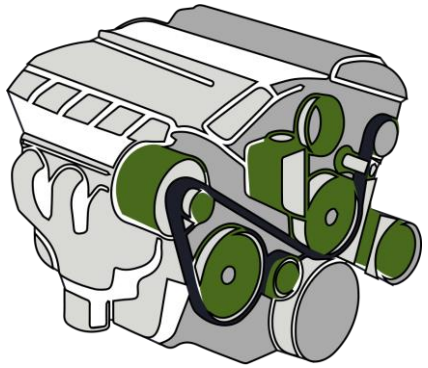
BIOSYNTHETIC
TECHNOLOGIES

Innoleo®

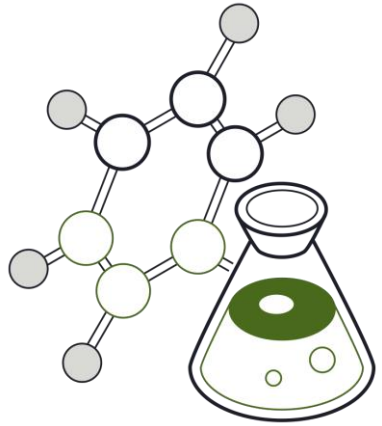
LCA of Estolides
Lubricant Expo Dusseldorf
09-2024

Agenda

- What is an Estolide for Base Oils?
- The 2022 LCA GHG emissions for: Fossil, Biogenic, CO2 Uptake, and Land Transformation
- The 2024 LCA GHG Update for Renewable Energy
- Comparison of Raw Material Sources on Estolide LCA results (Castor vs Coconut/Soy)
- Summary/Closing Thoughts



