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

Circular Economy Subprogram Overview

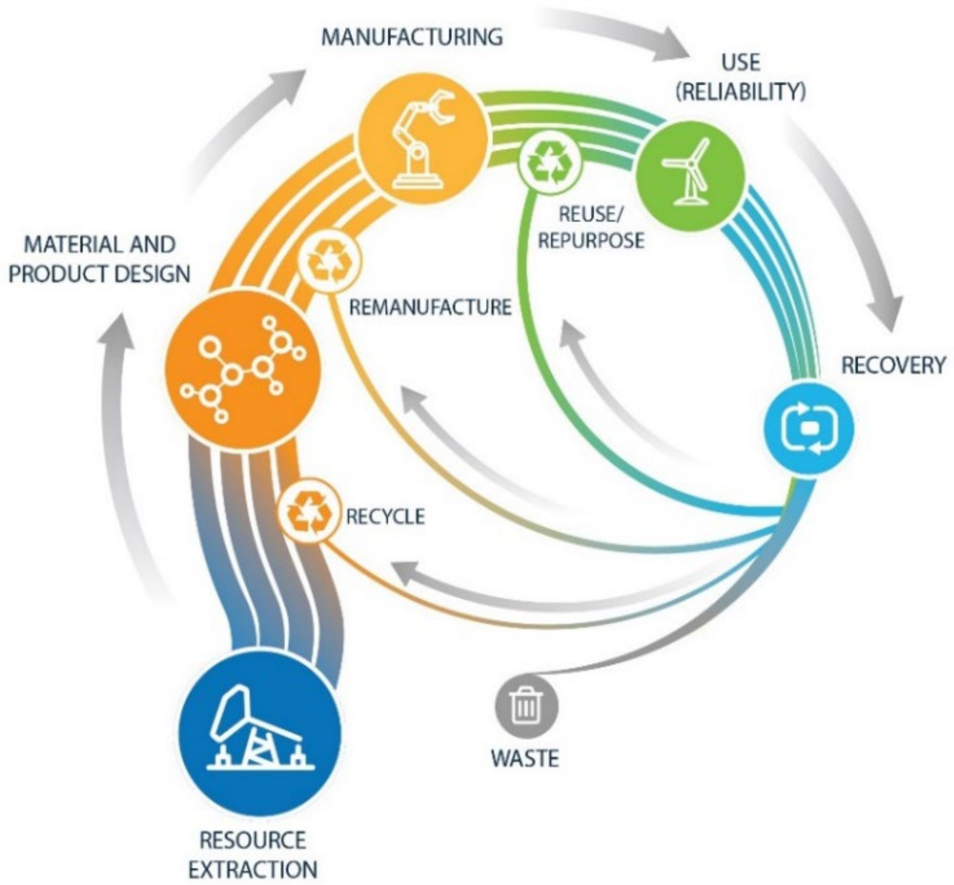
Peer Review 2023

Program Manager

Circular Economy: Mission and Context

A circular economy is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life.

- **Economy-wide Decarbonization**
  - Circular economy strategies and technologies enable economy-wide decarbonization through material efficiency, which reduces the demand of extracted materials.
- **Supply Chain Innovations**
  - Circular economy approaches, particularly when applied to limited elements needed for clean energy technologies, can help secure domestic supply chains.
- **Manufacturing Competitiveness**
  - With requirements for recycled content and taxes on virgin materials being discussed, cost-effective circular economy solutions will be needed to remain competitive.

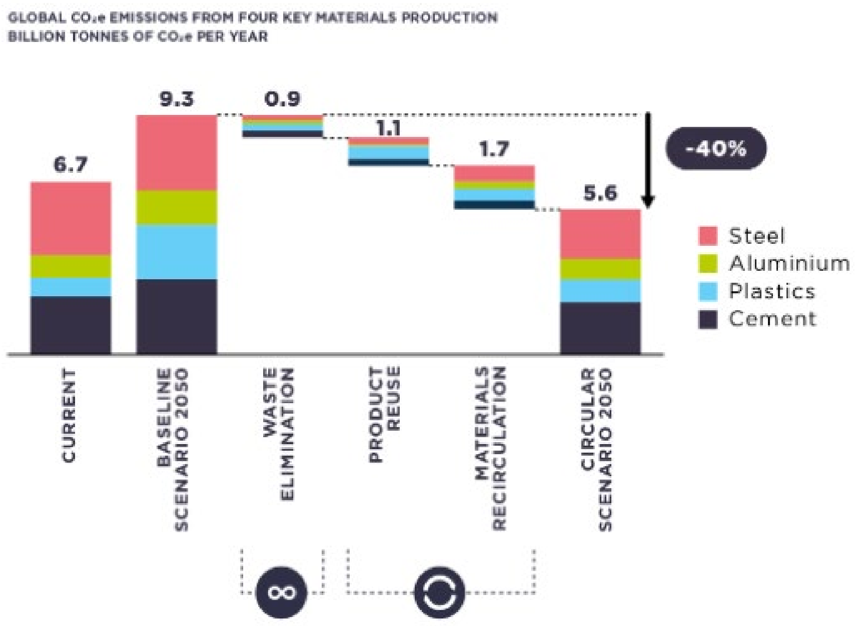


NREL, Circular Economy Model (2022)

