U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plastics Deconstruction and Redesign

April 3, 2023

Coralie Backlund

Technology Manager

Agenda Overview

- Schedule for the Technology Area Review
- Reviewer Welcome
- Plastics Overview
- BETO Efforts

Session 1: Plastics Deconstruction and Redesign

Monday April 3 – BOTTLE Consortium

Tuesday April 4 – FY19 Multi-topic and FY20 BOTTLE competitive awards

Wednesday April 5 – FY20 BOTTLE and FY21SUPR competitive awards

Schedule for April 3, 2023

1:00 PM	1:30 PM	30		Technology Area Introduction	BETO	Coralie Backlund
1:30 PM	2:00 PM	30	BOTTLE1	Introduction & BOTTLE Overview	BOTTLE Consortium	Gregg Beckham
2:00 PM	2:15 PM	15	BOTTLE2	Analysis	BOTTLE Consortium	Jason DesVeaux, Taylor Uekert
2:15 PM	2:45 PM	30	BOTTLE3	Deconstruction	BOTTLE Consortium	Yuriy Román-Leshkov, Taraka Dale
2:45 PM	3:00 PM	15		Q&A		
3:00 PM	*3:20 PM*	*20*		*Break*	*All*	
3:20 PM	3:35 PM	15	BOTTLE4	Upcycling	BOTTLE Consortium	Adam Guss
3:35 PM	3:55 PM	20	BOTTLE5	Redesign & Modeling	BOTTLE Consortium	Eugene Chen, Linda Broadbelt
3:55 PM	4:10 PM	15	BOTTLE6	Characterization	BOTTLE Consortium	Christopher Tassone, Meltem Urgun-Demirtas
4:10 PM	4:25 PM	15		Q&A		
4:25 PM	4:40 PM	15	BOTTLE7	Industry Projects & Engagement	BOTTLE Consortium	Kat Knauer
4:40 PM	4:50 PM	10		Q&A		
4:50 PM	*5:30 PM*	*40*		*Closed Door Comment Review Session*	*Reviewers*	

Reviewer Introductions

Name	Affiliation
Sharon Haynie	Independent Consultant - formerly Dupont -
Margaret McCauley	EPA
Michelle Seitz	AAAS Fellow
Wei Gao	Dow
Vera Schroeder	Safar VC

Plastics Strategy | BETO Specific Goals

- Support scale-up of **sustainable aviation fuels and other biofuels** with >70% reduction in GHG emissions relative to petroleum.
- Enable commercial production of **10+ renewable chemicals and materials** with >70% GHG reduction relative to relevant petroleum-derived counterparts
- Enable **1+ cost-effective and recyclable bio-based plastic** that mitigates ≥50% GHG emissions relative to virgin resin or plastic intermediates.

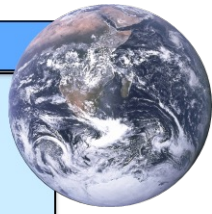
Plastics Strategy | Motivation

Climate

- Plastics contribute ~3% of global GHG emissions[1]
  - Improving the footprint of plastics is essential to decarbonize the industrial sector
- Recycling and making renewable plastics can reduce GHG emissions significantly[2]

Economy

- 95% of plastic waste is discarded, and the value of the material is lost[3]
- Transitioning from business as usual to green waste processing can add up to 730,000 jobs[4]



Environmental Justice

EERE is working to gain better understanding of impacts.

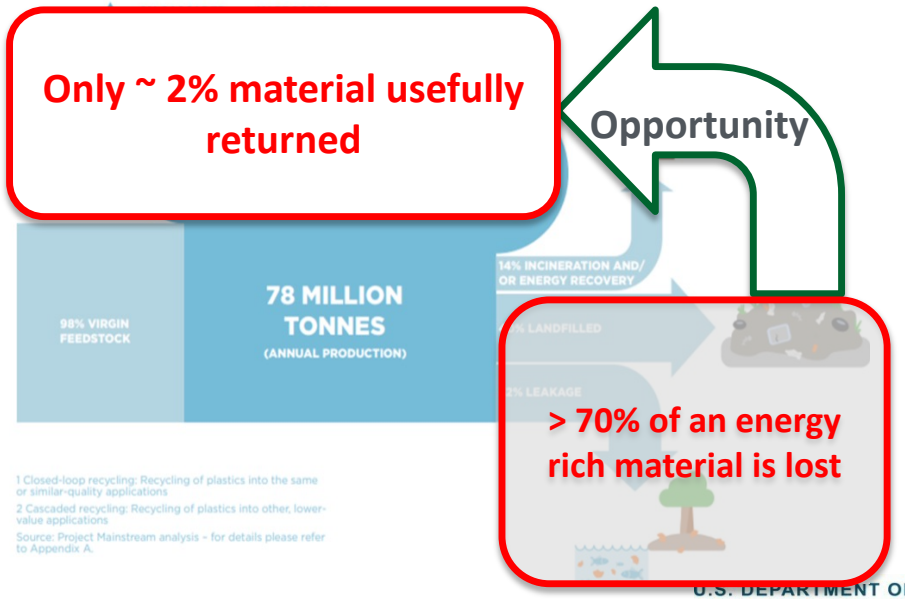
- Plastic-related GHG → climate change.[1] Effects of climate change are unequal.
- The US generates the most plastic waste of any country, and is one of the biggest coastal polluters[5]
- Net plastic exports go to developing countries[6]
- Irreversible environmental damage from plastic waste in the ocean is estimated to cost $2.5 trillion a year[7]

Solutions

- Recycling plastics saves >50% of GHG emissions[8]
- Making recyclable-by-design or biodegradable plastics from renewables saves GHG and energy from production to end of life[1]
- These new industries require domestic labor, providing new jobs

