Satellite After Fully Enclosed Recycler (SAFER)

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Technical approach

The unique aspect of this SAFER approach to satellite recycling is the full enclosure of the satellite before any recycling operations occur. This is not only the safest way to minimize the risk of any additional orbital debris, the enclosure itself allows for the use of gas pressure jets to move the satellite while producing a force that will guide debris from the satellite deconstruction operations into a sorter that then feeds a process that will reclaim aluminium and titanium (and optionally steel) while reducing the rest to vapor, gas and fine debris that can be safely released back into space. This is effectively a wind tunnel in space combined with a focused solar beam melting/cutting tool. Tons of N2 is used in a nearly lossless system, compressed, decompressed and blown by fans as needed. Many process controls feed bins and furnace/refiners to create refined products ready for LEO use.

Fortunately SAFER can borrow many concepts and technical components prototyped with NASA NIAC funding for asteroid mining by Trans Astronautica Corporation (TA) (Ref link). SAFER applies some of these concepts to effectively mining a man-made asteroid, namely an abandoned satellite. SAFER adds some components to sort and and process some of the materials into ready to use aluminum, titanium and optionally steel as well as used compressed gases to move the satellite as needed in front of the concentrated solar beam to achieve optimum deconstruction results. We will adopt the TA trademarked term Optical Mining ™ (which is patent pending) to discuss how concentrated solar can deconstruct solid objects, and refer to it as OM.

While OM on asteroid will have somewhat different results on a abandoned satellite, modifications to beam focus (perhaps more focused) can produce energy concentration on satellite surface that can melt or micro-explode most materials. In a near vacuum (we will get to why this is not pure vacuum later) these materials will become very hot as only local conduction will move energy away from the focus point. Material like plastics won't conduct much heat and simply vaporize or be reduced to very fine particles. Al will melt, and in micro-gravity will create free floating sphere-like collections of material that will slowly cool. This is a high risk assumption that needs testing (perhaps on the ISS) before a SAFER would be built. TA's work does not depend on this behavior, so they are not indicator that this is either likely or unlikely. This work (Ref Link) provides some insight into melting metal in micro-gravity. Also, ESA has worked with melting satellites (Ref link).

Engineers will monitor and guide the satellite in front of the OM with a real time broadband connection (perhaps via the same system that the SpaceX Polaris 1 mission will testing) to a ground operations interface in order to produce the best outputs until it is time to flush the particles and spheres into to sorter. Moving the satellite will be done mainly by applying compressed gas (pure N2 at mission start) to the surface from the right combination of gas jets on the inside of the enclosure and pointed inward, although there is a teleoperated arm/grabber as well. Note that many passes may be needed to fully process the space craft, perhaps one per 2-3 kg of non-vaporized material. Between flushing the OM cycles, the gas, which may eventually contain other gases from the satellite as well, will be compressed, creating a near vacuum again the the system. Losses of gas due to leaks may be restored by excess O2, CO2 produced in the OM process. Gas can be vented into space if it exceeds storage/pressure limits. As with TA's asteroid mining plans the enclosure must contain all of the gases without leakage, and we will postulate this is technology that SAFER can acquire from TA.

The N2 gas injection with the assistance of variable speed and direction fan can push-pull the particle rich N2 gas into the centrifuge collector/sorter (with ultrasonic speakers creating vibrations to enhance sorting efficiency) where higher density particles (Al, Ti …) will be forced to the outer rim. A timed door will inject these some particles with the help of gas pressure into refining units. These refining units will be not be described in depth, as it is a opportunity for other refining concepts to be plugged in as they prove themselves. After cooling pressurized gas will push the bars of metal into a storage unit that will eventually be picked up another vehicle for final transport to an orbit where it will be used.

Other lighter particles will leave the sorter and be injected into another solar furnace/disposal unit where they will be heated until only gas an particles that are small enough to pose no orbital debris threat remain. This will be vented to space.

SAFER will be allowed a great deal of time to deconstruct a satellite, perhaps years. This should not be seen as a negative, but a design parameter that allows for time to learn the best way to recycle these very complex objects. More time for mission completion also results in lower peak energy needed at any time, lowering mass, size and costs.

