AMERICAN FOREIGN POLICY COUNCIL

Space Policy Initiative

Space Policy Review

The Starship Singularity

By: Peter Garretson and Samuel Havard

The Big Picture

- The Starship system is a fully reusable super-heavy booster and spacecraft capable of launching 100 metric tons to low Earth orbit and returning to Earth.
- Starship's reusability makes possible the delivery of cargo to low Earth orbit for an ultra-low cost (below $1,000/kg immediately, and $100/kg in two to three years).
- Starship's ability to refuel in orbit means it can place 100 metric tons of payload anywhere in the solar system.
- The Starship system provides much lower costs to access the Moon, enabling the United States to accelerate the volume and cadence of its Lunar program by 4–40 times on the same taxpayer budget.
- Starship's giant payload bay (1,000 m³) and ability to return cargo to Earth after experimentation makes it a research and development platform.
- Starship's unique landing ability makes possible point-to-point intercontinental transport.

In May 2020, SpaceX freed the U.S. government from the bonds of Russian space launch services by sending astronauts into space on American-made reusable rockets. The company is once again about to embark on a potentially game-changing mission. In the coming months, SpaceX plans to conduct its first orbital test flight of Starship, the company's flagship super heavy-lift launch vehicle (Figure 1). ***Starship, due to its reusability, size, and power, will dramatically improve access to low Earth orbit by yielding low-cost launches of payloads up to 100 metric tons. This will support the expansion of public- and private-sector activity in space, including space tourism, space-based solar power, and the installation and servicing of telecommunications and military satellites.*** It will also serve as the bedrock of suborbital point-to-point travel networks, which will transport crews and cargo rapidly across the planet for commercial or national security purposes. Once in orbit, Starship's second stage can serve as a large space station and test bed for experimental space-oriented technology. Furthermore, Starship, supported by its refuelability, is set to supplement the development and settlement of locations in deep space, including the Moon and Mars. Given its incredible potential to revolutionize numerous areas of spaceflight, ***Starship provides something of a "singularity"—a point that disrupts previous trends, after which assumptions of limited growth must be questioned.***[1]

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WHAT IS STARSHIP AND WHY DOES IT MATTER?

The Starship system comprises two separate components—the fully reusable super-heavy booster, and the Starship itself, the first fully reusable upper stage that can operate as a spacecraft and return to Earth.[2] Starship's unique design and engineering approach makes available unprecedented launch capability at an unprecedented low price.

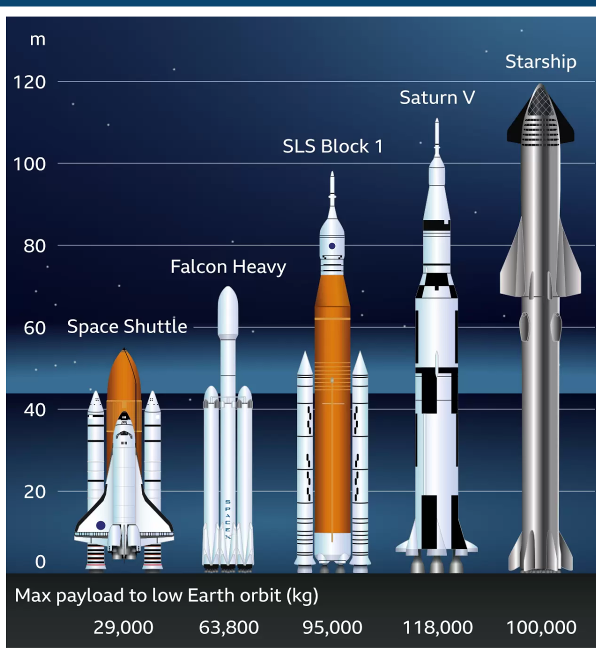
MASS-TO-ORBIT

A heavy-lift launch vehicle can deliver at least 50 metric tons to low Earth orbit.[3] Only Falcon Heavy, ULA's Delta IV and Vulcan Centaur, and NASA's Space Launch System (SLS) are in this category (Figure 2). Starship is one of the most powerful launch systems in the history of spaceflight—its numerous Raptor engines generate over double the maximum thrust of the former U.S. super heavy-lift launcher, the Saturn V rocket, which landed humans on the Moon.[4] These powerful engines enable Starship to launch 100 metric tons to low Earth orbit in a single launch. As a commercial (versus bespoke) system, Starship is available not only to government but also to the private sector. As a result, the U.S. government and industry can now place larger structures in orbit than was previously possible, such as private space stations, individual satellites, or mega-constellations. The ability to carry these larger payloads to low Earth orbit enables rapid space development and industrialization.