Plastics Strategy | Motivation

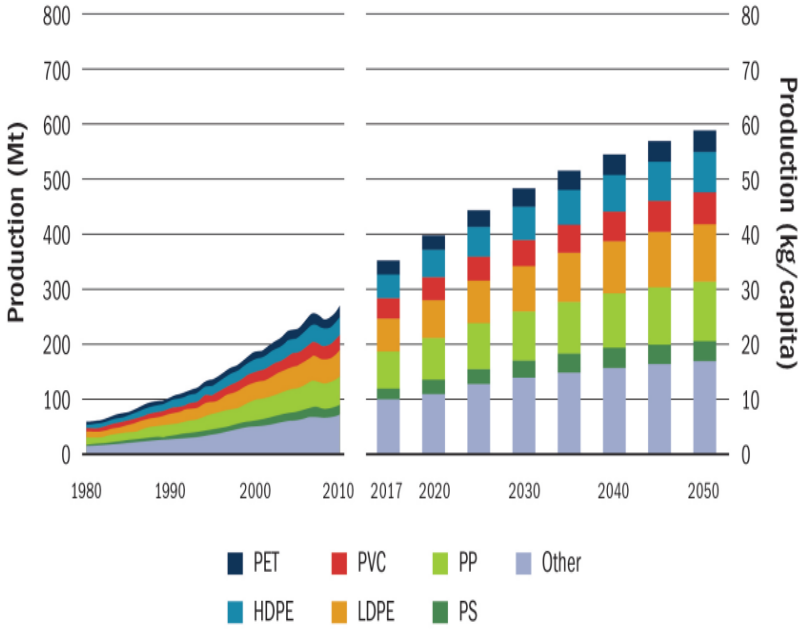
- Plastics are made **from non-renewable feedstocks** and are increasingly accumulating[1]
- Most plastic waste ends up in landfills and the environment[2]
- **>2% of total energy consumption in the US** is used to manufacture plastics, resins, and synthetic rubber
- Production of these materials generates roughly **3% of domestic GHG emissions**
- Plastic production uses **6% of global oil production** → anticipated to be 20% by 2050[1]

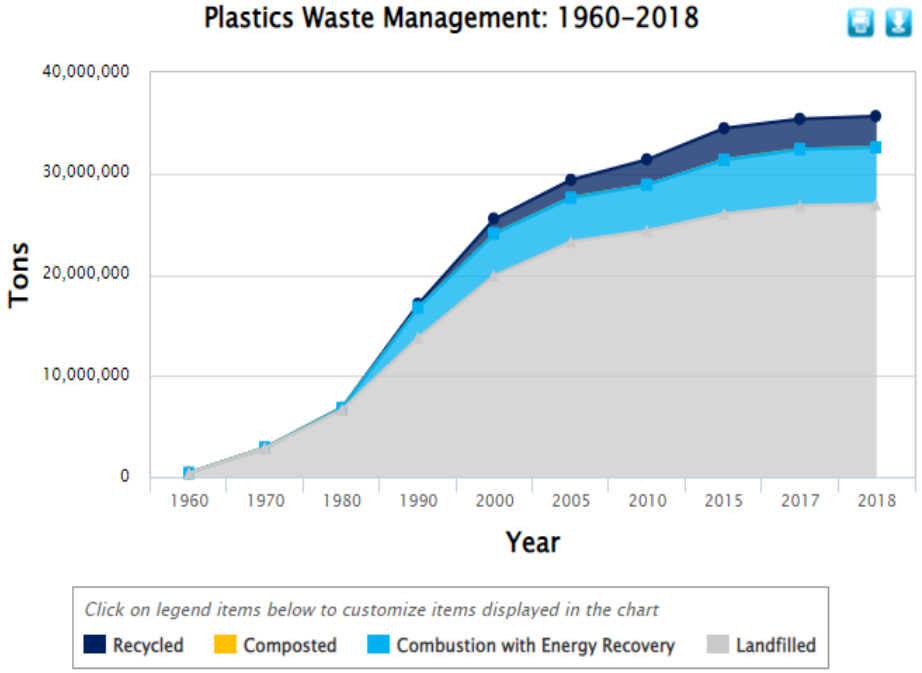


1. Ellen MacArthur Foundation. 2016.
2. Geyer et al. Science Advances .2017.
3. Zheng and Suh. Nature Climate Change. 2019.

Plastics Strategy | Motivation

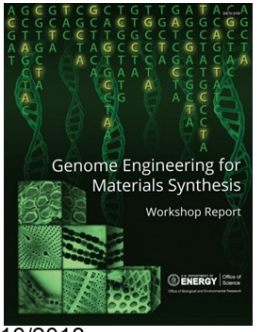
- Plastic waste presents many technical challenges
- Plastic production is projected to continue to increase substantially through 2050[1-2]
- Plastic recycling rates have plateaued[3]





1.. International Renewable Energy Agency (IRENA). 2018. Global Energy Transformation: A Roadmap to 2015. Abu Dhabi: IRENA.
2. International Energy Agency (IEA). 2018. The Future of Petrochemicals. Paris: IEA.
3. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data

Plastics Strategy | Approach



10/2018

12/2019

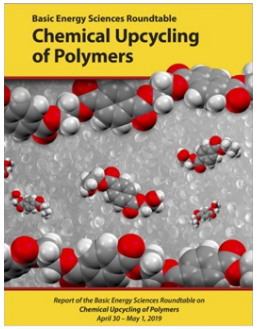
8/2020

1/2021

1/2023

2019 2020 2021 2022 2023

5/2019



11/2019

Plastics Innovation Challenge Launched

1/2020

11/2020

The Strategy for Plastics Innovation (SPI) has been informed by workshops and roundtables across the U.S. Department of Energy (DOE) and the federal government. Outputs from those events are listed in the following DOE and stakeholder reports.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plastics Strategy | Approach

Strategy for Plastics Innovation | Department of Energy

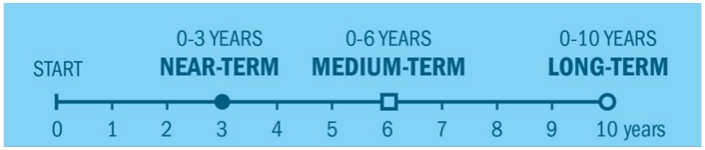
Vision

For the United States to lead the world in developing and deploying technologies that minimize plastic waste and promote energy-efficient and economic plastic and bioplastic design, production, reuse, and recycling.

