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changing the way we recycle

U.S. DEPARTMENT OF ENERGY

Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment

DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

BOTTLE 7 – Industry Projects & Engagement

April 3, 2023

Technology Session Review Area: Plastics Deconstruction and Redesign

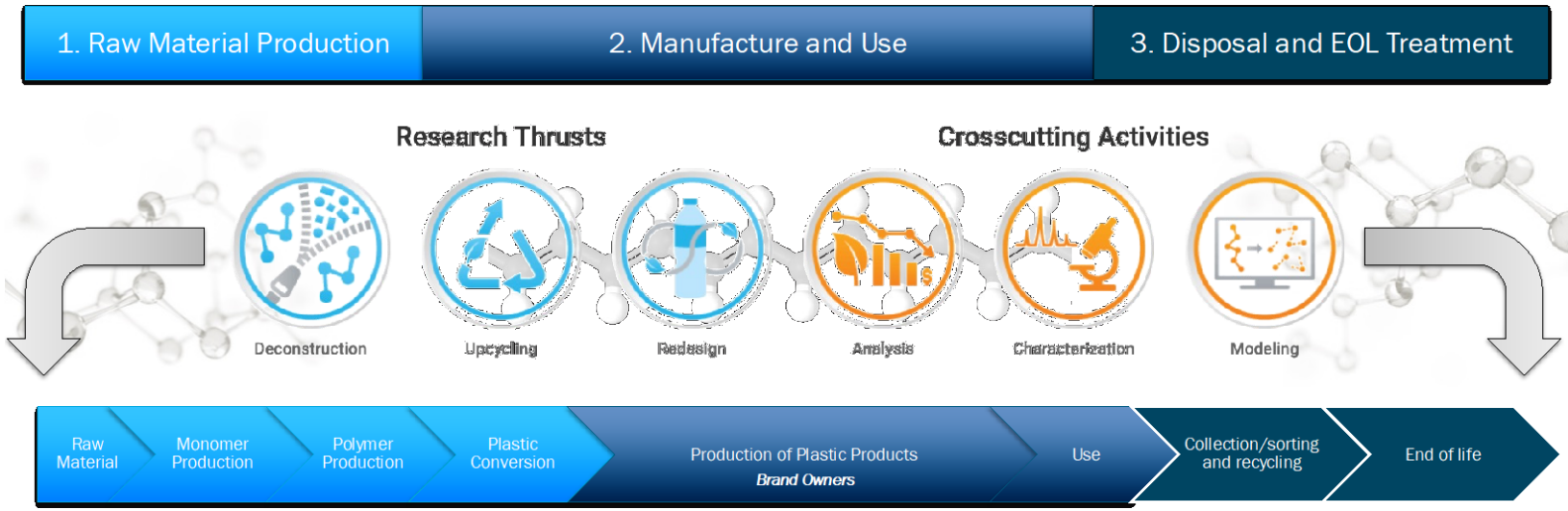
PI: Katrina Knauer, BOTTLE CTO, National Renewable Energy Laboratory

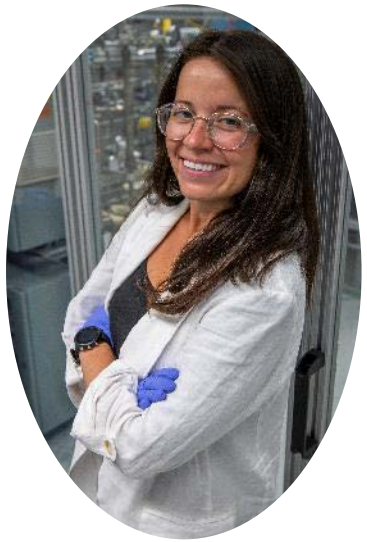
U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
BIOENERGY TECHNOLOGIES OFFICE
ADVANCED MATERIALS & MANUFACTURING TECHNOLOGIES OFFICE

Overview – BOTTLE industry engagement

BOTTLE's industry engagement history:

- BOTTLE created a centralized business development (BD) platform and focused BD effort
- Created a dedicated BD/research role (Chief Technology Officer) to streamline engagement and lead CRADA projects
- Onboarded BD tools to streamline BOTTLE engagement pipeline (Hubspot)
- Leveraged AOP-funded BOTTLE innovations portfolio to design projects with near-term industrial relevance
- Identified companies to target for collaboration using an industry landscape analysis and external consulting report
  - Initial traction with brand owners





BOTTLE CTO
Kat Knauer

BOTTLE's industry engagement goals:

- Solve real-world problems in plastics upcycling via targeted, company-funded projects
- Promote industrial engagement via streamlined access to BOTTLE partners and technologies
- Act as a supply chain navigator and collaborate with companies to scale and deploy BOTTLE technologies into the U.S. economy

BOTTLE Industry Engagement Approach

- Intro to BOTTLE and flagship projects
- Solicit challenges from companies
- Company shares key sustainability metrics

- Outline a scope of work (TRL 2-3)
- Initial tasks are usually 6-18 months (hiring for short projects can be challenging)
- Format funding as stage-gate approach

Stage 0: Prospecting

Set up meeting

Stage 1: Initial Engagement

Establish NDA

Stage 2: Knowledge Sharing

Brainstorming

Stage 3-4: Proposal & Contracting

Iteration & Negotiation

Stage 5: Opportunity Won

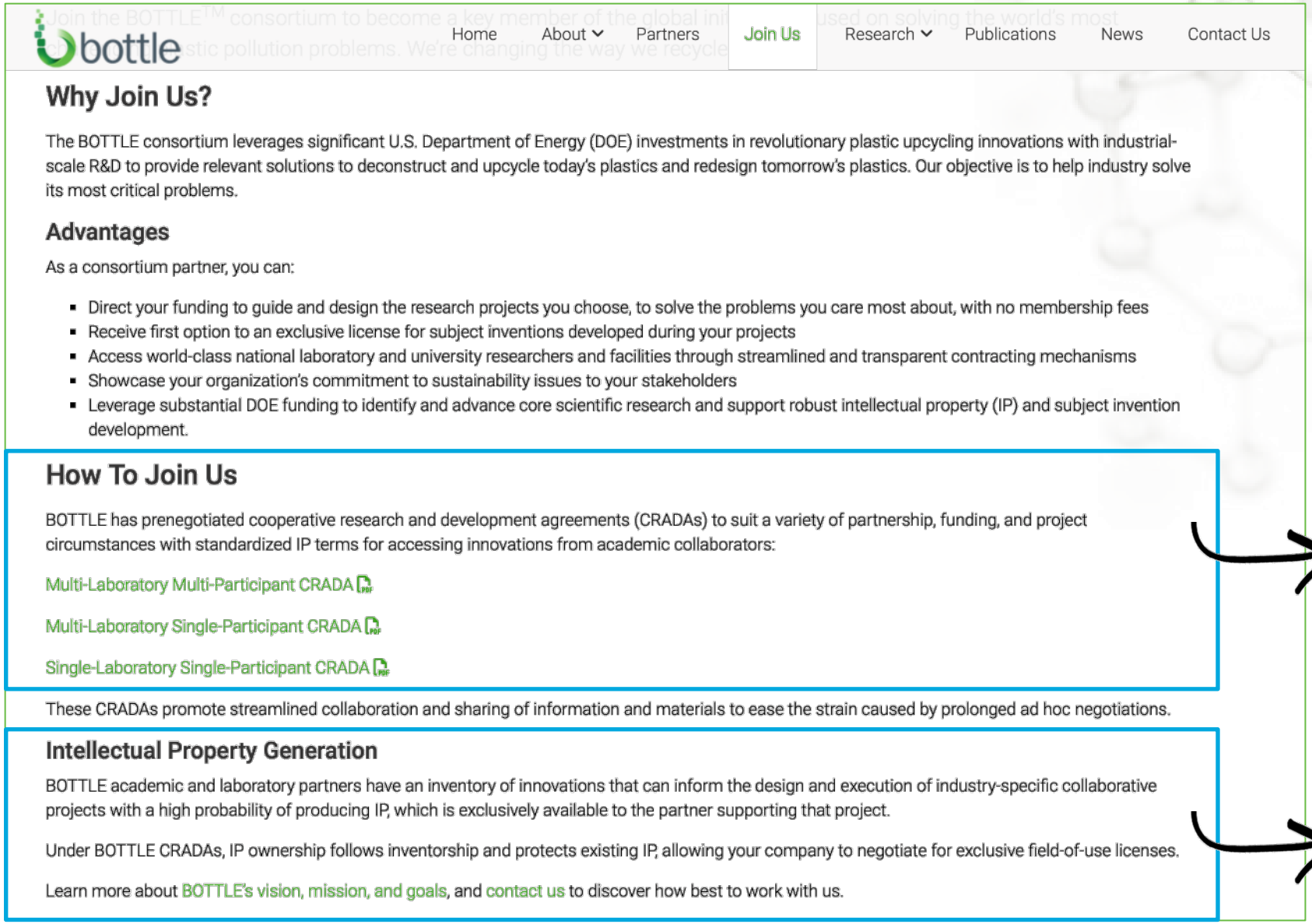
- Conferences
- Networking
- Market reports
- Publications and patents

