



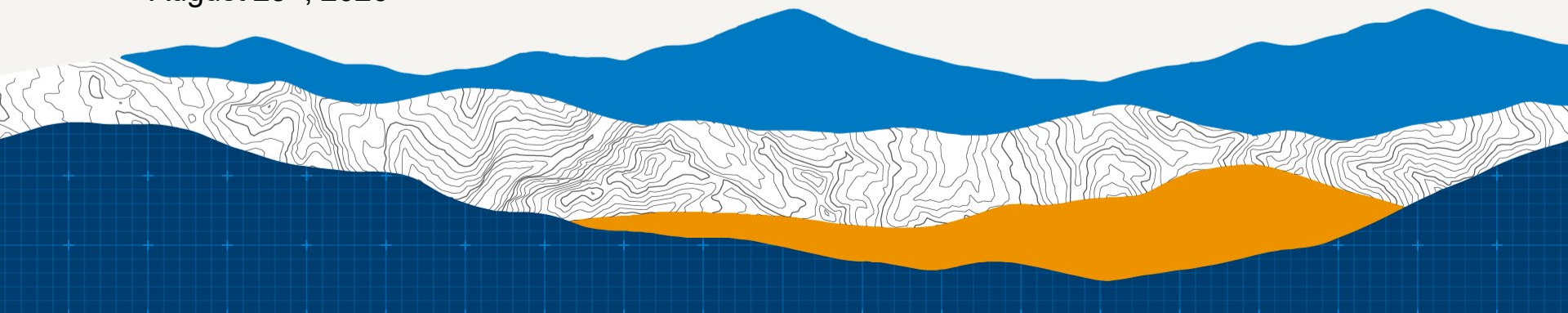
National Laboratory
of the Rockies

Optimal pathways from alternative carbon feedstocks to organic commodity chemicals

Taylor Uekert

tcbiomass+2026

August 25th, 2026



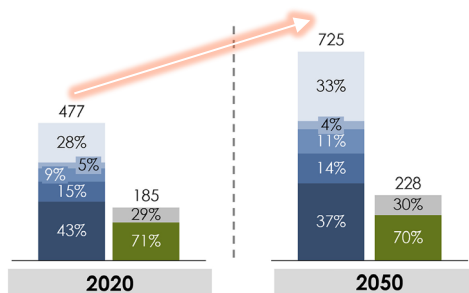
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Organic chemical demand
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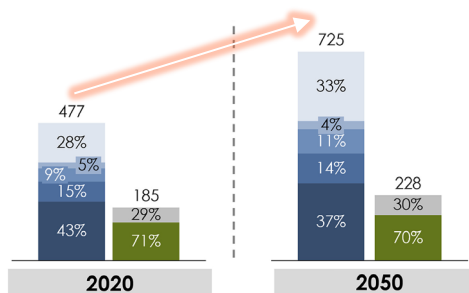


Left: Meng et al., *PNAS*, 2023, 120, e2218294120.

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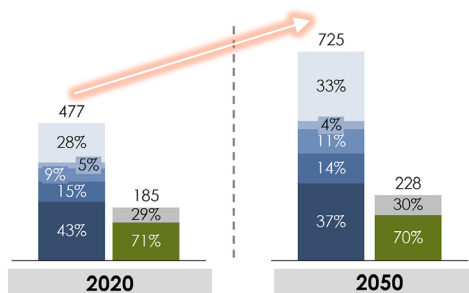


Left: Meng et al., *PNAS*, 2023, 120, e2218294120. **Center:** Independent Commodity Intelligence Services, "Outlook '23" (2022).

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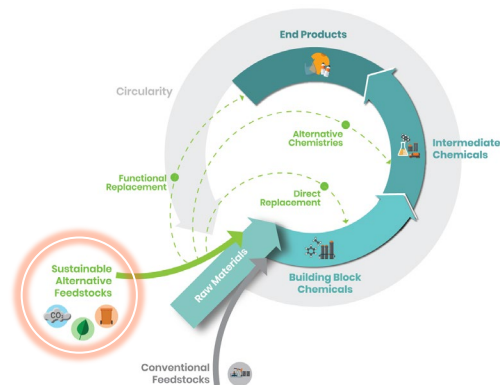
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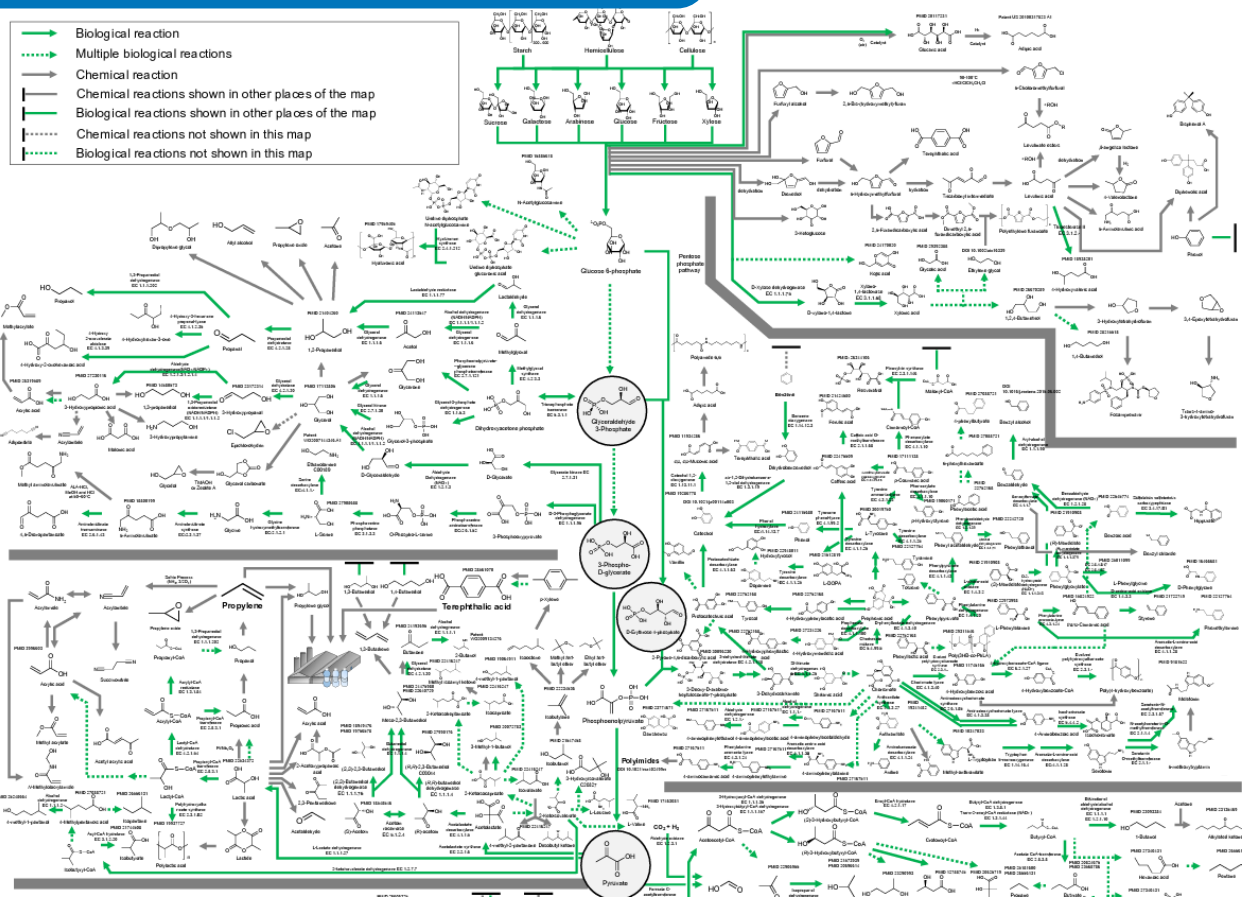
Chemicals from alternative feedstocks can help.



