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EDDE

ElectroDynamic Debris Eliminator:

Selective Removal and Recycling in LEO

Space Manufacturing #14

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Debris: Threat & Resource

- 80% of tracked LEO objects weigh <2 kg, but 90% of the debris mass is in the 1200 objects each weighing >700 kg.
- Most new small debris should come from collisions involving large objects, since they have nearly all the mass and area.
- Over 1000 tons metal (mostly aluminum alloys) are in upper stages alone, mostly clustered in high inclination orbits.
- 4 EDDE's working the 74º & 82º clusters can collect 2 ISS masses (>700 tons) within 6 years.
- This is enough to build structures ***far*** larger than can be launched by any plausible heavy-lift vehicles.
- Large structures can use reboost by electrodynamic tethers

Tackle Upper Stages First?

- If all spent stages are removed, the rate of generation of new debris by random collision will drop by a factor of ***4!***

Most upper stages:

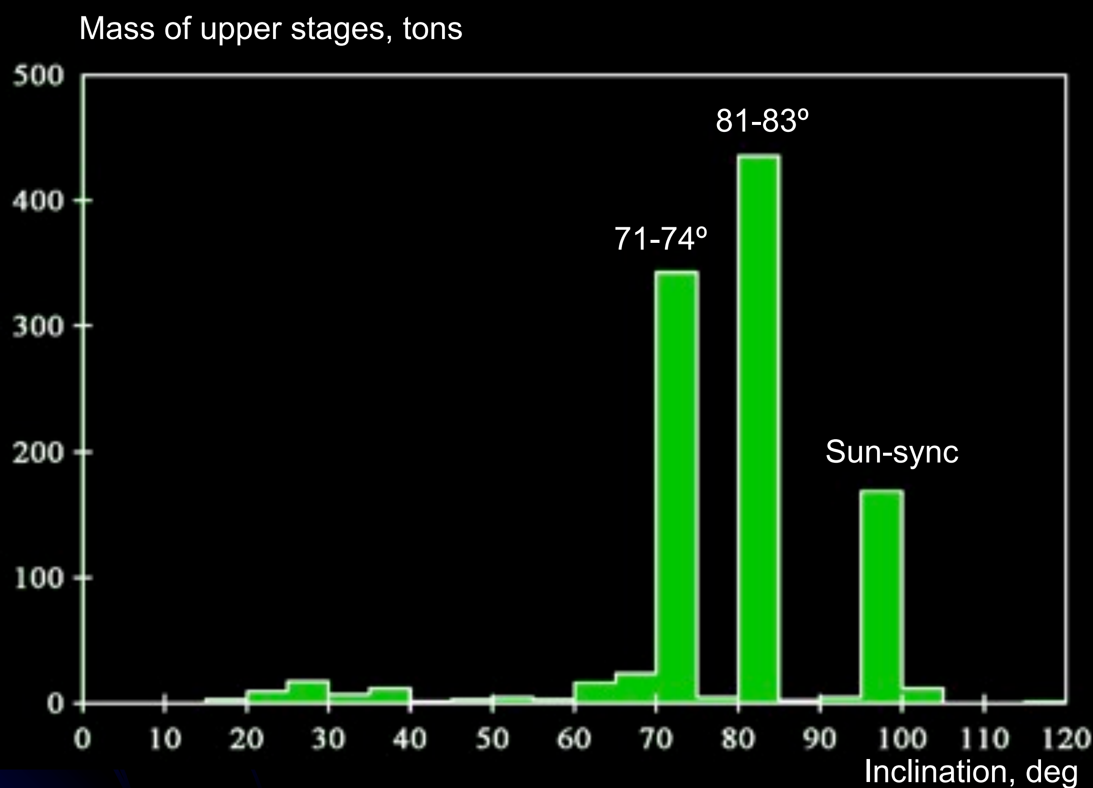
- Have simple shapes and few appendages
- Tumble slowly if at all, due to eddy current damping
- Provide less militarily sensitive information than payloads
- Are highly clustered and easy to collect
- **Have high content of aluminum for recycling**:
    - *Most of the mass is in accessible skin "acreage"*
    - *"Ventilating" a stage helps it burn up during reentry*

Mining Aluminum in LEO

Dual purpose of removal:

1000 tons **of mostly aluminum in old stages is enough to**

- **Radically reduce the rate of debris generation if removed**
- **Build structures far larger than feasible with heavy-lifters**



Some Processes & Products

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Collection only

- Allows use as ballast for ambitious slings

Cutting up tanks and other structures

- Creates "shingles" for shielding or other processing
- Ventilates remaining structure to ease reentry burnup

Metal bending & fastening

- Allows debris & radiation shields for any desired shape

Melt-processing

- Enclose and melt shingles; filter to remove refractories
- Do vapor deposit or molten spray inside thin balloons
- Allows better metal properties than with ingot processing
- Allows larger and heavier structures than heavy-lift does
- Surplus aluminum alloys may be used as rocket fuel

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Debris Processing Market

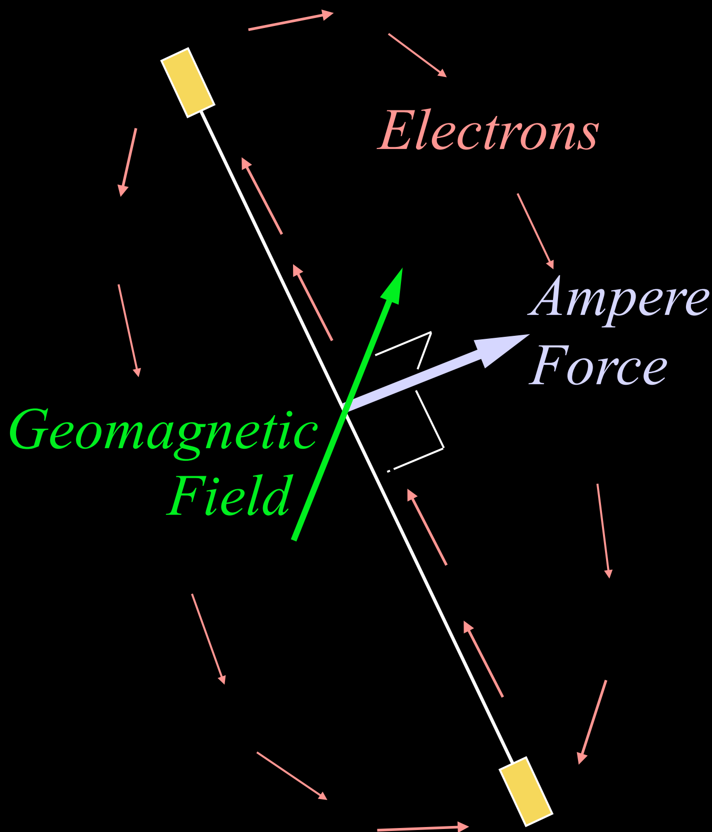
- It would cost ~$10B to launch 1000 tons into LEO.
- 1000 tons of “scrap metal” at 10% of that could be worth ~$1B.
- EDDEs can move 1000 tons for a small fraction of that cost.
- This leaves plenty of room for debris owners and buyers to find mutually-beneficial terms.
- Each EDDE can deliver 35 tons of “scrap metal” per year to processors at that inclination.
- The processors can build large habitats for lease, opening yet another new market.
- Tenants could include tourists, manufacturers, scientists, and satellite assembly/service units.

Very Large Structures?