Figure 1. Starship Super Heavy Launch Vehicle

Source: CBS News

Figure 2. Launch System Capability Comparison



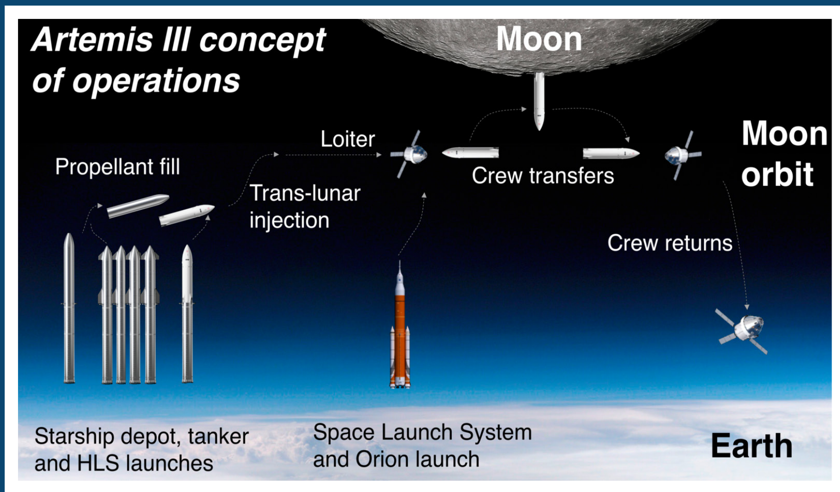
Source: BBC News

Starship can access higher Earth orbits as well. Currently, Falcon Heavy has more lift capacity than any other operational rocket, with the ability to deliver 26.7 metric tons into geosynchronous transfer orbit (GTO).[5] Unrefueled, Starship can carry 21 metric tons into GTO, but more than 100 metric tons with refueling.[6]

REFUELABILITY

Starship's unique ability to refuel in space means that after a refueling occurs in orbit, Starship can place the same 100 metric tons anywhere in the solar system, including heavy payloads to GTO, or to the Lunar or

Figure 3. SpaceX Refueling Concept of Operations



Source: Wikimedia Commons

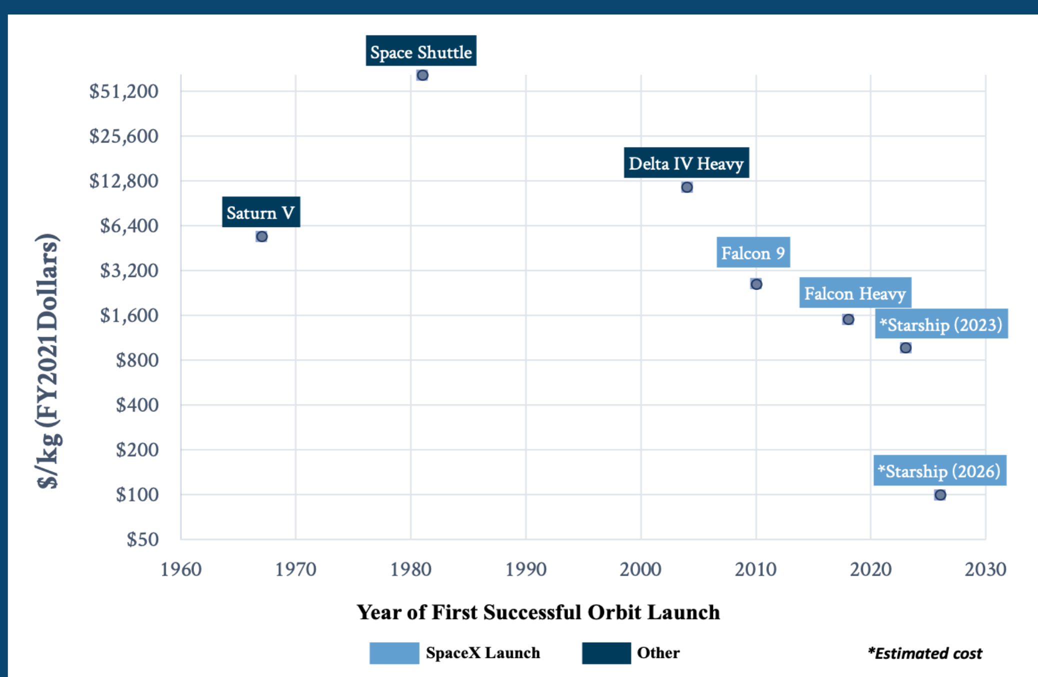
Martian surfaces (Figure 3). This also enables on-orbit maneuver for national security assets. Starship's refuelability permits the craft to travel distances far greater than any other super heavy-lift launcher. SpaceX envisions that a cargo Starship will be refilled with propellant on-orbit from Starship tanker and propellant depot variants. The cargo Starship will rendezvous with its sister refueling Starship variants, transfer the propellant, and then blast off on long-distance journeys into deep space.