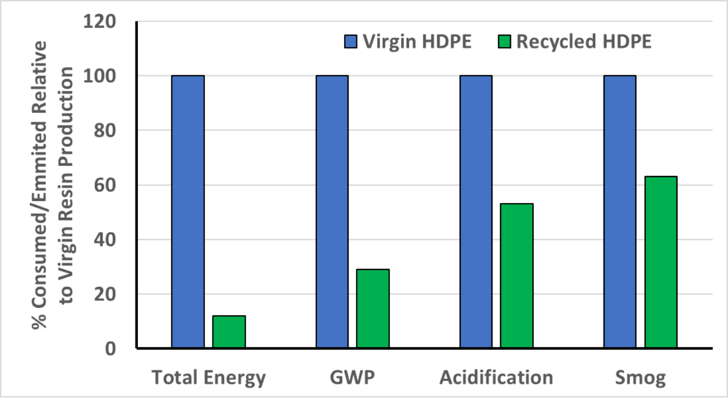
Circular Economy Impact on Energy, Environment, and Equity

A circular economy reduces material use, redesigns materials, products, and services to be less resource intensive, and recaptures “waste” as a resource to manufacture new materials and products.

Circular economy strategies have the potential to reduce global emissions by over 40% by 2050.



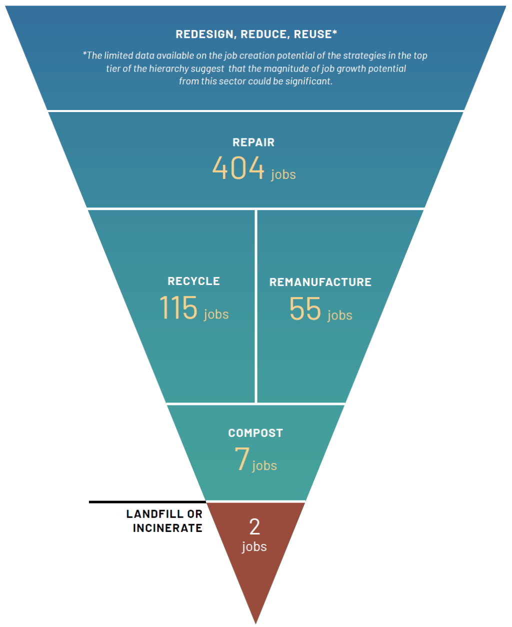
Benefits from circular economy approaches often extend beyond emissions and include energy savings and other indicators of human and environmental health.



Shifting to a circular economy can generate economic growth and jobs.

Figure 1: Waste Hierarchy with mean job generation figures per ten thousand tonnes of waste processed per year.

The data show that waste management approaches that have the best environmental outcomes also generate the most jobs.



1. Nicholson *et al*. *Joule* 2021, 5, 1–14 2. Kimmel *et al*. *Environmental Studies* 2014, 6. 3. Trenor *et al. ACS Macro Lett*. 2020, 9, 1376−1390 4. Virgin vs Recycled Plastic LCA White Paper APR 2020. 5. Ellen MacArthur Foundation, Completing the Picture: How the Circular Economy Tackles Climate Change (2021).

History of the Program

2015 QTR

Highlighted material efficiency as an important mechanism to reduce energy and emissions.

2017 – REMADE Est.

2019 – Plastics Innovation Challenge Launched

Li-ion Battery Prize Announced

2020 – BOTTLE Consortium Est.

BOTTLE FOA

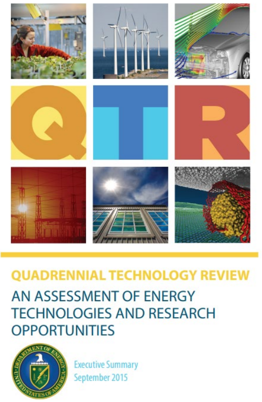
2021 – SUPR FOA

2022 – Circular Economy Regional Demos Topic

2023 – Strategy for Plastic Innovation

and

“Sustainable Manufacturing and the Circular Economy” Published



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AMERICAN MADE BATTERY RECYCLING PRIZE