Furnaces / Refiners (See red boxes in figures 1 and 3)

SAFER can accommodate various furnace and/or refiner designs of about the size of 1 cubic meter. This proposal suggests a focused solar beam refiner into a high temperature furnace containing Al or Ti particles that have been gathered. A high temp glass window allows the solar to cook the contents. Since the particles are suspended in gas, ultrasonic speakers may allow particles to be moved into a "bar" shape in the middle of the chamber (Ref link). After solar operations the bar cools (Ref Link), and doors are opened to push via gas flow the bar into a storage area in the mission module. The mission module, at the end of satellite deconstruction operations, will take the purified material to another orbit for use.

A related refiner design is the Bioleach Refiner that has been submitted to the Orbital Alchemy Challenge under a different proposal. This will require certain levels of particle size that hopefully SAFER can create. BioLeach is a bioreactor module based on bioleaching that can be used to recycle a variety of metals from space debris. Bioleaching has been a proven technology for metal extraction from a range of materials including electronic scrap. It was reported with an experiment on the International Space Station showing that it could be employed to mine useful elements from basaltic rocks in space (Ref Link). BioLeach comprises six subsystems involving function and control. Each subsystem has a certain degree of flexibility to accommodate different deployment scales and types of recovered metals, such as gold, platinum and iridium. The capability of extracting target metals perhaps in low concentrations from complex compositions makes it complementary to other furnaces on SAFER. With a clearly defined mission, selected microbial strains and an optimized process, BioLeach can be fully automated and scaled to required physical constraints, e.g. a 1m cube if needed, for being deployed on an automated or remotely operated satellite, such as SAFER. BioLeach can work with any system that breaks a satellite down to 0.5 mm “sand”. While SAFER could incorporate, it could work with others as well.

System design

The SAFER system is comprised of two parts on orbit (see figure 1). The larger, which we call SAFER, is a satellite than can move from abandoned satellite, to abandoned satellite, extracting mainly refined Al (and potential Ti and other metals) while it breaks down satellites and processes the debris to eliminate them as orbital debris threats. The smaller part is a “Mission Module” that is lofted for each mission, carrying refreshes of water and gas, and then taking on the recycled metals. The mission module then separates and take the products to the proper orbit for use, before eventually de-orbiting. Engineers using a broadband ground station view and control various aspect of the system on a 24x7 basis.

