

Waste Management Technology and the Drivers for Space Missions

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ABSTRACT

Since the mid 1980s, NASA has developed advanced waste management technologies that collect and process waste. These technologies include incineration, hydrothermal oxidation, pyrolysis, electrochemical oxidation, activated carbon production, brine dewatering, slurry bioreactor oxidation, composting, NO_x control, compaction, and waste collection. Some of these technologies recover resources such as water, oxygen, nitrogen, carbon dioxide, carbon, fuels, and nutrients. Other technologies such as the Waste Collection System (WCS - the commode) collect waste for storage or processing. The need for waste processing varies greatly depending upon the mission scenario. This paper reviews the waste management technology development activities conducted by NASA since the mid 1980s and explores the drivers that determine the application of these technologies to future missions.

INTRODUCTION

The nature of the missions and international agreements determine the requirements that NASA's technology must satisfy. For waste management the requirements can be grouped into overall functions that include water recovery, human metabolic waste collection, volume reduction, safening, stabilization, containment, disposal, and resource recovery.

With the announcement of the Vision for Space Exploration on January 14, 2004, NASA has embarked on a plan for a series of space missions to the moon, Mars, and beyond called Constellation. The plan calls for new launch vehicles and new human habitation vehicles on a schedule that stretches to beyond 2020.

The schedule for future missions determines when waste management technologies must be available. Near term needs are for the Crew Exploration Vehicle (CEV) which supports crewed missions to the International Space Station (ISS). Intermediate needs are for technologies to support missions for a return to the moon. These longer term missions envision establishment of a ten year base on the lunar surface. Far term missions include missions to Mars.

The length of the mission, the distance of the mission, and the cost of propulsion and resupply have direct effects on the requirement for waste management. For short duration missions the requirements may be for collection, compaction, and storage/disposal of waste. However, as the missions become longer and the destination more distant the emphasis shifts from volume reduction and disposal to stabilization, safening, and resource recovery. NASA's overall plans and the resultant roadmap for waste management are discussed in this paper.

NASA has supported waste management development through in-house development, NASA Research Announcement (NRA) grants, Small Business Innovative Research (SBIR) grants, and Small Business Technology Transfer (STTR) grants. In the 1990s the focus was on technologies to support fully regenerative life support systems. Technologies to recycle waste such as inedible plant residues were developed. Since about 2003 the focus has been primarily on collection, compaction, water recovery, and safening. A brief summary of the development in many of these areas of technology is provided in this paper.

As with all the other life support areas (air revitalization, water recovery, habitation, thermal) waste management technologies must not only satisfy requirements such as safening waste and providing water for the crew, the waste management technologies must satisfy requirements in the most cost effective manner possible. This means minimizing weight, power, and volume of the systems used for life support. Systems analysis is conducted to determine the costs and benefits of waste management technologies. This paper will present results of estimates of the system value of several technologies of current interest.

SOURCES FOR WASTE MANAGEMENT DEVELOPMENT DRIVERS

REQUIREMENTS

NASA's Project Constellation is aimed at missions to the moon, Mars, and beyond. Requirements have been established for these missions and are embodied in requirements documents such as "Constellation Architecture Requirements Document (CARD)" (1). This document states that "The Constellation Architecture shall provide the capability to establish and support a permanently habitable outpost on the lunar surface." Another top level document, "System Requirements for the Crew Exploration Vehicle System," (2) states that "The Constellation Architecture shall comply with the human system integration requirements defined in CxP 70024, Constellation Program Human-Systems Integration Requirements (HSIR)" (3).

The HSIR document is still a fairly high level requirements document, but does contain many items directly applicable to waste management. Most of the pertinent sections with particularly pertinent parts of the text follow.

Section 3.2.2.2.1 of the HSIR requires specific amounts of potable water for on-orbit consumption. Water is vented for temperature control during EVA, and the requirement for additional water for EVA as detailed in section 3.5.1.4.2 Water for Suited Operations: "The Constellation Architecture shall provide an additional 8 ounces of potable water per hour above nominal potable water provision as defined in 3.5.1.3.3 for crewmembers performing EVA operations, and available for consumption in the pressurized suit."