- Share BOTTLE capabilities and strategies
- Show line-of-sight to scale
- Preliminary TEA/LCA helps guide discussions
- Company also shares data/previous work

- Update project managers on kickoff and milestone dates
- Update subcontracting agreements for funds transfers to BOTTLE partners

Blue text – Key learnings since FY21 peer review *Red text – Key challenges*

Documents on BOTTLE website help accelerate contracting



bottle

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Why Join Us?

The BOTTLE consortium leverages significant U.S. Department of Energy (DOE) investments in revolutionary plastic upcycling innovations with industrial-scale R&D to provide relevant solutions to deconstruct and upcycle today's plastics and redesign tomorrow's plastics. Our objective is to help industry solve its most critical problems.

Advantages

As a consortium partner, you can:

- Direct your funding to guide and design the research projects you choose, to solve the problems you care most about, with no membership fees
- Receive first option to an exclusive license for subject inventions developed during your projects
- Access world-class national laboratory and university researchers and facilities through streamlined and transparent contracting mechanisms
- Showcase your organization's commitment to sustainability issues to your stakeholders
- Leverage substantial DOE funding to identify and advance core scientific research and support robust intellectual property (IP) and subject invention development.

How To Join Us

BOTTLE has prenegotiated cooperative research and development agreements (CRADAs) to suit a variety of partnership, funding, and project circumstances with standardized IP terms for accessing innovations from academic collaborators:

Multi-Laboratory Multi-Participant CRADA

Multi-Laboratory Single-Participant CRADA

Single-Laboratory Single-Participant CRADA

These CRADAs promote streamlined collaboration and sharing of information and materials to ease the strain caused by prolonged ad hoc negotiations.

Intellectual Property Generation

BOTTLE academic and laboratory partners have an inventory of innovations that can inform the design and execution of industry-specific collaborative projects with a high probability of producing IP, which is exclusively available to the partner supporting that project.

Under BOTTLE CRADAs, IP ownership follows inventorship and protects existing IP, allowing your company to negotiate for exclusive field-of-use licenses.

Learn more about BOTTLE's vision, mission, and goals, and contact us to discover how best to work with us.

BOTTLE CRADA templates available on website

IP management plan signed by all BOTTLE institutions

Progress and outcomes BOTTLE industry engagement

6 Executed industry CRADAs since FY21
8 Successful go/no-go meetings
2 CRADA extensions and follow-on funding

4 CRADA projects currently in contracting

Gaining traction with multiple players in plastic supply chain beyond brand owners

Expanding model to include philanthropic/VC groups

Company projects include deconstruction, upcycling, and redesign of plastics

Note: Logos omitted for proprietary partners

amazon – Deconstruction & redesign of polyesters

Overall goals:

- Develop a closed-loop, integrated recycling technology for mixed polyesters
- Develop a recycle-by-design and biodegradable PE alternative

Team size:

- >15 BOTTLE researchers

BOTTLE participants:

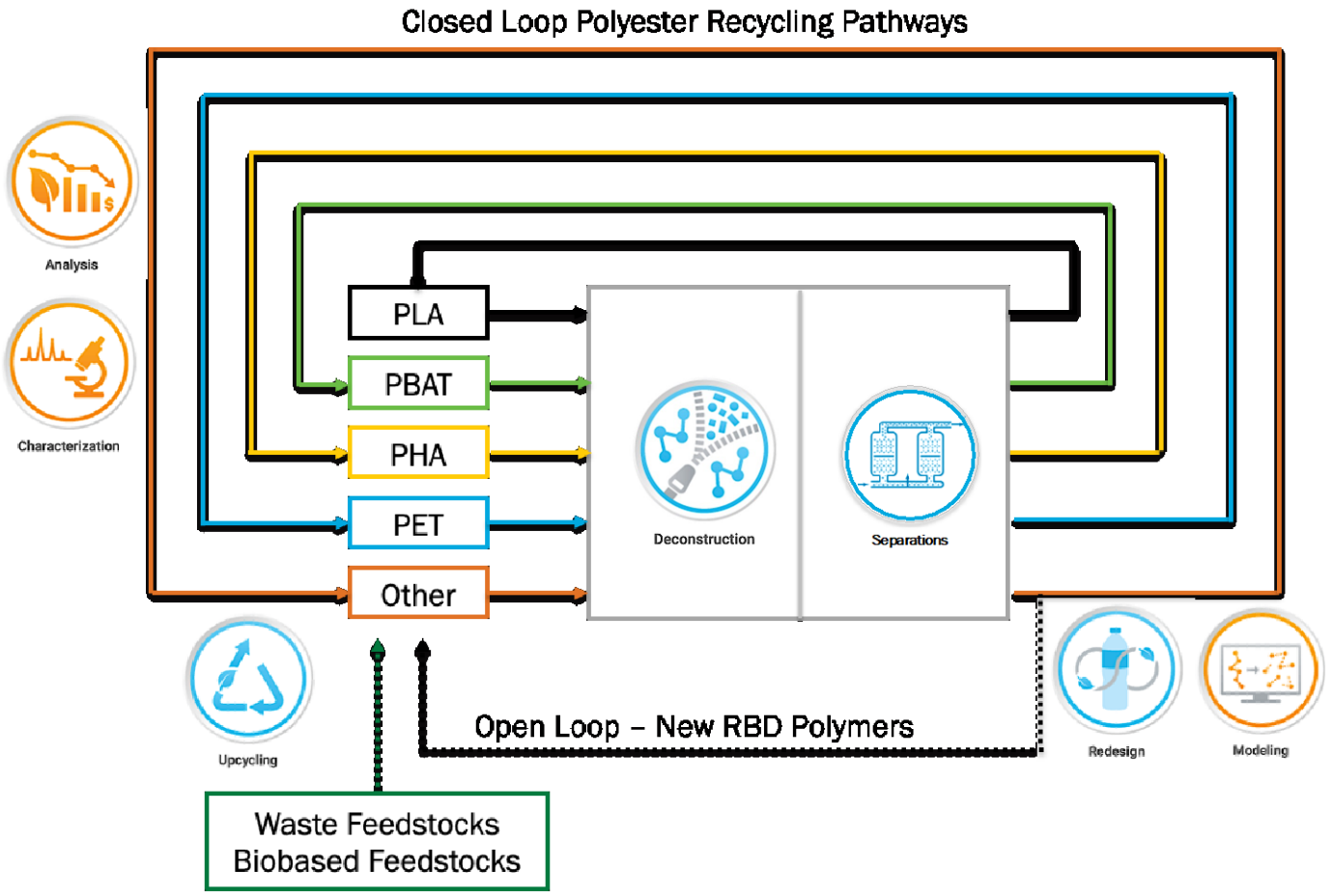
- CSU, NREL, SLAC

BOTTLE tasks:

- Deconstruction, Upcycling, Redesign, Characterization, and Analysis

BETO investment leveraged:

- PET deconstruction technologies[1-3]
- TEA/LCA data on PET deconstruction[4-5]
- Designer PHA portfolio[5-8]



