Logistics Reduction and Repurposing Beyond Low Earth Orbit

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All human space missions, regardless of destination, require significant logistical mass and volume that is strongly proportional to mission duration. Anything that can be done to reduce initial mass and volume of supplies or reuse items that have been launched will be very valuable. Often, the logistical items require disposal and represent a trash burden. Logistics contributions to total mission architecture mass can be minimized by considering potential reuse using systems engineering analysise. In NASA's Advanced Exploration Systems "Logistics Reduction and Repurposing Project," various tasks will reduce the intrinsic mass of logistical packaging, enable reuse and repurposing of logistical packaging and carriers for other habitation, life support, crew health, and propulsion functions, and reduce or eliminate the nuisance aspects of trash at the same time. Repurposing reduces the trash burden and eliminates the need for hardware whose function can be provided by use of spent logistical items. However, these reuse functions need to be identified and built into future logical systems to enable them to effectively have a secondary function. These technologies and innovations will help future logistics systems to support multiple exploration missions much more efficiently.

Nomenclature

ACS = advanced clothing system
AES = Advanced Exploration Systems
atm = atmosphere, standard
COTS = commercial off the shelf
CTBs = cargo transfer bags
DSH = Deep Space Habitat
ECLSS = Environmental Control and Life Support System
ESM = equivalent system mass
HMC = heat melt compactor
ISTAR = ISS Testbed for Analog Research
ISS = International Space Station
LRR = Logistics Reduction and Repurposing
L2L = logistics-to-living
LTL = logistics-to-living
psia = pounds per square inch absolute
SE&I = systems engineering and integration
TRL = technology readiness level
TTSG = trash to supply gas
WRSEA = Waste Reuse Systems Engineering Analysis

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I. Introduction

IN fiscal year 2012, NASA began about two dozen Advanced Exploration Systems (AES) technology development projects designed to reduce risk, lower life-cycle cost, and validate operational concepts for future human missions beyond Earth orbit. Goals of the projects include the following:

- Demonstrate prototype systems in ground test beds, field tests, underwater tests, and International Space Station (ISS) flight experiments.
- Use innovative approaches for rapid systems development and provide hands-on experience for the NASA workforce.
- Infuse new technologies into exploration missions.

One of these projects, called Logistics Reduction and Repurposing (LRR), is focused on improving the logistics approach for these missions by reducing the mass and volume of consumable items, finding ways to repurpose and use items and packaging that is launched, and reduce and reuse trash and other waste products created during the mission.

The LRR project involves six NASA centers and has five major tasks. Four of the tasks involve developing different technologies to fulfill the AES LRR goals and will result in engineering units or prototypic hardware. One task, called Waste Reuse Systems Engineering Analysis (WRSEA), is analytical and will be used to guide the direction of the technology development and integrate the resulting hardware within the LRR project and with other AES projects and future mission plans. The four hardware development tasks are:

- Development of an advanced clothing system (ACS) to reduce mass, volume, and flammability.
- Conversion of trash to useable products via heat melt compactor (HMC) processing.
- Conversion of trash to supply gas (TTSG) to make propellant from waste products.
- Use of logistics-to-living (L2L, or LTL) to repurpose launch packaging containers and other items.

The AES LRR project covers 3 years of activities that require coordination within LRR and with other AES projects. The top-level milestone schedule of AES LRR is shown in Fig. 1. The intent of this paper is to provide an overview of LRR's technology approach, including the rationale and potential benefits that will be investigated over the next 3 years. Future papers will focus on the progress and results of each LRR technology.

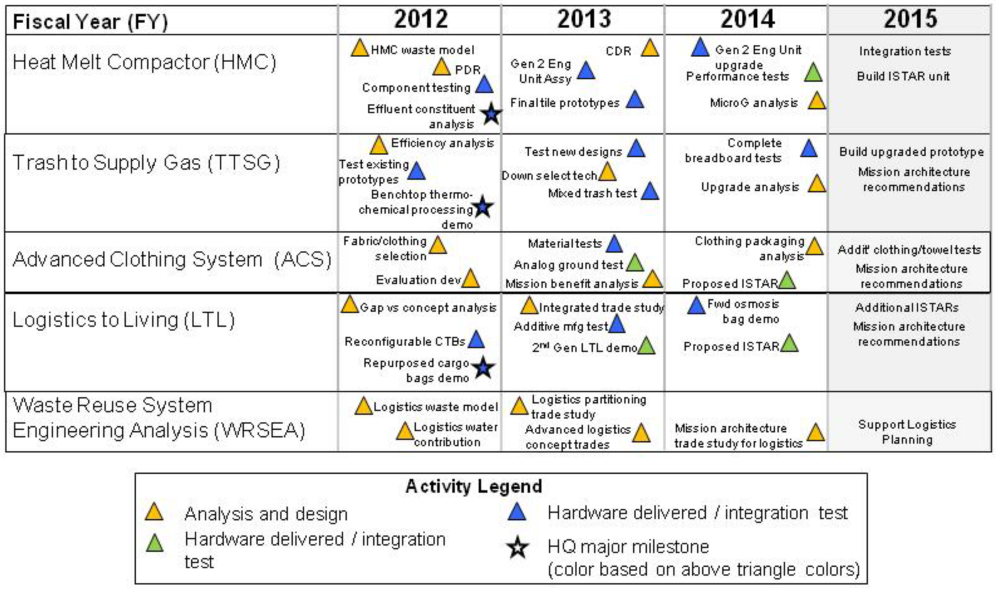

Figure 1. AES LRR milestone schedule for all five tasks.