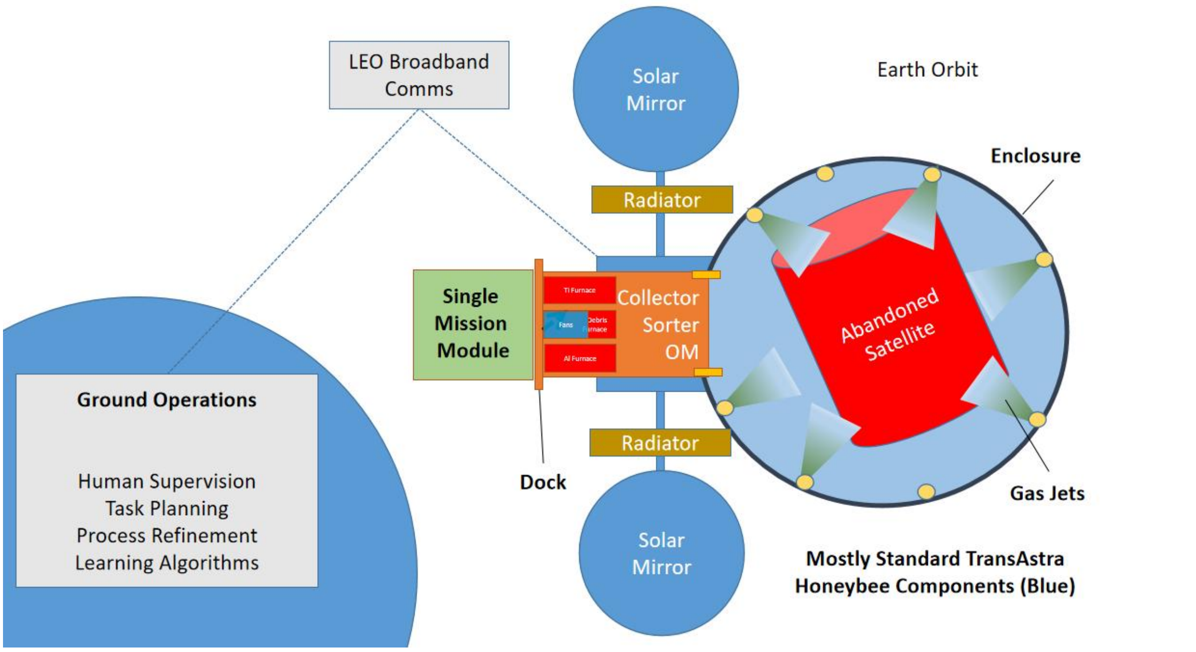


Figure 1. System high level cross section that shows what components may have TransAstra sourcing potential. Note, no TA CAD was used in any visuals in the proposal. Only public info.

Dimensions and mass estimates (see figure 2)

Although the SAFER system can be sized to accommodate different sizes of targets, this proposal will select Landsat 7 as a representative object, resulting in a enclosure diameter of 8m, and a mission module diameter of 3 m, well within the range of SpaceX’s F9 or FH. SAFER should be in the 15 T range empty with the mission module around 5 T, with water, fuel and compressed N2. Total packaged volume (vs deployed volume) will be around 400 cubic meters, which should fit with an FH extended Fairing. Mission Modules should fit in a ride share launch on F9, Vulcan …

A note on Abandoned Satellite Solar Array processing: The enclosure volume may or may not be able to contain both the satellite body and it's deployed solar array as found in orbit. In many cases the solar array will need to be disconnected from the satellite. The OM should be able to heat the connection to an extent that gas pressure blast should create a force for disconnection. These disconnected arrays can float nearby while the satellite body is enclosed first, then the solar array(s) may also be enclosed. A complex use of of thrusters and gas jets may be needed to orchestrate this maneuver.

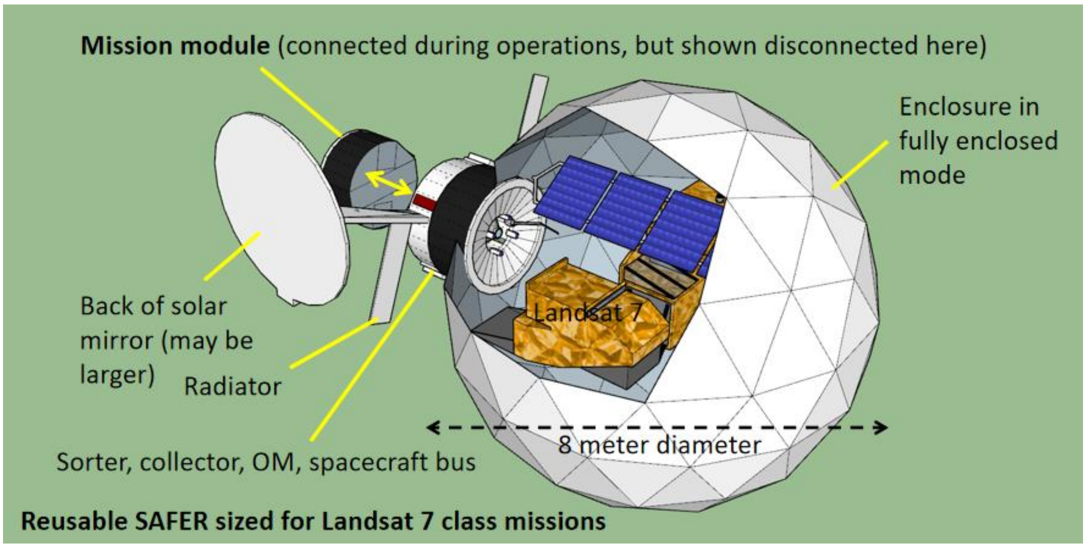


Figure 2. Overview: Mission Module, SAFER, LandSat 7 with clipped Solar Array enclosed Please note that some parts of the enclossure have been removed here to show the encloser interior.