[1]Nicholson, Rorrer *et al*. *Joule* 2019; [2]Knott, Erickson *et al*. *PNAS* 2020; [3]Werner *et al*. *Met Eng.* 2021; [4]Singh *et al*. *Joule* 2021; [5]Uekert *et al*. *Green Chem.* 2022; [6]Tang *et al*. *Nat. Commun*. 2018; [7]Tang *et al*. *Science* 2019; [8]Tang *et al*. *Angew. Chem*. 2020

KraftHeinz – Redesign of food packaging for end-of-life

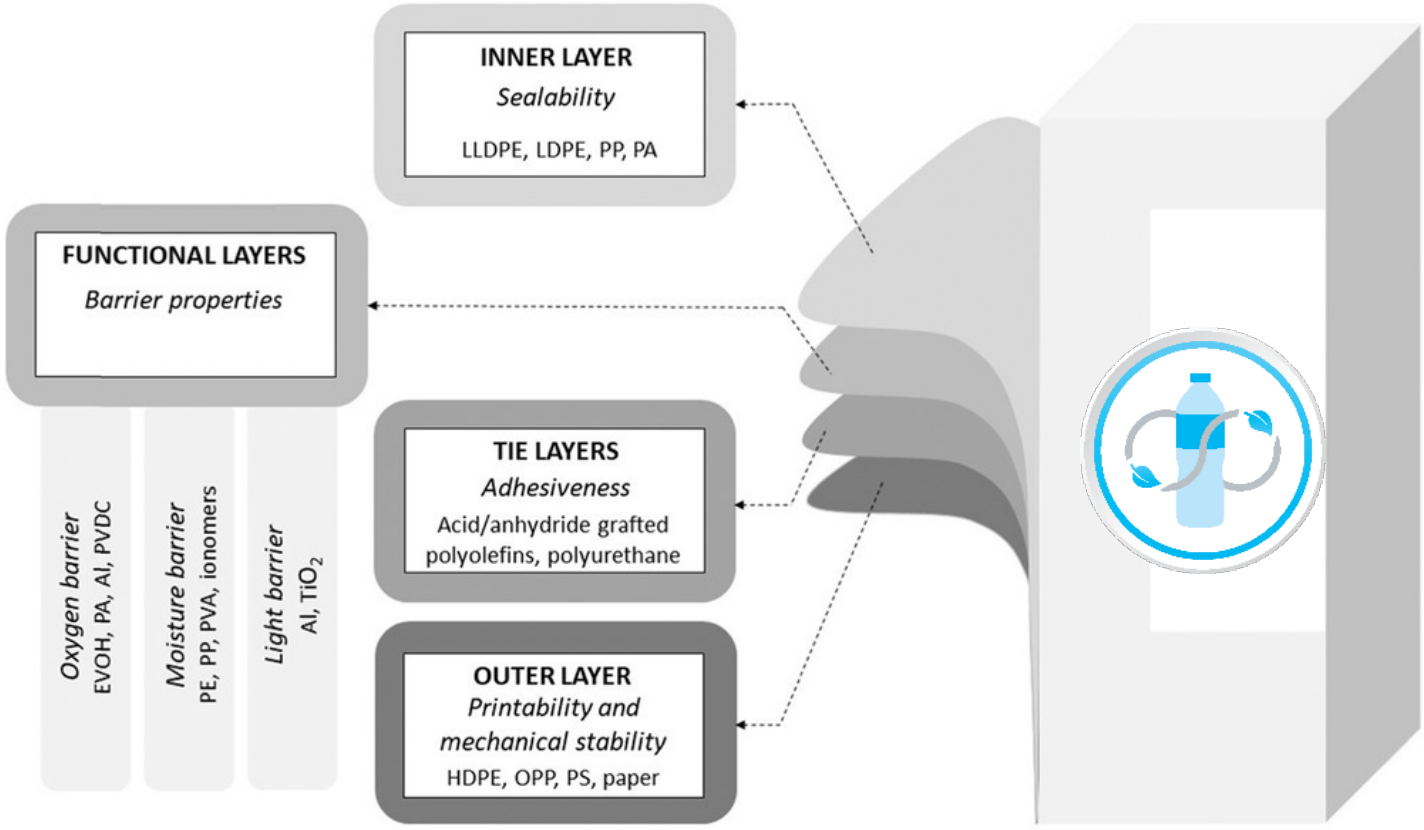
Overall goals:
- Develop sustainable packaging solutions for food products

Team size:
- 5 BOTTLE researchers

BOTTLE participants:
- CSU, NREL

BOTTLE tasks:
- Redesign, Modeling

BETO investment leveraged:
- Recyclable-by-design polymer portfolio[1]
- Poly(ID) and predictive modeling[2]



Multi-layer food packaging is not currently recyclable

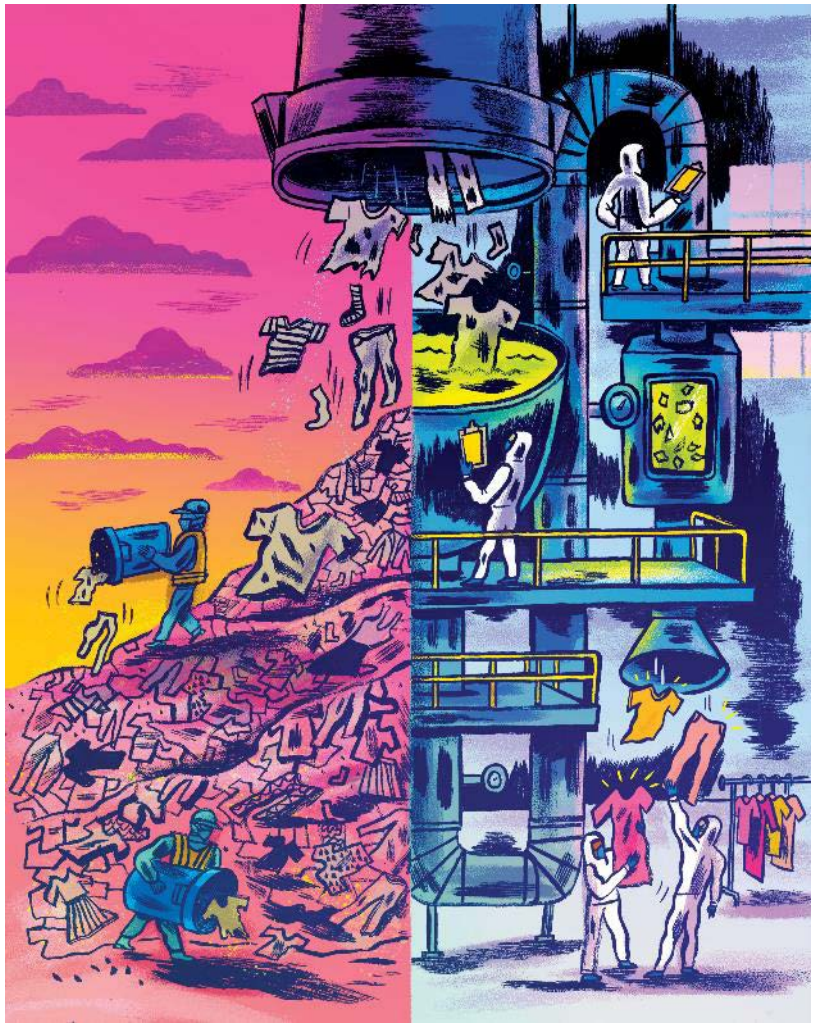
[1]Shi *et al*. *Sci. Adv*. 2020; [2]Shi *et al*. *Chem* 2021

Patagonia/BOTTLE projects – Circularity for textiles

Chemical recycling of mixed textiles

~63% Plastics
~26% Cotton
~11% Other[1]

Dye removal, recovery, and recycling



[1]Morlet *et al*. *Ellen MacArthur Foundation Report: A New Textiles Economy* 2018; [2]Image: Scott, A. *C&EN* 2022

Patagonia – Project 1: Mixed textiles deconstruction

Overall goals:
- Develop a catalytic deconstruction technology to upcycle mixed plastic waste