Objectives/Metrics

- Address **end-of-life fate for >90%** of plastics
- **≥50% energy savings** relative to virgin material production
- Achieve **≥75% carbon utilization** from waste plastics
- Develop **cost-competitive** recyclable-by-design plastic
- Design recycling strategies that **mitigate ≥50% GHG emissions** relative to virgin resin or plastic intermediates

Plastics Strategy | Approach



Deconstruction

- ● Thermal depolymerization
- □ Selective catalyst design
- ○ Biological/chemical deconstruction of mixed plastic waste

Upcycling

- ● Upcycling of easily recyclable materials
- □ Couple deconstruction with selective upcycling
- ○ Funnel deconstruction intermediates into valuable product

Recyclable by Design

- ● Organism design for novel plastic materials
- □ New chemistry for recyclable by design polymers
- ○ Multi component product recyclability

Scale and Deploy

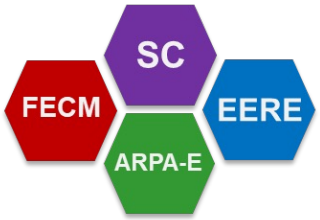
- ● Contaminant removal and effective sorting
- □ Improve physical recycling and recovery
- ○ Advance biological systems for recycling technologies

Research Directions

SPI Goals	Challenges	Thermal Processes	Chemical Processes	Biological Processes	Physical Recycling and Recovery	Design for Circularity
Deconstruction	Retain value	●	●	●	●	●
	Feedstock heterogeneity		●	●	●	
	Contaminant removal	●	●	●	●	
	Multicomponent materials		●	●		●
Upcycling	Recover value		●	●	●	●
	New material design		●	●		●
Recyclable by Design	Design for reuse		●	●		●
	Compatibility with recycling infrastructure	●	●	●	●	●
Scale and Deploy	Life cycle assessment implications	●	●	●	●	●
	Management of distributed resource	●	●	●	●	●
	Circularity	●	●	●	●	●
	Scale of plastics challenge	●	●	●		●

Plastics Strategy | Engagement

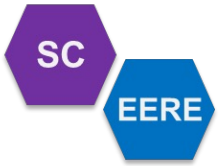
Thermal Processes



Current: Plastics Pyrolysis, CUWP, ARPA-E Energy Recovery,

Aspirational: High carbon efficiency, low energy thermal conversion of plastic waste to plastic oil

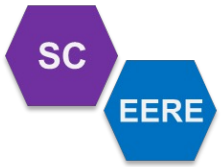
Chemical Processes



Current: Multiple FOAs, Components of EFRCs

Aspirational: Routes to high value products from plastic waste for majority of commodity polymers

Biological Processes



Current: BOTTLE Consortium, BER FOA

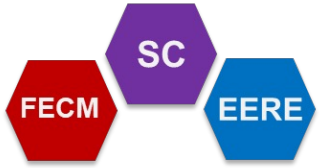
Aspirational: Low carbon plastics, bioprocesses to deconstruct plastic

Physical Recycling and Recovery

Current: REMADE, SBIRs

Aspirational: High recycling rates, Efficient sorting and same cycling of commodity plastics

Design for Circularity



Current: BOTTLE FOA, REMADE

Aspirational: Highly recyclable plastics with cost and utility parity versus conventional materials

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plastics Strategy | Conversion Specific Goals

Deconstruction, valorization and understanding the fate of plastics

- Leverage current plastics waste as a feedstock
- Develop methods for processing mixed/contaminated plastics
- Develop deconstruction approaches for flexible plastic packaging
- Integration of experimental, computational, and data science tools
- Understand end-of-life impacts of plastic
- Analysis of valorization pathways and markets

Designing bio-plastics for recyclability

- Understand relationship between polymer structure and desired functionality
- Develop synthesis, breakdown, separation, and manufacturing approaches that can be integrated with existing infrastructure
- Improve chemical and biological technologies to convert alternative carbon feedstocks into monomers and polymers

Plastics Strategy | 2021 Reviewer Comments

- A disciplined active management approach is required to focus on the most promising areas, including early-stage TRL projects to supply a pipeline of promising technologies, and sunsetting those that may not fulfill expectations.

- Introduce the concept of prototyping. Aim to identify products and technologies that can be put into the hands of "customers," where appropriate, to test at early and regular time points.

- Ensure the best use of industry/commercial/subject matter experts and robust industry advisory boards (IABs) from the onset of projects and throughout.

- The availability of feedstocks from plastic waste recycle/recovery is particularly uncertain, so it is worth considering how the technology area can influence this.

