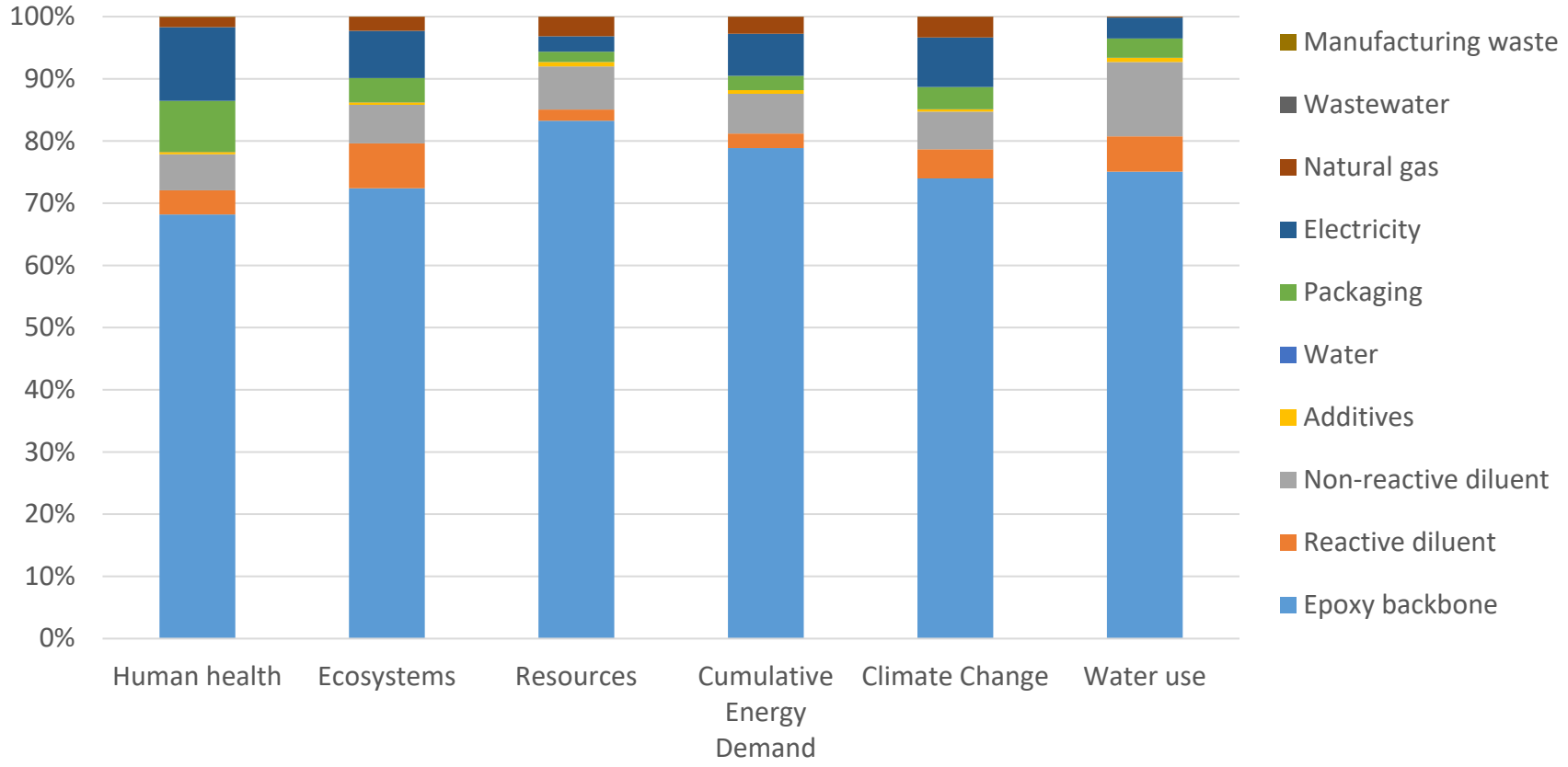
Contribution Analysis

Bio-based LER product



- The majority of the impacts come from the epoxy backbone.
- Non-reactive diluent contributes 6% - 12%, while reactive diluent contributes 2% - 7%.
- Electricity contributes 3% - 12%, while natural gas contributes less than 3%.
- Packaging (55-gallon steel drum) contributes 4% - 8%.