Team size:
- 4 BOTTLE researchers

BOTTLE participants:
- NREL

BOTTLE tasks:
- Deconstruction, Characterization

BETO investment leveraged:
- Applied foundational knowledge in autoxidation developed via AOP funds to apply technology to mixed textiles[1]

[1]Sullivan, Werner, Ramirez, Ellis *et al*. *Science* 2022

Patagonia – Project 2: Textile pretreatments for recycling

Overall goals:

- Develop a biobased extraction process to remove dyes and additives from PET rich textiles to enable textile-to-textile recycling with integrated downstream separations to recover dyes

Team size:

- 5 BOTTLE researchers

BOTTLE participants:

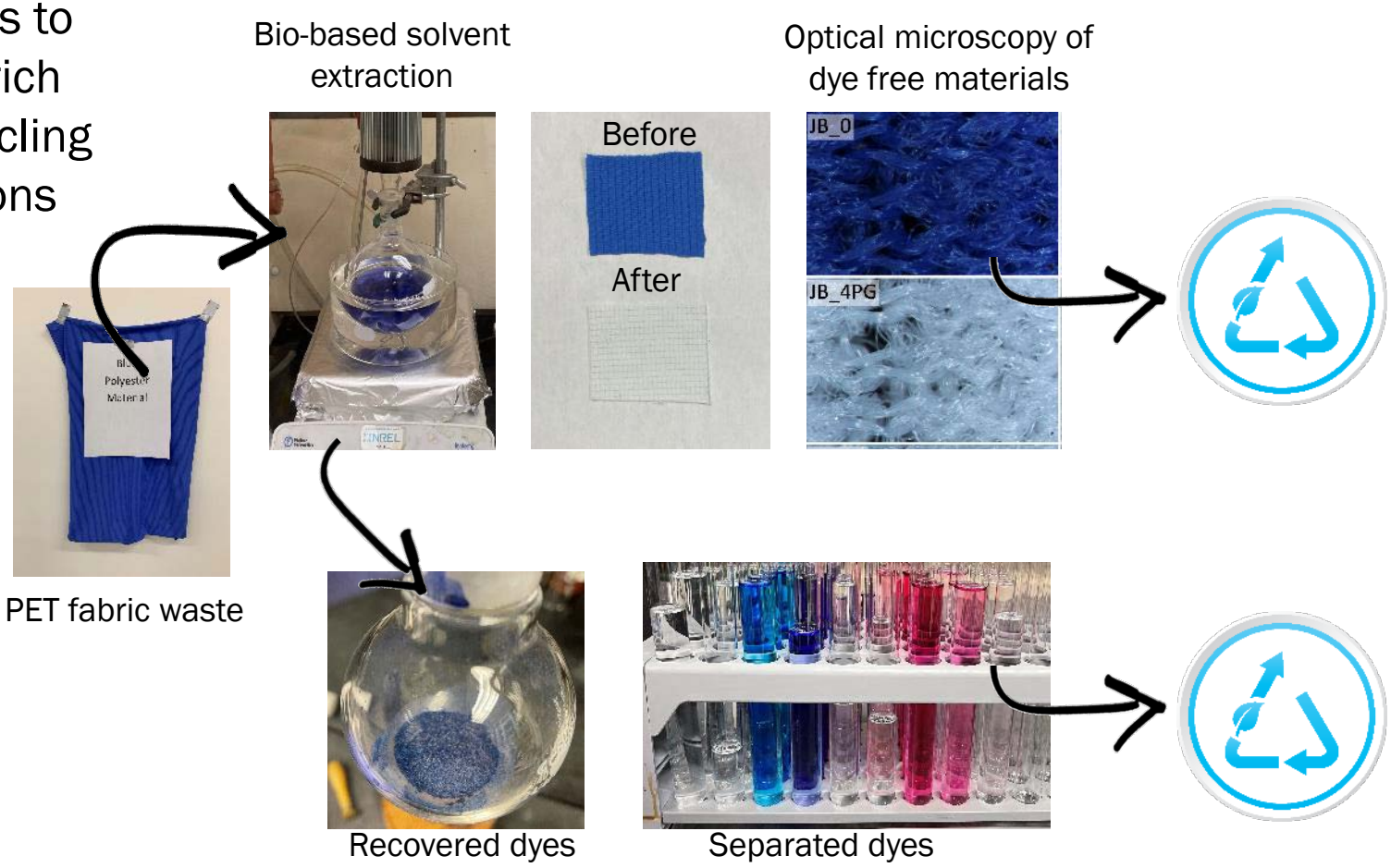
- NREL

BOTTLE tasks:

- Upcycling

BETO investment leveraged:

- Bio-based solvents from biomass[1]



[1]Stone, Webber *et al*. *Joule* 2022

P&G – Upcycling of polyethylene waste

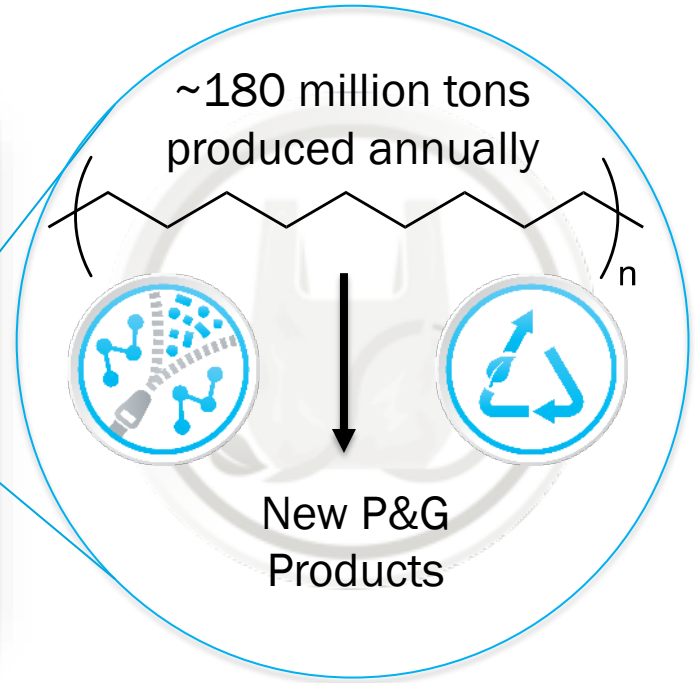
Overall goals:
- Develop a catalytic deconstruction technology to upcycle polyethylene waste

Team size:
- 5 BOTTLE researchers

BOTTLE participants:
- MIT, NREL

BOTTLE tasks:
- Deconstruction, Upcycling

BETO investment leveraged:
- Applying foundational knowledge in oxidation catalysis and deconstruction of polythylene[1,2]



[1]Sullivan, Werner, Ramirez *et al. Science* 2022; [2]Ellis, Rorrer, Sullivan *et al. Nature Catalysis* 2021.

– Deconstruction & upcycling of chlorinated plastics

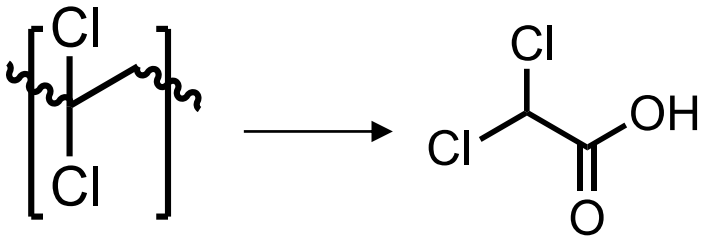
Overall goals:
- Develop an oxidative biological funneling technology to upcycle PVDC/PVC waste

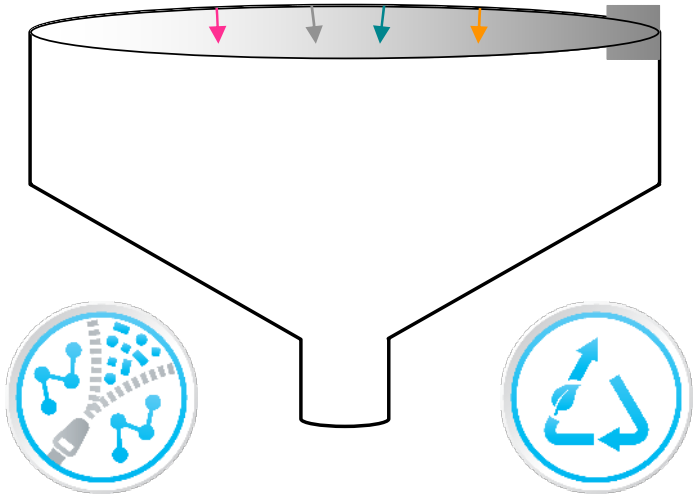
Team size:
- 5 BOTTLE researchers

BOTTLE participants:
- NREL

BOTTLE tasks:
- Deconstruction, Upcycling

BETO investment leveraged:
- Applied foundational knowledge in oxidation catalysis and *P. putida* engineering[1,2]





[1]Werner *et al. Met. Eng.* 2021; [2]Sullivan, Werner, Ramirez *et al. Science* 2022

– Upcycling of HIPs electronic waste

CANON VIRGINIA, INC.