Wastes such as vomitus, feces, diarrhea and wipes are quantified and collection and containment discussed in HSIR sections 3.5.3.1, 3.5.3.2, and 3.5.3.3. Concern about feces hazards is addressed in section 3.5.3.2.2: "Fecal waste collection must be performed in a manner that minimizes possible escape of fecal contents ... because of the high content of possibly pathogenic bacteria contained in the stool and because of the potential of injury to crewmembers and hardware that could result from such dissemination." Section 3.5.3.4.1 places a requirement on the collection device for simultaneity and access: "The vehicle shall allow an

unsuited crewmember to defecate and urinate simultaneously, without completely removing lower clothing." Section 3.5.3.4.2 places an important contingency requirement on the commode system: "The vehicle shall provide for contingency collection and containment of feces and urine."

Odor control is directly addressed, although not quantitatively in section 3.5.3.5 Odor Control. Section 3.5.3.5.1 addresses odor control for Waste Management Equipment: "The vehicle shall provide odor control for the waste management equipment. ... odors can have an adverse affect on crew performance." Section 3.5.3.5.2 requires "Auditory and Olfactory Privacy."

Section 3.5.3.7 Trash addresses trash accessibility, odor control and prevention of release. Subsection 3.5.3.7.1 Waste Management Trash requires: "The vehicle should provide readily accessible trash collection, with odor control, for waste management items." Odor is also addressed in Section 3.5.7.2 Trash Management Odor Control. Within section 3.5.7.3 Trash Management Contamination Control is the requirement: "The trash management system shall prevent the release of trash into the habitable environment. ... Many microorganisms present a risk to the crew, and should not be allowed to spread."

Trash must be contained: Section 3.5.7.4 Trash Management Hazard Containment requires: "The trash management system shall prevent the escape of ... harmful chemicals and biological wastes. ... Chemical or biological waste can also cause injury and transmit disease."

Another constraint on waste management for space is the requirement for planetary protection, which is established by international treaty. Article IX of the Outer Space Treaty of 1967(4) states:

"parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose..."

Implementation of the Treaty mandate and detailed requirements are established by the Planetary Protection Officer for NASA and by the Committee on Space Research (CoSPAR) of the International Council of Science.

The goal of waste management technology development is to develop technology that will satisfy space mission requirements in a cost effective manner. The requirements can be grouped into general areas identified as functions.

WASTE MANAGEMENT TECHNOLOGY FUNCTIONS

Generally the waste management functions are collection, transportation, processing, storage, and disposal. Although this description is inclusive, not all these areas need technology development. A technical grouping of functions receiving development attention includes human metabolic waste collection, water recovery, volume reduction, safening, stabilization, containment, disposal, and resource recovery.

Human Metabolic Waste Collection

The commode system is commonly called the Waste Collection System (WCS) in NASA hardware description. For microgravity missions collection of metabolic wastes is a non trivial problem, although most of the technology development in this area has been performed by an outside contractor.

Water Recovery

Many wastes such as trash, concentrated water brines, and food scraps contain substantial quantities of water that can be recovered. Removing water from wastes also tends to suspend biological activity, thereby stabilizing the residuals.

Volume Reduction

Volume is very limited on space vehicles. Volume reduction or compaction recovers valuable space that would otherwise be consumed by waste storage. In some cases, volume reduction also facilitates transportation of waste.

Safening and Stabilization

Safening means processing the waste to make it safe for the crew or harmless to planetary surfaces. Once safened, stabilization assures that the waste does not change its state.

Containment and Disposal

Contained waste is isolated from the crew and/or planetary surfaces. Stored waste must be contained. Waste is disposed when the final act of handling or accessing is completed. Disposal can be onboard, overboard, in space, and on planetary surfaces.

Resource Recovery

Waste can be processed for reuse for the initial function, or it can be converted to new useful materials. Water recovery is an example, but was discussed separately above because it is a major need early on in the progression of missions. Other examples include cleaning clothes for reuse, converting waste to gases such as oxygen and nitrogen for air revitalization and to

minerals for use as food growth nutrients, and pyrolyzing waste to form activated carbon and fuel.

ROADMAPS

NASA Missions

NASA's Exploration Systems Architecture Study (ESAS) Final Report (5) includes a roadmap for the human return to the Moon, continued Shuttle operation, ISS support, and Mars development as seen in Figure 1. This roadmap lays the groundwork for the schedule for waste management technology development. Key milestones for technology development are the Crew Exploration Vehicle (CEV) flight, Lunar Lander development, and the Lunar Outpost buildup.