Left: Meng et al., *PNAS*, 2023, 120, e2218294120. **Center:** Independent Commodity Intelligence Services, "Outlook '23" (2022). **Right:** Department of Energy (2024).

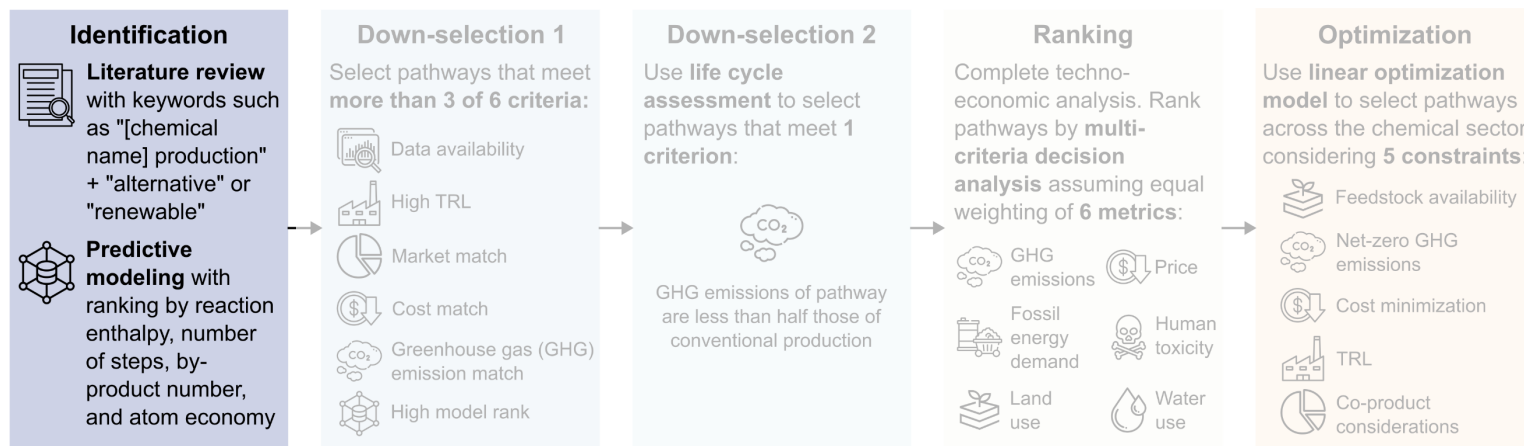
Goal

In a vast solution space, can we use analysis to prioritize alternative production pathways for today's organic chemicals?



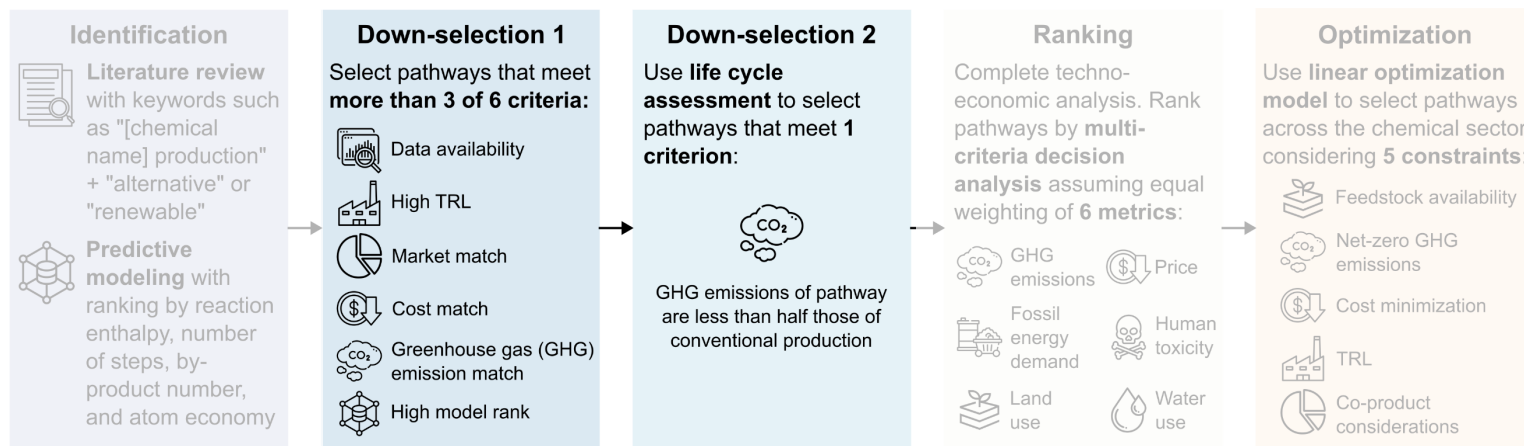
Key assumptions & methods (1)

- Considered 51 high-volume chemicals and 6 feedstock classes (herbaceous and woody biomass, CO₂, CH₄, and food and plastic waste)
- Identified 235 unique pathways from feedstock to chemical through a combination of literature review and predictive modeling (DORAnet¹).