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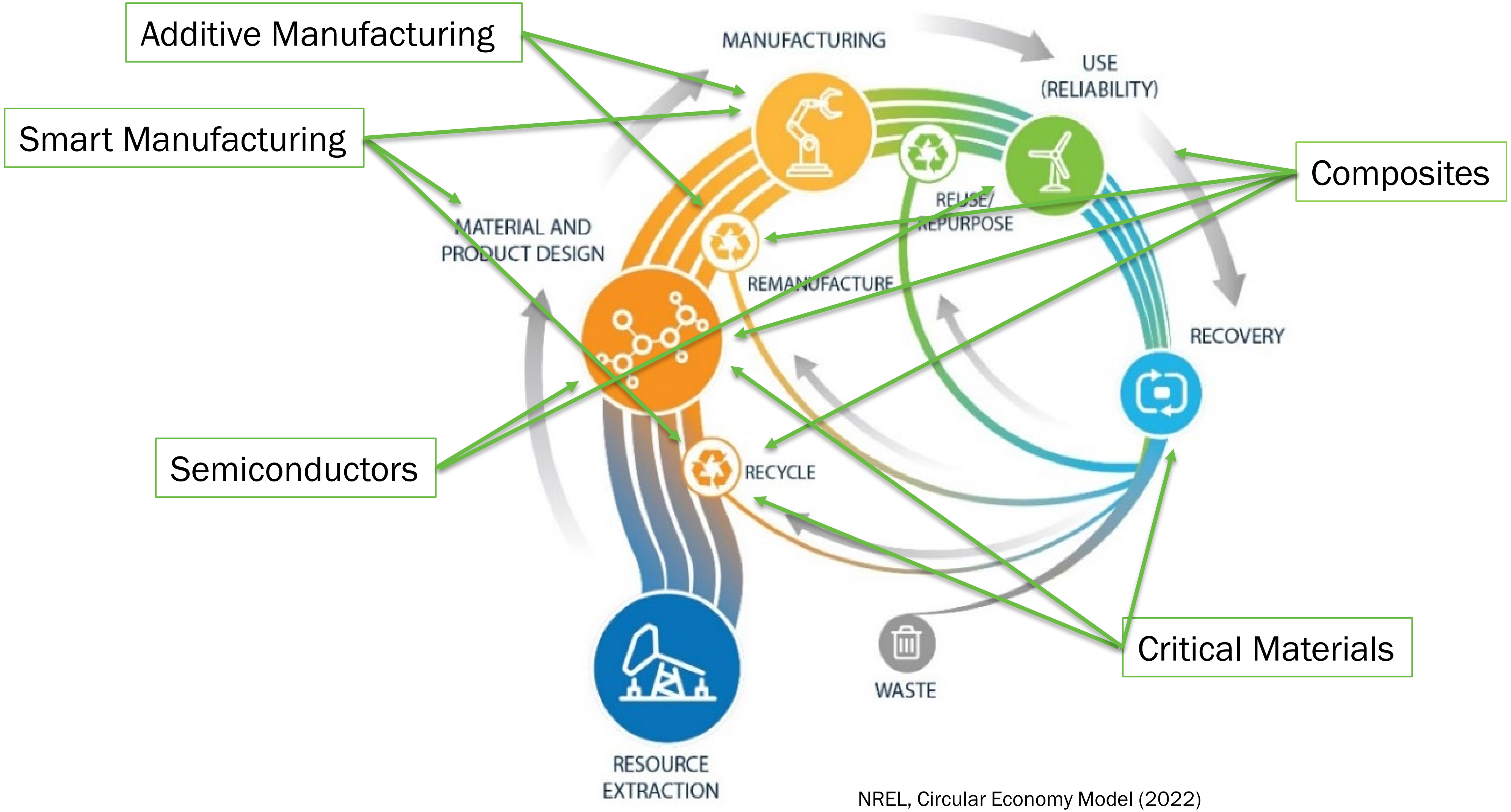
Connections across the Office



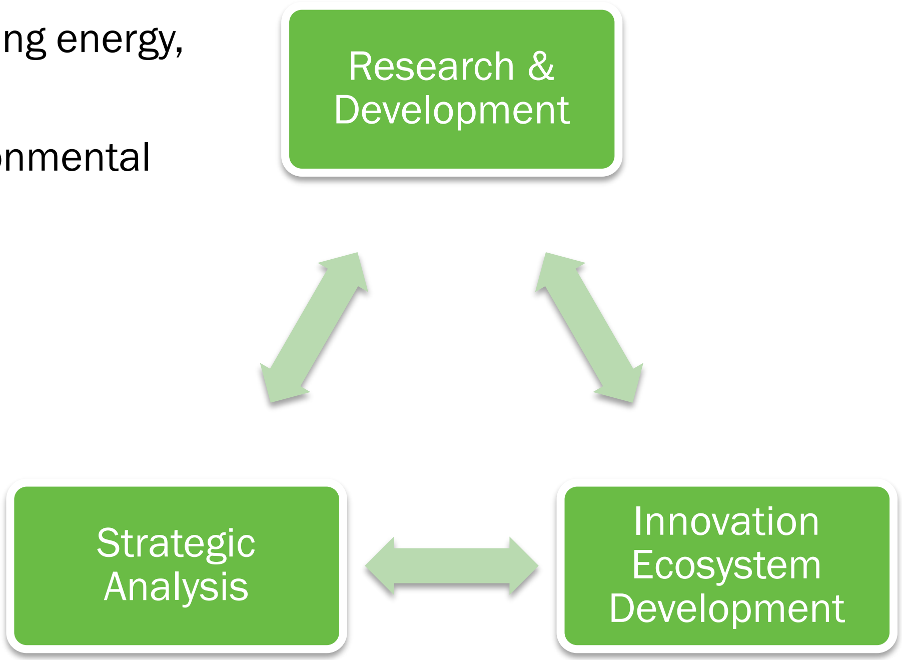
NREL, Circular Economy Model (2022)

Circular economy approaches are embedded in programs across AMMTO and across DOE

Circular Economy Scope and Priorities

Invest in cross-cutting innovations that promote material circularity to:

- Minimize lifecycle impacts, including energy, emissions, and waste
- Promote energy, equity and environmental justice (EEEJ)
- Remain economically competitive



Develop and leverage analysis and LCA capabilities for better decision making.