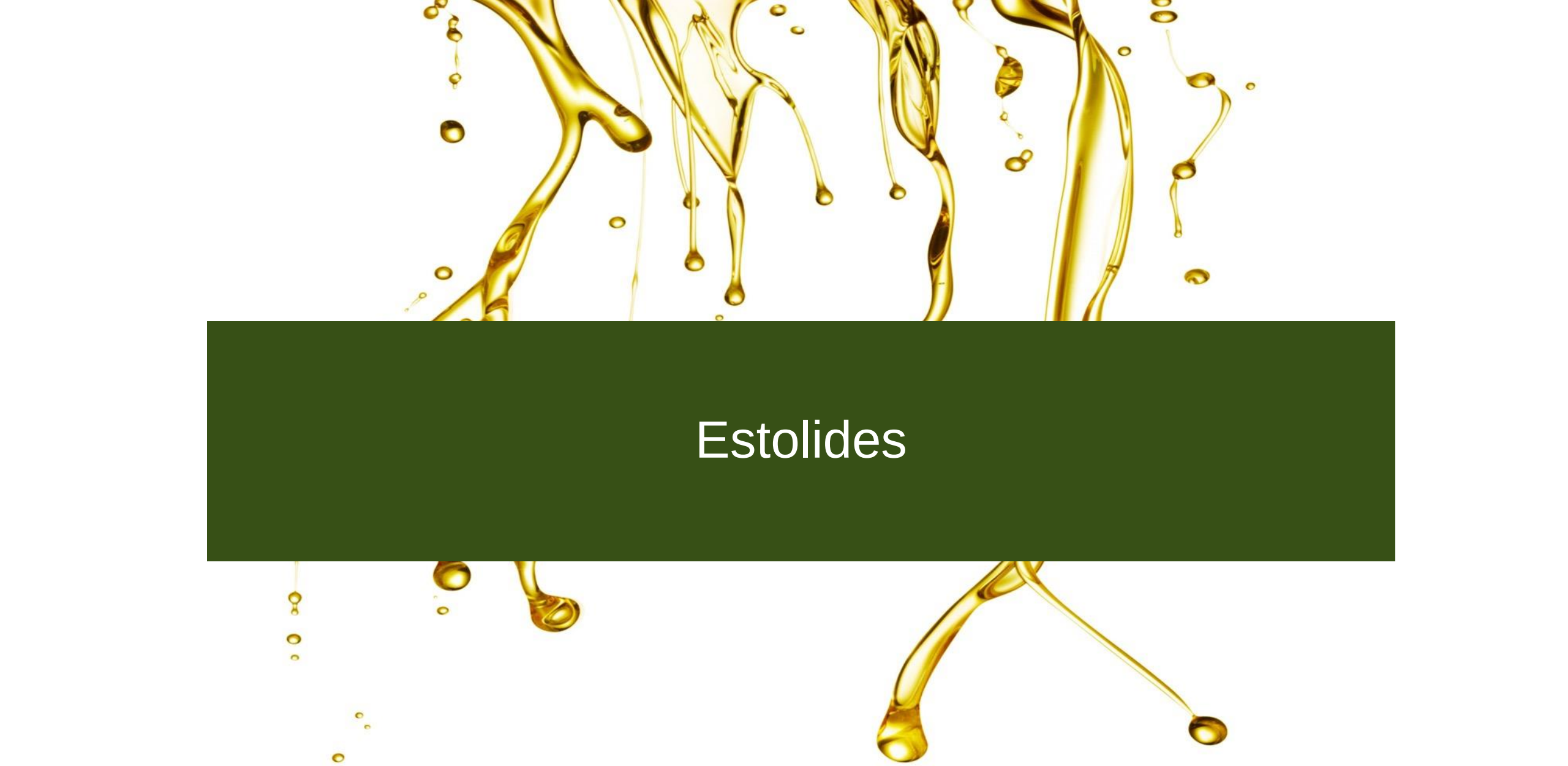
Performance



Technical Excellence

Sustainability

Commercial Scale

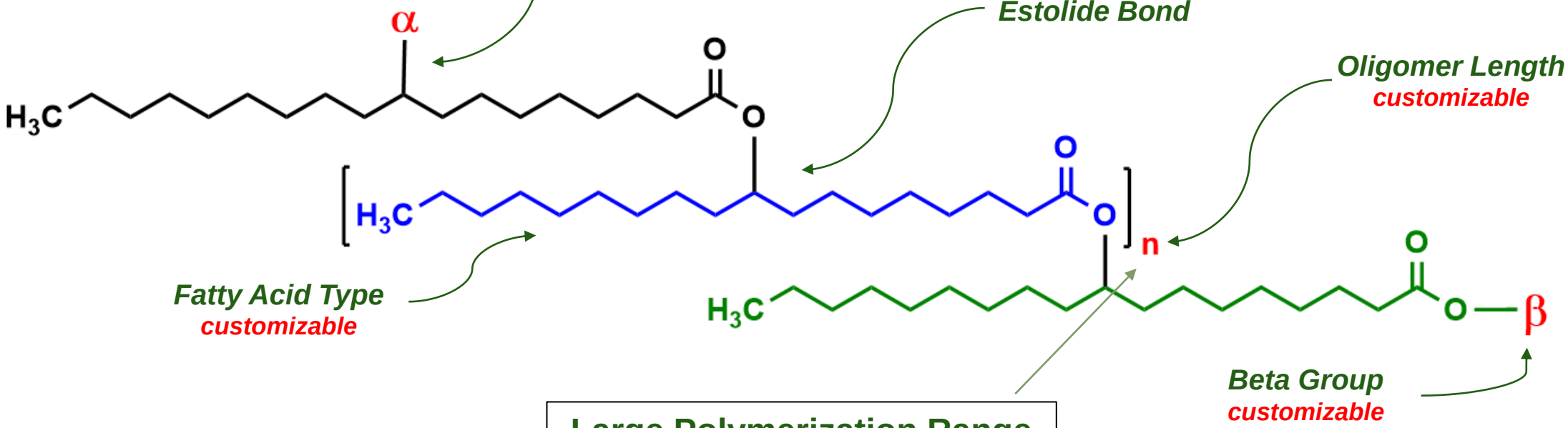


Estolides

BT Products – Estolides as Sustainable BASE OILS

Customizable
Tailor Properties at all Viscosity Ranges

Secondary Ester Bond
Sterically Hindered
Enhanced Hydrolytic Stability



Alpha Group
customizable

Estolide Bond

Oligomer Length
customizable

Fatty Acid Type
customizable

Large Polymerization Range
1 – 25+ Oligomers
Large Viscosity Range

Beta Group
customizable

Physical Properties - Estolides

	BT4	BT22	BT22LP	BT75	BT75LP
Kinematic Viscosity @ 100°C, cST	4.8	22	22	75	75
Kinematic Viscosity @ 40°C, cST	22	150	145	680	580
Viscosity Index	145	170	185	195	210
Pour Point, °C	-21	-21	-42	-21	-33
Flash Point, °C	240	270	270	290	250
Total Acid Number, mg KOH/g	0.3	0.3	0.3	1	1
Gardner Color	3	4	6	5	8
Water, ppm	500	500	500	500	500
Specific Gravity	0.91	0.92	0.93	0.92	.93