- Coordination and collaboration across government funding agencies (e.g., NSF/DOE EERE) and R&D development arms of agencies (e.g., DOT, EPA) would be an efficient use of taxpayer dollars

Plastics Strategy | Funding Approach

	FOA	AOP
Selection Method	Competitive	Lab Call
Open to the Public	✓	☒
National Lab Participant	Only as Subrecipient	✓
Go/No-Go Decision Points	✓	✓
Verifications	✓	☒
Award Modifications Method	Contracting Officer (CO)	AOP Tool Change Control

FOA = Funding Opportunity Announcement

AOP = Annual Operating Plan

Plastics Strategy | Portfolio Development

Small Business Innovation Research (SBIR) Calls

- FY2020: Phase 1 Novel Utilization Strategies for Ocean Plastic Waste
- FY2020: Phase 2 Reshaping Plastic Design and Degradation for the Bioeconomy
- FY2021: Phase 1 compatibilizers of existing plastics
- **FY2022: Phase 2 compatibilizers of existing plastics**

Plastics Strategy | Portfolio Development

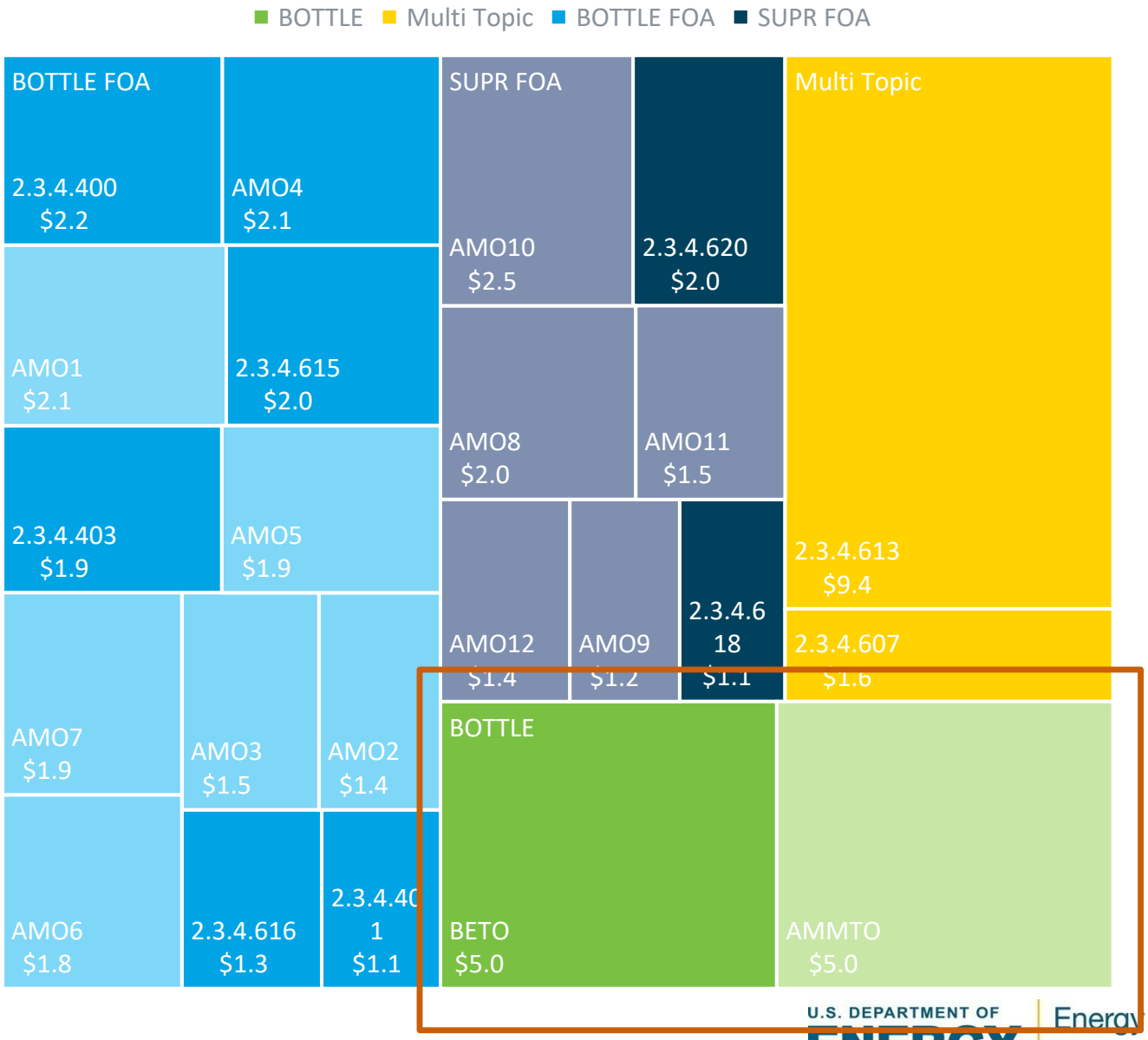
2019 — Multi Topic FOA
- Renewable Energy from Suburban and Urban Waste
- Designing Highly Recyclable Plastics

2020 — BOTTLE Consortium
- ≥**50% energy savings** relative to virgin material production
- ≥**75% carbon utilization** from waste plastics
- ≥ **2x economic incentive** above price of reclaimed materials

2020 — BOTTLE FOA
- Highly recyclable or biodegradable plastics
- Novel Methods for Deconstruction
- BOTTLE Consortium collaborations

2021 — SUPR FOA
- Novel processes to upcycle films
- Design of films for infinite recyclability or biodegradability