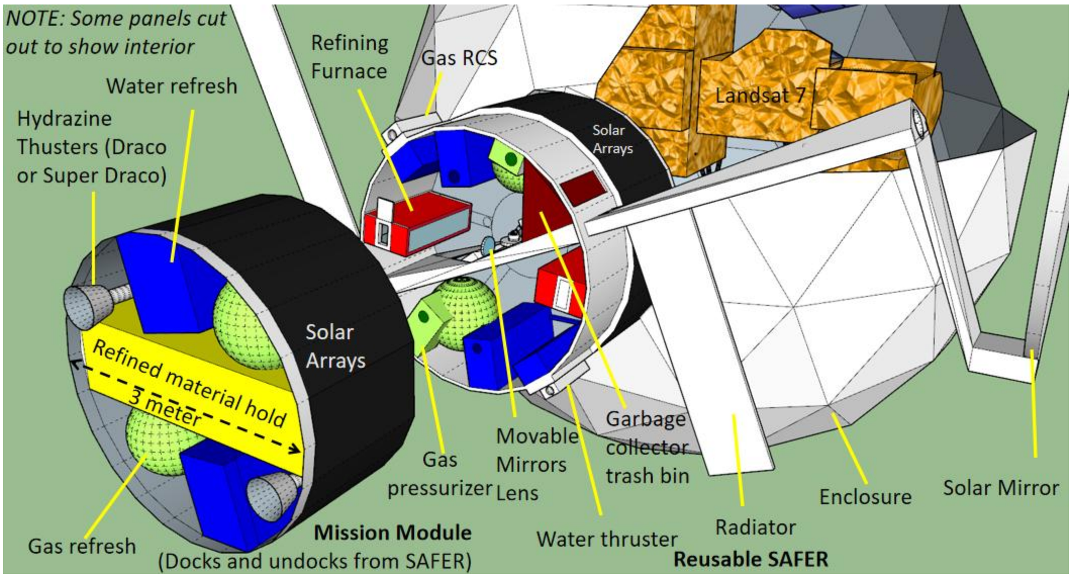


Figure 3. Mission Module, SAFER detail of major space consuming components. Batteries, solar mirror boosted solar array, computers, controllers, momentum wheels, comms and many gas tubes not shown. Note that some panels are not shown to show interior details

Processing will be a front to back flow of particles and debris cooked or micro-exploded off of the satellite body. Figure 4 depicts the OM heating a small area of the satellite that melts into particles while the gas injectors create a gas flow that guides them back into the collector/centrifuge.