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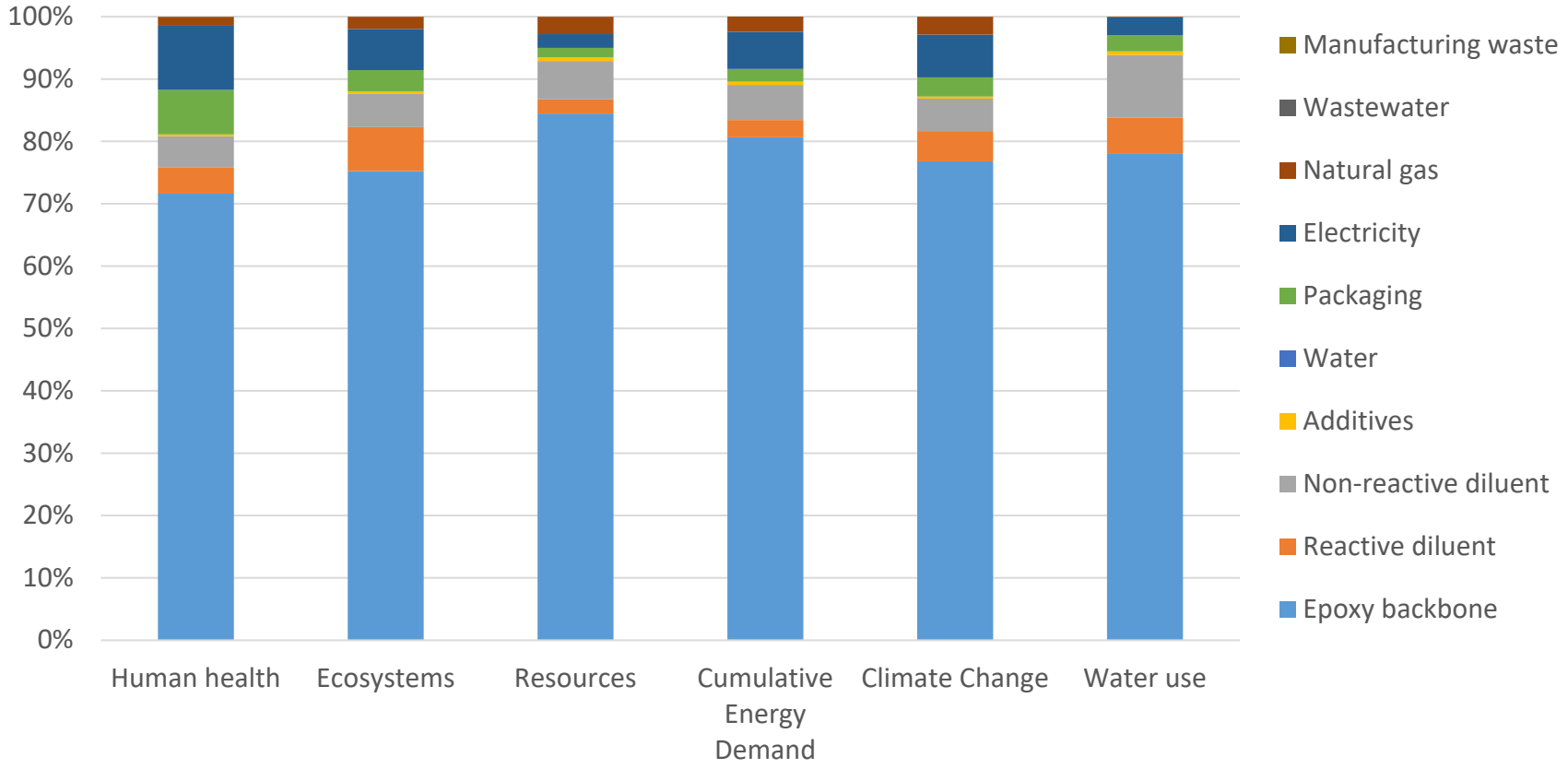
Contribution Analysis: Industry average petrochemical based LER product

What are the environmental hotspots?

Contribution Analysis

Industry average petrochemical based LER product



- The majority of the impacts come from the epoxy backbone.
- Non-reactive diluent contributes 5% - 10%, while reactive diluent contributes 2% - 7%.
- Electricity contributes 2% - 10%, while packaging (55-gallon steel drum) and natural gas contributes less than 7%.