II. Waste Reuse Systems Engineering Analysis

The systems engineering and integration (SE&I) function will be carried out in the WRSEA task; personnel will work closely with the LRR project manager. This task is critical to ensure proper integration and architectural decisions among the various logistics reduction and repurposing technologies. After all, if the project is successful in reusing trash for other functions such as building materials, radiation protection, and propellant, there will be competition between the benefiting systems for this (waste) resource. WRSEA will help establish which use or uses of this material are most beneficial to exploration missions overall.

Systems analysts will start by considering all consumable items launched, using the ISS as a baseline and real-world data sources to create a typical logistics model including the composition of consumables. These data will be compared against exploration mission scenarios to determine the best waste-processing methods for material reduction and reuse. Figure 2 illustrates the results of a preliminary analysis of the quantity of consumables that are required to support four crew members for 1 year away from Earth. The analysis focused on logistical supplies directly supporting the crew and life support systems. These consumables were divided into the broad categories of Crew Consumables, Subsystem Maintenance, and Water. Future work will take this baseline based on ISS and tailor it for exploration missions.

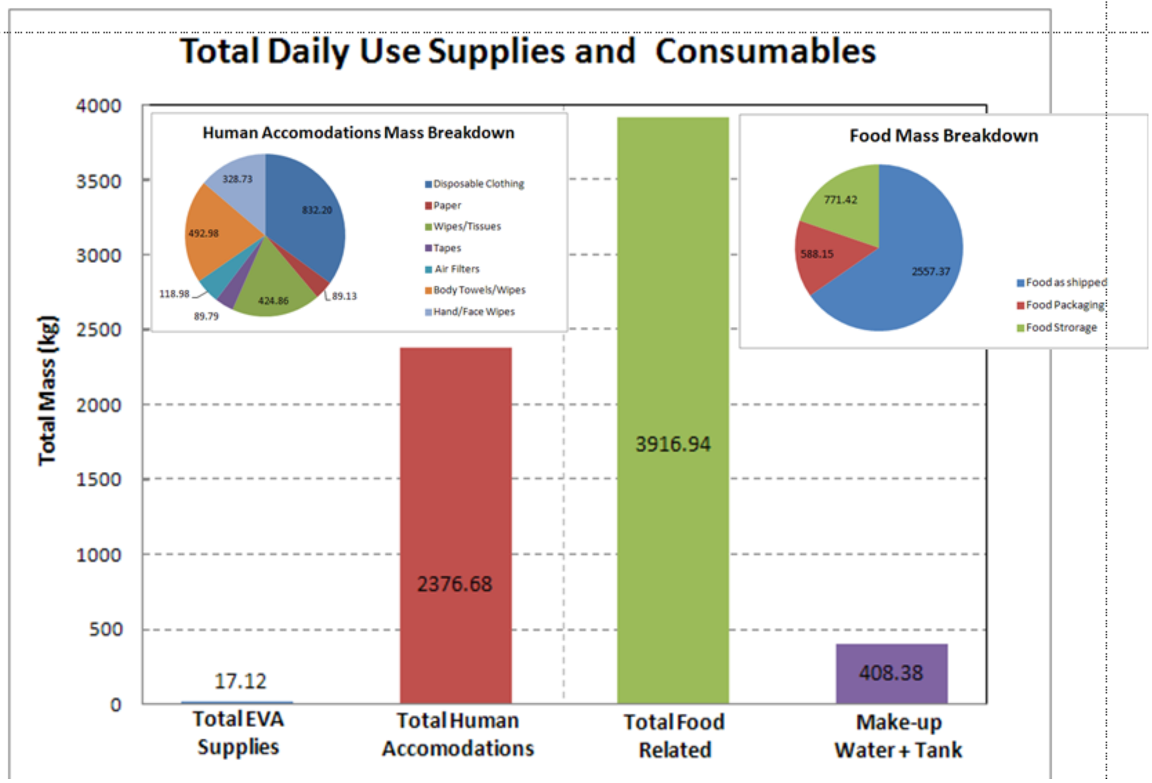

Figure 2. Preliminary logistics analysis results for four crew members for a 1-year mission.

These data will also form the basis of mission analysis of how logistics are used. What happens to these items once in space has also been considered and a companion waste model has been created, as shown in Fig. 3. As exploration missions are defined in greater detail and as the LRR technologies progress and provide performance data, this cradle-to-grave analysis will be periodically repeated to allow adjustment of the four LRR hardware work plans. Also, the analysis results will enable development of requirements and design features required of logistical components to enable effective reuse on-orbit. Detailed data generated by the analysis are essential to the rigorous systems analysis that will optimize how material recycling occurs on future long-duration missions. Mass, power, volume, thermal control, and crew time trade studies will all be conducted to allow sound programmatic decisions since these parameters often compete with each other. An equivalent system mass (ESM) technique developed by the Advanced Life Support project will be used to include all these factors.[1]

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Figure 3. LRR Waste Model for a crew of four.

Mission parameters such as availability of resources (e.g., carbon dioxide from Mars atmosphere) or solar or thermal environments can affect the selection of optimum technology approaches, therefore several reference missions will be considered. In one of its first tasks, WRSEA defined two primary reference missions for the LRR project.