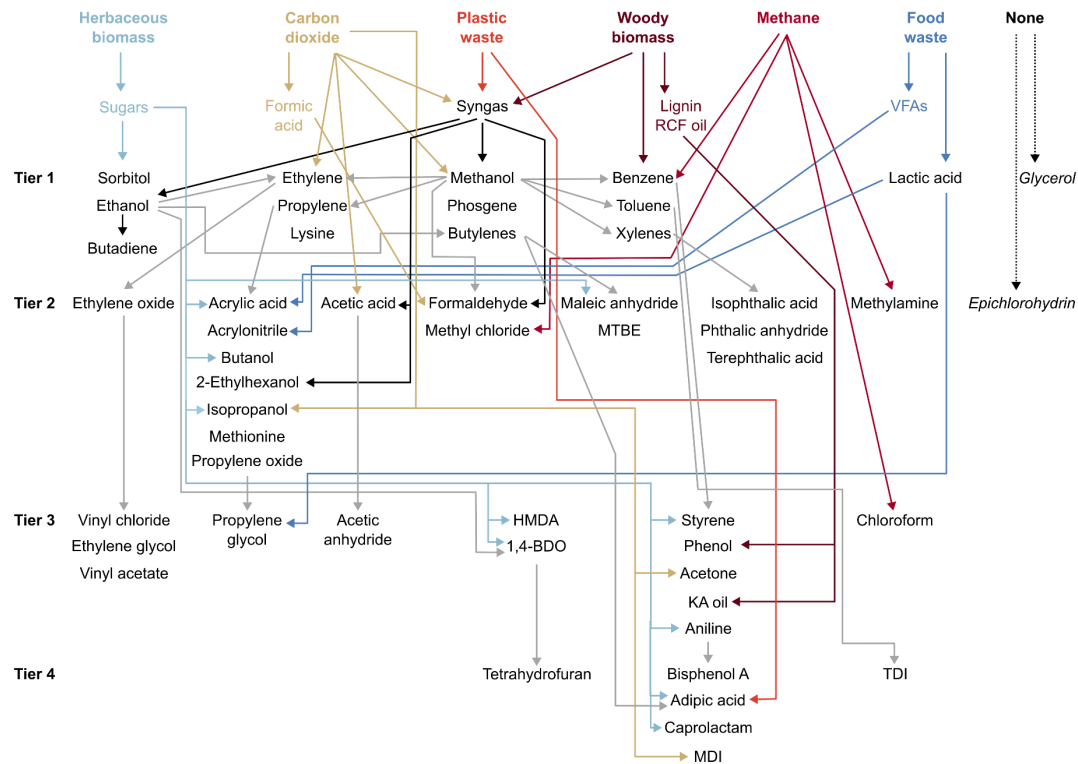
Key assumptions & methods (2)

Pathways were screened for adherence to criteria representing technical, economic, environmental, and analytical feasibility.



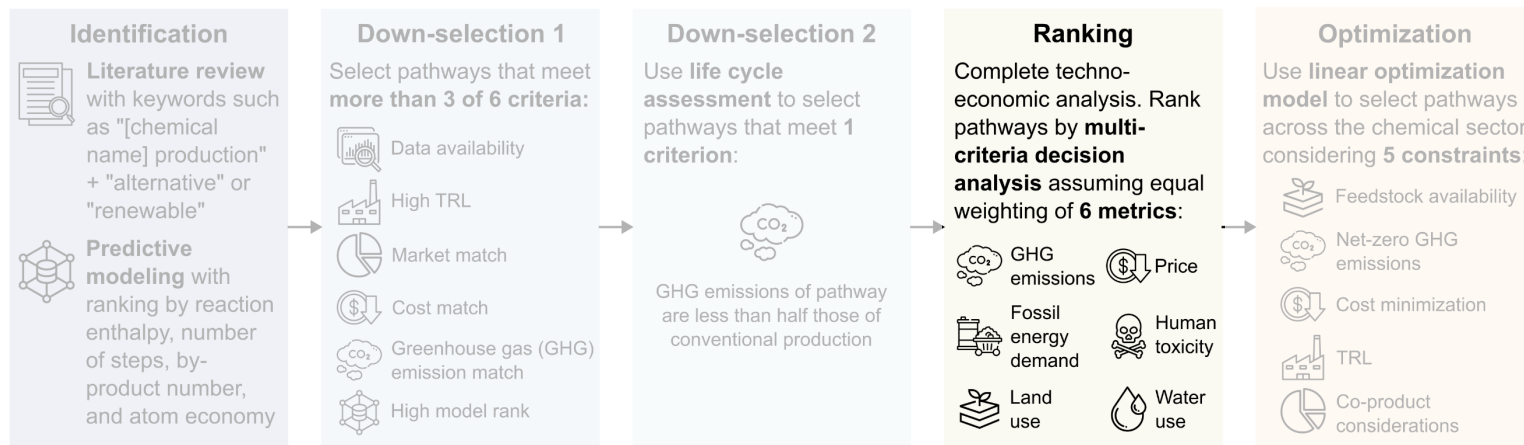
Down-selected pathways

Alternative pathways that met all down-selection criteria were identified for all chemicals except glycerol and epichlorohydrin.