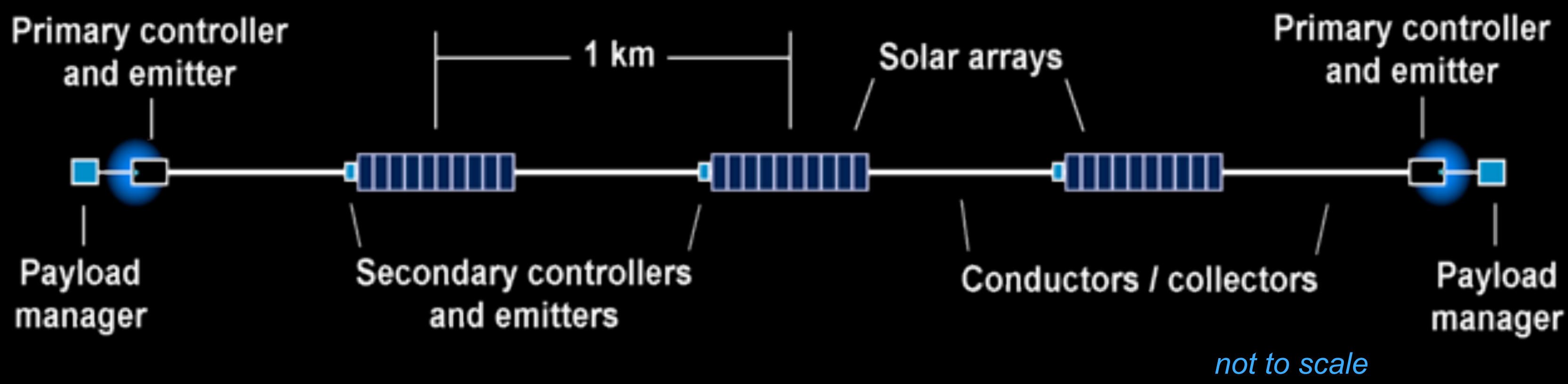
- 3 psi structure up to volume of National Air & Space Museum
- Fabricated from upper stages collected from 60º-83º deg
- Hosts spacious crew quarters, storage, and processing rooms
- Can be maintained in orbit by a 50 kW electrodynamic tether
- Low gravity can keep things in place & settle loose particles
- Almost certainly not the best use—but one to get you thinking!

Electrodynamic Propulsion

- Propellantless, solar powered
- Demonstrated in orbit by NASA JSC on the Plasma Motor Generator (PMG) flight



The EDDE Vehicle



- ElectroDynamic Debris Eliminator (EDDE)
- Each EDDE is ~100 kg, 2 EDDEs fit into ESPA slot
- Propellantless, virtually unlimited delta V
- Can climb ~200 km/day, descend up to ~1000 km/day, and change inclination or node by ~2^{o}/day in LEO
- Can move multi-ton payloads in LEO at a small fraction of the launch costs per kg