1. Mission to Asteroid 2008-EV5 with focus on a Deep Space Habitat (DSH). This mission includes an uncrewed period of about 2 ½ years and a period of a little over 1 year with four crew members in the DSH at 8 pounds per square inch absolute (psia) pressure. The mission also includes a multi-purpose crew vehicle and a multi-mission space exploration vehicle.
2. ISS Continuation. This mission considers logistical supplies to support the ISS for 10 more years in low Earth orbit.

As mentioned, WRSEA will help determine the most effective use of waste products for the reference missions. This will involve performance analyses and trade-off analyses. Since many chemical process technologies are under consideration for TTSG, analysis will be combined with testing to determine the leading technology to be further developed. Specific technologies are described further under TTSG; however, Fig. 4 is an example of one process flow diagram that engineers developed as part of a mass balance analysis on the competing technologies. Following down-selection, the fidelity of modeling and analysis will increase further to allow important design and scaling factors to be sufficiently understood before prototype design is undertaken.

In addition to conducting trade studies between competing designs or technologies within the hardware tasks, the WRSEA team will perform analyses to determine the best use of different categories of waste, whether it be for life support, propulsion, or other purposes. Waste hydrogen, for example, could be used to make more methane for propulsion or more water for life support. Within LRR, the decision must be made as to which trash goes to the HMC and which goes to TTSG. Desired by-products or constraints, such as tiles for radiation protection or crew interation with certain types of waste, may help answer this question. However, final answers may not be available until a flight program begins. Thus, the LRR project will develop each technology to handle as broad a range of waste products as practical. In later years of the project, the WRSEA team will also conduct more integration analysis as products of the various tasks are tested together with each other and with life support and habitation systems from other AES projects. Finally, the WRSEA team will provide mission architecture inputs for AES DSH and other projects periodically so that the benefits of integrating novel logistical packaging and on-orbit reuse can be demonstrated in AES analogs to validate overall mass and volume savings predictions.

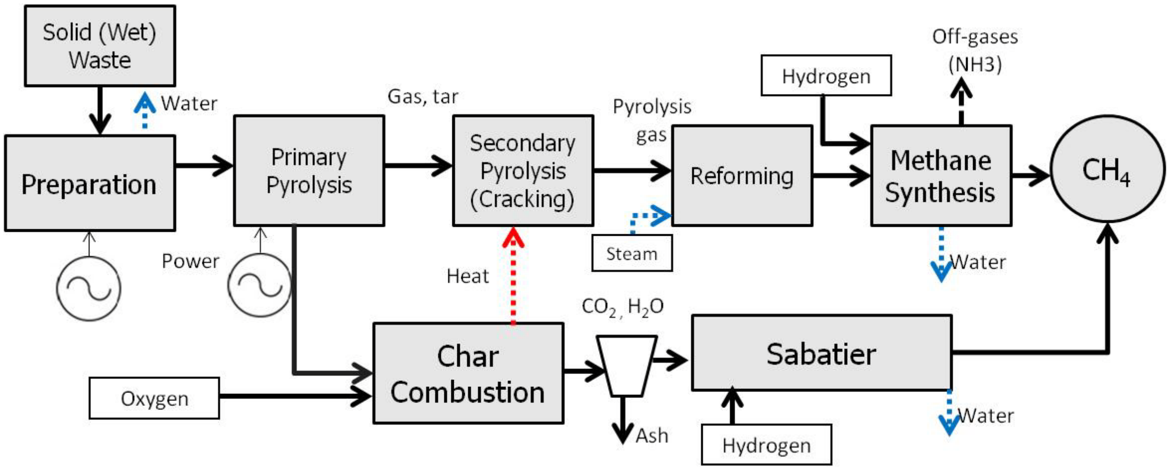

Figure 4. Example process flow diagram: incineration TTSG candidate technology.

III. Advanced Clothing System

Clothing is typically not considered in technology development; consequently, it has evolved very little from the early Space Shuttle days. Existing clothing is primarily cotton based. Clothing accounts for a significant portion of the logistical mass launched on current space missions: 363 kg and 1.1 m^3 for an ISS crew of six each year[2]. The clothing becomes trash when it is too dirty to wear since no space laundry is currently available. Although the WRSEA team will keep an eye on the trade-off between clothing mass and laundry equipment, the AES LRR ACS task will focus on a systematic investigation of using advanced lightweight and antimicrobial fabrics that extend space flight clothing's usable life.

A. Rationale for Advanced Clothing System's Ability to Reduce Logistics

Increasing clothing wear time will decrease up-mass and reduce the disposal burden. Fewer clothing items per mission directly reduces logistical mass. If sufficient clothing wear time can be achieved, then the need for development of a space laundry system can be delayed. Previous studies[2] have shown that with clothing usage rates of 0.2 kg/crew-day (current ISS), the break even point for a laundry system compared to disposable clothing is 270 days. This does not include washable towels. If advanced clothing can reduce the clothing usage to 0.1 kg/crew-day, the break-even point becomes 635 days, assuming current ISS water processing technology. This is within the range of many human exploration missions under consideration. Hence, ACS can provide a very robust solution with low-impact failure modes compared to a likely complex laundry system.