Convene the full supply chain and accelerate technology development by creating or cultivating innovation ecosystems.

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Leverage previous investments in Strategy for Plastic Innovation, BOTTLE™ consortium, and REMADE Institute.

Current Portfolio

BOTTLE FOA Projects ($17M) – Broadly covers plastic deconstruction, upcycling, and redesign for circularity.

SUPR FOA Projects ($9M) – Targeted at addressing recycling challenges for flexible packaging.

Circular Economy Regional Demonstrations ($10M) – Seeking to scale technologies and bring together supply chains for a regional pilot demonstration.

Research & Development

Strategic Analysis

Innovation Ecosystem Development

REMADE Institute ($70M) is a Manufacturing USA™ Institute that enables R&D promoting circular material solutions across the value chain for metals, fibers, plastics, and e-waste.

BOTTLE Consortium ($30M) is a lab-led consortium that conducts collaborative RD&D to develop scalable technologies for plastic deconstruction, valorization, and redesign.

Strategic analysis is incorporated into larger efforts like REMADE and BOTTLE to guide their efforts.

In addition, AMMTO funds analysis efforts that can guide and support decision making at DOE and throughout the community.

Future Opportunities: Diversifying ReX Approaches

- Current portfolio emphasizes recycling pathways, particularly for plastics.
- Future work will assess and address the lifecycle impacts of and technology development needs of ReX pathways.

Circular Economy

Increasing Circularity

Linear Economy

	Strategy	Description
Smarter product use and manufacture	**R0** - Refuse	Making products redundant by abandoning their function or by offering the same function with a radically different product
	R1 - Rethink	Make product use more intensive
	R2 - Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of products and their parts	**R3** - Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfills its original function
	R4 - Repair	Repair and maintenance of defective product so it can be used for its original function
	R5 - Refurbish	Restore an old product and bring it up to date
	R6 - Remanufacture	Use parts of discarded products in a new product with the same function
	R7 - Repurpose	Use discarded products or their parts in a new product with a different function
Useful application of materials	**R8** - Recycle	Process materials to a commodity level with same or lower quality
	R9 - Recover	Incineration of materials with energy recovery

Figure ES 2. Circular economy strategies (collectively Re-X) with descriptions and circularity ranking

After Potting et al. (2017), which is based on Rli (2015).

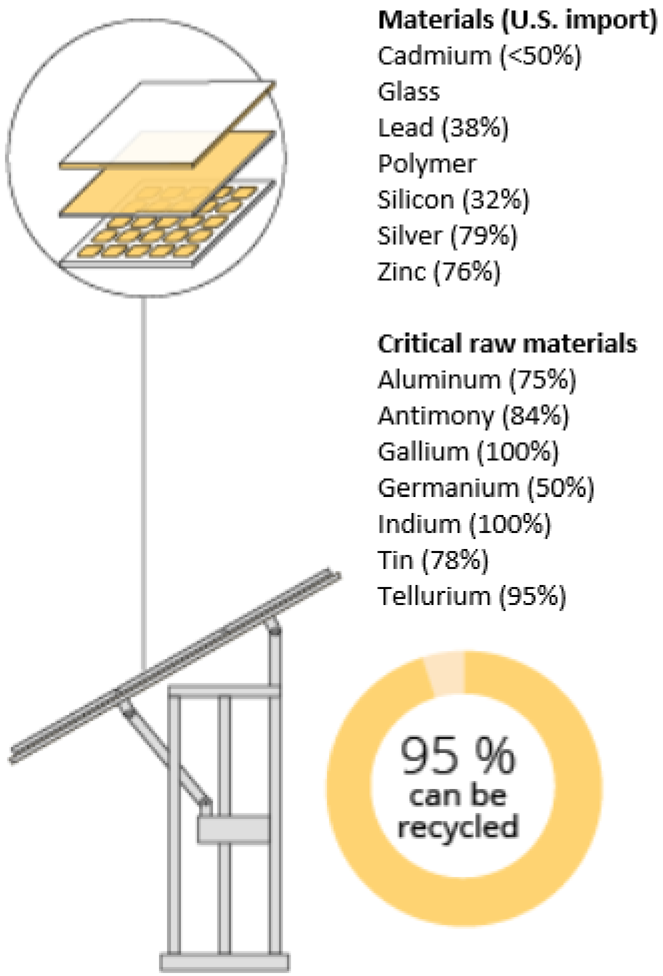
Sustainable Manufacturing and the Circular Economy, DOE (2023).

Future Opportunities: Cross-Cutting Technology Development

- Cross-cutting technologies are those that can be applied to multiple material classes and ReX pathways.
- Potential thrusts include:
    - Smart/Digital Manufacturing
    - Sorting and Separations
    - Rapid Characterization Methods
- In addition, a better understanding of EEEJ impacts of various ReX pathways is essential to informing future direction and prioritizing pathways.

Future Opportunity in Materials: Clean Energy Technologies

- The increase in production of clean energy technologies, including solar photovoltaic panels, wind turbines, and batteries are critical in the transition to economy-wide decarbonization.
- Material demands to meet production and the resource-rich waste arising from end-of-life clean energy infrastructure is projected to grow up to 30-fold over the next 10 years.
- Due to the rapid technological advancements of clean energy technologies, equipment can be subject to rapid obsolescence, creating challenging technical and logistical issues for managing waste streams.
- Circular economy approaches can secure critical supply chains, increase U.S. industrial competitiveness, and advance economy-wide decarbonization of the U.S. transition to net-zero.