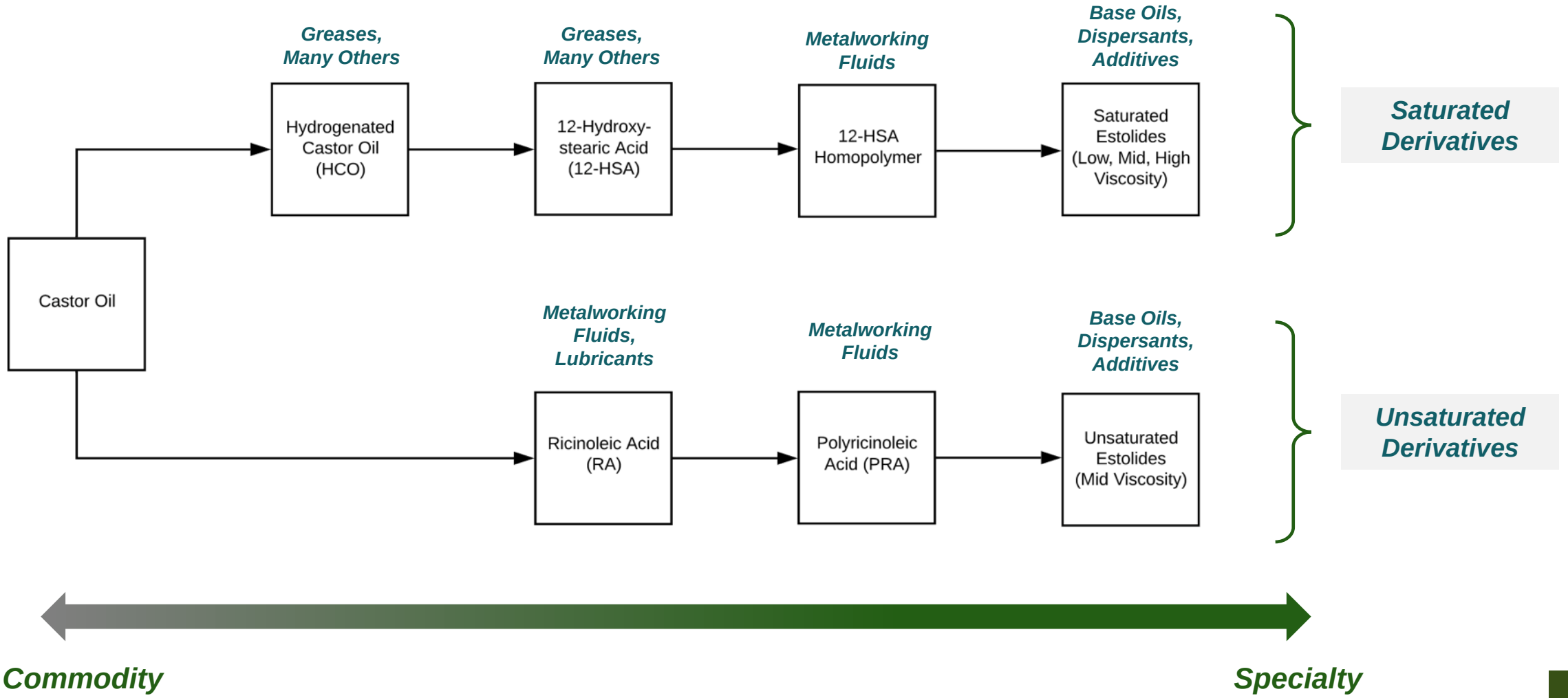
Estolides from Castor

Castor Field in India

Gujarat Province India

Background on Products

Value Chain



2022 Estolide LCA

LCA - Our Scope Selections

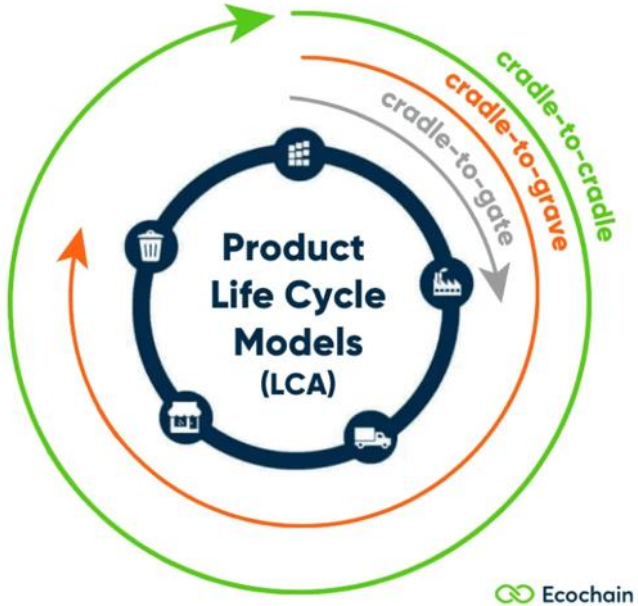
- LCA was developed to be an internationally standardized methodology to assess the environmental impact of product systems (ISO 14040 & ISO 14044). ISO 14067 is a subset of these standards, focused on carbon footprints.
- ISO standards require **3rd party critical review of LCA**, if data is intended to be used to support marketing claims or make comparative assertions. LCA completed by **Environmental Resource Management** and **Audited by Dr. Matthias Finkbeiner from Technical University Berlin, Germany**
- While the general methodological framework is defined by the standards, there are still lots of choices to make when finalizing the goal/scope of the project

Impact Categories

- **Climate Change**
- Ozone Depletion
- Acidification
- Eutrophication
- Ecotoxicity
- Human Toxicity
- Water Use
- Land Use
- Particulate Matter Emissions
- Many others…

Scope Types

- Cradle-to-grave
  - Raw materials
  - Manufacturing
  - Distribution
  - Use
  - Disposal
- **Cradle-to-gate**
  - **Raw materials**
  - **Manufacturing**



ERM

Climate Change (Emissions) & Cradle-to-Gate Selected

Project Definition

System Boundary: ***Cradle-to-gate***

- Includes raw material extraction/harvesting, inbound raw material transport, packaging for inbound/outbound materials, manufacturing activities, waste management, associated energy use/water/steam

Included	Excluded
▪ Raw material extraction/ harvesting	▪ Capital goods and infrastructure
▪ Inbound raw material transport	▪ Employee commute
▪ Packaging for inbound and outbound materials	▪ Outbound distribution (i.e., after materials leave the factory gate in India)
▪ Manufacturing activities	▪ End of life
▪ Waste Management	▪ Consumer use
▪ Associated energy use, water, steam	
▪ Packaging and Transportation of co-products to deliver them to beneficial reuse site	