Lightweight garments constructed of polymer rather than cotton-based fabrics have several inherent advantages from an integrated spacecraft perspective. Antimicrobial coatings combined with high wicking and low moisture retention should remain odor-free longer. Drying of heavy, moisture-laden clothing on the ISS has resulted in surface mold and fungal issues.[3] Used exercise ACS clothing should dry much more rapidly, thereby reducing microbial proliferation within the clothing and on surfaces within the spacecraft. Less odor generation will reduce the burden on atmospheric trace contamination control systems. Fewer odors should facilitate longer repeat wearing of clothing before it is ultimately disposed of on-orbit.

On the ISS, air return filters and fan intakes require regular maintenance and vacuuming of debris to reduce pressure drop and maintain performance. The filter debris contains a significant amount of fabric lint of which a substantial portion is from clothing.[4] ACS polymer-based fabrics will reduce particulate (lint) loading on the air filters of the Environmental Control and Life Support System (ECLSS), which should reduce crew maintenance time and reduce the chance of filter damage during maintenance. Currently, clothing is manually rolled up and disposed of in bags; however, inherent spring back limits compression. Changing the fabric from mostly cotton-based to lightweight polymer-based opens up other disposal options that include heating the clothing to form microbially and dimensionally stable tiles that can be used for very efficient trash storage or as part of a radiation shield. Heat stabilization of used clothing with the HMC will be discussed.

B. Advanced Clothing System Technical Approach and Status

The ACS task will examine innovative materials, such as X-STATIC® fabrics (Noble Biomaterials, Inc., Scranton, PA), polyethylenimine-coated fabrics, and J-Ware apparel, to establish a full range of capabilities for antimicrobial treatments. Advanced lightweight antimicrobial fabrics will be selected from Commercial Off-the-Shelf (COTS) garments to represent a range of technical options that have the potential to reduce overall clothing mass compared to the ISS. Fabrics will also be evaluated for flammability, off-gassing, and compatibility with expected exploration vehicle oxygen levels. However, the keystone to ACS is acceptance by the crew members for daily use. A usability study will help the team assess repeated use of garments in a controlled environment to assess human factors, comfort, appearance, and odor. The clothing use study will include ground test personnel and representatives for the crew office, and may be conducted using ground analogs of the ISS. In the second year of the project, clothing articles will be evaluated on the ground for up to 2 weeks at a time over several cycles. In the third year of the ACS task, ISS crew members will be selected to participate in an innovative ISS Testbed for Analog Research (ISTAR) demonstration using garments selected from the ground tests. The ISS test will compare existing and advanced fabrics to demonstrate their acceptability for long-term use.

These data will be used to tailor and derive future development and garment selection. This should enable future ISS operations to continue to reduce clothing resupply rates. This will also enable reduced mass for exploration mission clothing and clothing-induced contamination of the DSH air recovery systems, and improve overall crew hygiene.

The ACS task has conducted an initial mark survey of garments to meet ACS goals. The experimental design of the long-term use experiments is under way and includes human factors engineering, material specialists, and statistical controls to maintain an objective approach. Experimental design and garment selection will be finalized by August 2012. Ground analog testing will begin in spring of 2013.

IV. Heat Melt Compactor

Space mission trash contains a wide range of mixed crew items, packaging, food waste, hygiene waste, and unneeded/broken equipment. By mass, the trash typically contains approximately xx% food, xx% water, xx% plastic, and xx% other[5]. Trash management on existing spacecraft is very low tech. It involves little more than limited sorting, short storage durations, and disposal in visiting vehicles or return to Earth. Trash is sorted into "wet" and "dry" flexible bags and squeezed or manually compacted to reduce its volume. Manual compaction typically results in an approximately 50% volume reduction but requires additional tape and bags to constrain it. Although there is volume reduction, in a short time the stored trash volume becomes significant because it is generated at ~xx kg/crew-day. Stored trash is biologically active and will generate odors and off-gassing to the crew cabin. Although the ISS hosts visiting vehicles approximately every other month (vehicles that can remove trash), future deep space missions will have no, or very limited, visiting vehicles for disposal. Trash disposal to space will likely be limited because each disposal results in lost atmospheric gas from an airlock, and the vacuum can result in rapid release of trapped gas and water vapor that can contaminate the vehicle exterior. Additionally, space disposal requires a change in momentum or trajectory to avoid potential to recontact the discarded items. Mid-course corrections to deep space missions will be relatively few and spaced far apart so trash will need to be stored until just before the corrections. Destinations involving Lagrange points will not have feasible disposal options because trash will have a tendency to stay or return to the Lagrange point. Planetary protection protocols for Mars or near-Earth asteroids will likely place stringent requirements on surface trash disposal that will likely have significant mass and volume penalties to enable the required robustness. Advancements in on-orbit trash management are needed to improve habitability conditions for long-duration exploration missions.