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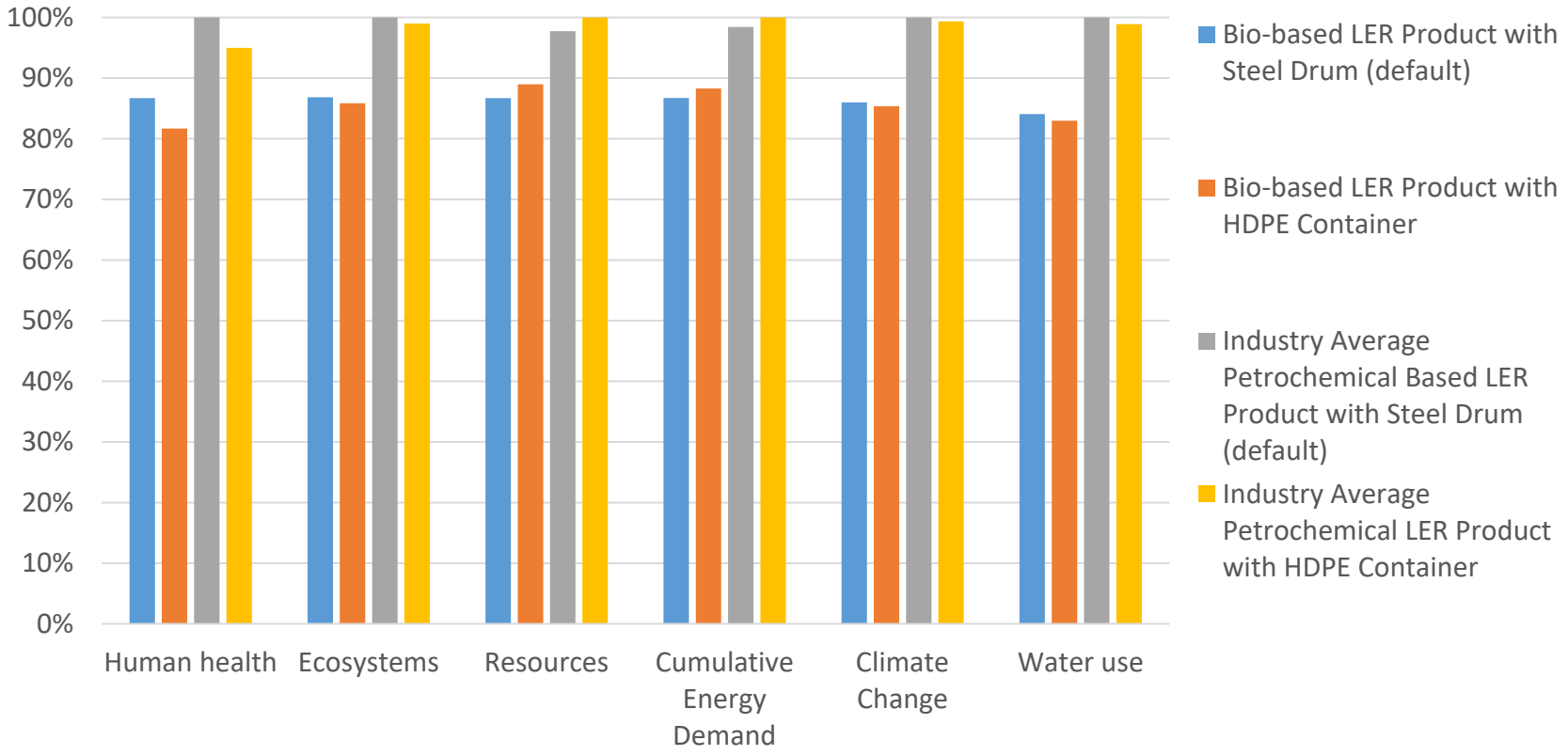
Sensitivity Analysis

How sensitive are the results?

Sensitivity Analysis

Packaging type



- The LER products are packaged in either a 55-gallon steel drum or in a 1-gallon HDPE container. The default scenario uses the 55-gallon steel drum.
- Results are reduced by 1% - 5% when packaged in a 1-gallon HDPE container.