Plastics Strategy | Current Portfolio



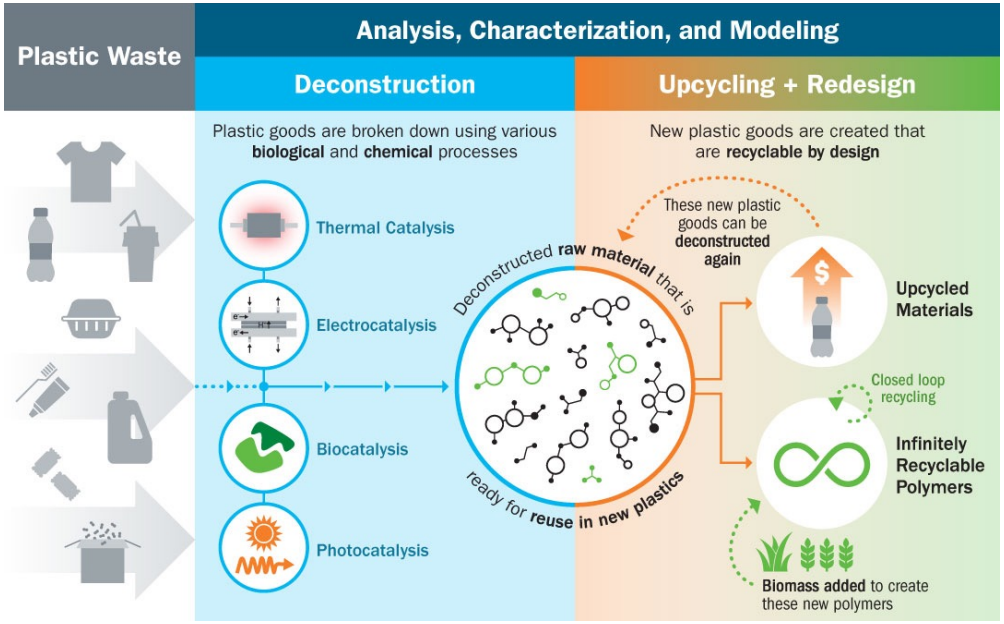
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plastics Strategy | BOTTLE Lab Call

BOTTLE Consortium

- ≥**50% energy savings** relative to virgin material production
- ≥**75% carbon utilization** from waste plastics
- ≥ **2x economic incentive** above price of reclaimed materials

- BOTTLE started with NREL, LANL, ORNL, CSU, MIT, MSU
- FY20 Lab Call invited national laboratory researchers to contribute to the Consortium's goals: Recipients: ANL, SLAC, & NU



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Schedule for April 3, 2023

1:00 PM	1:30 PM	30		Technology Area Introduction	BETO	Coralie Backlund
1:30 PM	2:00 PM	30	BOTTLE1	Introduction & BOTTLE Overview	BOTTLE Consortium	Gregg Beckham
2:00 PM	2:15 PM	15	BOTTLE2	Analysis	BOTTLE Consortium	Jason DesVeaux, Taylor Uekert
2:15 PM	2:45 PM	30	BOTTLE3	Deconstruction	BOTTLE Consortium	Yuriy Román-Leshkov, Taraka Dale
2:45 PM	3:00 PM	15		Q&A		
3:00 PM	*3:20 PM*	*20*		*Break*	*All*	
3:20 PM	3:35 PM	15	BOTTLE4	Upcycling	BOTTLE Consortium	Adam Guss
3:35 PM	3:55 PM	20	BOTTLE5	Redesign & Modeling	BOTTLE Consortium	Eugene Chen, Linda Broadbelt
3:55 PM	4:10 PM	15	BOTTLE6	Characterization	BOTTLE Consortium	Christopher Tassone, Meltem Urgun-Demirtas
4:10 PM	4:25 PM	15		Q&A		
4:25 PM	4:40 PM	15	BOTTLE7	Industry Projects & Engagement	BOTTLE Consortium	Kat Knauer
4:40 PM	4:50 PM	10		Q&A		
4:50 PM	*5:30 PM*	*40*		*Closed Door Comment Review Session*	*Reviewers*	

Ground Rules

Presenters: We will give you a 5 minute warning. When your time is up, we will verbally let you know. Please wrap up quickly.

Reviewers: Please ask questions during the Q&A period. Be considerate to allow all reviewers the opportunity to ask a question.

General public: We will field questions as time allows after the reviewers have asked questions.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