The Development Process

Figure 2 is a general roadmap for waste management technology development. The top part shows the relationship of mission requirements as missions progress from near term to far term. For near term missions of short to medium length (about 10 days to 100 days) the need is for volume reduction, storage, disposal, and some minor resource recovery (primarily water). As the missions become longer, stabilization and sterilization become increasingly important and resource recovery becomes more extensive. Planetary protection becomes very important for Mars missions. For long duration sustainable planetary surface missions, food production eventually becomes cost effective and resource recovery becomes much more complete.

Waste Technology Development to Support NASA Missions

Upon completion of development, technologies are infused into the Constellation Project. Generally a technology must be at a high technology readiness level (TRL) to be ready for infusion. Figure 3 shows how waste management technologies can be developed to meet the infusion dates. Most of the waste management technologies are currently at roughly TRL 3 or lower, which means that significant development must be completed before the infusion date. A typical example is technology for water recovery and drying. There are currently several different technologies that might work including freeze drying, air drying and heated drying. Each of these approaches has its own theoretical or practical advantages. Benchtop or breadboard versions of these technologies must be tested to determine the most promising approach to continue. After downselection, one drying technology will be advanced further. Perhaps two technologies such as compaction and drying can be combined to reduce volume, recover water, and stabilize the waste in one unit. Shifting mission dates and changing requirements and priorities can change the actual path taken such that infusion dates change and some technologies may be dropped while others may be added.

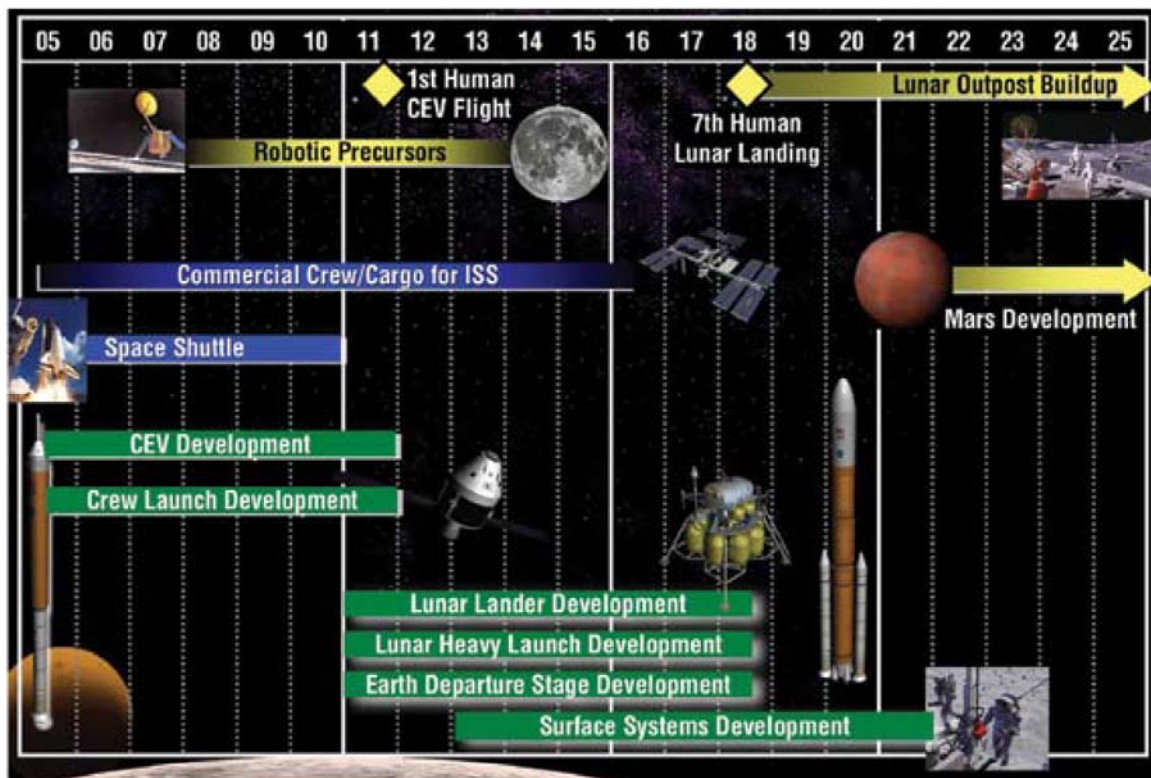


Figure 1. Roadmap from Constellation Architecture Requirements Document (CARD) - NASA CxP 70000 Baseline - Release Date: December 21, 2006.