A. Rationale for Heat Melt Compactor Ability to Reduce Logistics

Although the HMC might be considered for the sole purpose of trash management, it can also provide a logistical savings when integrated into the vehicle concept of operations. The HMC accepts a wide range of wet trash, dry trash, and water processing brines. Trash can be compacted to reduce it to approximately 10% of its original (hand-compacted) volume. The HMC also can heat the trash to dry it, sterilize it, and melt any plastic. If the trash placed in the HMC contains over 20% plastic, the HMC will compact and melt it to form a solid rigid tile that does not spring back. The plastic within the trash is heated to approximately 160°C (~320°F) to soften it and allow it to extrude through the trash during compression. The compressed trash is then cooled and the tile is removed. The lack of spring back and a relatively consistent shape has several advantages. Crew time should be saved because the crew no longer needs to bag and manually compress the trash. The HMC-processed trash represents manually 20-fold volume reduction from uncompacted trash. This will have a direct reduction to the number of trash bags required – a minor but measurable reduction to logical up-mass. A less obvious, yet important, benefit is that, over time, stowed logistical packaging and trash can be compacted to 5% of its original volume, resulting in a net increase in habitable volume. As an example, assume logistical packaging (foam, cargo bags, etc.) represents 20% of the total volume of supplies. For every 1 m^3 of logistics, there is 0.2 m^3 of waste, which the HMC will reduce to 0.02 m^3. This results in a net habitable volume increase of 0.18 m^3. If the logistical items themselves (e.g., food, clothing, wipes) are able to be processed by the HMC, the net increase in habitable volume is even more significant. Over time, this can significantly increase the habitable volume of the spacecraft.

The HMC tile represents a dense mass of organic material (mostly carbon and hydrogen) that can be considered for reuse. The hydrogen content in particular is useful for passive shielding against solar radiation. The biologically stable HMC tiles can be deployed in layers along portions of the vehicle interior to develop several centimeters of thickness. Uncompacted and unprocessed trash is undesirable for shielding due to its significant volume and potential for microbial proflication and odors. Early in the flight, the unused logistics can provide radiation shielding at the loss of habitable volume. Over the course of a long-duration mission, several hundred kilograms of dedicated shielding could be deployed, and could reduce the crew radiation exposure and increase the habitable volume. HMC can indirectly save vehicle mass by offsetting dedicated radiation shielding mass and allowing a smaller vehicle shell to provide the same habitable volume.

The third HMC benefit is the recovery of water from trash. Currently, wet trash can contain approximately 20% water by mass bound up primarily in food residual; drink bag ullage and wipes. The HMC will vaporize water, which minimizes the organic contaminants that are transported to the condensed product water. The product water can either be delivered to the vehicle water recover system or stored in bags for future use or deployment as a water wall for additional radiation shielding. An advanced concept of operations includes the investigation of processing water processor brines to increase the current water recovery rate from approximately 70% to approximately 98%. This has the potential to save hundreds of kilograms of up-mass over the course of a year.

With the removal of water, low moisture content is present in any organic food residual. The HMC operation temperatures provide either wet or dry sterilization conditions to inactivate all microbial organisms. If the vehicle maintains a relatively low humidity (<50% relative humidity) and the tiles are stored in a dry location, microbial regrowth and the associate noxious odors should be minimized. The reduction of odors will reduce the load on the vehicle trace contaminant control system and provide a more hygienic crew volume.

B. Heat Melt Compactor Technical Approach and Status

Prior HMC development under previous NASA projects has been well documented.[7] The current LRR HMC task will evolve the first-generation benchtop ground unit to a flight-like second generation unit over a 3-year period. The first generation unit established the basic range of trash compositions, temperatures, and pressures required to produce stable tiles. It also demonstrated the ability to consistently remove the water content and reduce or eliminate microbial activity. Systematic testing is under way with the generation 1 unit to understand the off-gassing constituents in the air and contaminants in the condensed water. These test data will be used to design and size the trace contamination control and condensing heat exchanger for the second generation HMC. Concurrently, several trade studies are occurring in 2012 to support a preliminary design review in June. The goal is to fabricate a flight-like engineering unit of key portions of the HMC generation 2 unit by the spring of 2013. The second-generation unit will be used to test out operational concepts, process variables, and component functionality. The engineering unit will then be upgraded in 2014 and be ready for closed-environment integration tests with other life support hardware. This will enable validation of crew use, waste water processor compatibility, and vehicle trace contaminant control technologies. Figure 5 shows the first-generation HMC, a box of trash representing uncompacted input, and the compacted trash output tile.

Figure 5. Left: first-generation HMC. Right: example of compaction of loose trash to a stable HMC tile.

V. Trash to Supply Gas

A dramatic approach to repurposing logistics is to deconstruct it into constituent molecular components and recombine them into gases that can be used on long-duration spacecraft. High molecular weight organic compounds make up the majority of logistical and crew trash. These hydrocarbon chains can be broken down into smaller molecular carbon compounds (carbon monoxide, carbon dioxide, methane, and others) with moderate temperatures (500-800°C (932-1472°F)) and pressures (1- 200 atmosphere, standard (atm)). Depending on the desired gas end products and the selected processes, oxygen and water may be inputs or outputs. Similarly, the selected processes will determine the inert gas, liquid/tar, or solid/ash that must be managed. These by-products can represent a very compact and stable reduction of the trash. Overall, this activity of converting TTSG will capitalize on previous trash disposal and in situ resource utilization technologies. The intent is that in situ manufactured gases can reduce the amount that must be launched.

A. Rationale for Trash to Supply Gas Ability to Reduce Logistics

Methane propulsion is being investigated for several proposed vehicles and missions. The successful production of methane or other product gases from trash could directly reduce the required launch mass of propellant and tanks. The TTSG processes require equipment that will decrease the methane launch savings; however, the overall savings is still estimated to be substantial. Methane or other TTSG products could also be used as fuels in fuel cells for power production.