Overall goals:

- Develop a green pretreatment technology for high impact polystyrene (HIPs) to yield a high-quality product for e-waste recycling

Team size:

- 5 BOTTLE researchers

BOTTLE participants:

- MIT, NREL

BOTTLE tasks:

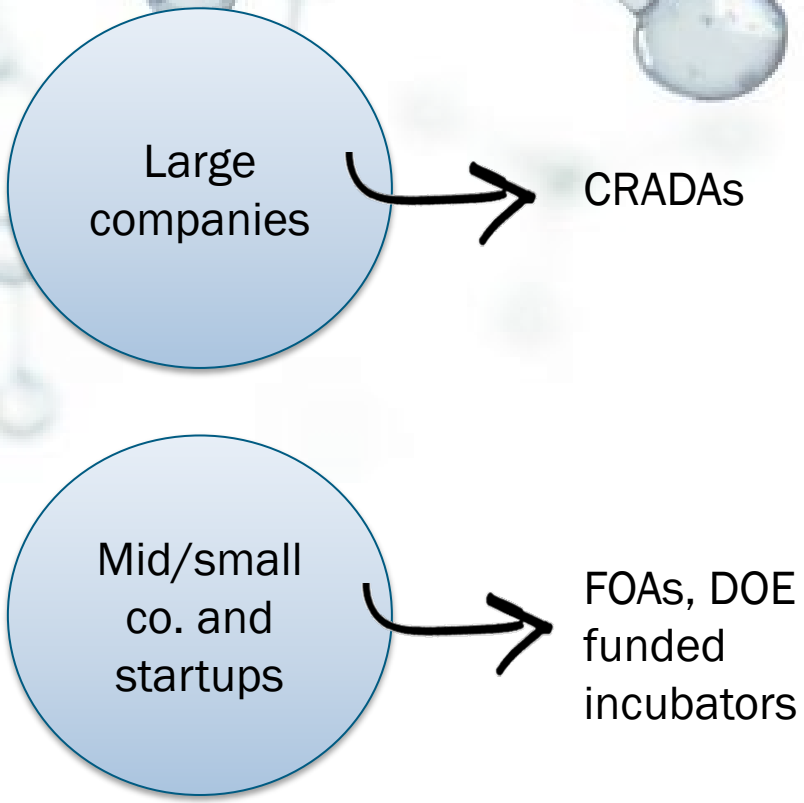
- Upcycling

BETO investment leveraged:

- Applied foundational knowledge in green chemistry and bio-based solvents

Impact

- >40 BOTTLE researchers on industry projects
- >150 Industrial partners engaged
- 31 Patent applications (5 CRADA subject inventions)
- 6 Industrial CRADAs executed
- 4 Industrial CRADAs in contracting
- 3 FOA CRADAs executed and started
- 2 BOTTLE spin-off companies: Tereform & Eco Polymers



Quad Chart

Timeline

- Active Project Duration: 10/1/2020 – 9/30/2023
- Total Project Duration: 10/1/2019 – 9/30/2023

	FY23 Funding	Total Award (FY21-23)
DOE Funding	$10,000,000	$30,000,000

Project Partners

ANL, CSU, LANL, MIT, MSU, NREL, NU, ORNL, SLAC, UoP

TRL at Project Start: 1
TRL at Project End: 4

Funding Mechanism

Bioenergy Technologies Office FY21 AOP Lab Call (DE-LC-000L079) – 2020

Project Goals

- Develop selective, scalable processes to deconstruct and upcycle today's plastics and thermosets
- Redesign tomorrow's plastics to be recyclable-by-design (RBD) and derived from bio-based feedstocks
- Work with industry to catalyze new upcycling paradigms and novel feedstocks

End of Project Milestones

- Deconstruction: Achieve hydrogenolysis of polyolefins in a continuous process with a selectivity profile of >60% to a single product. Deliver cutinase variants with the ability to reach over 80% conversion extent on crystalline PET in a pH-controlled bioreactor.
- Upcycling: Deliver a submission-ready manuscript that describes consolidated bioprocessing of PET plastic to an RBD monomer using a thermophilic microorganism.
- Redesign: Deliver a submission-ready manuscript on designer PHB with PE/PP-like performance via controlling stereomicrostructures that includes TEA, LCA, and biodegradation studies.
- Analysis: Deliver designs on autoxidation, hydrogenolysis, PET conversions, and at least 5 redesigned polymers in accordance with the primary BOTTLE metrics of carbon, economics, energy, and GHG emissions
- Modeling: Deliver an integrated set of tools that enable prediction of RBD polymers for a target application and their syntheses

Thank you!

Argonne NATIONAL LABORATORY

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Thai Scheve
Reni Truhtcheva - *Owikoti*
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Northwestern University

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Erik Rognerud
Nic Rorrer
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Katie Stevenson
Kevin Sullivan
Taylor Uekert
Allison Werner
Sean Woodworth
Geetanjali Yadav
Robin Cywar
Shaik Afzal
Brenna Black
Richard Brizendine
Bonnie Buss
Erika Erickson
Mikhail Konev
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Avantika Singh
Megan Browning
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Gayle Bentley, BETO
Jay Fitzgerald, BETO
Kate Peretti, AMMTO
Michelle Seitz, AMMTO