Project Definition

Impact Category: ***Climate Change (Global Warming Potential)***

- Four greenhouse gas (GHG) sources/sinks were considered, in units “kg CO2e” (GWP100):
  1. **Fossil Emissions** = emissions from fossil-derived carbon sources (e.g. coal, oil, natural gas, etc.)
  2. **Biogenic Emissions** = emissions from bio-derived carbon sources (e.g. trees, crops, plants, grasses, algae, etc.)
  3. **CO2 Uptake** = emissions captured by biomass sources (“carbon sinks;” negative emissions associated with any biomass used in the process, which includes castor oil, biomass fuel, etc.)
  4. **Land Transformation** = emissions associated with land use, land use change, and land occupation impacts (transformation of organic carbon content in the soil)

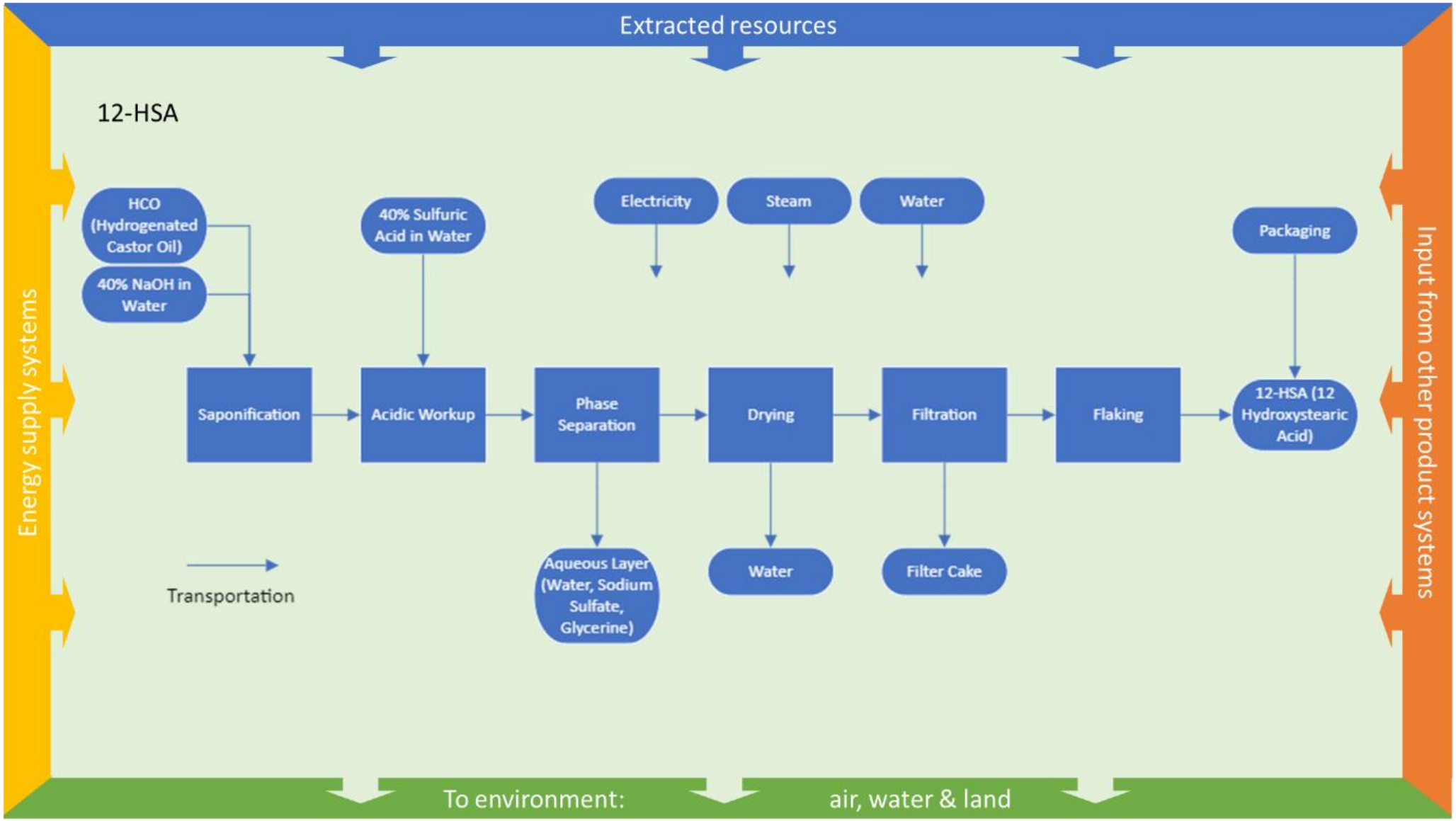
Products Evaluated

- Hydrogenated castor oil, 12-hydroxystearic acid, saturated estolides (low, mid, high viscosities), ricinoleic acid, polyricinoleic acid, and unsaturated estolides (mid viscosity only)

Databases & Software

- SimaPro v9.4.0.2 LCA simulation software was used to build the model
