Enabling Plastics Circularity through Deployable, Modular Systems That Utilize Hybrid Biological/Chemical Processing Technology

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Background/Objectives. Virgin plastic production continues to generate massive greenhouse gas emissions, as only 14% of the 78 million tons of plastic packaging produced each year are collected for recycling and only 2% are recycled into the same or similar-quality applications, largely due to a lack of economically viable recycling options. This lack of robust and efficient recycling approaches impacts civilian society, but also presents profound challenges for the military. Currently at forward operating bases (FOBs), recalcitrant waste is typically incinerated in massive burn pits that threaten the health of surrounding personnel and the environment. Under DARPA's ReSource program, our team is developing a suite of technologies to enable upcycling of military plastic waste, predominantly polyethylene (PE) and polyethylene terephthalate (PET), into high value chemicals for the warfighter, employing hybrid deconstruction and upcycling processes for high efficiency. Battelle is developing a modular system that addresses these "tactical waste" needs of a FOB, but can be scaled or reconfigured in subsequent iterations to support distributed plastic recycling in the civilian sector, such as in municipal waste management facilities or plastic manufacturing facilities. The system produces useful materials like lubricant oil by leveraging mechanical, chemical, biochemical, and biological processes to break down, build up, and separate target compounds. The durable system operates semi-autonomously, requiring users only to pre-sort their waste.

Approach/Activities. Activities to date have focused on optimizing base biological catalysts for feedstock breakdown and product buildup. Low temperature plastic breakdown is achieved through enzyme biocatalysis. Enzymes are optimized through deep learning approaches (PET) and high throughput screening of environmental sourced enrichments of contaminated sites (PE). Engineered microbes are optimized to utilize plastic breakdown products to produce and accumulate lubricant base oils. The team also developed low energy approaches for waste pre-processing and product recovery that are amenable to continuous and scalable operation.

Results/Lessons Learned. PET degradation of up to approximately 98% over 48 hours has been determined gravimetrically and by HPLC of monomer release. A bioprospecting campaign for polyethylene degrading strains showed ~5 enriched samples with both growth on polyethylene and release of byproducts consistent with oxidation, as determined by GC-MS detection of ~C8-C20 alkanoic acids, alkanoic alcohols, and terminal alkenes. We showed up to approximately 5 to 10% conversion by mass of multiple plastic breakdown products to microbial oils that will be further purified and upcycled in future work as base oils for high value lubricants. For pre-processing, a room temperature surface crazing treatment for increasing PET reactive surface area by three-fold was developed. For separations, we achieved 36% recovery at 96% purity of microbial base oil with an oil-water hydrocyclone enrichment and decanting process. In future phases of development, these processes will be further optimized and scaled for commercial use, with efficiencies and process profitability modeled through technoeconomic modeling.