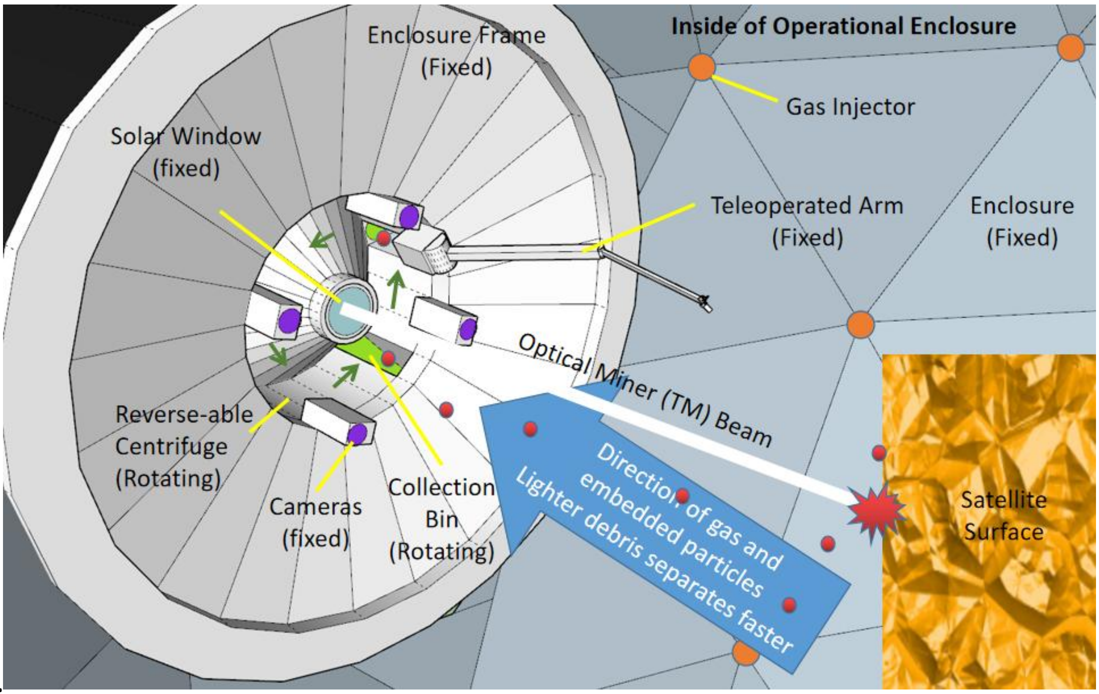
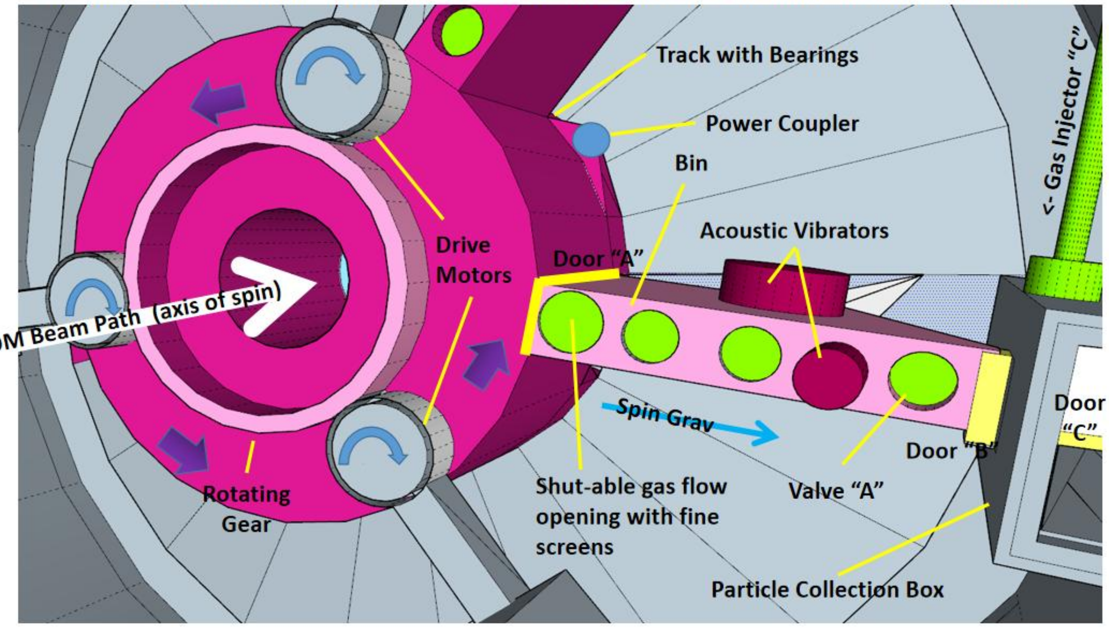


Figure 4. Detail of Rotating OM window & Centrifuge, and fixed Cameras, Arm and Gas Injectors

Assembly shown in stopped and locked position so bin can feed collection box via moving door



Gray parts are fixed to spacecraft and do not rotate **Magenta - pink parts rotate quickly**

Figure 5. Detail of back of centrifuge

Table 1 and 2 summarize what parts of the SAFER design cover functionality and materials set out as goals for the Orbital Alchemy challenge.

Functionality	**SAFER**
Safety operations	Fully enclosed remotely teleoperated ops, assured de-orbit

Disassembly	OM targeting most heat-able sat parts
Materials separation	OM cooking chunks in vacuum. Different melt points separate materials. Gas flow will move lighter material to collector faster. Vibrating centrifuge can move denser particles and debris to outside, were gas flow will pull items at bottom into collector box
Cleaning	Refining in solar furnace,
Feedstock forming	Refining in solar furnaces or Refiners, such as the Bioleach refiner
Storage(& Delivery)	In Mission Module

Table 1. Orbital Alchemy Functional Coverage

Material	**SAFER Outcome**	**Melt C**
Aluminum	Cleaned, refined, shaped for transport	660
Titanium	Cleaned, refined, shaped for transport	1,668
Kevlar	Vaporized and used as part of process	500
Plastics	Vaporized and used as part of process	270
Silicon	Vaporized and used as part of process	1,410
Ceramics	Fragmented and sent to trash bin	2,000
Residual fuels	Vaporized and used as part of process	N/A
Other volatile liquids and gasses	Vaporized and used as part of process	N/A
Steel	Cleaned, refined, shaped for transport	1,560
Gold	With optional Bioleach Refiner (diff OA proposal)	1,060

Table 2. SAFER processing of different materials

Technical Maturity

A key part of the concept is that it borrows heavily from TransAstra's work in asteroid mining, which some elements have received NASA funding. In many ways the recycling of an large abandoned orbital object is mush like asteroid mining.