- Primary data was collected for all internally-controlled processes – Production Data from August 2021 to September 2022
- Ecoinvent 3.8 database was used as main secondary source of data (e.g. regional energy grids, non-castor materials)
- GaBi 2020 database was used for castor oil (more complete dataset than was in Ecoinvent)

Process Flow Diagrams – 12HSA as Example



Summary of Emissions

Numbers shown are "kg CO2e" units (GWP100), associated with production of 1 MT product

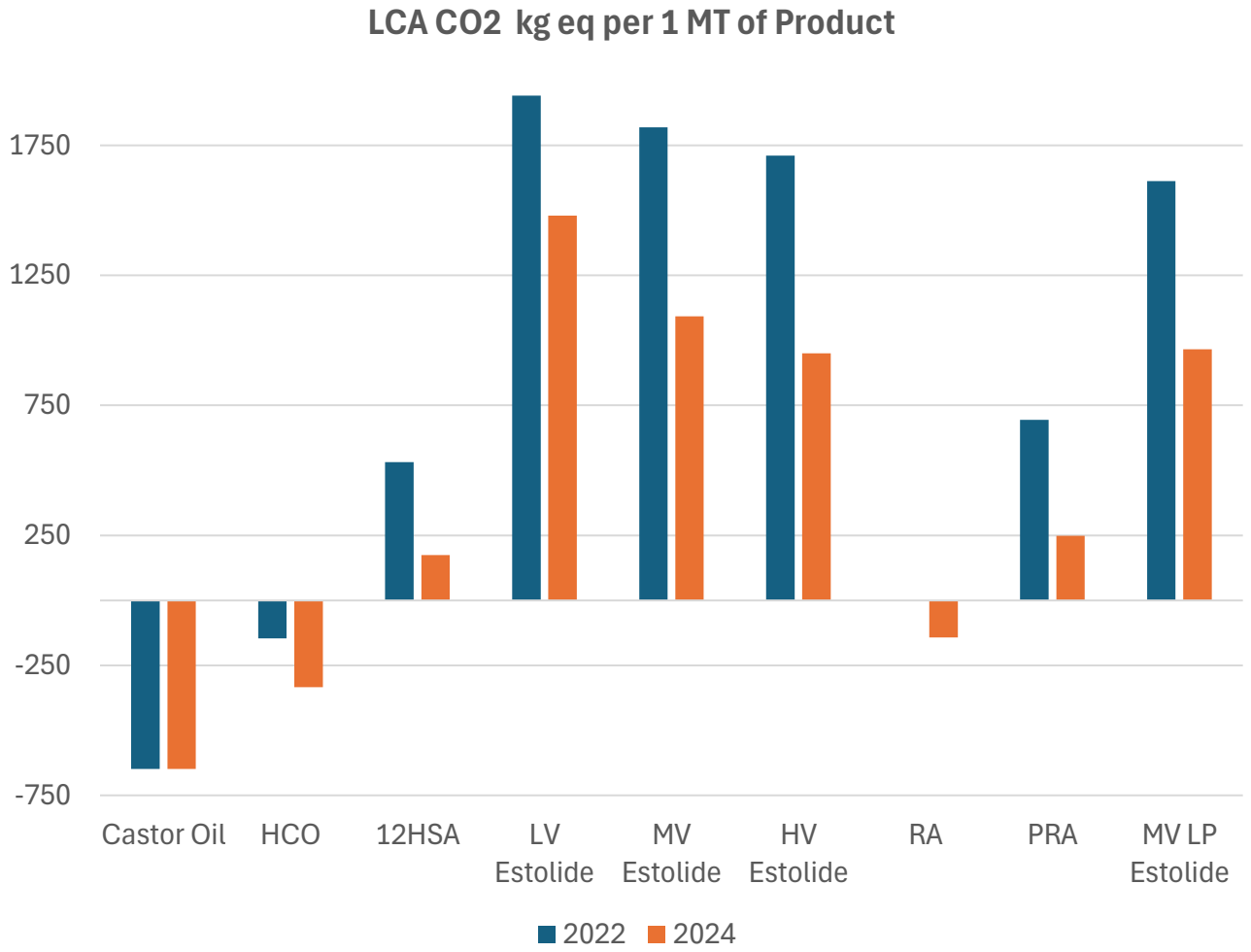
				Saturated Estolides					Unsaturated Estolide
	Castor Oil	Hydrogenated Castor Oil	12-Hydroxy-stearic Acid	Low Vis	Mid Vis	High Vis	Ricinoleic Acid	Polyricinoleic Acid	Mid Vis
Fossil Emissions	1592	1835	1797	2627	2507	2469	1563	1952	2443
Biogenic Emissions	33	360	636	924	1130	1156	267	643	977
CO2 Uptake	-2659	-2725	-2201	-1980	-2164	-2231	-2134	-2204	-2129
Land Transformation	386	385	301	383	329	318	303	304	331
Net Emissions	**-648**	**-145**	**533**	**1954**	**1802**	**1712**	**-1**	**695**	**1622**