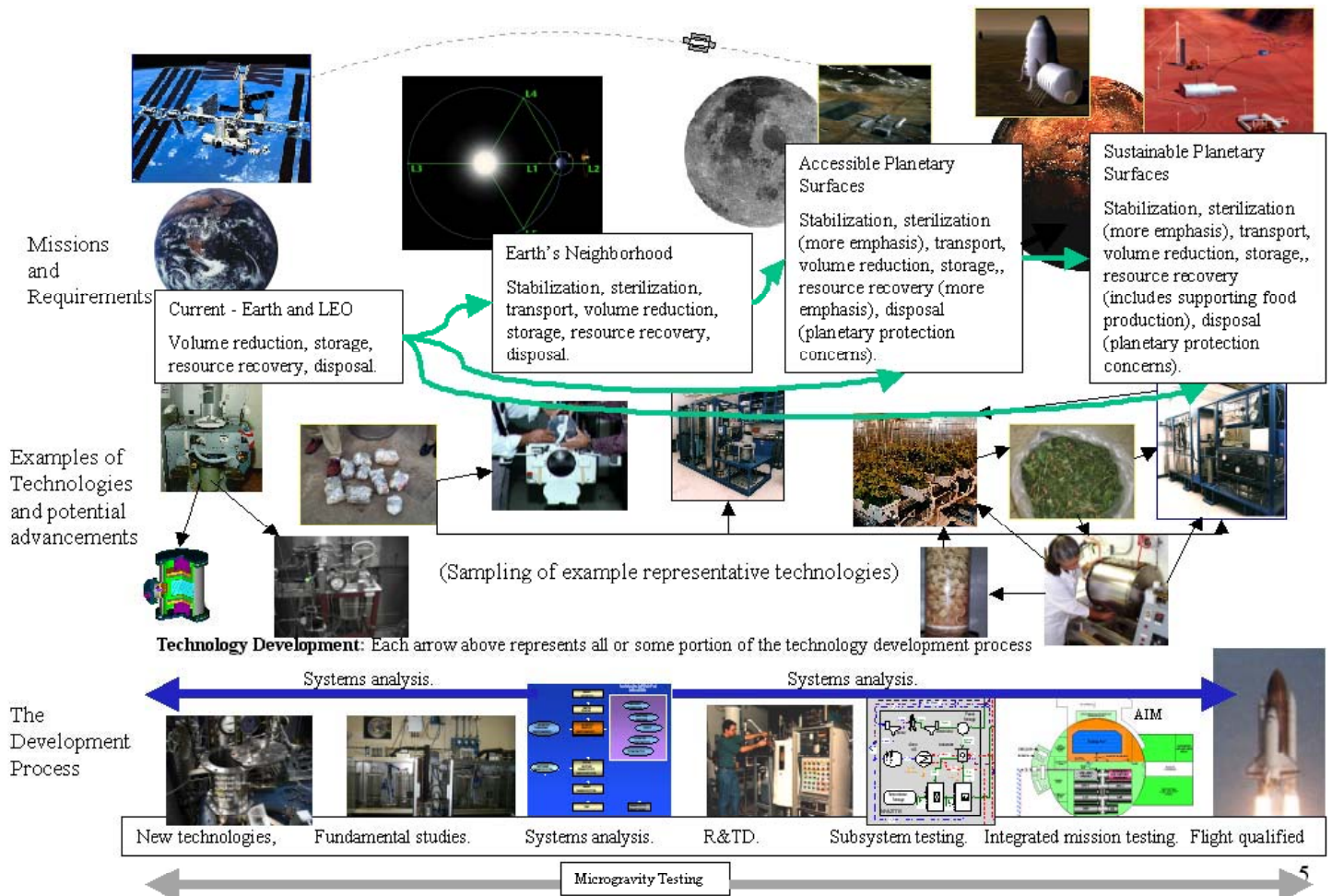


Figure 2. Development of Waste Management Technology – Missions, Progress, and Process.