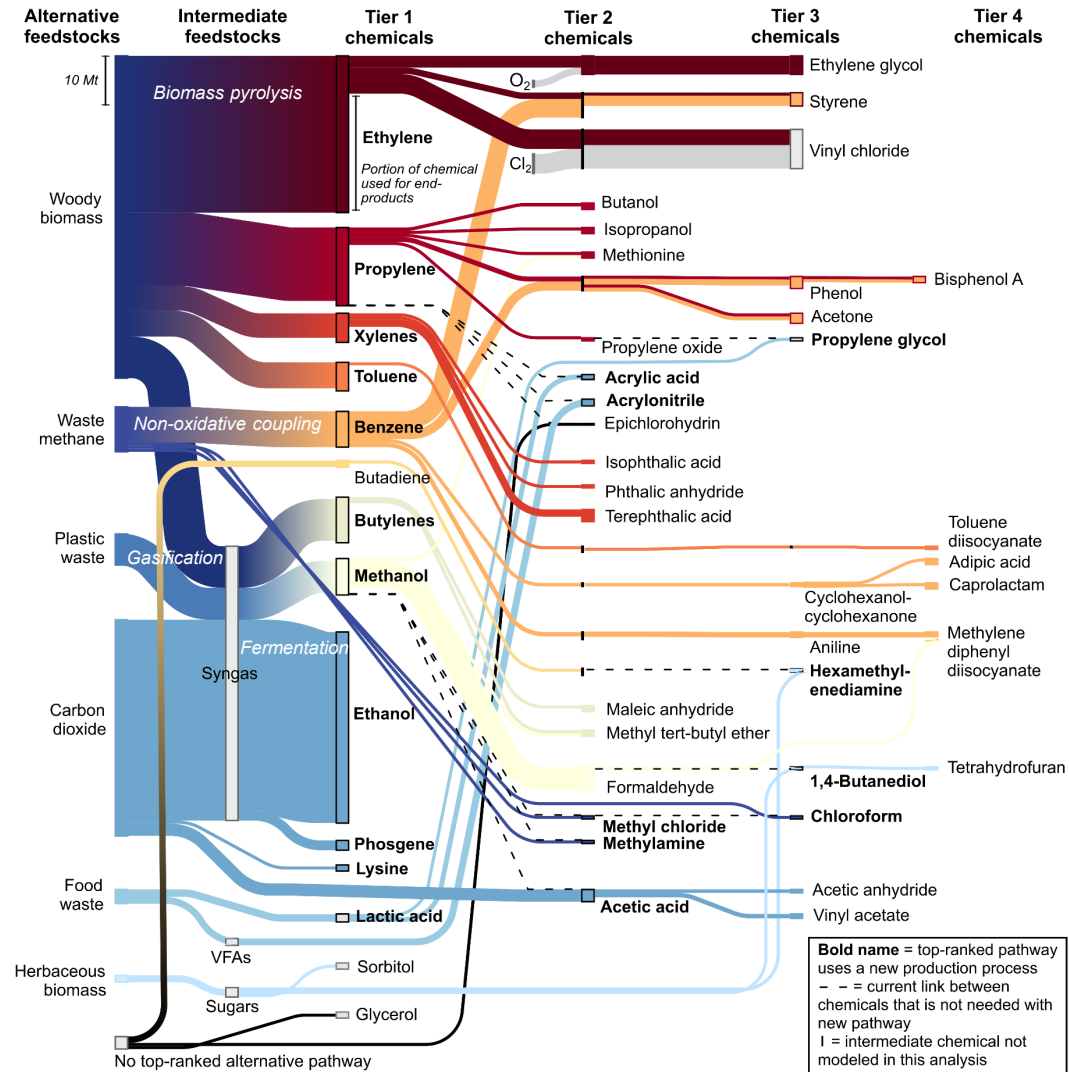
Key assumptions & methods (3)

Down-selected pathways were ranked assuming equal weighting of emissions, cost, energy demand, toxicity, land use, and water use.



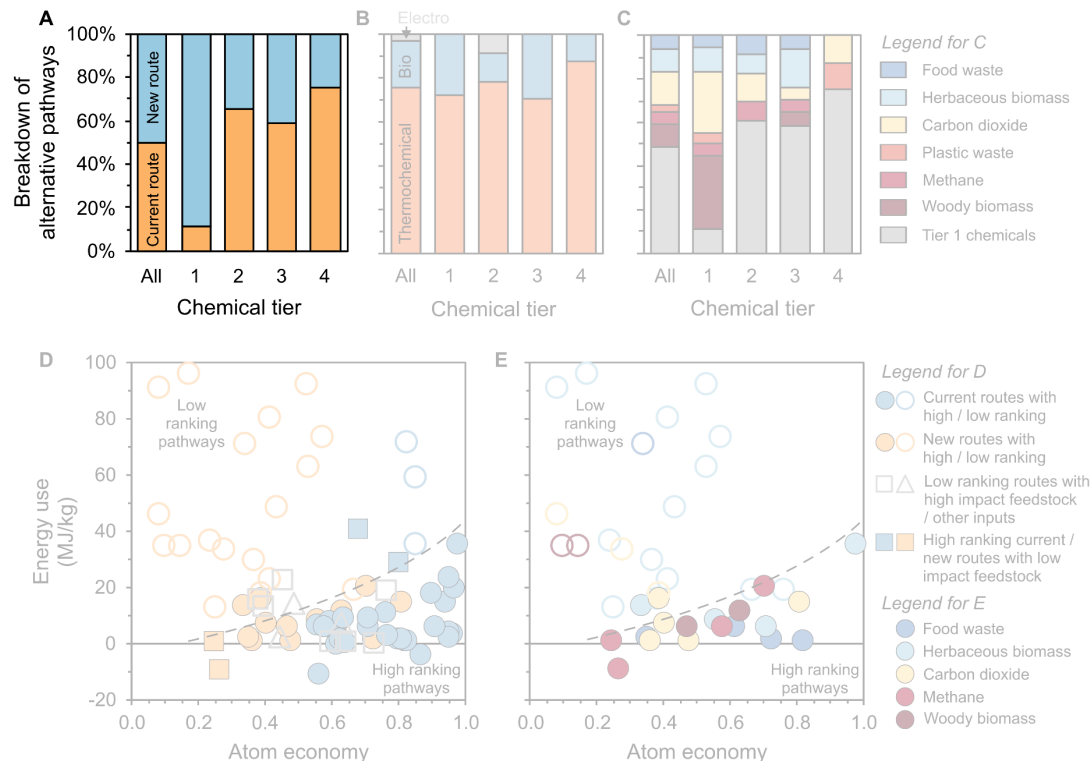
Top-ranked pathways

- Economically and environmentally feasible alternative pathways exist for all but 3 chemicals (glycerol, epichlorohydrin, butadiene).
- Woody biomass is expected to be a limiting resource.