- Castor oil and hydrogenated castor oil have negative emissions, ricinoleic acid has neutral emissions, and remaining derivatives have net positive emissions (cradle-to-gate)
- The further downstream from castor, the higher the emissions due to additional processing (energy and chemicals)
- The largest contributors to fossil emissions were **(1) castor oil (fertilizers)** and **(2) electricity used in the process as India primarily utilizes Coal for energy production**
- For biogenic emissions, the use of biomass (castor cake) in the on-site steam boiler is the main driver
- Impacts associated with **waste activities/treatments were found to be <1% of all impacts** for all products modeled, since most co-products and side streams are sold back into other markets

2024 LCA Update

2024 Life Cycle Assessment Update (No Critical 3rd Party Review)

- The 2022 LCA showed Carbon Emission from Coal-Fired Energy was the #2 source of Estolide emissions
- Average Energy Load for India Based Production Facility: ~3.0 MW
- **New Renewable Energy Installations**
  - Roof Top Solar: 2.1 MW
  - Wind Turbines: 2.2 MW
  - Total Renewable Energy: 4.3 MW
- 31% reduction in Fossil Emissions for 2024 LCA
  - This is a **best-case** scenario, real world numbers will be in-between 2022 and 2024 numbers
  - Some fossil emissions from Castor farming and processing still remain
- Will need a full year of actual power usage to confirm model and allow for 3rd Party Critical Review per ISO standards