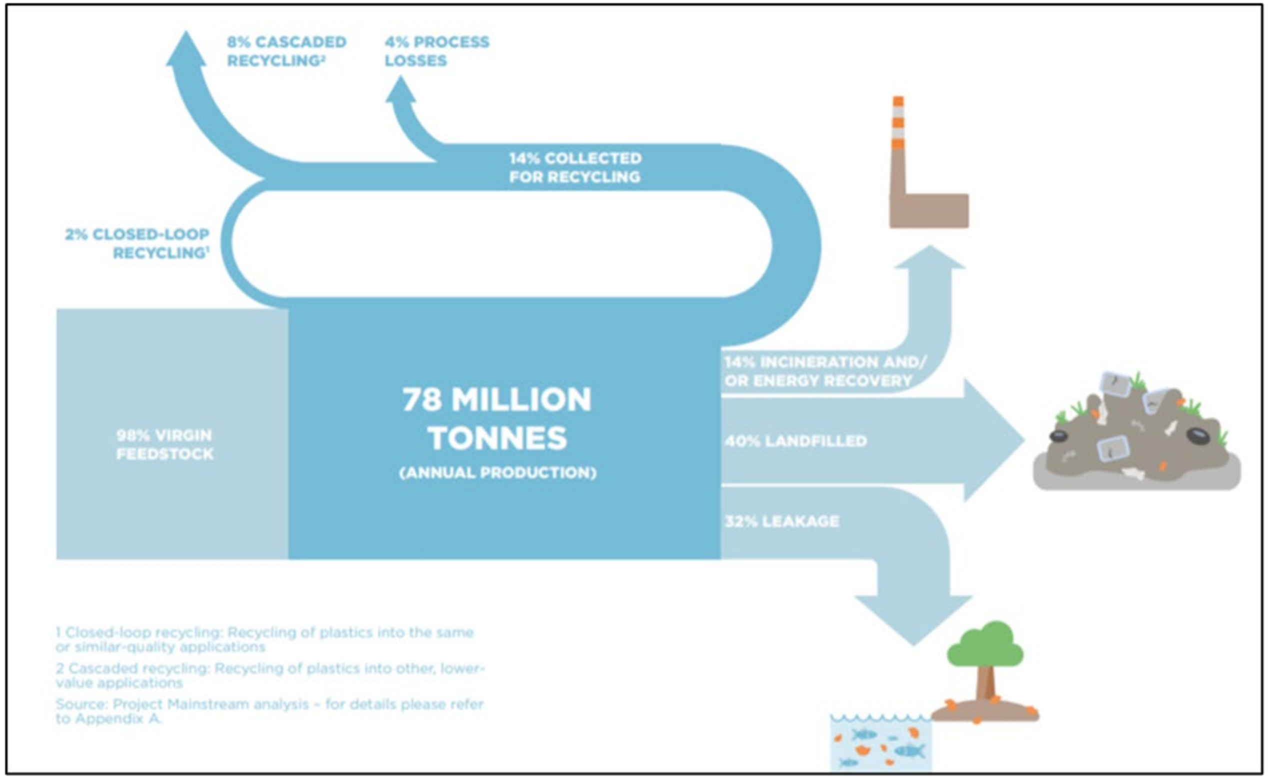


EEA, Emerging waste streams: Opportunities and challenges of the clean energy transition from a circular economy perspective (2021) edited to include U.S. Critical Materials (U.S. Geological Survey, 2022).