Sub-system	**Source**	**TRL**	NASA $?
Satellite bus	TA (HoneyBee)	2	
Propulsion (Solar Water based)	TA (HoneyBee)	2	
Optical Miner ™ (Cutting Beam)	TA (HoneyBee)	3 (Ref link)	NIAC III
Large Object Enclosure	TA (MicroBee)	4 (Ref link)	NIAC
Particle Flow System	Make	2	
Gas management system	Make	2	
Gapless Broadband Comms	Starlink	5 (Polaris mission)	
Solar Furnace(s)	Make	3 (Ref link)	NIAC
Particle Movement with Sound	Make	3 (Ref link)	

Table 3. SAFER challenging component sourcing and TRL estimates

It is likely, given NASA funding of aspects of TA technology with significant progress shown to date and the growing interest in orbital debris removal that a SAFER operational trial could occur before 2030.

Operations

SAFER should be considered a toolbox of satellite deconstruction and recycling tools that can be safely exercised in orbit. There are many different forces and process manager components (OM focus, doors, gas valves, centrifuge speeds …) that can be combined, sequenced and potentially ignored depending on the part of the satellite being processes at a given time. For instance, at some points the OM maybe yielding very pure aluminium that will not need centrifuge processing. At other times operators may encounter a mix that may need spin gravity + acoustic vibration processing. Expect many sensors of many types to be monitoring the inputs and outputs of the process. The flow of gas in this mini-wind tunnel is the way particles liberated by the OM make their way to stowed purified Al and Ti or vaporized plastics that can be vented to space. Doors maintain sorting purity during transitions, say from spinning centrifuge to stopped and filling one of many Particle Collection Boxes (figure 6). These Boxes can then feed solar furnaces, a BioLeach refiner (Solar not used for this) or act as a trash collector. A 1 minute video attempts to visualize the flow (Link here) for one of these paths.