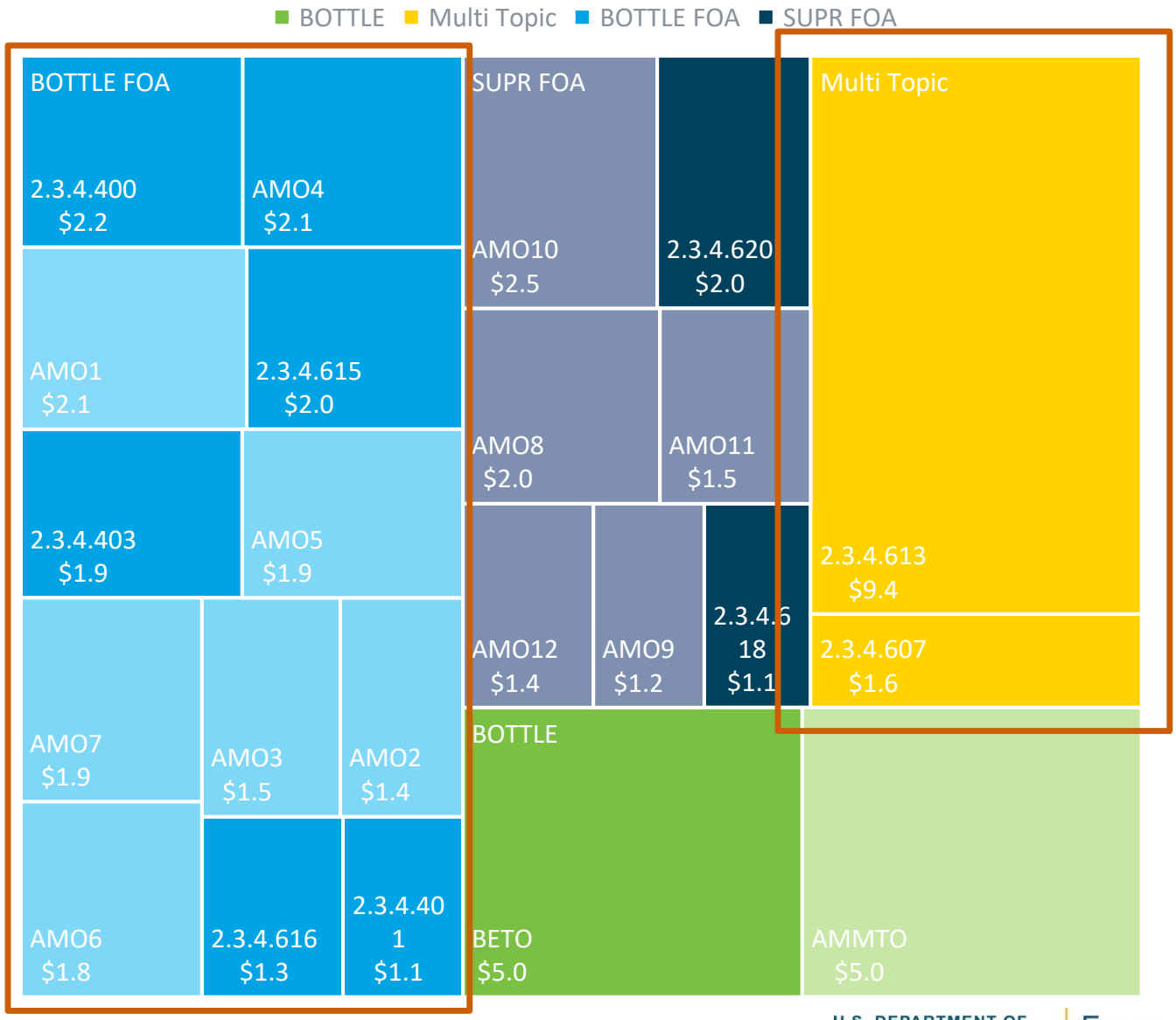
Plastics Deconstruction and Redesign

April 4, 2023

Coralie Backlund

Technology Manager

Plastics Strategy | Current Portfolio



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plastics Strategy | 2019 Multi-Topic FOA

Multi Topic FOA

- Renewable Energy from Suburban and Urban Waste
- Designing Highly Recyclable Plastics

Topic Area 6: Renewable Energy From Suburban and Urban Waste

- Congress issued specific direction: "establish a **multi-university partnership** to conduct research and enhance educational programs that improve alternative energy production derived from urban and suburban waste"
- The research component of applications must comprise roughly 80-90% of the proposed project budget, and 10-20% of the proposed budget should support the educational elements.

Topic Area 8a: Designing Highly Recyclable Plastics

- Novel biobased plastics that have improved performance attributes over incumbent plastic and can be cost effectively chemically recycled
- Plastics must be synthesized from biobased feedstocks
- Explore performance-advantaged plastics with superior end-of-life consideration

Plastics Strategy | 2020 BOTTLE FOA

BOTTLE FOA

- Highly recyclable or biodegradable plastics
- Novel Methods for Deconstruction
- BOTTLE Consortium collaborations

Topic Area 1: Highly recyclable or biodegradable plastics

- Recyclable through chemical, biological, or hybrid methods (50% monomer recovery)
- Ability to biodegrade in relevant conditions or compost in industrially-relevant conditions (60% in 180 days)
- Performance advantage (outperform traditional plastics for a specific application)

Topic Area 2: Novel Methods for Deconstruction

- 40% energy savings when compared to production of the same or similar product from virgin material
- Chemically recyclable, >35 % recovered monomers or intermediate chemicals

Topic Area 3: BOTTLE Consortium Collaborations

Schedule for April 4, 2023

DAY 2 Tuesday, April 4, 2023						
8:00 AM	*8:30 AM*	*30*		*Registration, Breakfast*	*All*	
8:30 AM	8:45 AM	15		Technology Area Daily Intro	BETO	Coralie Backlund
8:45 AM	9:15 AM	30	2.3.4.616	Hybrid Approach to Repurpose Plastics Using Novel Engineered Processes (HARNESS)	Battelle Memorial Institute	Kate Kucharzyk
9:15 AM	10:15 AM	60	2.3.4.613	Multi-University Center on Chemical Upcycling of Waste Plastics (CUWP)	University of Wiscons	George Huber
10:15 AM	*10:30 AM*	*15*		*Break*	*All*	
10:30 AM	11:00 AM	30	2.3.4.607	ResIn: Responsible Innovation for Highly Recyclable Plastics	Northwestern University	Linda Broadbelt
11:00 AM	11:30 AM	30	2.3.4.400	Trojan Horse Repeat Sequences for Triggered Chemical Recycling of Polyesters for Films and Bottles	Iowa State University	Eric Cochran
11:30 AM	12:00 PM	30	2.3.4.401	Upcycling PET via the VolCat Process	IBM	Greg Breyta
12:00 PM	*1:00 PM*	*60*		*Lunch*	*All*	
1:00 PM	1:30 PM	30	2.3.4.403	Designing Recyclable Biomass-Based Polyesters	University of Wisconsin, Madison	George Huber
1:30 PM	2:00 PM	30	2.3.4.615	Production of high-performance biodegradable polyurethane products made from algae precursors	University of California, San Diego	Michael Burkart
2:00 PM	2:30 PM	30	AMO.04	Hybrid Chemical-Mechanical Separation and Upcycling of Mixed Plastic Waste	Case Western	Mike Hore
2:30 PM	3:00 PM	30	AMO.06	Circular Economy of Composites Enabled by TuFF Technology	U Delaware	Joseph Deitzel
3:00 PM	*3:20 PM*	*20*		*Break*	*All*	
3:20 PM	3:50 PM	30	AMO.02	Highly Recyclable Thermosets for Lightweight Composites	U of Akron	Junpeng Wang
3:50 PM	4:20 PM	30	AMO.03	Modular Catalytic Reactors for Single-Use Polyolefin Conversion to Lubricating Oils from Upcycled Plastics (LOUPs)	Iowa State	Aaron Sadow
4:20 PM	*5:00 PM*	*40*		*Closed Door Comment Review Session*	*Reviewers*	