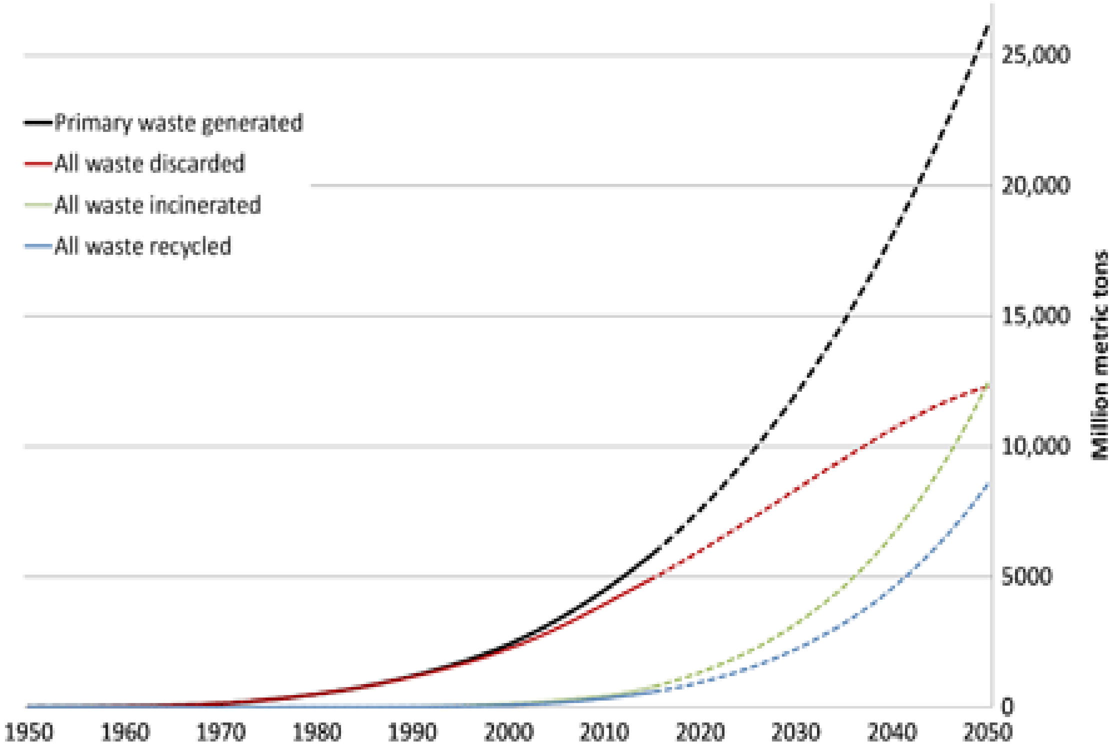
BOTTLE FOA and SUPR FOA Overview

Why Plastic Waste?

In 2019, the United States recycled 5% of its plastics and disposed of 86%, resulting in market value losses totaling $7.2 billion. Plastic consumption accounts for 3% of US GHG Emissions and, globally, plastic waste is projected to triple by 2060.



Cumulative Global Plastic Waste



[1]Geyer et al. Science Advances 2017. [2]Zheng and Suh. Nature Climate Change 2019. [3]Beckham and co. Joule 2021

Strategy for Plastics Innovation Objectives

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Vision

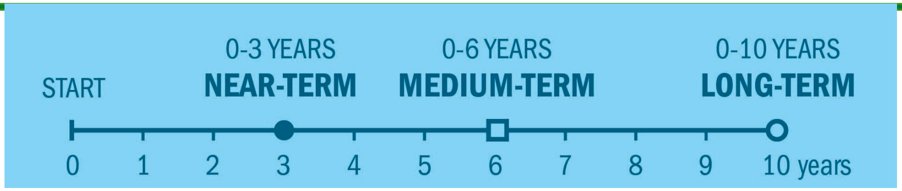
For the United States to lead the world in developing and deploying technologies that minimize plastic waste and promote energy-efficient and economic plastic and bioplastic design, production, reuse, and recycling.

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

Strategy for Plastics Innovation | Department of Energy

Strategy for Plastics Innovation Goals for 2030



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 products

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	●	●	●	●	●
Deconstruction	Feedstock heterogeneity		●	●	●	
Deconstruction	Contaminant removal	●	●	●	●	
Deconstruction	Multicomponent materials		●	●		●
Upcycling	Recover value		●	●	●	●
Upcycling	New material design		●	●		●
Recyclable by Design	Design for reuse		●	●		●
Recyclable by Design	Compatibility with recycling infrastructure	●	●	●	●	●
Scale and Deploy	Life cycle assessment implications	●	●	●	●	●
Scale and Deploy	Management of distributed resource	●	●	●	●	●
Scale and Deploy	Circularity	●	●	●	●	●
Scale and Deploy	Scale of plastics challenge	●	●	●		●

AMMTO Focus on Deconstruction, Upcycling, and Redesign

The BOTTLE FOA and Single-Use Plastic Recycling (SUPR) FOA were designed to improve plastic circularity by developing deconstruction and upcycling pathways for plastic waste and redesign polymers for circularity.