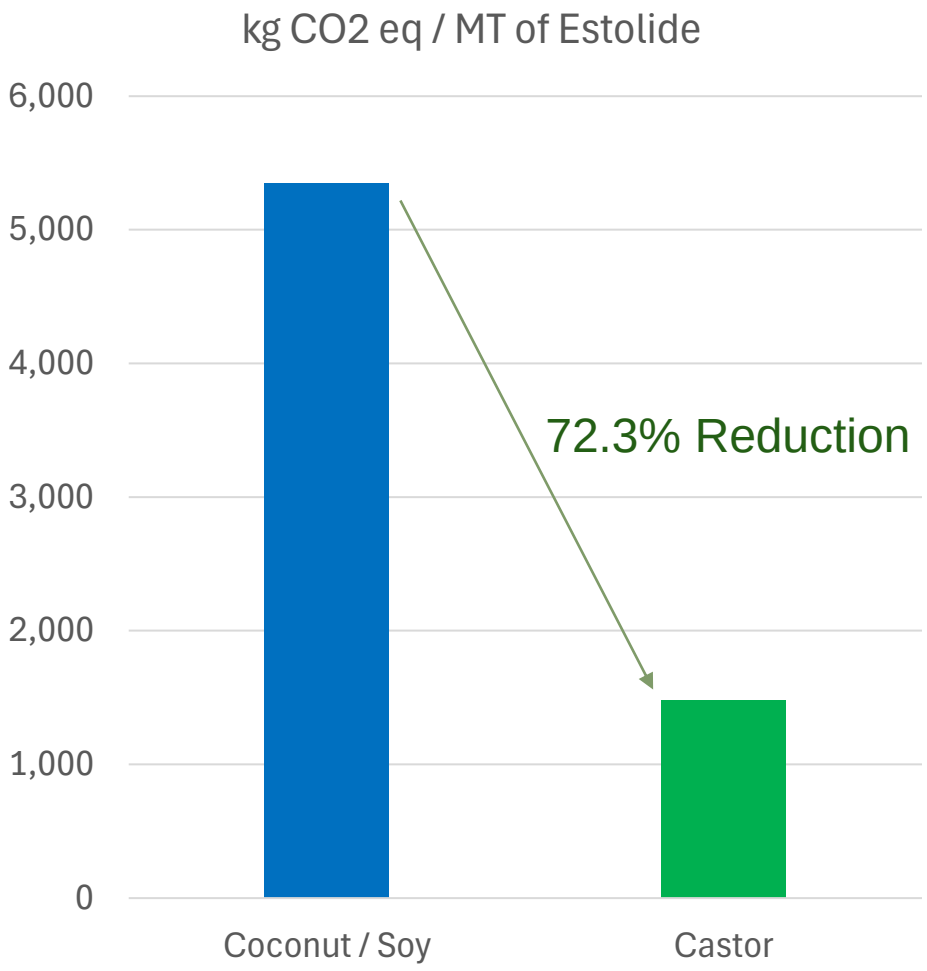


What do we do now?

- LCA Data needs to be used to make smart and rational decisions that can realistically impact emission using data/science
- The only Carbon Emission item that can still be significantly improved in the production of Estolides is Castor Farming itself
  - Lower Fertilizer/Herbicide Use
  - Higher Yield per Acre
- Biosynthetic Technologies has joined the World Castor Sustainability Forum to work on the largest remaining carbon emission in our value chain

LCA of Estolide Raw Material Feed

Comparisons



Vegetable Oils

- It's common for vegetable oils with LOW LAND TRANSFORMATION EMISSIONS to have negative emission profiles under cradle-to-gate boundaries
- In the case of castor oil, lack of deforestation & growth on semi-arid land make the crop favorable.

Other Estolides

- On a previous LCA, estolides partially derived from coconut/soy oil had net emissions of 5345 kg CO2e per MT of product, mainly driven by the negative effects of coconut agriculture on ecosystems. This is nearly 3x the results from this study.
- Feedstock choice can heavily influence emissions.

Closing Comments

- The methodology to produce high-quality LCA/PCF data exists for the Lubricant Industry
- Transparent and open use of the process, boundary conditions, and critical review should build trust in the numbers/data being generated
- Don’t treat the results as a competition, use them to make smart choices that have real world impact to **your** emission numbers
- Share this data with your customers so their LCA/PCF data can be updated for accuracy
- Be open to your results and let it challenge previously held assumptions (we learned bio-based and sustainable aren’t always the same thing, the details matter)

The BT Team sampling
Sustainable Ethanol (Bourbon)

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THANK YOU

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