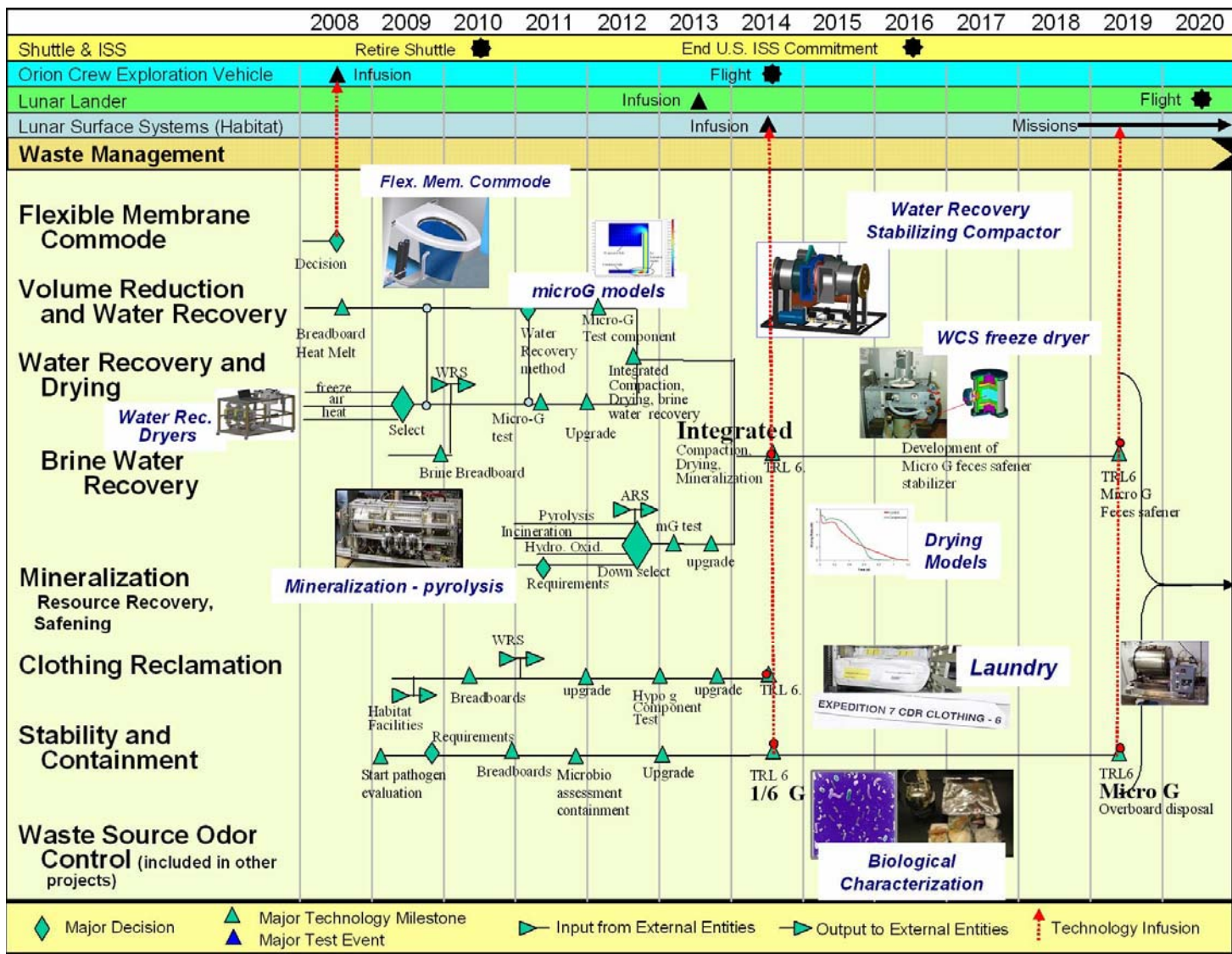


Figure 3. Roadmap for Development of Waste Management Technologies to Meet Infusion Dates.

Overall, the plan is for technologies to be ready for infusion when needed by the missions. Mission dates, funding availability, priorities, and other programmatic factors will affect the development, but the need for the technologies will remain according to the nature of the missions; and near Earth missions of short duration will need technologies very different than distant missions of long duration.

HISTORY- READINESS LEVEL

Waste management for missions from Mercury to International Space Station (ISS) has focused mostly on collection, storage, and disposal. Trash and human metabolic waste has been collected in bags and containers, stored temporarily, and usually returned to Earth. On Apollo, some waste was disposed on the moon. On ISS, some waste is incinerated during atmospheric re-entry in used Russian Progress Vehicles. The most sophisticated waste management technology flown to date is the collection system for

feces in the Waste Collection System (WCS) for Shuttle and ISS. The history of the various WCS systems is covered in a paper by Broyan (6).