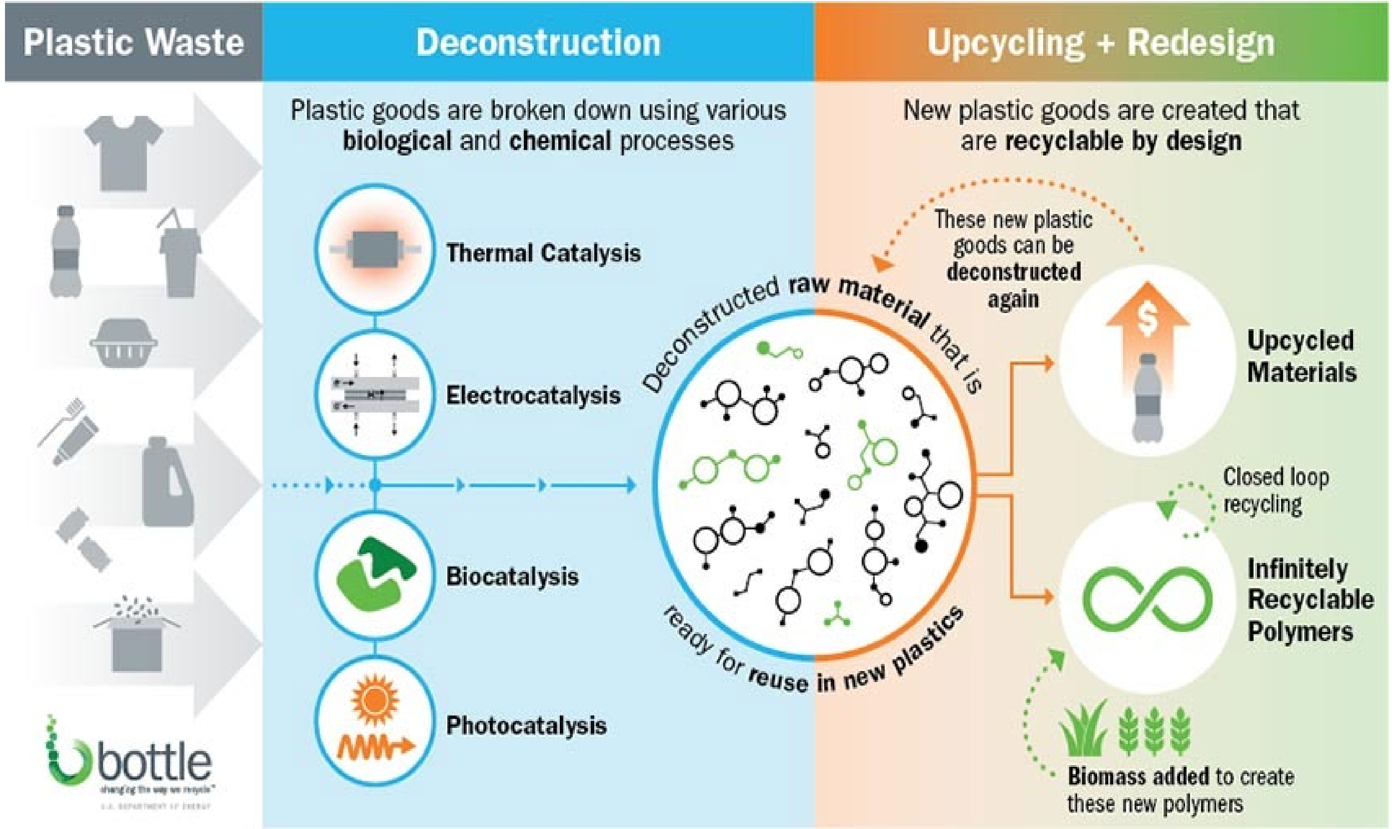
Efforts were designed to be complementary to the BOTTLE™ Consortium and the REMADE Institute.

BOTTLE FOA:

- Develop novel polymers that are designed for infinite recyclability or biodegradability.
- Create innovative deconstruction pathways for existing polymers that generate high-value products.
- BOTTLE™ Consortium Collaborations to Tackle Challenges in Plastic Waste.

SUPR FOA:

- Develop recycling and upcycling pathways for plastic films that are economically favorable, lower greenhouse gas emissions, and reduce the embodied energy of plastics.
- Redesign of multi-layer films to be inherently recyclable or biodegradable.



Example Project from BOTTLE FOA

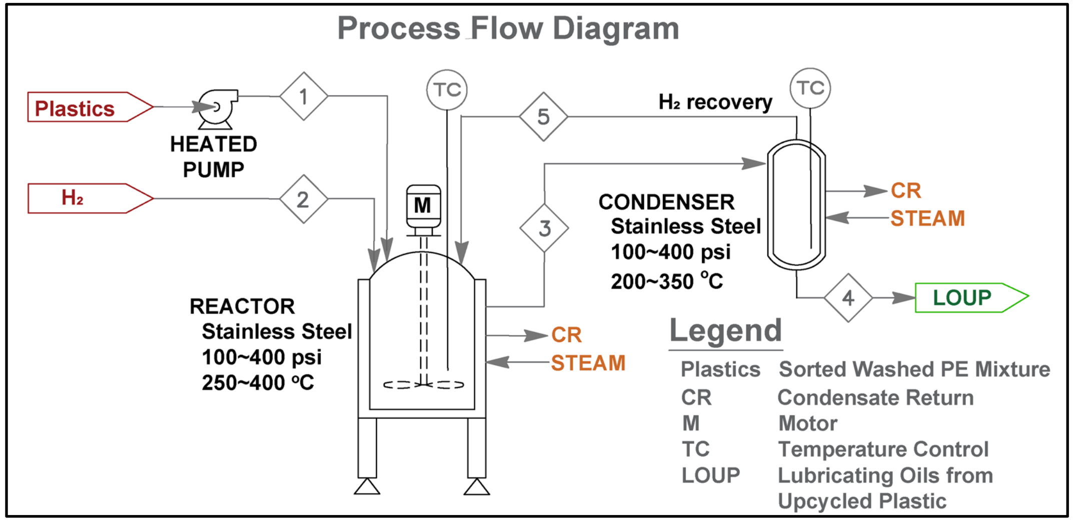
Federal funds: $2,500,000
Cost-share: $702,509
Total budget: $3,202,509

Project Goal: Develop a modular, low-temperature (< 300 °C) and low pressure (15 bar) continuous lab-scale process for the catalytic conversion of single-use waste polyolefins (POs) to higher value high performance LOUPs.

Start of project status: batch process that converts polyethylene using Pt/STO by hydrogenolysis to a lube oil in >95% yield by mass.