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

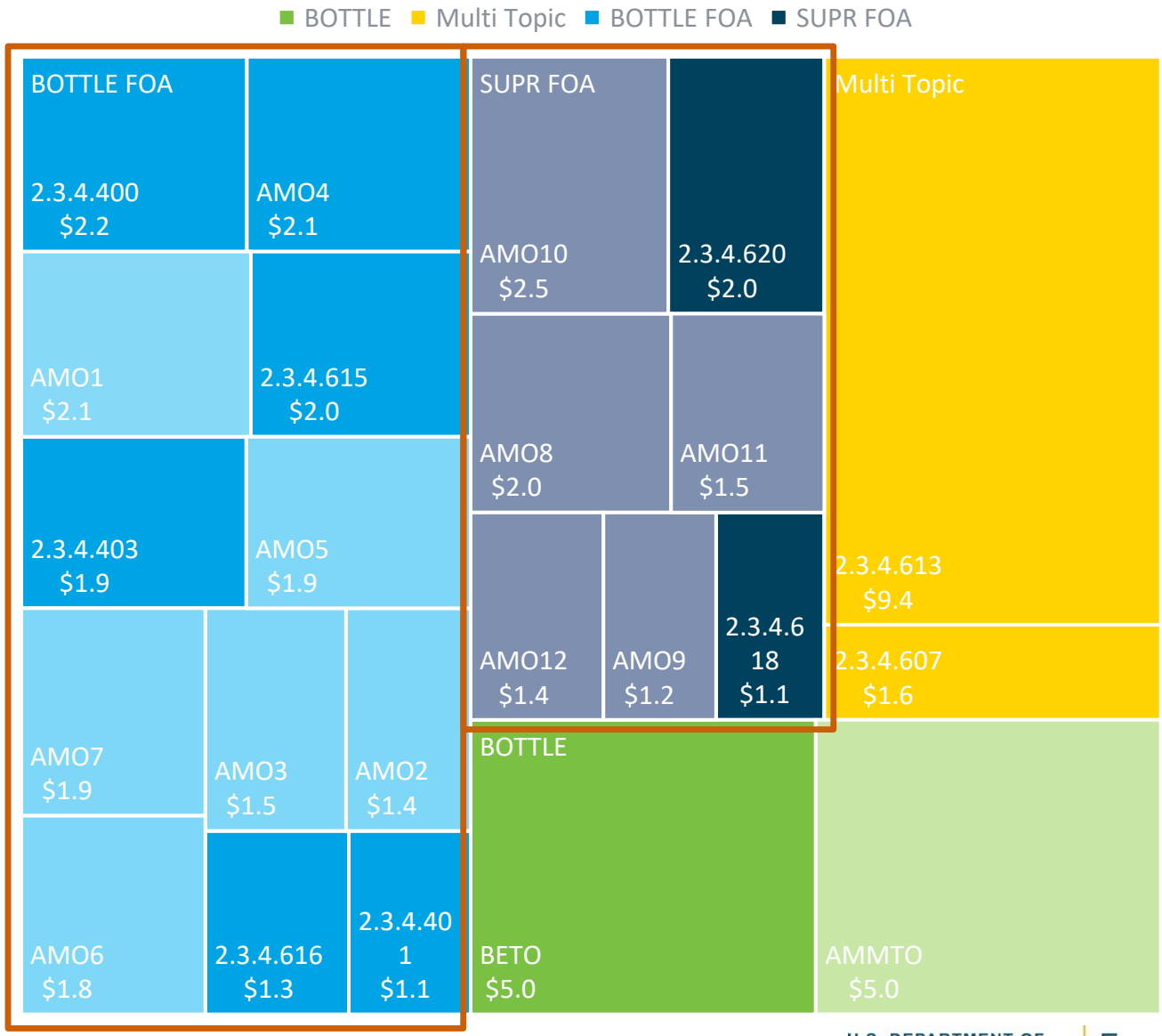
Plastics Deconstruction and Redesign

April 5, 2023

Coralie Backlund

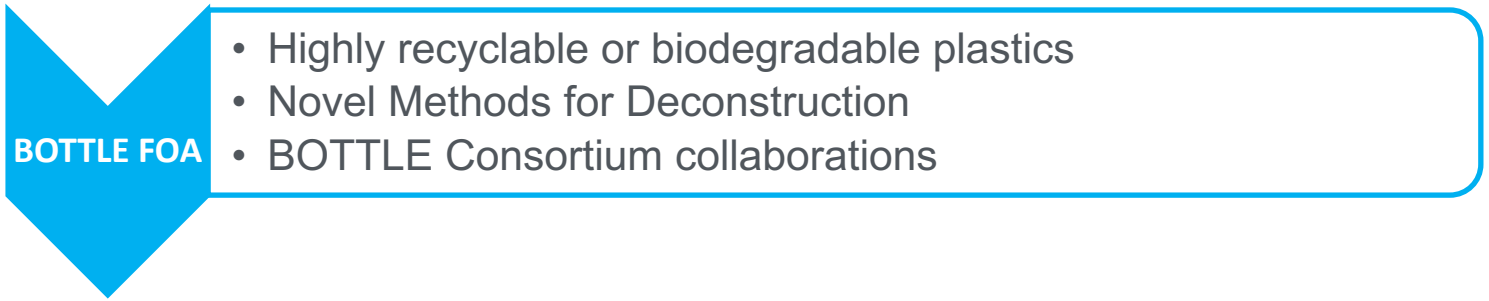
Technology Manager

Plastics Strategy | Current Portfolio



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Plastics Strategy | 2020 BOTTLE FOA