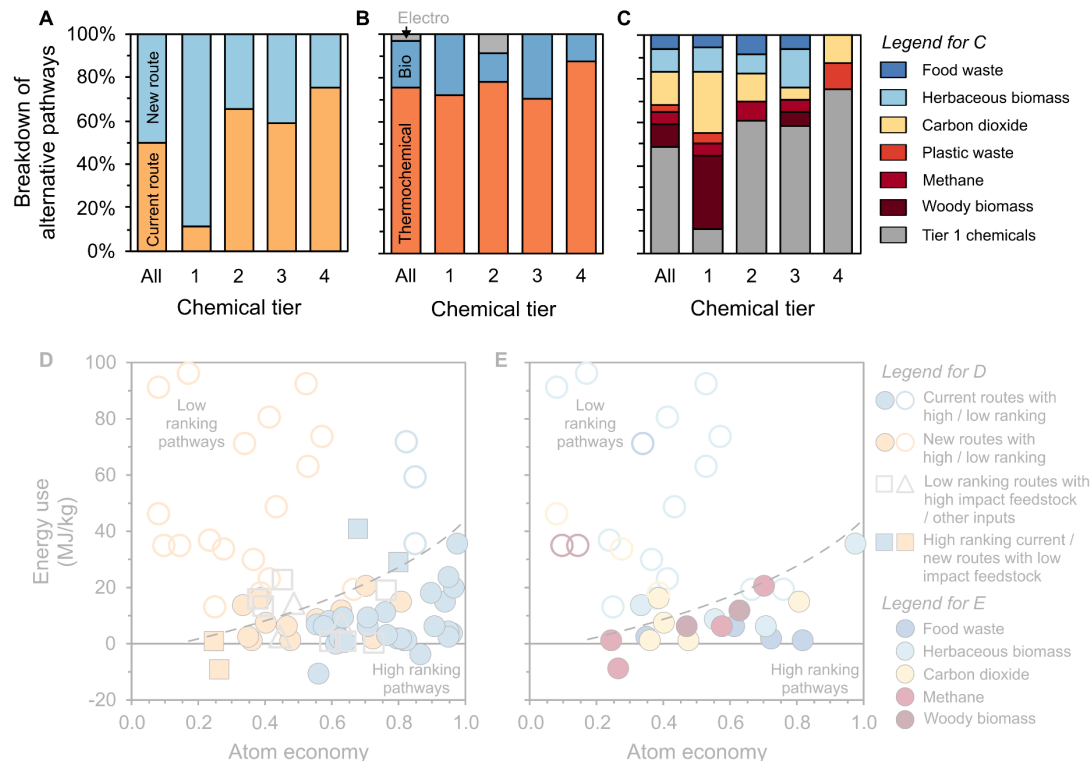
Characteristics of pathways

- Half of alternative pathways can leverage existing conversion routes (e.g., from Tier 1 chemicals); the other half require R&D.



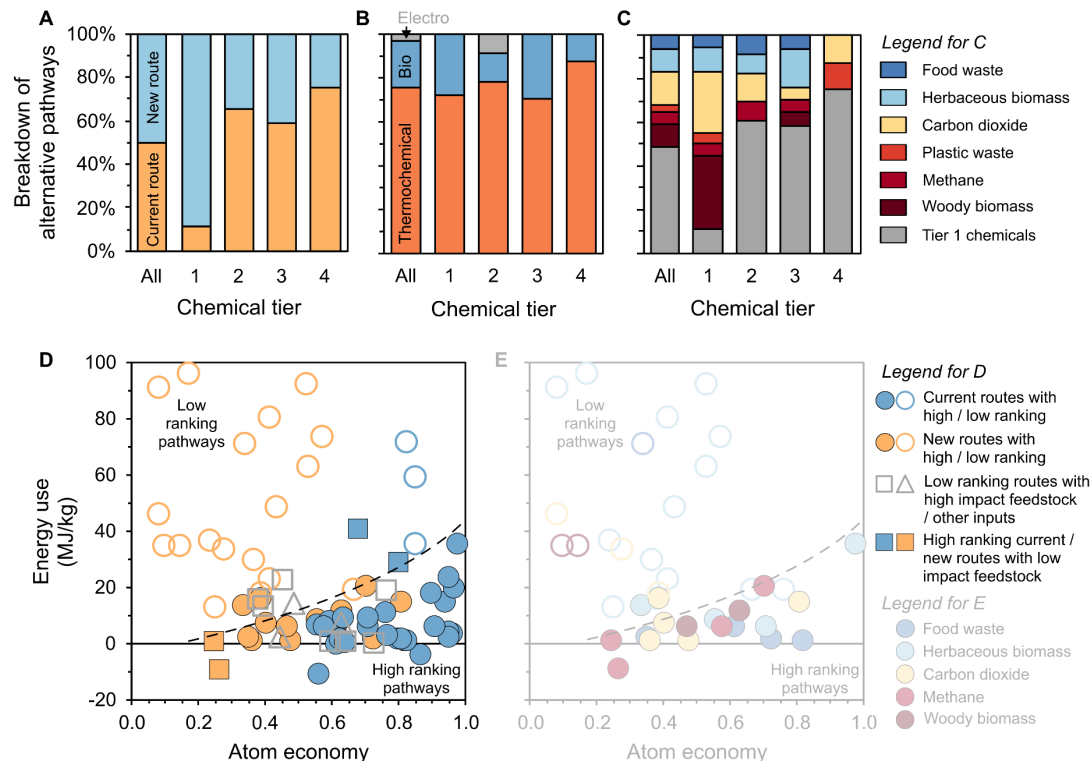
Characteristics of pathways

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- Thermochemical routes continue to dominate.