In addition to gas production, TTSG can eliminate the need for significant solid waste storage. Just about any wastes, including feces, can be processed by the technologies under consideration. TTSG provides increased habitable volume over time, to an even greater degree than HMC, because the products are moved out of the habitable volume to tanks and the ash/tar is a small percent of the input. The residual material gas/liquid/solid should be completely biologically inactivated and stable.

B. Trash to Supply Gas Technical Approach and Status

Six technologies are being investigated as the primary trash decomposition process. These technologies include: pyrolysis, gasification, combustion, ozonation, catalytic reduction, and steam cracking. The major process characteristics are listed in Table 1. The technology readiness level (TRL) for trash to gas processing in space is relatively low (~TRL 2-3). TTSG will take advantage of previously delivered Small Business Innovative Research hardware and in-house hardware, some of which have been reported upon in previous publications.[8,9] The hardware will be modified for initial testing to establish performance with simple materials and then with typical ISS trash. The initial data will determine conversion efficiencies, residuals, and contamination issues under different operation conditions. These data will be use to perform ESM calculations for technology comparisons. During the second year, 2013, the TTSG task team will refine successful TTSG technologies. In particular, activity will focus on low-temperature catalytic decomposition and post-processing technologies that will enable methane formulation as an end product. By the end of 2014, the down-selected second generation of TTSG will be assembled and tested to TRL 4-5 level.

Table 1. TTSG Technologies Currently Under Investigation by the LRR Project Team

General Technology	Subtypes	Process Options	Residence Time	Temperature	Pressure	Oxygen	End Products/ By-products	Associated Downstream Process(es)	Issues	Past Work
THERMAL TREATMENT	**Pyrolysis (Thermal decomposition)**	Fast pyrolysis	Short (1 sec)	400-650 °C	~1 atm	None	Liquids, tars, char, gases	Steam Reforming, Water gas shift, Methanation	tar	ARC & Adv Fuels Research; KSC
		Slow pyrolysis	Long (>100 sec)	< 400 °C	~1 atm	None	Liquids, tars, char, gases	Steam Reforming, Water gas shift, Methanation	tar	
	Gasification	Direct/ Partial oxidation	Long	500-800 °C	~1 atm	Substoichiometric	Synthesis gas (CO + H2)	Water gas shift, Methanation	waxy residue	KSC
		Indirect/ Steam gasifier	Long	1000 °C	5 atm	Substoichiometric	Synthesis gas (CO + H2)	Water gas shift, Methanation		GRC
	Combustion	Incineration mass burn/auger feed	Short (2 sec)	1000 °C	~1 atm	Excess Oxygen	CO2, H20, ash	Sabatier	NOx reduction	
CHEMICAL OXIDATION	**Ozonation**	Wet ozonation				Ozone (O_3)				ARC
	Aqueous phase oxidation	Wet air oxidation		150-325 °C	20-200 atm	Saturated O_2				GRC
		supercritical water gasification		400-600 °C	220 atm					ARC
CATALYTIC DECOMPOSITION		TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	GRC

VI. Logistics to Living

L2L can be defined as repurposing or converting logistical items (e.g., containers, foam, components) into useful crew items or life support augmentation on-orbit after the items have provided their primary logistics function. The intent is that by repurposing items, dedicated crew items do not have to be launched and, consequently, overall launch mass is decreased. Logistical reuse can occur on several levels, including (1) transforming cargo carriers (i.e., bags, racks, foam) for other purposes on-orbit, (2) embedding additional features in cargo carriers to provide secondary functions, (3) modifying how logistical items are packaged in the vehicle to allow more efficient packaging, and (4) repurposing the logistical area of the spacecraft after the logistics are consumed.

A. Rationale for Logistics to Living Ability to Reduce Logistics

Repurposed L2L items can directly reduce logistical up-mass. For example, currently, a significant amount of cargo is transferred to the ISS packed in foam or soft articles and then placed in rectangular cargo transfer bags (CTBs). The CTBs are used to keep items organized on-orbit until the items are used. CTBs are then used to store and transfer dry trash and directly contribute to trash if they do not have a second purpose. If CTBs can be redesigned to be unfolded, they can be used to construct a variety of crew outfitting items. Possible crew items that can be constructed include habitation partitions, acoustical liners, and furniture (primarily for planetary applications). If the CTBs are further augmented to include bladders, membranes, or adsorbents, water walls, or radiation protection, water storage and waste water treatment are possible reconfiguration options. An advanced area of L2L is the investigation of in situ manufacturing from on-orbit materials including the use of logistical packaging as a feed stock.

B. L2L Technical Approach and Status

The repurposing of logistical items is a very broad area. The initial area of study will be investigating repurposing of the CTBs, as shown in Fig. 6. Some conceptual demonstrations of foldable CTBs have been conducted in the Habitation Demonstration Unit.[6] The current L2L activity will use the previous work as a starting point. Brainstorming with a multi-NASA-center team representing engineering, human factors, operations, and deep space habitation development members has already generated a list of possible reuse options. The options are now being compared against the potential mass benefits. Selected concepts will be developed and demonstrated in the AES DSH field test in August 2012.