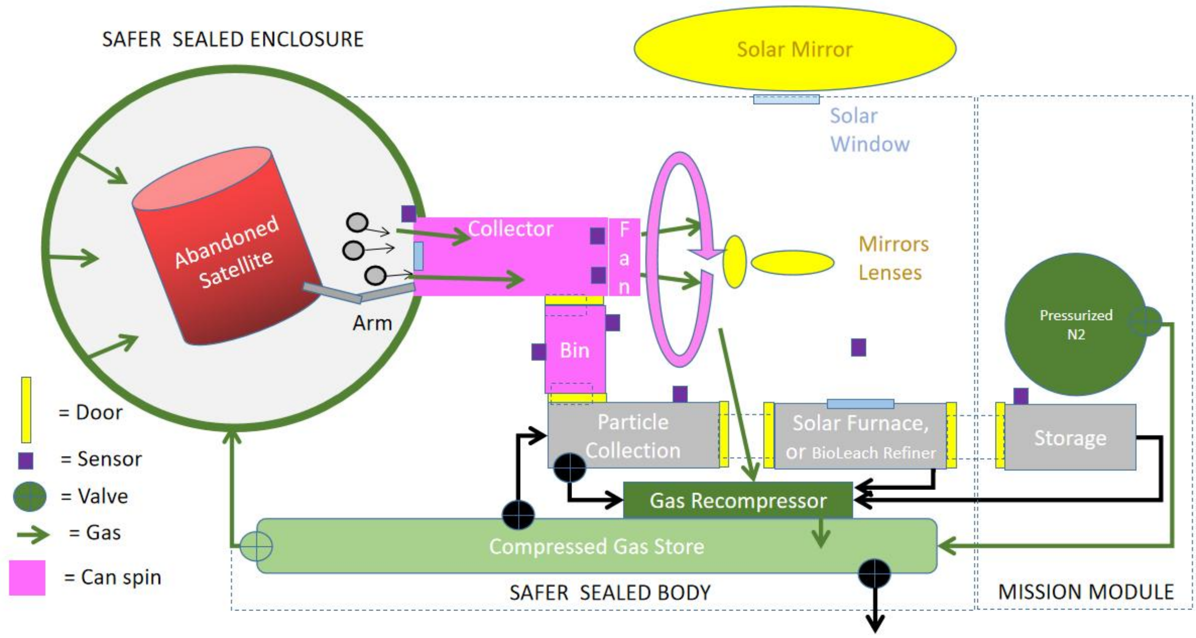


Figure 6. Gas flows and doors push material from left to right.

All the process combinations are too complicated to describe in 8 page limitation of this document, so one might look at SAFER as a toolbox to be built, tested and then optimized in orbit with a 1T+ satellite. Many aspects of this toolbox might be built and 2D simulated at a 100x smaller version. Other parts may be tested at a small scale on the ground or orbit. The OM for satellite components might be validated much like TA validated it's OM for asteroid material at a NASA solar test facility.

SAFER will also need to maintain orbit, and keep proper orientation to the sun. Water fueled "steam thrusters" (a key TA concept) will be refueled with the Mission Module. Small orbit changes to move from satellite to satellites can also be accomplished as needed. The Mission Module has a limited amount of hydrazine and 2 hydrazine thrusters to dock with SAFER, stay with SAFER during ops, collecting refined outputs, then finally undocking and thrusting to deliver refined outputs to the correct orbit. A new Mission Module will arrive for the next satellite to process.

Power requirements

As with the TA asteroid mining concepts, there is extensive use of direct reflected solar for heating. Mirrors and lenses work in conjunction with large gimbled solar reflectors to direct concentrated sunlight where needed, be it the OM, water based propulsion or furnace. The use of reflected solar as the power source for satellite disassembly, heating of furnaces and some propulsion greatly reduces the solar array required power needs. As particles will be moved primary by gas flow from many jets (since we can't use gravity and grabbing particles is impractical), electrical power need is gas flow management. One might imagine an industrial fan power as a good proxy, putting the peak power need in the 5000W range. This will only be needed a small fraction of the time, so Li batteries may back up 1000Wh of solar electrical collection. This is also needed for the time (approx 45 minutes very 90 minutes) SAFER in the Earth shadow in LEO. Radiators are used to maintain thermal balance.

Cost effectiveness

SAFER should completely disassemble a target satellite, reducing some components to gas that is vented to space, and recycling metals such as Al alloys for use by other projects in Earth orbit. It does this within a completely contained environment that should minimize the risk of additional orbital debris. The large part of the system is reusable, which should help reduce the cost aspects relative to ROI calculations. A small mission specific vehicle that is launched on a single F9 will both remove useful products and refresh consumable needed to process each object, enabling the large SAFER vehicle to move from object to object (within a small variation of orbital inclination, with SSO being a good place to prove SAFER). While the value of the recycled materials could be significant (500 lbs x 1000 $/lbs to orbit + 500 lbs @ $5/lbs = around $1/2 million) the value in removing space debris might be higher. ESA is funding Clearspace-1 (Ref link) at nearly $100M to do this. SAFER will probably cost $400M to R&D and launch, but with a mission reuse expection of 10 mission this would could be as low as $40M per mission. The Mission Module R&D and first launch might be in $200M range. Afterwards, it might cost around $40M per mission to build and launch as part of F9 or Vulcan mission ride share.

Safety, "first do no harm" apex goal of this design proposal.

This is a remotely operated satellite so no astronauts are at risk. Fully enclosed recycling operations minimizes the change of creation of new space debris of a size that can harm an astronaut or satellite. SAFER operates with enough fuel reserve to deorbit it within 2 years and an enclosed satellite as well. Although it is hoped that the system can break everything in a satellite down so that the enclosure is empty of everything but gas and dust, the system can thrust down to 250 km to open the enclosure and dump remains such as ceramic fragments into a orbit that should quickly deorbit.

Final note, please forgive the tortured acronym for SAFER, but as orbital debris solution proposers we wanted the emphasize the need to minimize this risk of new orbital debris.