REUSABILITY ENABLES LOW-COST ACCESS TO SPACE

Starship is also fully reusable. For over a decade, SpaceX has been developing reusable rocketry through its Falcon 9 and Falcon Heavy programs. Unlike traditional rocket launch manufacturers that discard boosters after launch, SpaceX recycles boosters by engineering them to land back on Earth softly after being used for liftoff. Starship will employ similar technology in order to make the upper-stage spacecraft reusable. Reusability sets Starship apart from any other super heavy-lift launch systems. By comparison, NASA's SLS is fully expendable, meaning that every launch requires completely new engines, boosters, fuel tanks, capsules, and the like—an expensive and inefficient way of doing business. This expendability requires a large quantity of resources and significant time to build each new rocket, making spaceflight both costly and difficult to scale. In contrast, the efficiency of the Raptor engines and reusability of its boosters and other parts enable SpaceX to reduce the cost of launching payloads by significant margins.[7]

Starship's reusable design makes it a more efficient super heavy-lift option than any of the current alternatives. This breakthrough in rocket efficiency will expand humanity's access to space—significantly decreasing the costs surrounding space development (Figures 4 and 5). The cost to send a payload into space is a crucial variable in determining the feasibility of space development.

Figure 4. Heavy-Lift Space Launch Comparison



Source: State of the Space Industrial Base 2021 Report

Figure 5. Cost Comparison

	Launch Cost	Mass (kg)	Launch cost/kg	Launch cost/MT
NASA SLS	$4,100 M	70,000	$58,571	$58 M/MT
SpaceX Falcon Heavy	$97 M	63,800	$1,520	$1.5 M/MT
SpaceX Starship (initially)	$97 M	100,000	$970	$0.9 M/MT
SpaceX Starship (in 2-3 yrs)	$10 M	100,000	$100	$0.1 M/MT

Source: American Foreign Policy Council

Initially, Starship may be priced at what the market will bear, in order to recoup development costs. But since SpaceX will want to drive business to its new launcher, it is likely to price Starship at least competitive with its existing Falcon Heavy, currently at approximately $100 million per launch. The ability to launch 100 metric tons for $100 million provides an incredible gain in efficiency for U.S. spacefaring, as it means ***cutting the cost to orbit by nearly 40 percent from today's lowest-cost option ($1,520/kg on Falcon Heavy) to an unprecedented $970/kg.***[8]

However, the design of Starship makes it possible to achieve much lower costs. Since no part of Starship is thrown away, and because it is designed for many reuses, the cost to build each Starship system can be spread out (amortized) over the total number of flights. This means that, like passenger aircraft, the cost to operate a Starship could approach the cost of propellant (the cost of the methane and liquid oxygen to fuel it).[9] In fact, SpaceX founder ***Elon Musk has forecast that within two to three years a Starship might launch for just $10 million***—assuming an increased frequency of launch. That would translate to a cost of just $100,000/metric ton (or $100/kg)—***15 times lower than the lowest price to orbit today.*** Starship represents an exponential improvement over current NASA launch capabilities, and the reusability and efficiency of Starship will help facilitate travel beyond Earth's orbit.