Most of NASA's internal physical chemical waste management technology development has been conducted at Ames Research Center (ARC), and most of NASA's internal biological waste management technology development has been conducted at Kennedy Space Center (KSC). External physical chemical and biological development has been conducted for NASA by universities and commercial groups via SBIRs, NRAs, and NASA Specialized Centers for Research and Training (NSCORT). In the 1980s ARC conducted research on wet oxidation (7). In the 1990s advanced life support focused on technology for the far term missions and especially for regenerative (food growing) life support systems. Consequently waste management technology development included technologies for closing the loop and recycling waste materials to provide carbon dioxide and nutrients for

plant food growth systems. Both physical chemical and biological oxidation systems were developed. Since roughly 2000, the development has emphasized near term physical chemical means of managing waste. Following is a description of many of the waste management activities that have been conducted since the mid 1980s including waste collection, compaction, freeze drying, biological characterization, microwave drying, air drying, incineration, hydrothermal oxidation, microgravity gasification, biological processing, source gaseous contaminant control, and resource recovery.

Flexible Membrane Commode (FMC) for Microgravity Application

The most modern WCSs are the Russian WCS and the NASA extended duration orbiter (EDO) WCS. The Russian WCS is currently installed on ISS. The EDO WCS was successfully tested on Shuttle. These WCSs are too massive for direct application to the Crew Exploration Vehicle (CEV) and the lightweight flight tested alternative, the Apollo bag system, does not meet CEV requirements. Consequently, a project to develop a lightweight microgravity WCS was conducted from 2006 to early 2008 at ARC and Glenn Research Center (GRC) (8, 9).

The FMC is a bag system similar to the Apollo system but has the air flow for odor control and waste transport and confinement similar to the EDO WCS. The FMC is intended, therefore, to have the advanced features of the EDO with the reduced mass of a bag system. Figure 4 shows a conceptual picture of the FMC. The system is intended to fold away into the wall when not in use in order to save space.

The bag is a three layer system. The outside layer provides containment, the inside layer permits air passage while holding back liquids and solids inside the bag. The middle layer of the sandwich is a reticulated foam layer that permits airflow to travel between the other two layers to the outlet port. Figure 5 shows the air flow profile as established by modeling. The spacer foam includes activated carbon for odor control. The air flow inside the bag keeps waste inside the bag in the same manner as it does on the EDO WCS.



Figure 4. Conceptual Drawing of the FMC System.

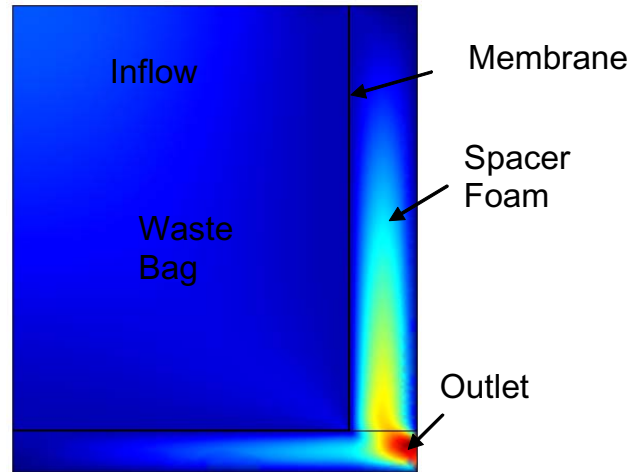


Figure 5. Computed Waste Velocity Field. The flow increases according to color in the order: dark blue, light blue, yellow, red. (9)