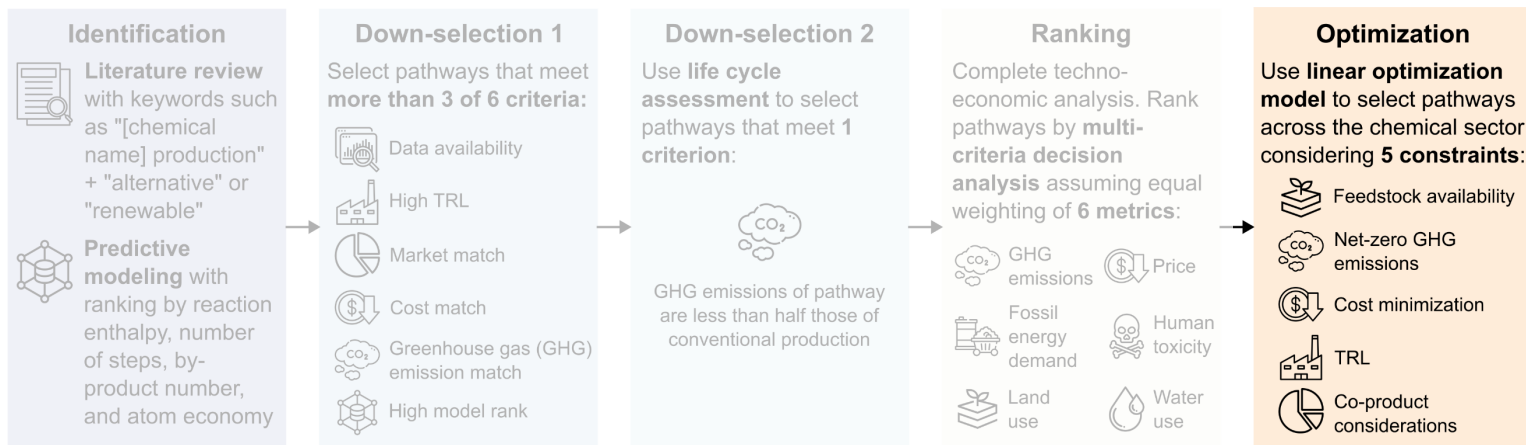
Characteristics of pathways

- Half of alternative pathways can leverage existing conversion routes (e.g., from Tier 1 chemicals); the other half require R&D.
- Thermochemical routes continue to dominate.
- Optimal pathways tend to have low energy use and high atom economy.

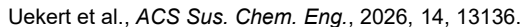


Key assumptions & methods (4)

All down-selected pathways were included in a full-sector optimization model designed to meet chemical demand within set feedstock constraints for minimal cost and net-zero emissions.

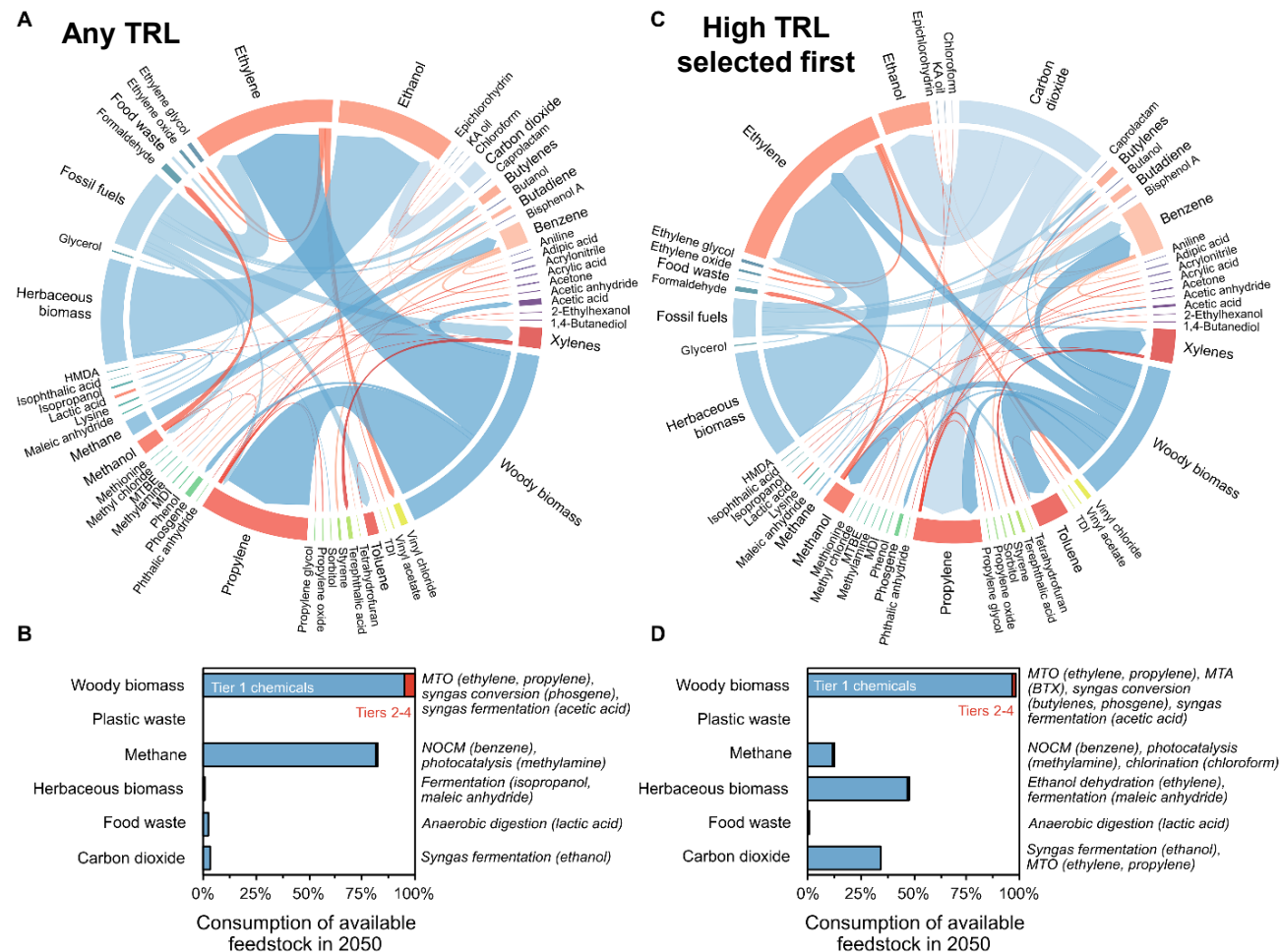


Producing just 11 chemicals from alternative feedstocks could reduce costs by 11% while eliminating emissions.