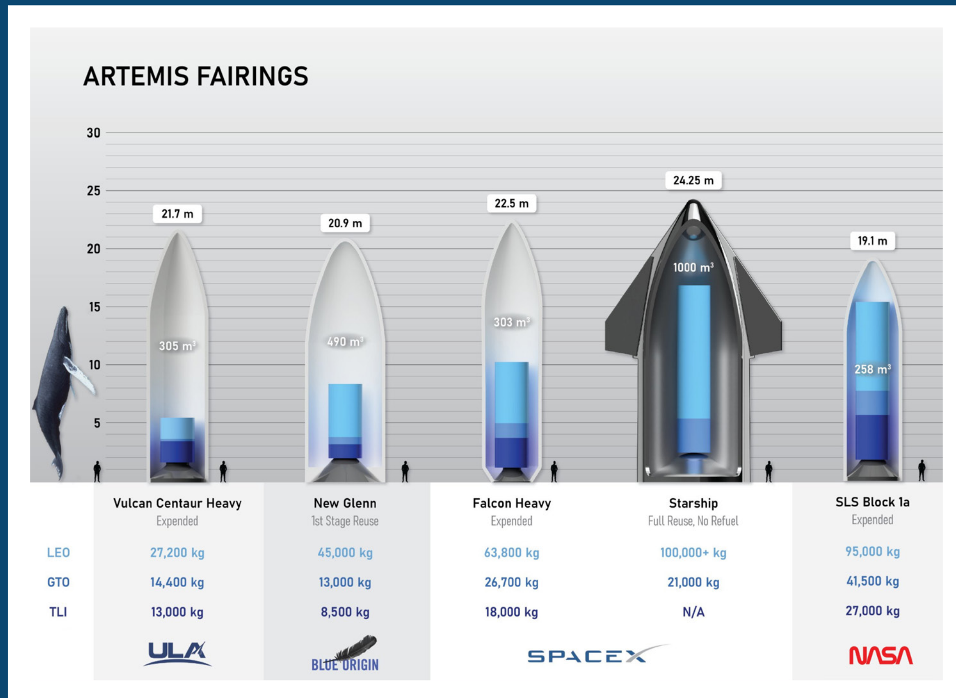
REUSABILITY ENABLES LOW-COST ACCESS TO THE MOON

Starship will enable a significantly more ambitious Lunar program and facilitate substantially faster Lunar industrial development. NASA has emphasized the importance of heading back to the Moon, as evidenced by recent developments of its Artemis program. SpaceX's Starship has the potential to take Lunar exploration and development even further. Starship is already more affordable than the Space Launch System, the current platform used to launch Artemis, and Starship's cost per launch will decrease over the course of its development and deployment. The cost-saving implications of this comparison are profound. In order to sustain Lunar missions, one cargo Starship will need to be supplemented by 10 refueling tankers. ***This means that the price of Lunar missions will range anywhere from $110 million to $1.1 billion, depending on whether SpaceX sets launch prices closer to the current Falcon cost of $100 million or the promised future cost of $10 million.*** Nevertheless, launch prices in this range will mean that Starship will conduct Lunar missions at anywhere from 25 percent to 2.5 percent of the cost of SLS's Lunar missions (current SLS cost/Lunar mission is $4.1 billion).[10]

Being able to sustain reduced launch costs will be critical to developing the Moon and extending humanity's economic sphere further out into the solar system. Any crewed stations, industrial facilities, or long-term permanent settlements will benefit substantially from a steady supply of food and repair parts. Furthermore, the lower-priced launches can accelerate the development process overall. The faster that building materials and machinery can be transported to extraterrestrial settlements, the faster the settlements can grow and develop. This launch advancement comes as a relief, allowing the United States to regain focus on Lunar development after several decades of neglect.