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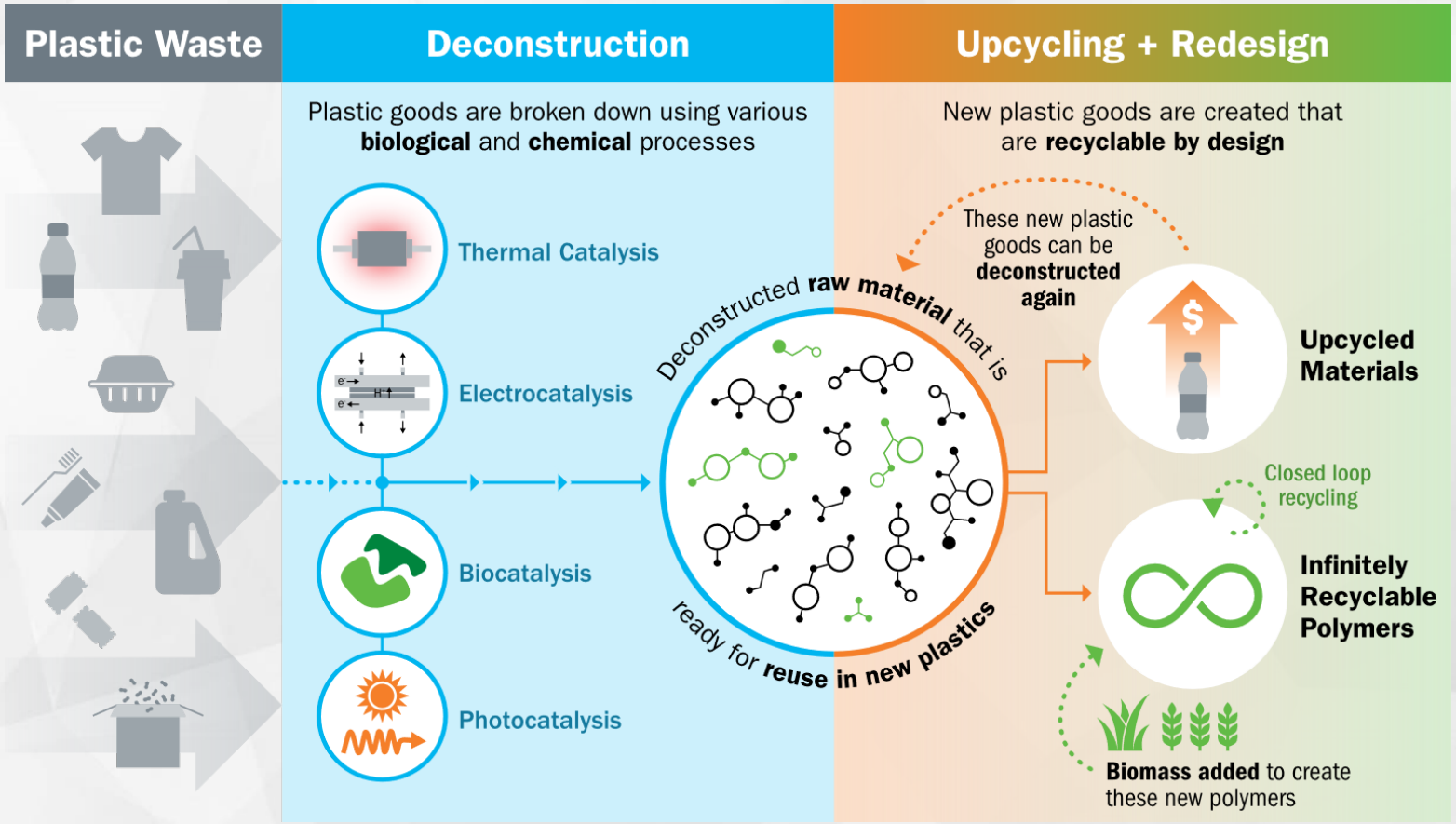
Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment

Q&A section



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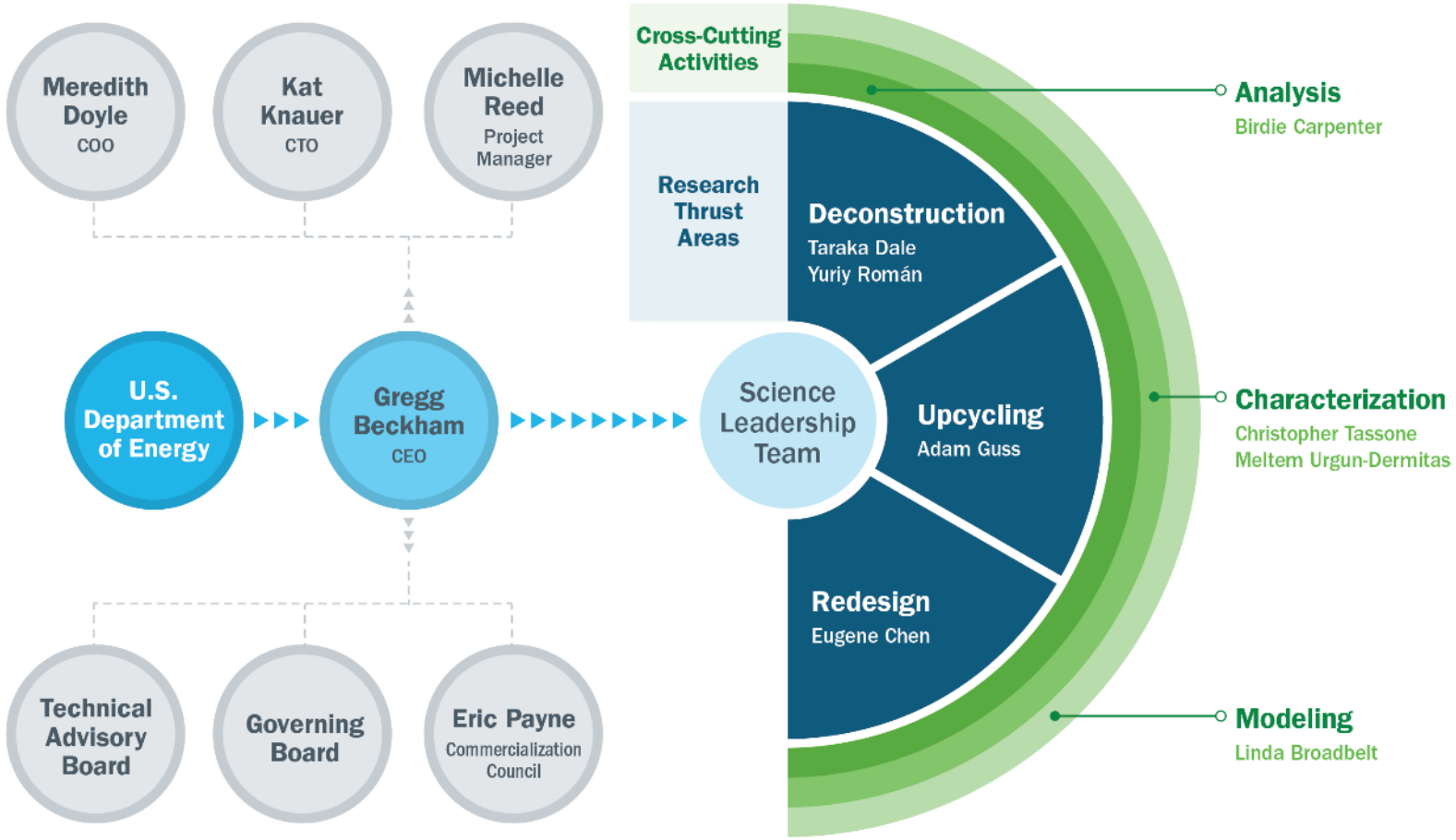
Additional Slides

Leadership Team Structure



BOTTLE Leadership Team (LT):

- CEO, COO, & PM
- Oversee the Management task
- *Role focused on leadership of BOTTLE*