A Spinning Capture Net

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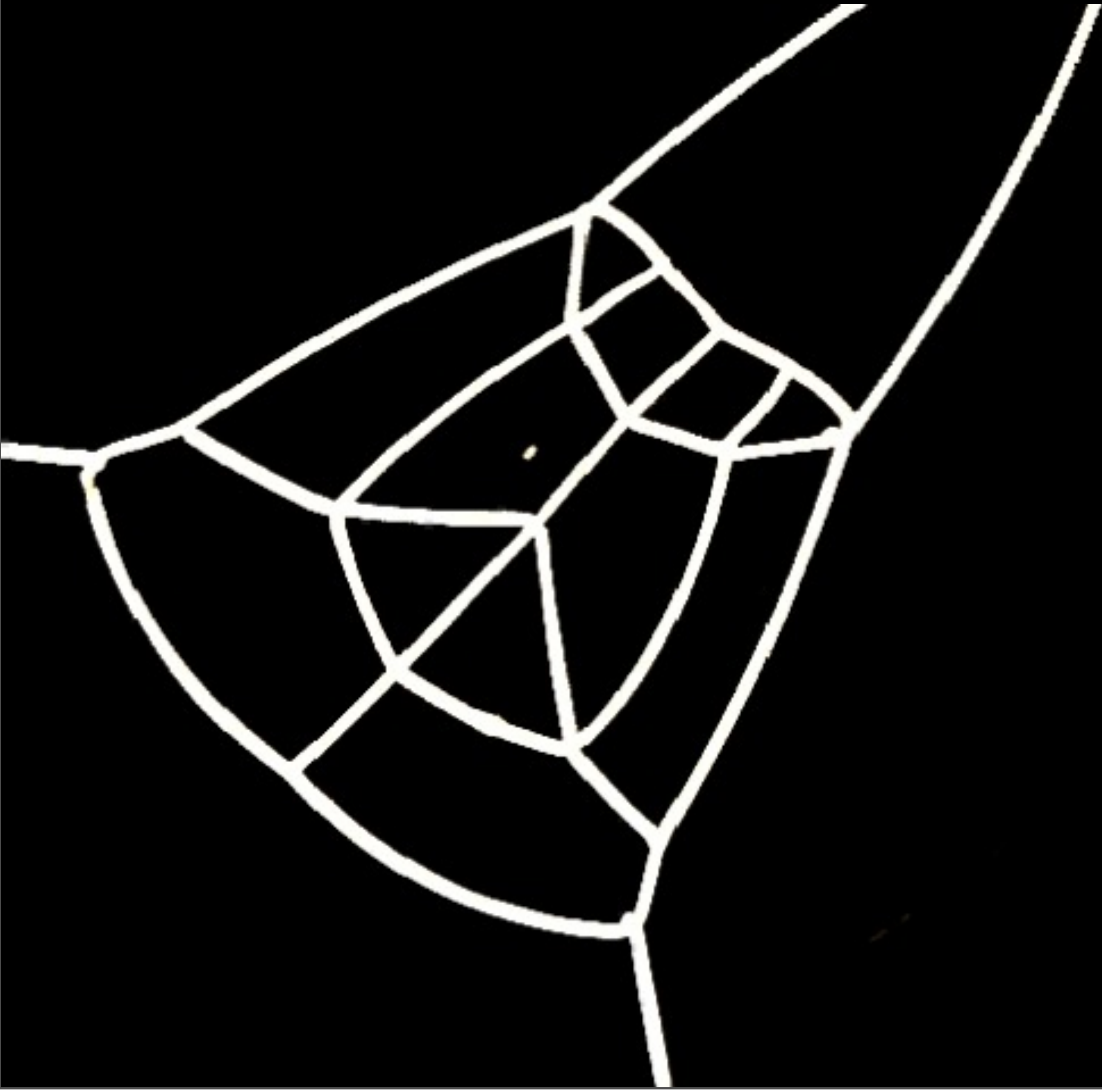
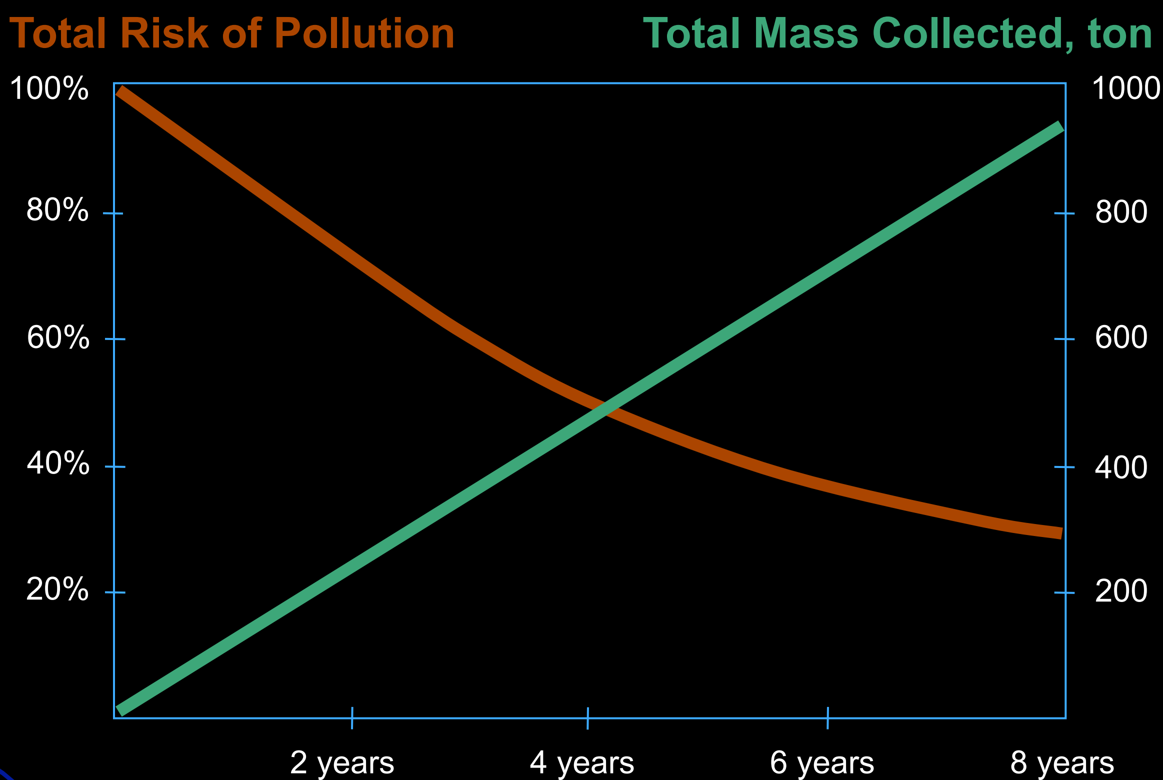
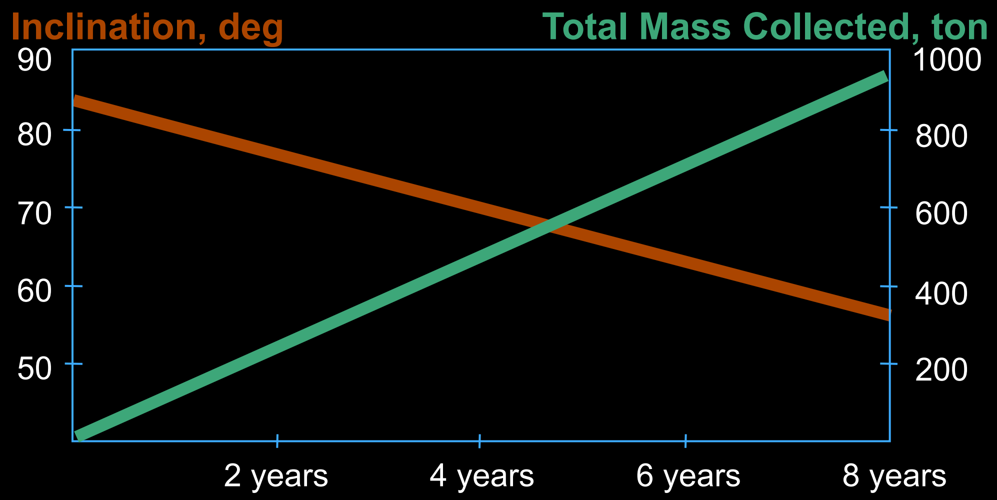