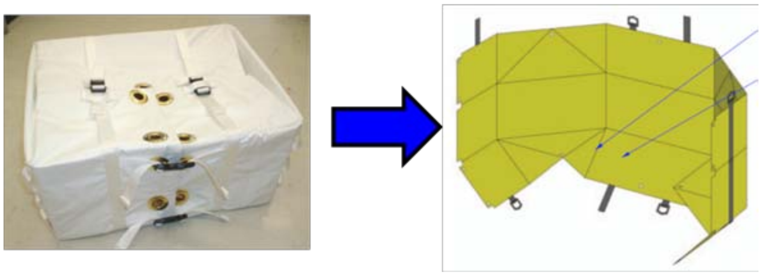

Figure 6. One concept of a CTB unfolding into a sheet for use as a partition.

A second generation of the CTBs will be developed in 2013, and will be based on evaluations from the prior year. How logistics are interfaced with the launch vehicle to enable repurposing of the logistics area on-orbit will be examined. Initial in situ manufacturing will be investigated to determine which replacement components offer the most benefit. The practicality of fabrication will be considered for a field analog. In the third year, 2014, L2L will generate a mission-level implementation plan for logistical repurposing. The plan will include relevant trade studies to estimate the benefits to DSH and other missions. Third-generation configurations of CTBs to demonstrate key parts of the repurposing will be demonstrated at a system design review for vehicle integration.

VII. Relation of Logistics Reduction and Repurposing Tasks to Typical Vehicle Logistical Flow

Logistics is a major subset in the habitation domain of a spacecraft. The movement of logistics into the original launch vehicle, their movement for use on-orbit, and their eventual storage and disposal is relatively complex, crosses many subsystems and impacts many technical disciplines. For purposes of this paper, the habitat includes habitation domain (livable space), vehicle systems/structure domain, and the ECLSS domain. The habitation domain includes all the crew-centric interior systems that enable the crew to use the spacecraft, logistical systems, and crew health systems. Figure 7 illustrates a generalized flow of the logistics system (yellow shading), which depicts crew and logistics functions. Related habitat and ECLSS functions are located around the circumference. Arrows represent the major flows of logistics from ground processing on the left, through crew functions in the logistics domain, and their interactions/disposal with the habitat and ECLSS functions.

AES LRR’s four hardware tasks address a portion of the total logistics flow and are indicated with color-coded arrows in Fig. 7.

HMC primarily resides in the solid waste processing function in reducing the volume, stabilizing, and allowing storage of the trash. Water that is vaporized, removed, and condensed can be transferred to the Water Recovery or Radiation Protection (water wall) functions. HMC waste gases may need to be internally pretreated and then released to the cabin for Atmoshpere Recovery to remove the final trace contaminants. Additionally, the HMC will reject heat to the cabin and ultimately to the thermal function. The HMC tile may be used for radiation protection, temporary storage before TTSG processing, or disposal in a used accent vehicle. Within the habitation domain, the HMC increases habitable volume (crew accommodations), reduces trash odor, and improves general cabin hygiene.

TTSG primarily resides in the solid waste processing function. It will use collected solid trash and produce methane that may be used for propulsion and oxygen for Atmosphere Recovery. Water could be produced with some technologies, and that would interface with Water Recovery. The TTSG processing temperatures will likely require thermal cooling loops for heat rejection. The residual tar, char, or ash will need to be collected and disposed of as solid trash. TTSG non-condensable gases will require trace contamination processing within the unit or by the habitat atmosphere recovery system.

ACS represents its own logistical function. Clothing interacts directly with the crew members. Clothing can also be used as equipment cushioning during launch so it interacts with logistical storage. Used clothing becomes solid trash and represents a significant source of cabin odor that becomes a load on the trace contaminate control system.

L2L is a distributed logistics function and allows translation between the functions. Repurposing of cargo carriers might allow deployment of crew accommodations (e.g., enclosures, walls). Additionally, L2L may need to influence the crew cabin structure to improve launch configurations and modify/add features to allow repurposing on-orbit. L2L will facilitate the deployment of HMC tiles in modified cargo carriers or other methods.