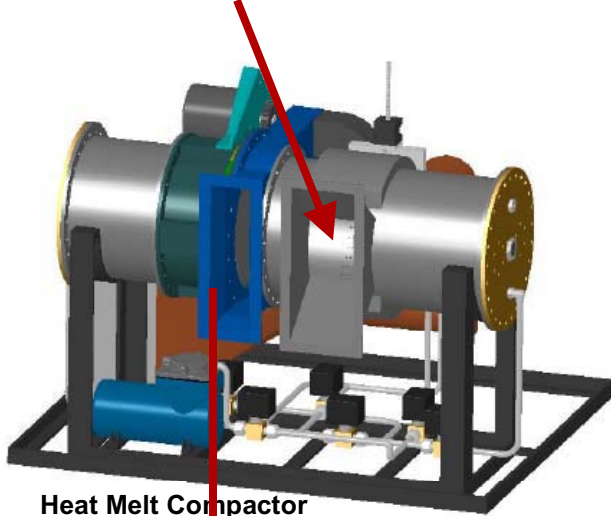
Compaction and Heat Melt Drying

Compaction development has been conducted at ARC since 2003 (10, 11). Habitable volume in space is too valuable to be used for long term storage of uncompacted waste. Two kinds of compaction have been explored for application to space missions. Unheated compaction recovers the volume only. Plastic heat melt compaction takes advantage of the plastics that are typically present in waste, usually above 30%. A minimum of about 20% plastic is necessary for the plastic heat melt process to fully enclose the resulting plug of waste with melted plastic. The compaction ratio of typical wastes in the heat melt compactor is up to 90% over hand compaction. The waste is heated to a temperature in the range of 140 to 180 degrees C. The temperature and time needed depends on the types of plastic present and whether sterilization is desired. Sterilization and water recovery can both be achieved in addition to the compaction. Upon cooling, the plastic encapsulation prevents spring back of the compacted material and prevents the waste from becoming rewetted or inoculated with microbes. Thus, the plastic encapsulated material is quite stable. Figure 6 shows a conceptual picture of the heat melt compactor, example waste material, and the resulting plastic waste disk.

An unheated waste compaction device has also been developed (10). This compactor was primarily developed for CEV application. It saves volume and mass compared to hand compacting waste into a wall storage locker. It uses a telescoping pneumatic ram with adjustable pressure from 15 to 50 psi gauge pressure to compact the waste 75% over hand compaction. The unit in Figure 7 is about 2 feet tall and is designed to handle all the waste from 6 days of a CEV mission. This unit is designed to permit removal of the waste via an internal bag for overboard disposal mid-mission. A bag, as shown in Figure 8, was developed for this compactor to handle wet wastes without leaking (12). The three layer bag uses a layer of polyethylene to the wall to adsorb up to 2 liters of water per bag.



Waste In
(Paper, plastic,
food, tape,
clothing, etc.)



Heat Melt Compactor



Waste Out
Processed
Waste Disk

Figure 6. Heat Melt Waste Compaction.(11)

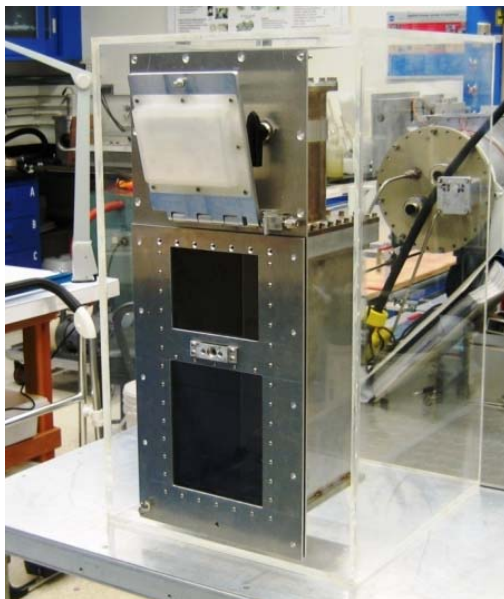


Figure 7. Unheated Waste Compaction.



Figure 8. Wet Waste Containing Microgravity Compaction Bag.

Freeze Drying

Drying waste recovers the water in the waste and stops biological activity, thereby stabilizing the waste. An NRA funded through ARC investigated the use of freeze drying for recovering water and stabilizing the feces produced by the EDO commode (14, 15). Figure 9 shows the canister component of the EDO WCS that could be replaced with a freeze drying canister and a diagram of the heat recycling system using thermoelectrics that make this an energy efficient system.

Microwave Drying

Another approach for drying wastes is to use microwaves to supply the heat energy for vaporizing water in the wastes. Although significant energy is required to make the microwaves, the microwaves have the advantage of delivering energy directly to the water molecules, which can save on heat loss to the environment and to parts of the waste that are already dry. Through two phase II SBIRs starting in 2004, Umpqua Research Inc. has developed two microwave drying approaches (16, 17). One approach is to evaporate at ambient pressure. The other approach uses vacuum and freezing of the water in conjunction with the microwaves. Figure 10 shows a diagram of the microwave freeze drying process, and Figure 11 shows a diagram of the microwave ambient pressure microwave drying process. NASA ARC is currently evaluating the results and the hardware produced by these SBIRs.