Collecting Upper Stages



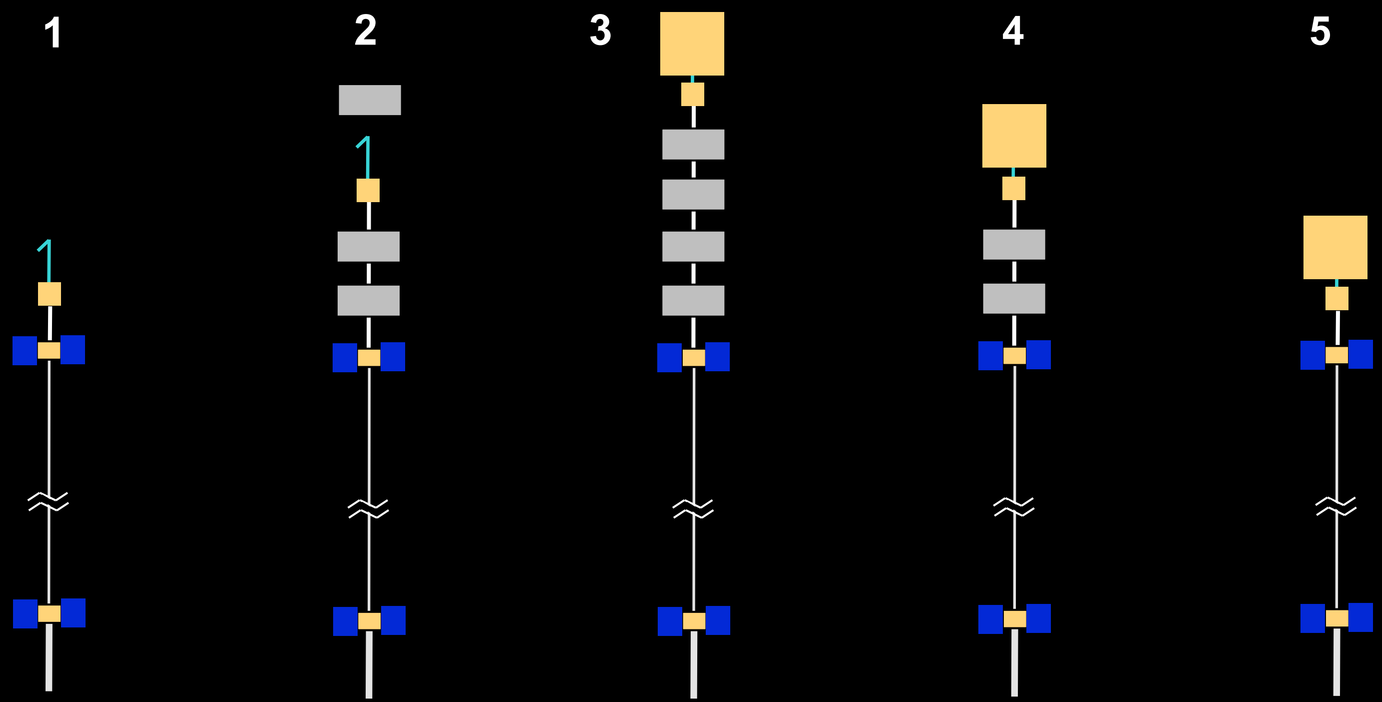
- 2 EDDE's in the 82º cluster + 2 EDDE's in the 74º cluster
- ***Each*** pair can collect an equivalent of ISS mass in 6 years