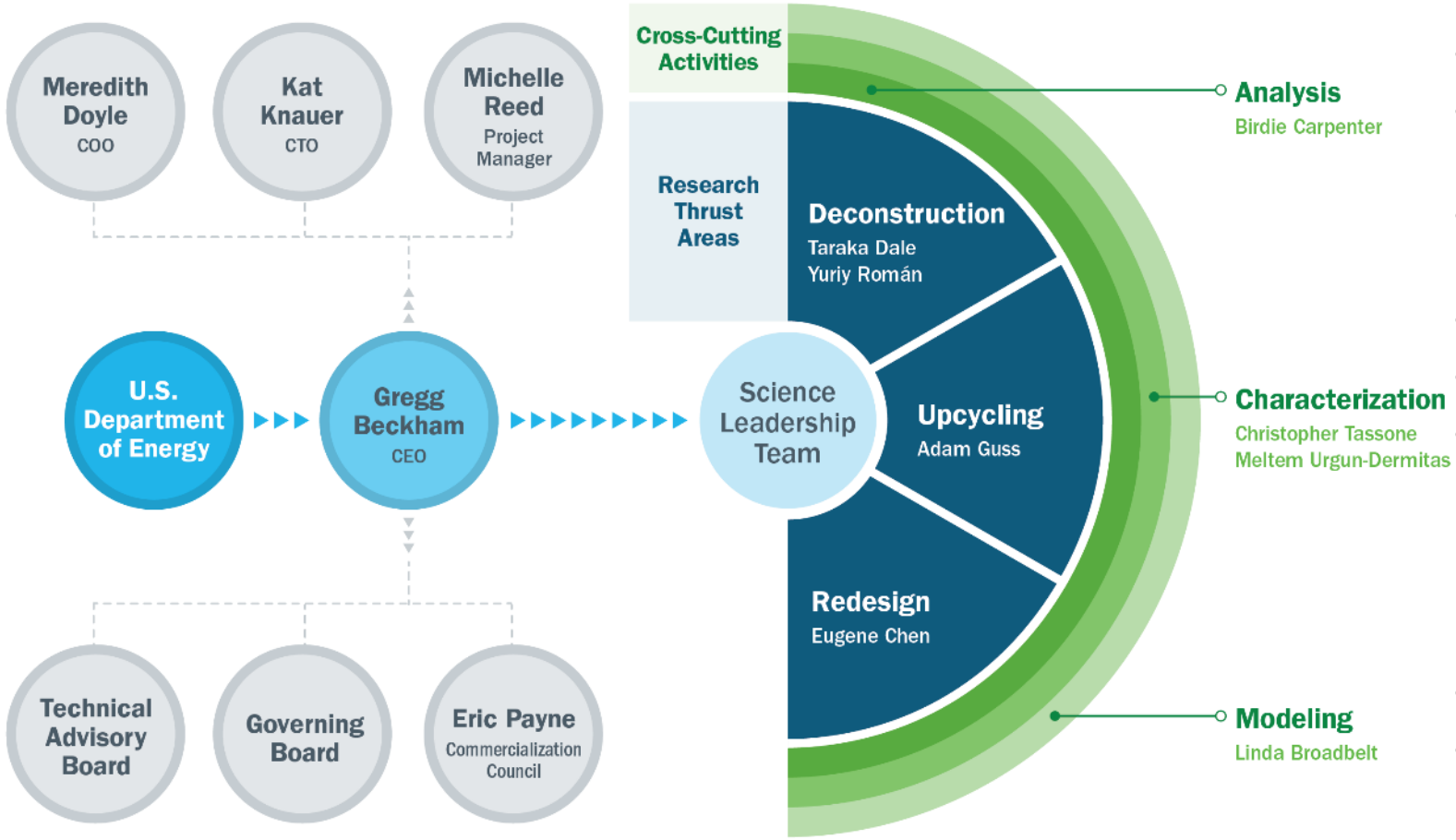
Governing Board (GB):

- BOTTLE LT, lab and several univ. leads, DOE
- Yearly strategic planning meeting
- *Role focused on management, strategy*

Science Leadership Team (SLT):

- CEO, all institutional leads, DOE
- Yearly planning meeting, teleconferences quarterly
- *Role focused on research execution*
- Annual Portfolio Review responsibilities
- Implement and supervise research projects at each institution

Technical Advisory Board and Comm. Council



Technical Advisory Board (TAB):

- Feedback on R&D, operations, management
- Invited diverse group of thought leaders from academia, government, industry, non-profits
- TAB represents key points in the plastics value chain to ensure robust assessment of BOTTLE
- Convene annually with the All-hands meeting
- Provide written evaluations to DOE, BOTTLE LT
- Includes leads of complementary R&D efforts in this space

Commercialization Council:

- Representative from each partner institution
- Central “storefront” for accessing BOTTLE IP through partnership and licensing
- Promote rapid deployment of BOTTLE IP

Publications

In preparation

Amy A. Cuthbertson, Clarissa L. Lincoln, Joel Miscall, Lisa Stanley, David T. Moore, Brenna A. Black, Nicholas A. Rorrer, Gregg T. Beckham, Characterization of polymer properties and identification of additives in commercial research plastics, in preparation.

Shaik Afzal, Avantika Singh, Scott R. Nicholson, Taylor Uekert, Eric C.D. Tan, Abhijit Dutta, Robert M. Baldwin, Gregg T. Beckham, Techno-economic analysis of mixed plastic waste gasification for the production of methanol and hydrogen, in preparation for *Energy Env. Sci.*

Rosie Graham, Erika Erickson, Richard K. Brizendine, Davinia Salvachúa, Zhongping Tan, Gregg T. Beckham, John E. McGeehan, and Andrew R. Pickford, Enzymatic deconstruction of poly(ethylene terephthalate) is not improved by the use of carbohydrate-binding modules at industrially-relevant solids loadings, in preparation for *Chem Catalysis*.

Julie E. Rorrer, Amani M. Ebrahim, Ydna Questell-Santiago, Clara Troyano-Valls, Arun S. Asundi, Simon R. Bare, Christopher J. Tassone, Gregg T. Beckham, Yuriy Román-Leshkov, Selective hydrogenolysis of polyethylene and polypropylene waste to liquid hydrocarbons over bifunctional Ru/acid catalysts, in preparation.

Geetanjali Yadav, Avantika Singh, Abhijit Dutta, Scott R. Nicholson, Kylee Harris, Calvin Mukarakate, Joshua A. Schaidle, Cody J. Wrasman, Yuriy Román-Leshkov, Robert M. Baldwin, Gregg T. Beckham, Techno-economic analysis of pyrolysis of mixed plastics waste, in preparation for *Energy Env. Sci.*

Submitted

Houqian Li, Robert D. Allen, Xianglan Bai, Gregg T. Beckham, et al., Expanding plastics recycling technologies: chemical aspects, technology status and challenges, submitted to *ACS SusChemEng.*

Publications

In review

Richard K. Brizendine, Erika Erickson, Stefan J. Haugen, Kelsey J. Ramirez, Joel Miscall, Davinia Salvachúa, Andrew R. Pickford, Margaret J. Sobkowicz-Kline, John E. McGeehan, Gregg T. Beckham, Effect of particle size and substrate crystallinity on enzymatic depolymerization of poly(ethylene terephthalate), in review at ACS SusChemEng.

Kevin P. Sullivan, Allison Z. Werner, Kelsey J. Ramirez, et. al., Tandem chemical oxidation and biological funneling for upcycling of mixed plastic waste, in review at Science.

In revision

Anelia Milbrandt, Kamyria Coney, Alex Baggett, Gregg T. Beckham, Quantity, distribution, market value, and energy value of plastic waste in the United States, in revision at Resources, Conservation, and Recycling.

Allison Z. Werner, Rita Clare, Thomas D. Mand, et. al, Tandem chemical deconstruction and biological upcycling of poly(ethylene terephthalate) to b-ketoadipic acid by Pseudomonas putida KT2440, In revision at Metabolic Engineering.

In press

Scott R. Nicholson, Julie E. Rorrer, Avantika Singh, Mikhail O. Konev, Nicholas A. Rorrer, Alberta C. Carpenter, Alan J. Jacobsen, Yuriy Román-Leshkov, Gregg T. Beckham, The critical role of process analysis in chemical recycling and upcycling of waste plastics, in press at Ann. Rev. Chem. Biomolec. Eng.

Publications

2023

Taylor Uekert, Avantika Singh, Jason S. DesVeaux, Tapajyoti Ghosh, Arpit Bhatt, Geetanjali Yadav, Shaik Afzal, Julien Walzberg, Katrina M. Knauer, Scott R. Nicholson, Gregg T. Beckham, and Alberta C. Carpenter, "Technical, economic, and environmental comparison of closed-loop recycling technologies for common plastics," ACS Sustainable Chemistry & Engineering (2023) 11, 3, 965–978.

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Taylor Uekert, Scott R. Nicholson, Avantika Singh, Jason S. DesVeaux, Tapajyoti Ghosh, John E. McGeehan, Alberta C. Carpenter, Gregg T. Beckham, "Life cycle assessment of enzymatic poly (ethylene terephthalate) recycling," Green Chemistry (2022) 24, 6531-6543.

Guido Zichittella, Amani M. Ebrahim, Jie Zhu, Anna E. Brenner, Griffin Drake, Gregg T. Beckham, Simon R. Bare, Julie E. Rorrer, and Yuriy Román-Leshkov, Hydrogenolysis of polyethylene and polypropylyne into propane over cobalt-based catalysts, JACS Au. (2022) 2, 10, 2259–2268.

Kevin P. Sullivan, Allison Z. Werner, Kelsey J. Ramirez, et. al., Mixed plastics waste valorization through tandem chemical oxidation and biological funneling, Science (2022) 378, 207-211.