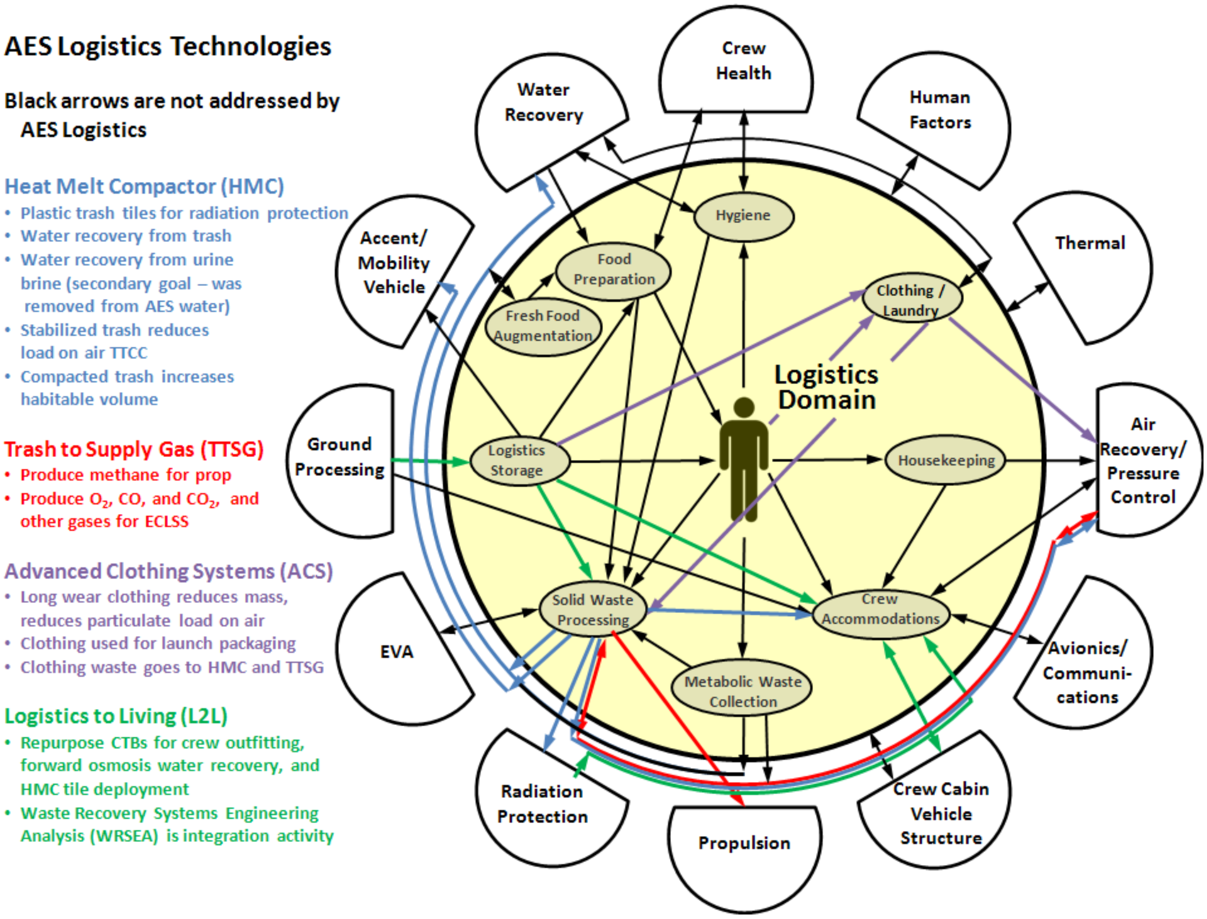

Figure 7. Logistics domain depicting flow of logistical items through crew functions and interfacing habitat and ECLSS functions.

VIII. Conclusion

Logistics are a major portion of the mission mass and volume, as experienced on the ISS and anticipated for future DSH missions. Efforts to enable multiple uses of the same launch mass rather than launching separate masses to meet each function are strongly needed to reduce mission mass. The AES Logistics Reduction and Repurposing project team is developing four technologies (ACS, HMC, TTSG, and L2L) to facilitate logistics reduction, reuse, and recycling. Of the logistical areas being addressed by AES LRR, it is estimated that the overall volume can be reduced by 50% and an associated mass savings at the integrated vehicle level. The WRSEA task team will systematically use ESM to analyze the technologies and distinguish between those that substantially reduce logistical mass and volume and those that do not. Throughout each of the 3 years, the LRR project team will coordinate with the AES Habitation, AES Radiation Protection, AES Morpheus, and AES Analog projects to identify and demonstrate technologies to help validate the operational concepts and identify any unanticipated interface issues with habitat and ECLSS systems. Within the first year of AES LRR, the primarily benefits will be identified and characterized to begin influencing long-term mission planning. Logistics repurposing holds great promise for enabling the best use of limited launch mass and vehicle volumes.

Acknowledgments

This paper summarizes the work that was performed by numerous Ames Research Center, Glenn Research Center, Johnson Space Center, Jet Propulsion Laboratory, Kennedy Space Center, and Marshall Space Flight Center engineers, analysts, functional specialists, technicians, and crew members. The AES LRR project is funded by the NASA Headquarters Advanced Exploration Systems Division.

References

[1]NASA/TM—2003-212278, "Advanced Life Support Equivalent System Mass Guidelines Document", Levri, J., et al.

[2] Ewert, M. K., Jeng, F. F., "Lundry Study for a Lunar Outpost", 2009-01-251, 40th International Conference on Environmental Systems, SAE International, Warrendale, PA, 2009.

3 find Williams ECLSS paper that describes fungal on orbit.

4 find Williams ECLSS paper describing clogged air filters – or old shuttle document of filters.

[5] Strayer, R. F., Hummerick, M. E., Richards, J. T., McCoy, L. E., Roberts, M. S., "Characterization of Volume F trash from four recent STS missions: weights, categorization, water content", AIAA 2011-5126, 41st International Conference on Environmental Systems, American Institue of Aeronautics and Astronautics, Reston, VA, 2011.

[6] Howe, A. S., Howard, R., "Dual Use of Packaging on the Moon: Logistics-2-Living", 39th International Conference on Environmental Systems, SAE International, Warrendale, PA, 2009.

[7] Pace, G. S., Delzeit, L., Fisher, J., "Testing of a Plastic Melt Waste Compactor Designed for Human Space Exploration Missions", 39th International Conference on Environmental Systems, SAE International, Warrendale, PA, 2009.

[8] Nabity, J. A., et al., "Low Temperature Ozone Oxidation of Solid Waste Streams", 40th International Conference on Environmental Systems, AIAA 2010-6034, 2010.

[9] Serio, M. A., et al., "Microwave-Assisted Pyrolysis of Solid Waste", 41st International Conference on Environmental Systems, AIAA 2011-5124, 2011.