CLOSE THE LOOP: IN-SPACE MANUFACTURING OF PURE PLASTIC FROM WASTE. F. D. Gaertner, E. Bar-Ziv, F. Long, Dept. of Mechanical and Aerospace Engineering, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931 (contact: flong@mtu.edu).

Introduction:

Space exploration is expensive. The cost to launch a kilogram to space has been on the decline, however, the requirements for a successful mission have increased the needed payload mass and expected waste streams [1]. Issues with excessive space debris in-orbit and underdeveloped waste resource utilization already exist without the additional pressure of longer duration missions. To avoid costly resupply missions or excessive resource payloads, an efficient recycling infrastructure must be developed.

Many promising solutions have arose to combat these issues: the theoretical architecture developments of Space JANITOR [2], in-space additive manufacturing using mechanically recycled metallics and polymerics [1], and repurposing beverage packaging for resupply mission purposes [3], to name a few. Waste polymeric materials would be particularly useful to utilize, as they play a significant role in space exploration [4] and their material properties are beneficial for other in-space manufacturing (ISM) processes and products. Thermoplastics, like polyolefins (low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polypropylene (PP)), ethylene vinyl alcohol (EVOH), and polystyrene (PS), provide unique processing challenges that must be carefully considered when comparing current mechanical and chemical recycling methods to an ISM processing framework.

To process thermoplastics mechanically, separation via air or water is required for preprocessing of the feedstock. It cannot process complex plastic compositions, like multilayer films and other varieties of mixed plastics, due to sorting limitations [1], [5]. Chemical recycling methods are uneconomical due to the significant amount of processing energy required to break the covalent bonds [5]. Any contaminants will poison the catalyst, which further increases the process cost [5]. Solvent-targeted recovery and precipitation, or STRAP, is a promising physical recycling technique based on dissolution and precipitation that can produce high-quality resins from plastic waste with low cost and energy [6]. These advantages could be key in utilizing in-situ materials during longer duration missions, or, amidst infrastructure development.

Methods:

Process Development:

Figure 1 describes the STRAP process flow, designed based on results from lab-scale experimentation. Assorted plastic waste is shredded and fed into a vessel with a temperature-dependent solvent for dissolution. Once the targeted plastic is dissolved, the solution is filtered and cooled to promote precipitation of the polymer resin. The undissolved plastics, separated out via filtering, can be used in secondary cycling with alternative solvents. The precipitated material can be used as a pure plastic source for feedstock and manufacturing purposes.

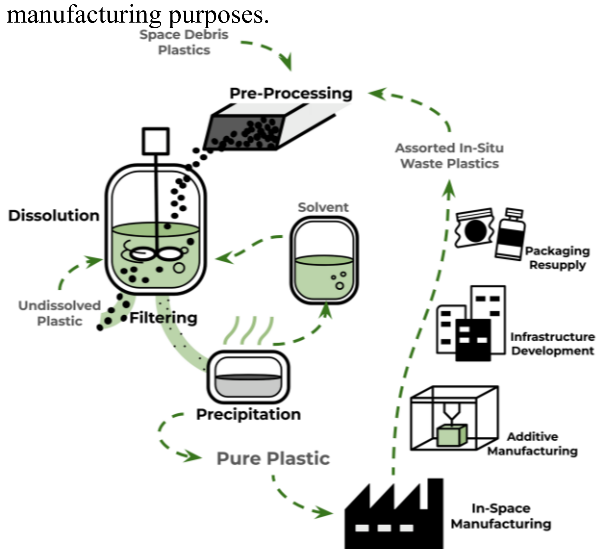

Figure 1. Process flow diagram of STRAP and its potential role in continuous ISM development

Initial developments of STRAP have been largely supported by the computational modeling and lab-scale work done by University of Wisconsin, Madison. The computational model uses a molecular dynamics simulation to predict polymer solubilities with temperature and composition dependence [7]. Verification of the predicted solubilities is completed through lab and pilot-scale testing.

Work at Pilot-Scale:

The pilot-scale plant development at Michigan Technological University focuses on the shift to STRAP within industry. Processing occurs in an oxygen-free environment at ambient pressure, with internal tank temperatures kept below the solvent boiling point. These operating parameters keep the plant energy and cost efficient without affecting the precipitated plastic quality.

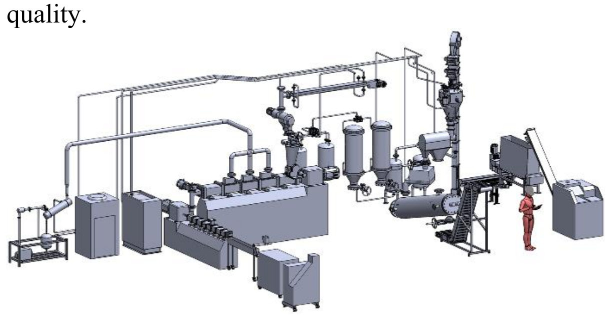

Figure 2. 3D representation of STRAP at pilot-scale

Results:
Successful results using STRAP at lab-scale have produced high-quality plastics from multilayer films, single-use products, and other mixed plastic waste with similar mechanical and thermal properties to that of virgin-grade material [6], [8], [9]. Figure 3 provides images of the different resulting pure plastics after the STRAP process.

Figure 3. Pure plastic after STRAP processing of waste: A. PE (left) and EVOH (right) from single use pharmaceutical waste [9]*, B. PS (left) and PP (right) from single use Keurig cups C. PE from multilayer films* [8]*, D. PP from super sack fabric*

Additional promising tests and results have been achieved via the components of the pilot-scale, with more results expected in mid-April following approval for solvent use in the facility.

Discussion:
STRAP could be an economically viable long-term option to assist longer duration missions and ISM efforts. This method solves issues within mechanical and chemical recycling spaces by avoiding intensive preprocessing, utilizing lower energy process parameters, and providing the capacity to process complex plastics. Continuous development of the polymer solubility database has the potential to extend to other common polymers used in space exploration as well. Paired with orbital space debris collection technologies and in-situ plastic waste streams, we can close the loop of ISM of pure plastic from waste.

To quickly exemplify the advantages of using STRAP on the lunar surface that are not present in its terrestrial application: it is already oxygen-free and the thermal extremes from direct sunlight and lunar nights could be leveraged for lower cost dissolution and precipitation. The development of an architecture model for space-based STRAP processing plants could significantly improve the circularity and sustainability of space missions.

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