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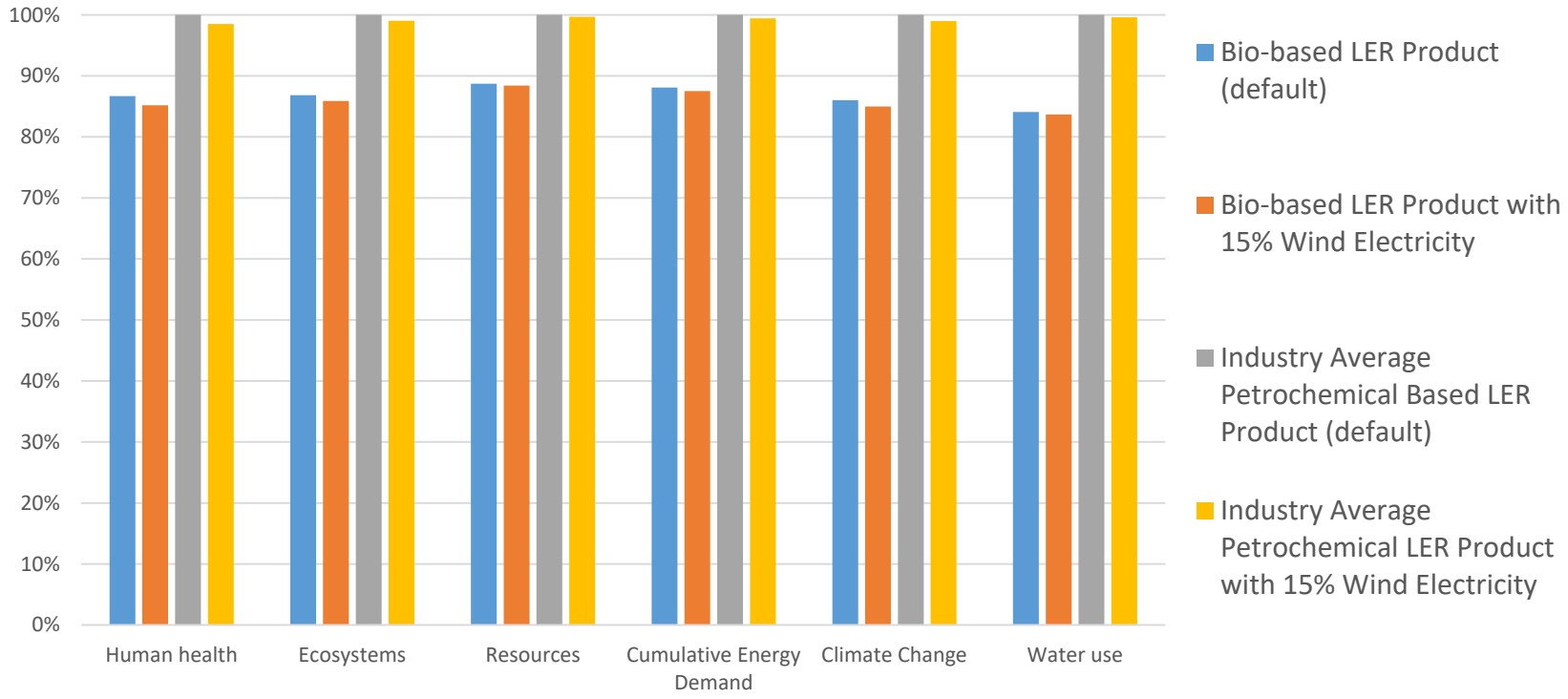
Sensitivity Analysis

Renewable energy



- In the default scenario uses average US electricity for manufacturing energy. Entropy Resins sources around 15% of its electricity from renewable sources at its Bay City, Michigan facility.
- When this is applied, the overall results are decreased by 1% - 2%.

Key Findings & Observations

Key Findings & Observations

- Compared to the industry average petrochemical based LER product, the bio-based LER product has 11% - 16% fewer environmental impacts in all impact categories, driven by the epichlorohydrin.

- The majority of the cradle-to-gate impacts of both the bio-based and industry average petrochemical LER product come from the epoxy backbone, which are driven by BPA.

Recommendations & Next Steps

- Investigate ways to reduce energy usage during manufacturing, along with increasing the use of renewable energy.

- Obtain and create primary data for the epoxy backbone and its constituents, including BPA, as well as reactive diluent, as data from suppliers becomes available.

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Thank you!

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