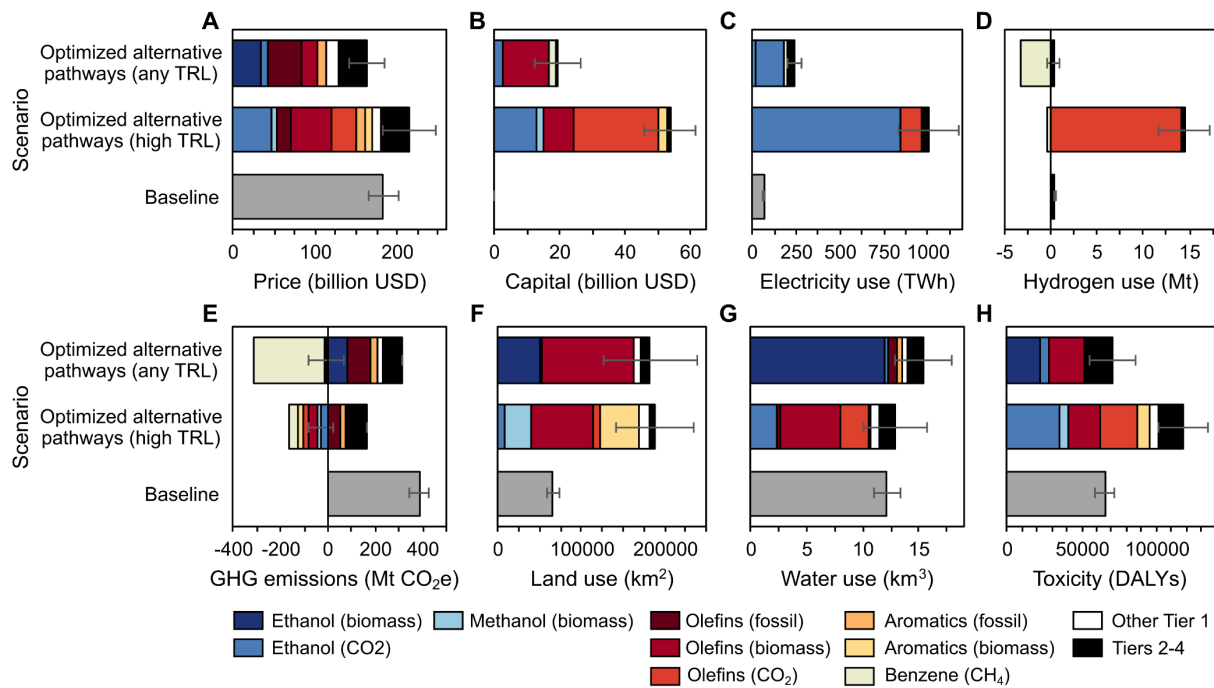
Optimization results

Prioritizing high technology readiness level (TRL) conversions results in a different mix of pathways and feedstocks.



Optimization implications

- Emissions and costs could decrease when using alternative feedstocks, but electricity and land use may increase.
- R&D remains crucial as using a variety of low TRL and high TRL pathways enables better outcomes.



Key chemicals

Prioritize scaling of alternative pathways for Tier 1 chemicals that enable plug-and-play in existing supply chains:

- Ethylene
- Propylene
- Benzene
- Methanol

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Prioritize R&D into emerging alternative (thermochemical) pathways with high atom economy, low energy demand, and feedstock diversity for select Tier 2-4 chemicals:

- 1,4-Butanediol
- Acrylic acid
- Acrylonitrile
- Chloroform
- HMDA
- Propylene glycol
- Acetic acid
- Lactic acid
- Methylamine
- Methyl chloride
- Isopropanol
- Maleic anhydride