A "Sweeper" Scenario



- Deploy 4 EDDEs and a metal processor with electrodynamic propulsion at 83º and ~600 km
- Collect upper stages from the 82º-83º cluster, build a processing hangar, and add to hangar as more mass is collected & processed
- "Sweep" the range from 83º to 60º, collecting upper stages and growing the structure from the recovered aluminum
- Reach ISS and integrate retired ISS components into structure

A “Collect First” Scenario



1. Deploy “storage tethers” in 74º & 82º orbits at ~600 km
2. EDDEs capture and deliver stages at nodal co-incidence
3. Develop, launch and capture a large recycling device
4. Retrieve tether and process stored stages one at a time
5. Products ready for EDDE delivery to “marketplace orbits”

Operational Issues

- Permission / agreement to capture debris object
- Transfer of national registration, if required
- Liability & insurance for EDDE operator, debris owners
- Agreement on disposal or recycling method
- Safety requirements on debris capture and removal
- Flight plans and ground support for collision avoidance
- A foundation for most other space manufacturing:
  - Design future upper stages for easy in-orbit recycling?
  - Open new design/fab options for large power-sats, etc.
  - Thoroughly test many novel processes

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Technology Maturation

- SEDS-1, NASA Marshall
- PMG (Plasma Motor Generator), NASA JSC
- SEDS-2, NASA Marshall
- TiPS, Naval Research Laboratory
- ProSEDS, NASA Marshall
- METS, Tether Applications
- TetherSat, Naval Academy
- TEPCE, Naval Research Laboratory
- Mini-EDDE (proposed)

All tethers and deployers by Tether Applications

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EDDE's Advantage

- The task: ***remove all*** 2465 objects over 2 kg from LEO (2166 metric tons total)

Propulsion System	Isp, sec	Est. Number of Vehicles	Est. Total Mass in Orbit	Est. Cost of Debris Removal
Bipropellant	300	900	800 tons	$30,000/kg
NH_3 Arcjet	800	300	250 tons	$10,000/kg
Ion Thruster	3000	120	65 tons	$4,000/kg
VASIMR	10000	30	25 tons	$1,000/kg
EDDE	**—**	**12**	**1 ton**	**$300/kg**

- 12 EDDEs can remove all objects >2 kg in 7 years
- ***Or collect much of the mass, and deorbit the rest…***

An Integrated Solution

- A bilateral US-Russian trade agreement can solve ***most*** of the debris problem, and help set the stage for solving the rest.
- Clusters of upper stages in high inclinations are the best early targets for debris risk reduction ***and*** recycling.
- A pair of EDDEs working in an upper stage cluster (74^{o} or 82^{o}) can collect an equivalent of ISS mass within 6 years.
- A large recycling, manufacturing, and servicing facility can be built of aluminum recovered from upper stages, and it can use electrodynamic propulsion for reboost and collision avoidance.
- Facility can recycle all items from future launches and provide full service to LEO satellites, using EDDE “delivery trucks.”

Debris Removal, or Collection