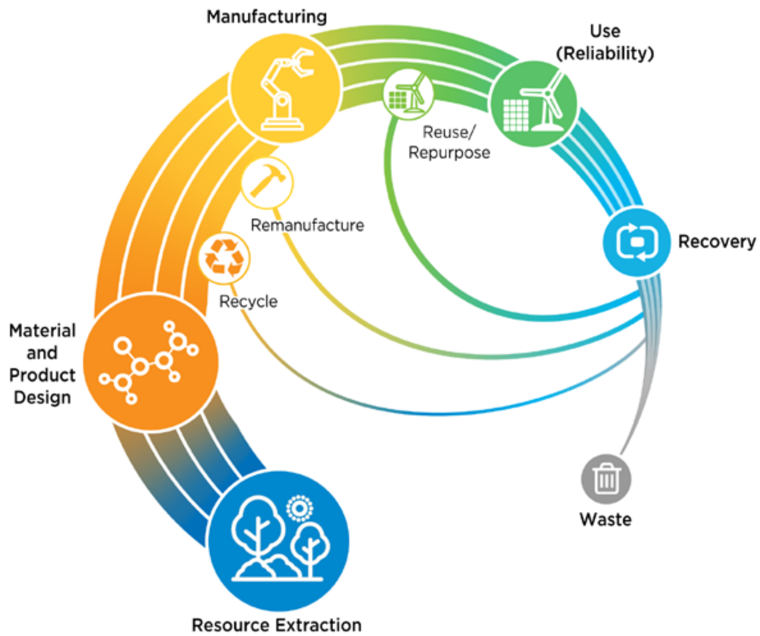
Circular Economy for Energy Materials

Designing to Reduce, Reuse, and Upcycle for a More Sustainable Planet

Our global economy is on the cusp of a dramatic transformation away from a traditional linear approach—making, using, and landfill disposing of goods—to a more circular one where end of life is considered at the onset and the concepts of reducing, reusing, and chemically recycling or upcycling of goods becomes the new norm. Conventional/mechanical recycling is applicable to some materials but is underused and ineffective for a true circular economy vision. This vision ensures raw materials are used once to produce a product; and, at end of life, the product is chemically recycled back to its core building blocks to enable an infinite loop of product manufacture, use, deconstruction, and remanufacture.



The need for circularity and sustainability must be viewed in the context of other megatrends—population growth, urbanization, resource competition, cyberthreats, and global economic development. The current linear approach is simply not sustainable in light of these growing trends, and a more circular approach is critical to the long-term health of our planet.

To that end, NREL is leading a Circular Economy for Energy Materials (CEEM) initiative to enable circular materials, processes, and devices for the future energy sector.

NREL's vision involves designing sustainable manufacturing processes, life-time performance, cost, and end-of-life considerations into future energy materials and devices at the time of manufacture. It also entails transitioning bench-scale innovations to fully integrated, pilot-scale solutions in partnership with industry, to ensure accelerated commercialization.

Polymer and Composite Upcycling

At the very heart of the conversation around circularity lies plastics, or synthetic polymers. Polymers are among the most prevalent materials used throughout our economy because they are lightweight, durable, easily formulated into many product classes, cheap to manufacture, and applicable to a massive variety of end uses. Because of these beneficial qualities, an estimated 8 billion tons have been produced globally since their inception; but only 600 million tons have been recycled, leaving the vast majority of plastic products at end of life to go directly to landfills – or worse, leak to the natural environment. Moreover, the United States is the largest generator of plastic waste in the world today.

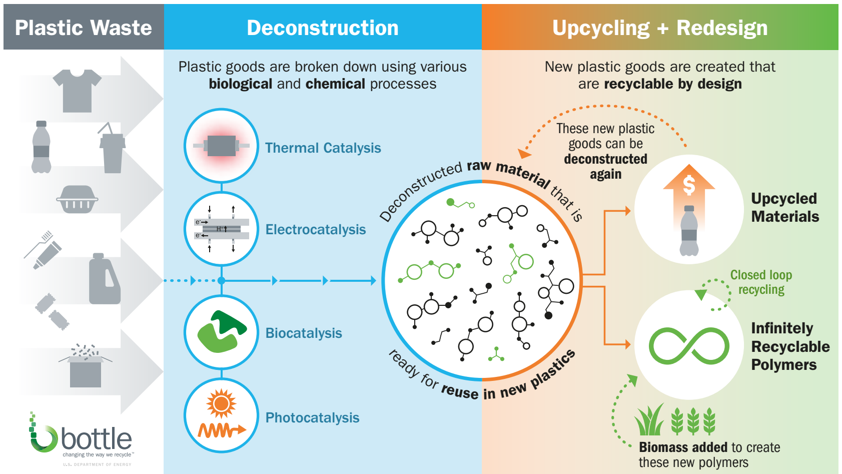
For the small percentage that does get recycled, current recycling practices and processes rely on "mechanical recycling" that yields a lower-quality and lower-value product that typically gets used once more before being discarded. NREL is developing innovative technologies to deconstruct today's plastics into core chemical building blocks for efficient recycle or upcycle. These processable intermediates, now generated from waste plastics instead of purchased as new raw material, can be re-assembled to create equal or even higher-value end-use products.

Furthermore, NREL is designing the next generation of products that consider circularity from the onset. New ways to reassemble these chemical building blocks into next-generation plastics that maintain all desirable properties during useful life, but enable much easier deconstruction at end of life, are both attainable and necessary.