Rosie Graham, Erika Erickson, Richard K. Brizendine, Davinia Salvachúa, William E. Michener, Yaohao Li, Zhongping Tan, Gregg T. Beckham, John E. McGeehan, Andrew R. Pickford, The role of binding modules in enzymatic poly(ethylene terephthalate) hydrolysis at high-solids loadings, Chem. Catalysis. (2022) 2644-2657.

Sang-Min Shin, Ramesh K. Jha, and Taraka Dale, Tackling catch-22 situation of optimizing a sensor and transporter system in a whole cell biosensor design for an anthropogenic small molecule, ACS Synthetic Biology (2022), 11, 3996-4008.

Publications

Julie E. Rorrer, Amani M. Ebrahim, Ydna Questell-Santiago, Jie Zhu, Clara Troyano-Valls, Arun S. Asundi, Anna E. Brenner, Simon R. Bare, Christopher J. Tassone, Gregg T. Beckham, and Yuriy Román-Leshkov, The role of bifunctional Ru/acid catalysts in selective hydrocracking of polyethylene and polypropylene waste to liquid hydrocarbons, *ACS Catal*. (2022) 12, 22, 13969–13979.

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- Renewable bio-advantaged plasticizer generated by reductive cross coupling of lignin-derived aromatics, 22-124: U.S. provisional patent application 63/379,217
- Process for sequential acetolysis-autoxidation of plastic streams, 22-107: U.S. provisional patent application 63/383,293
- Methods and systems for dye removal from polymer textiles, 22-106: U.S. provisional patent application 63/384,137
- Biodegradable elastomeric thermosets from microbially-produced polyhydroxyalkanoates, 19-104: U.S. provisional patent application 63/386,011
- Light-driven C-C bond cleavage enabled by polyoxometalate photocatalysts, 21-95: U.S. provisional patent application forthcoming

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- Hydrogenolysis of Polyethylene and Polypropylene into Propane over Cobalt-Based Catalysts, 22-81: U.S. provisional patent application 63/340,322
- Catalysts for Depolymerizing Plastics, 20-22: 17/370,244
- Plastic Degrading Fusion Proteins and Methods of Using the Same, 20-86: PCT/US21/31610
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- Method to Produce Branched-Chain Polyhydroxyalkanoates and Branched Chain 3-Hydroxyacids from Glucose, 21-63A: 63/321,207.
- Upcycling Mixed Waste Plastic Through Chemical Depolymerization and Biological Funneling, 20-123: PCT/US21/63725.
- Genetically engineered Pseudomonas strains capable of metabolizing ethylene glycol, 17-26: 11,021,721
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- Bio-derived biphenyl compounds (Polycarbonates), 18-81: 16/791,873
- Bioderived monomers as replacements in petroleum-based polymers and copolymers (novel bio-based plasticizers), 19-38: 16/790,093
- Conversion of dicarboxylic acids to monomers and plasticizers, 19-41A: 16/995,338
- Bio-derived Epoxide Triazine Networks and Methods of Making the Same, 20-26: 17/324,222
- Bio-derived Epoxy-Anhydride Thermoset Polymers for Wind Turbine Blades and Anti-Static Coatings, 20-59: 17/494,514
- Plastic waste derived polymers and resins and methods of making the same (PET upcycled to 3D printing materials). 20-37: 17/371,421
- Mixed Waste Plastics Compatibilizers for Asphalt (filed by ASU), 21-53: 63/148,423

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- Bioderived Benzoxazines, 20-130: 17/690,131
- Novel Routes to Bis-furan Diacids, Dialcohols and Diamines, US 9840485
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- Chemically Recyclable Polymers to Combat Single-Use Plastics, PCT Patent Pending: WO 2021/113325
- Synthesis of Crystalline Polymers from Cyclic Diolides, US Utility Patent Pending: US 2019/0211144
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- High-Speed, Stereoselective Polymerization for Renewable Bio-derived Plastics, US Utility Patent: US 9309332

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Bio-based Polymers with Performance & Recyclability Advantages, Braskem, virtual seminar, November 2022.

Design Principles and Chemocatalytic Methods for Circular Polymers and Biodegradable Plastics, BASF Lecture in Organic Chemistry, November 2022.

Developments in Advanced Recycling, TA Instruments Webinar, October 2022.

Design of Polyolefin-like Polyesters with Closed-loop Lifecycles, ACS WRM Polymer Symposium, October 2022.

Adopting a sustainable plastics supply chain, RISE 2022, September 2022.

Presentations

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Advances in lignin and plastics conversion, VITO, September 2022.

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Techno-economic analysis and life cycle assessment for catalytic fast pyrolysis of mixed plastic waste, BioEnergy TRP Meeting, National Renewable Energy Laboratory, August 2022.

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Presentations

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Presentations

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Selective chemical recycling of mixed plastics waste, Polymer Physics Gordon Research Conference, July 2022.

Plastics recycling and upcycling in the BOTTLE Consortium, NASEM Committee on Repurposing Plastic Waste, July 2022.

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Development of chemical recycling approaches for plastic waste, Enzyclic Consortium (via webinar), January 2022

Development of chemical recycling approaches for plastic waste, UIUC, December 2021

Design Principles and Synthetic Methodologies for Circular Polymers with Intrinsic Recyclability and Tunable Properties, Pacifichem Conference, December 2021

New building blocks for performance-advantaged renewable and recyclable polymers, Pacifichem (via webinar), December 2021

Discovery and characterization of PET degrading enzymes, University of Rochester microplastics workgroup seminar series, December 2021.

Design Principles and Synthetic Methodologies for Intrinsically Circular Polymers and Biodegradable Plastics, Columbia University, November 2021

Selective Hydrogenolysis of Polyethylene and Polypropylene to Liquid Alkanes over Tunable Ruthenium-Based Heterogeneous Catalysts, 2021 AIChE National Conference, Boston, MA, November 2021.

Plastics recycling and upcycling, ACS Converge (via webinar), October 2021

Presentations

Genetic tools and microbial engineering for biological production of sustainable fuels and chemicals, Presented to Weekly Seminar for DOE CCI/SULI Students. October 2021

Heterogeneous Catalytic Deconstruction and Upcycling of Waste Polyolefins, Biodesign Institute at Arizona State University, SM3 Seminar Series, October 2021.

Domestication of diverse non-model microbes for plastics upcycling and sustainable fuel and chemical production, Biological Sciences Departmental Seminar, Michigan Technical University. October 2021.

Catalysis for valorization of lignin and plastics, Great Plains Catalysis Society (via webinar), June 2021

The critical role of economic and environmental analysis to guide research in lignin valorization and plastics upcycling, Keynote Invited Lecture, ACS Green Chemistry and Engineering (via webinar), June 2021

Towards Intrinsically Circular Thermoplastics and Reprocessable Thermosets, Dow Chemical Company, virtual seminar, May 2021

Recent progress in performance-advantaged bioproducts and plastics upcycling, Arizona State University (via webinar), April 2021

Recent adventures in biomass conversion and plastics upcycling, Rutgers University (via webinar), April 2021

Presentations

Recent adventures in biological plastics upcycling, MIX-UP Consortium (via webinar), April 2021

Framing challenges and opportunities for chemical recycling of waste plastics, ACS Presidential Symposium on Chemistry and the Future of Plastics (via webinar), April 2021

Recent updates in plastics upcycling from the BOTTLE Consortium, ExxonMobil Research and Engineering, April 2021

Design Principles and Synthetic Methodologies for Circular Polymers and Biodegradable Plastics, KAUST, Physical Science and Engineering Division, virtual seminar, April 2021

Heme and non heme iron enzymes and renewable carbon, University of San Antonio Texas, April 2021

A flexible kinetic assay efficiently sorts potential biocatalysts for BHET hydrolysis, Symposium on Biomaterials, Fuels, and Chemicals, April 2021

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Design Principles for Circular Plastics with Tunable Properties, CellPress LabLinks: The Circular Plastics Economy: Linking Across Scales, virtual event with 440 registered attendees. March 2021.

Process analysis for enzymatic PET recycling, Global Research and Innovation on Plastics annual meeting (via webinar), March 2021

Presentations

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Biological processes for lignin and plastics conversion, University of California Riverside (via webinar), January 2021

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