Proposed work includes:

- Optimizing and scaling catalyst production
- Scaling production of the lube oil through conversion to a continuous process
- Converting feedstock from "clean" to real feedstocks
- Characterization of the lube oil product to ensure benefits over incumbent



	Key Milestones & Deliverables
BP 1	• Produce LOUPs (3 g) from waste HDPE films using Pt/STO catalyst in >35% yield
BP 2	• Large-scale Pt/STO synthesis and LOUPs production • 20% improvement in tribological properties
BP 3	• Produce LOUPs on 100 mL scale • Demonstrate tribological properties under ASTM test conditions to verify commercial viability

STATE | Chevron Phillips Chemical — Performance by design. Caring by choice. | TEXAS A&M UNIVERSITY | Argonne NATIONAL LABORATORY

Example Project from SUPR FOA

Federal Share: **$1,609,056**

PI: Girish Srinivas, PhD, MBA

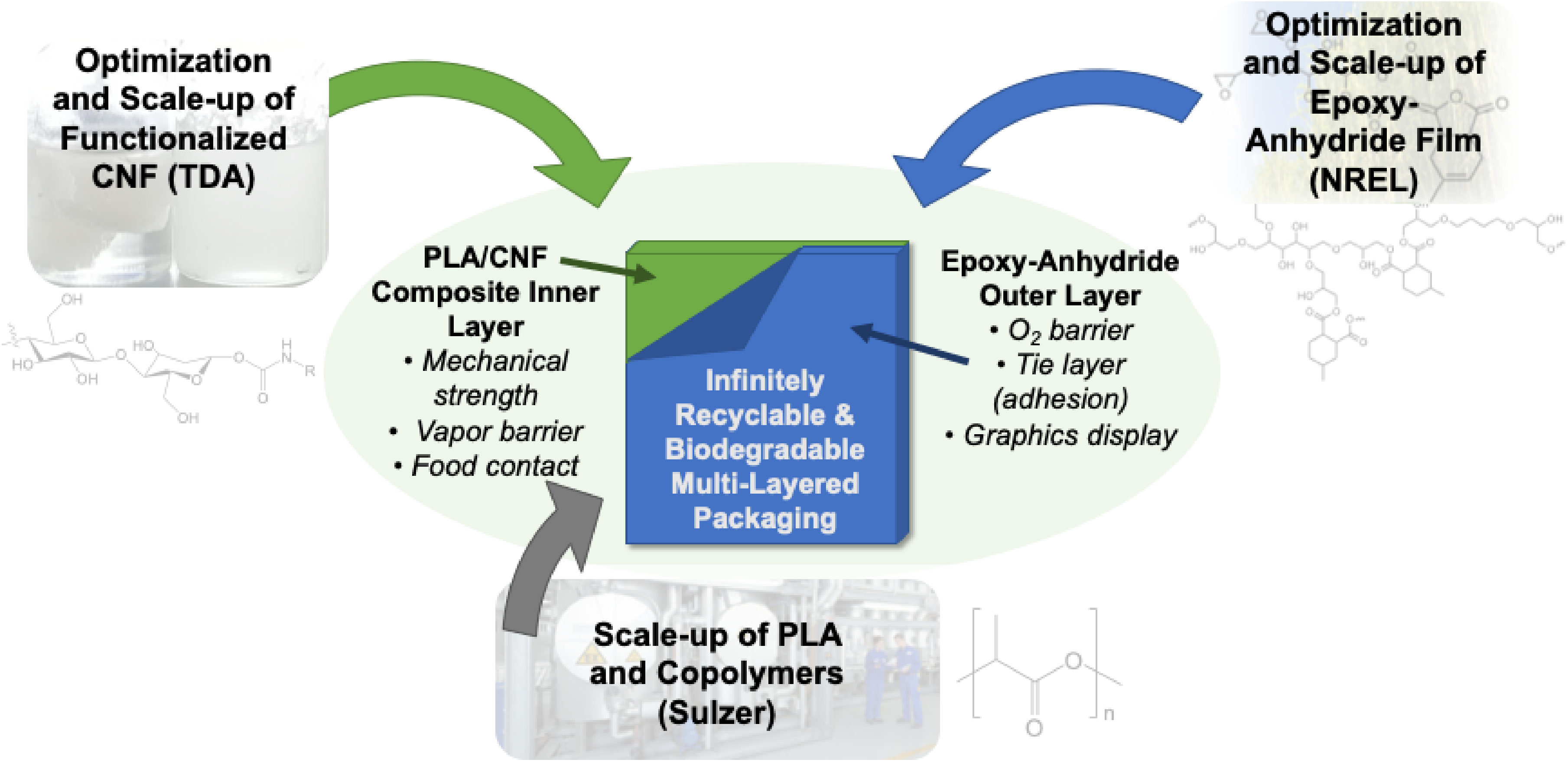
Location: TDA Research, Inc

Cost Share: $402,370 (20%)

Partners: National Renewable Energy Laboratory (NREL), Sultzer

<u>Project Impact Targets (Min – Stretch):</u>
Performance meets or exceeds requirements
Cost Savings: parity – 20%
Carbon Utilization (wt% carbon recycled): **50% - 100%**

Innovation: This project combines several innovative bio-based materials into a single, compostable multi-layer film (MLF) that can displace conventional MLFs in food-contact applications. The ability to compost may be desirable in certain applications, particularly that have food contact. However, recycling pathways will also be explored to retain the embodied energy of the materials.



Questions?