NREL and its partners are working to enhance a naturally occurring enzyme capable of depolymerizing poly(ethylene terephthalate), or PET, which is a polymer used in plastic bottles, clothing, and carpet. Recently published NREL research on the re-engineering of the enzyme has revealed how it can digest plastic up to six times faster. NREL has also developed a PET substitute that can partially use reclaimed PET, but also incorporates degradable, bio-based monomers into the polymer during its reconstruction.

But this is only the beginning when it comes to needed research for the circularity of plastics, polymers, and composites. NREL is also addressing polymers like polyethylene, polypropylene, rubber materials, polyurethanes, polystyrene, polyvinyl chloride, and others.

The Department of Energy has recognized these efforts and has formed a new multi-institution consortium (Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment, or BOTTLE), led by NREL, to begin addressing these needs in sincerity. The vision for BOTTLE is to deliver selective, scalable technologies to enable cost-effective plastics recycling, upcycling, and increased energy efficiency. Its mission includes both creating robust processes to upcycle the waste plastics of today as well as to develop new plastics that are inherently recyclable by design.



Advanced Energy Materials and Technologies

The concept of circularity, however, transcends plastics. Advanced energy technologies – like wind turbines, solar cells, and batteries – are beginning to provide the energy sector with critical low-carbon, low-cost electricity and energy storage options. However, while they have been designed with cost and performance in mind, we must also consider end-of-life implications for these technologies, especially as they begin to approach terawatt scale.

As of 2019, U.S. cumulative installed capacity of solar and wind energy reached 76 GW and 105 GW, respectively, with complementary adoption of stationary battery storage. By 2019, there were more than 1 million electric passenger vehicles (EVs) on U.S. roads, many containing lithium-ion batteries; and, by 2040, EV sales are projected to reach 500 million globally. For all of these technologies, waste is expected to significantly rise over time as older generations reach end of life.

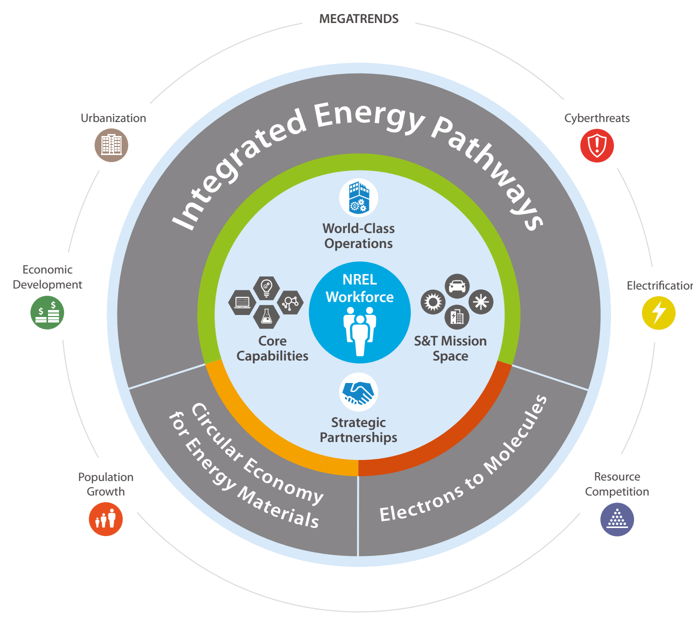
Current photovoltaic (PV) and wind blade recycling technologies, much like plastics, rely on mechanical approaches and result in low-quality, low-value products. As wind energy grows, finding a way to chemically deconstruct and reuse the composites in wind turbine blades and effectively recycle structural materials will be critical.

At NREL, scientists have developed a bio-based, recyclable-by-design composite material that meets industry specifications for glass fiber-reinforced composites similar to those used in wind turbine blades today. Full recyclability has been demonstrated via a catalytic glycolysis process, scale-up has begun, and evaluation with advanced aging and fatigue measurements to determine its viability as a substitute for today's wind turbine blade materials has commenced.

In addition to the waste problem, this growing global demand for low-carbon energy technologies is increasing our dependence on critical materials for wind generation and vehicle motors, solar photovoltaic power generation, batteries, and fuel cells. These critical materials are subject to scarcity shortages and price volatility and it is imperative that we find energy-efficient, environmentally friendly, low-toxicity, and economically competitive technologies to reduce, reclaim, reuse, remanufacture, and recycle these materials. Through this effort, we can offer a secondary supply source and further minimize the need for energy-intensive primary source mining and processing.

For example, the predicted growth of lithium-ion batteries in transportation and grid storage will have a significant impact on the demand for critical materials, like cobalt, placing pressure on global materials supply. Cost-effective recycling of lithium-ion batteries will be crucial. Current practices use hydrothermal treatments, but do not recover many elements and degrade the value of the battery materials. NREL is working on advanced recycling technologies, enabled by a priori design, to enable reuse of >90% of the battery system, including the reuse and reconditioning of cathodes, anodes, and the electrolyte.

NREL has also started an effort to leverage leadership in perovskite PVs and module reliability to develop capabilities that address sustainability concerns for crosscutting metal halide perovskites and advanced bifacial solar technologies. The work is targeting several key areas including: (1) improving the stability and performance of "green solvent" inks used in perovskites fabrication; (2) identifying scalable approaches to substrate reuse, module design, recycling and upcycling, and long service lifetime; and (3) identifying the circularity of the module supply chain to maximize the use of reclaimed feedstocks and minimize virgin material use.



NREL's 10-Year Plan: A Vision for the Future

NREL Transforming ENERGY

National Renewable Energy Laboratory
15013 Denver West Parkway, Golden, CO 80401
303-275-3000 • www.nrel.gov

NREL prints on paper that contains recycled content.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

NREL/FS-6A31-78908 • January 2021