Topic Area 1: Highly recyclable or biodegradable plastics

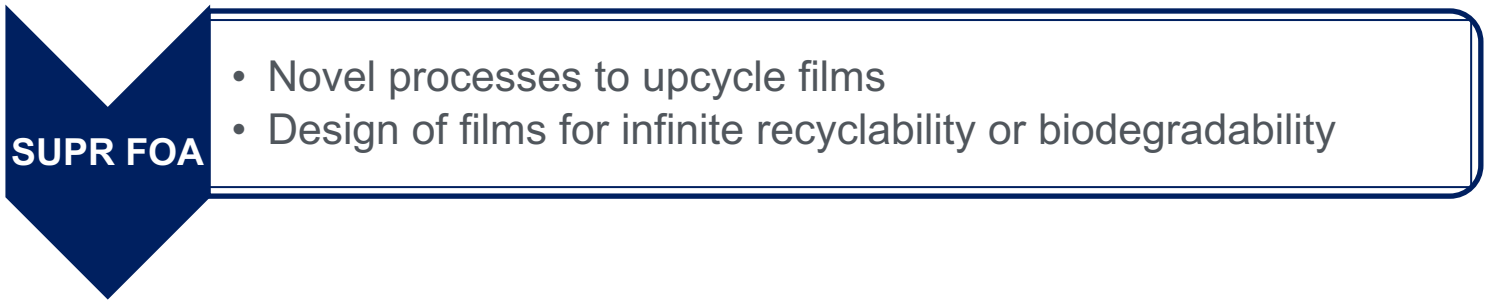
- Recyclable through chemical, biological, or hybrid methods (50% monomer recovery)
- Ability to biodegrade in relevant conditions or compost in industrially-relevant conditions (60% in 180 days)
- Performance advantage (outperform traditional plastics for a specific application)

Topic Area 2: Novel Methods for Deconstruction

- 40% energy savings when compared to production of the same or similar product from virgin material
- Chemically recyclable, >35 % recovered monomers or intermediate chemicals

Topic Area 3: BOTTLE Consortium Collaborations

Plastics Strategy | 2021 SUPR FOA



Topic Area 1: Novel processes to upcycle films

- Valorization of conventional waste films into higher value products
- Methods to recover pure polymer resin from conventional multilayer packaging
- Approaches that improve the economics of same-cycling conventional films

Topic Area 2: Design of films for infinite recyclability or biodegradability

- New substitute multilayer materials designed for recyclability or biodegradability
- Biodegradable substitute materials yielding benign degradation products
- Bio-based plastics capable of use in multi-layer package applications that are infinitely recyclable and/or biodegradable

Schedule for April 5, 2023

DAY 3 Wednesday, April 5, 2023						
8:00 AM	*8:30 AM*	*30*		*Registration, Breakfast*	*All*	
8:30 AM	8:45 AM	15		Technology Area Daily Intro	BETO	Coralie Backlund
8:45 AM	9:15 AM	30	AMO.05	Upscaling of non-recyclable plastic waste into CarbonSmartTM monomers	LanzaTech	Ching Leang
9:15 AM	9:45 AM	30	AMO.01	Degradable Biocomposite Thermoplastic Polyurethanes	UCSD	Jon Pokorski
9:45 AM	10:15 AM	30	AMO.07	Recyclable and Biodegradable Manufacturing and Processing of Plastics and Polymers based on Renewable Branched Caprolactones	U Minnesota	Paul Dauenhauer
10:15 AM	*10:30 AM*	*15*		*Break*	*All*	
10:30 AM	10:50 AM	20	AMO.08	A closed loop upcycling of single-use plastic films to biodegradable polymers	Iowa State	Xianglan Ba
10:50 AM	11:10 AM	20	AMO.09	Integrated Chemolytic Delamination and Plasma Carbonization for the Upcycling of Single-Use Multi-layer Plastic Films	U Mass Lowell	Hsi-Wu Wong
11:10 AM	11:30 AM	20	AMO.10	Catalytic Deconstruction of Plasma treated Single-Use Plastics to Value-added Chemicals and Novel Materials	NC A&T	Debasish Kuila
11:30 AM	11:50 AM	20	AMO.11	Process Intensified Modular Upcycling of Plastic Films to Monomers by Microwave Catalysis	WVU	Yuxin Wang
11:50 AM	*1:00 PM*	*70*		*Lunch*	*All*	
1:00 PM	1:20 PM	20	AMO.12	All-Polyester Multilayer Plastics (All-Polyester MLPs): A Redesign for Inherently Recyclable Plastics	MI State	Muhammad Rabnawaz
1:20 PM	1:40 PM	20	2.3.4.618	Infinitely Recyclable and Biodegradable Films for Improved Food Packaging	TDA	Ally Robinson
1:40 PM	2:00 PM	20	2.3.4.620	Development of Infinitely Recyclable Single-Polymer Chemistry Bio-based Multilayer Films Using Ethylene/Carbon Monoxide Copolymers	Braskem	Hadi Mohammadi
2:00 PM	*3:00 PM*	*60*		*Closed Door Comment Review Session*		