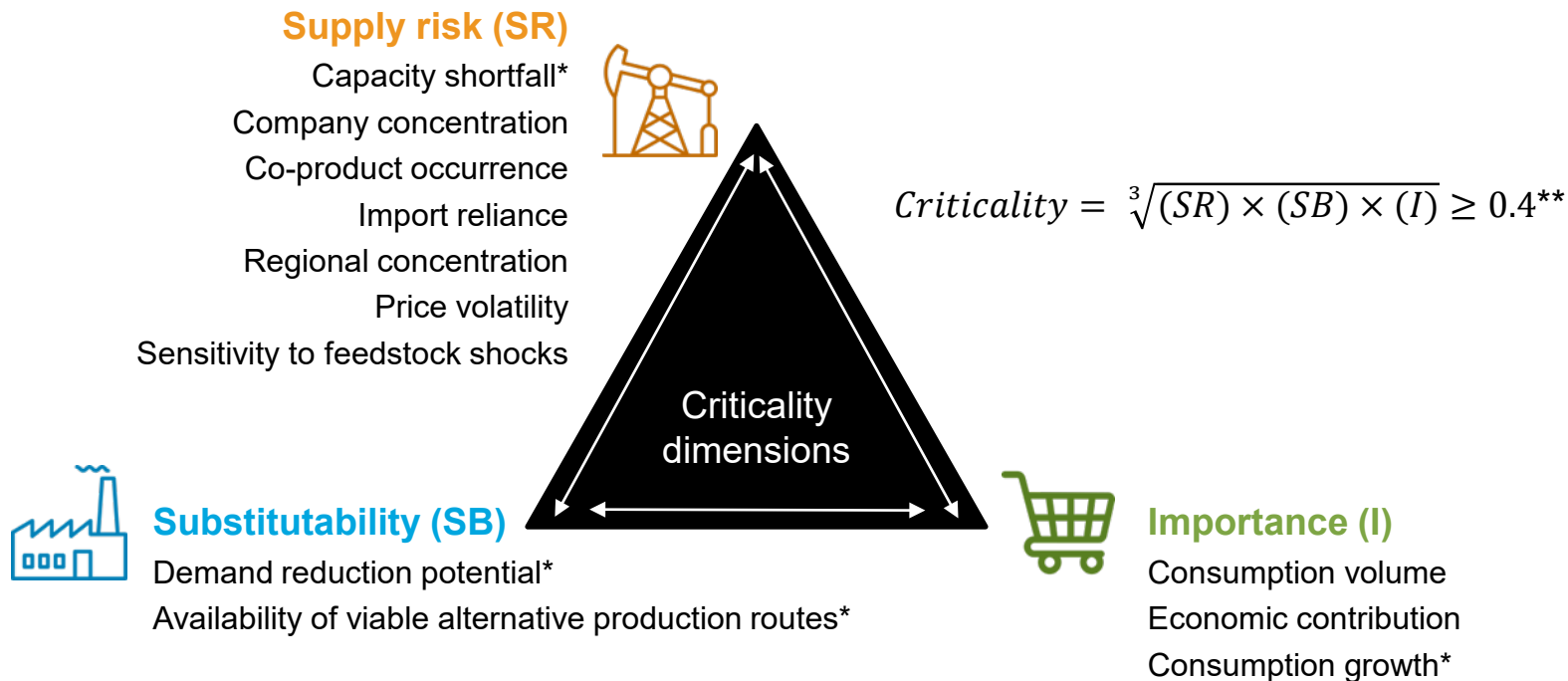
*MCDA
optimal*

*All-TRL
scenario
optimal*

- Butadiene
- Epichlorohydrin
- Formaldehyde
- Glycerol
- Methyl tert-butyl ether

*Missing
economically
viable pathways*

Beyond cost and impact: defining chemical “criticality”



* Metric is time horizon dependent (2035 or 2050)

** Calculation based on Nassar & Fortier, *Methodology and Technical Input for the 2021 Review and Revision of the U.S. Critical Minerals List*, 2021

Short-term (2035) criticality

			IMPORTANCE 			SUPPLY RISK 							SUBSTITUTABILITY 	
Chemical name	Rank	Score	Consumption volume	Consumption growth	Economic contribution	Capacity shortfall	Company concentration	Co-product occurrence	Import reliance	Price volatility	Regional concentration	Sensitivity to feedstock shocks	Availability of alternative production routes	Demand reduction potential
Glycerol	1	1.00	0.01	0.43	0.60	0.89	0.12	1.00	0.74	0.68	0.17	0.58	1.00	1.00
Ammonia	2	0.97	0.46	0.79	0.56	1.00	0.22	0.00	0.48	0.81	0.00	0.93	0.33	1.00
Lysine	3	0.93	0.01	0.65	1.00	0.03	0.28	0.00	0.00	0.15	0.92	0.94	1.00	1.00
Methionine	4	0.81	0.01	0.72	1.00	0.03	0.63	0.00	0.22	0.53	0.17	0.51	0.67	1.00
Phosgene	5	0.73	0.05	1.00	0.29	0.68	0.22	0.00	0.00	0.18	0.23	0.93	0.67	1.00
Benzene	6	0.71	0.13	0.49	0.30	0.00	0.14	0.67	0.78	0.39	0.14	1.00	0.67	1.00
Ethanol	7	0.68	1.00	0.04	0.44	0.00	0.05	0.00	0.00	0.41	0.38	0.94	0.67	1.00
Ethylene	8	0.63	0.82	0.37	0.29	0.08	0.14	0.33	0.00	0.25	0.91	0.03	0.67	0.84
Chlorine	9	0.58	0.27	0.39	0.28	0.00	0.24	0.50	0.09	0.15	0.27	0.59	1.00	1.00
Sulfuric acid	10	0.57	0.70	0.24	0.34	0.00	0.22	0.00	0.40	0.59	0.05	0.10	1.00	0.98
Sorbitol	11	0.53	0.01	0.19	0.73	0.01	0.35	0.00	0.00	0.01	0.33	0.94	1.00	1.00
Propylene	12	0.51	0.39	0.19	0.29	0.00	0.17	0.67	0.00	0.42	0.13	0.66	0.67	0.93
Epichlorohydrin	13	0.47	0.01	0.16	0.34	0.00	1.00	0.00	0.40	0.17	0.49	0.51	1.00	1.00
Maleic anhydride	14	0.46	0.01	0.39	0.30	0.19	0.28	0.00	0.00	0.52	0.46	0.72	0.67	1.00
Sodium hydroxide	15	0.46	0.23	0.58	0.26	0.00	0.22	0.50	0.01	0.12	0.27	0.59	0.67	0.67
Butylene	16	0.45	0.22	0.03	0.40	0.00	0.17	1.00	0.00	0.25	0.12	0.77	0.67	1.00
Lactic acid	17	0.44	0.01	0.06	0.43	0.00	0.58	0.00	0.33	0.22	0.33	0.94	1.00	1.00
Toluene	18	0.44	0.13	0.00	0.40	0.00	0.14	0.67	0.11	0.38	0.33	1.00	0.67	1.00
Xylenes	19	0.43	0.13	0.08	0.34	0.00	0.20	0.67	0.00	0.37	0.30	1.00	0.67	1.00
1,4-Butanediol	20	0.42	0.01	0.19	0.29	0.03	0.42	0.00	0.00	0.52	0.95	0.36	1.00	1.00

Criticality is heavily concentrated in Tier 1 (platform), bio-based, and inorganic chemicals, with each molecule exhibiting unique combinations of risk areas.

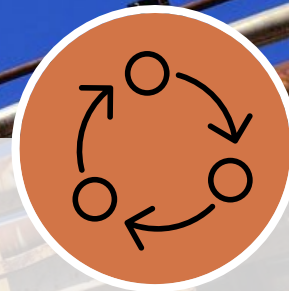
Takeaways



Analysis enables robust decision-making for chemicals and beyond



R&D should target high-potential direct replacement chemicals and explore other functional replacements



A holistic approach incorporating full life cycles and other metrics (e.g., supply chain) will be critical



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Questions?

Contact: taylor.uekert@nlr.gov



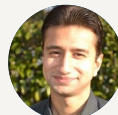
Ling Tao



Gregg
Beckham



Birdie
Carpenter



Jibran
Zuberi



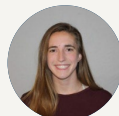
Linda
Broadbelt



Arpit
Bhatt



Bruno
Klein



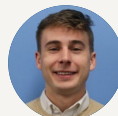
Elisabeth
Van Roijen



Eric Tan



Greg
Avery



Jake
Kenny



Jenny
Huang



Quan
Zhang



Tapajyoti
Ghosh

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