NOT JUST THE MOON, BUT ACCESS TO ALL ROCKY BODIES

Figure 6. Comparison of Spacecraft Fairings



Source: Ken Kirtland

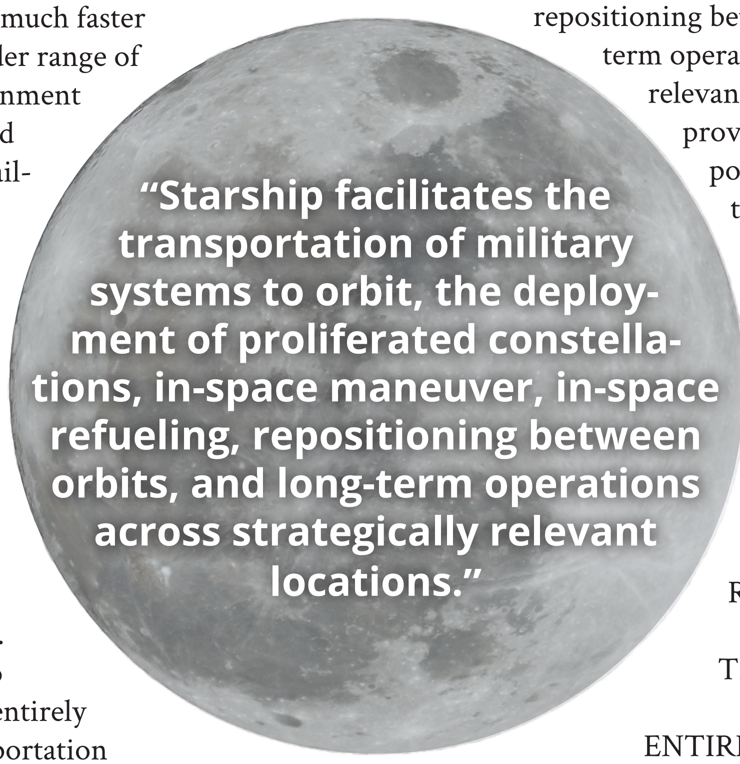
Starship's launch capabilities make it more affordable to launch and send probes out to explore the solar system and beyond. Moreover, the transportation system is not only a launch mechanism. SpaceX intends on making the Starship system itself into a deep-space exploration vehicle. Starship is designed to be the main vehicle supporting SpaceX's push to develop the Moon and Mars. This distinguishes it from all other heavy-lift launch systems, which require separate spacecraft systems to access other planetary systems or return payloads to Earth. The Starship system is designed with the capability to propel objects beyond low Earth orbit and to land on destination worlds. Starship's power and efficiency will be a crucial asset in launching humanity's exploration and development of the solar system beyond the Moon. The system will provide transportation and logistical support to assist humanity's push toward destinations like Lagrange points and near-Earth asteroids.

In the long term, SpaceX intends Starship to be the main vehicle and building block for the settlement of Mars. Starship's unique combination of aerobraking and propulsive reentry solve the difficult problem of transiting the Mars atmosphere. The company plans to construct and send a multitude of Starships to Mars, using the Starship spacecraft stage as a capsule for landing on the red planet's surface.[11] Starship can then use Martian oxygen and methane stores to refuel for journeying back to Earth.[12] Starship will be key in Martian city building because of its ability to transport 100 metric tons per launch to the planet—providing the early settlers with materiel, infrastructure, and industrial equipment needed to jump-start a self-sustaining colony. Settlement and city building will require a steady stream of technology, parts, and building materials. Starship will be crucial in transporting these essential components for Martian development.

A REUSABLE 1,000 CUBIC METER SPACE STATION AND TEST BED

Very few spacecraft can return payloads to Earth and serve as a development platform. Only the Space Shuttle and Boeing's X-37B have been able to provide this capability in the past, but both vehicles have far less volume (both pressurized and unpressurized). The pick-up-truck-sized X-37B had only about 3 cubic meters (m^3) of volume, while the Space Shuttle featured 300 m^3 in its unpressurized cargo bay and 71.5 m^3 of pressurized volume.[13] But Starship not only can lift the most mass, but it has the largest payload bay, with a 9-meter fairing and a truly gargantuan internal payload volume of 1,000 m^3—far larger than anything else available (Figure 6). Clearly, Starship provides a superior platform for research in space than its predecessors.

In fact, the pressurized volume of one Starship (1,000 m^3) is essentially equivalent to that of the International Space Station (1,005 m^3).[14] Today, many devices are tested on the International Space Station, but unlike the ISS, Starship would be a test bed that can return objects to Earth, enabling much more rapid prototyping, space qualification and testing, as well as rapid return of industrial products. Thus, Starship itself can serve as a laboratory for scientific discovery and innovation, offering the potential to greatly accelerate space-based research and development. Already the X-37B has proven valuable as a test bed and space maneuver vehicle. Starship, with a much larger payload volume (330 times) and unprecedented ability to maneuver in space (known as delta-v) and refuel provides similar capabilities at a much grander scale, and likely at a lower per-mission cost. Moreover, because Starship is a commercial system, it can offer these services to the private sector, enabling much faster innovation by a much broader range of actors, since access to government platforms like the X-37B and the entire ISS is often unavailable, severely restricted, or has limited capacity and is badly bottlenecked.



SUBORBITAL POINT-TO-POINT & ROCKET CARGO

Starship's impact goes far beyond simply supplying faster and more efficient launches of cargo into orbit. Starship has the potential to become the keystone of an entirely new mode in a global transportation infrastructure network, making possible ultra-high-speed transit of cargo and passengers across the world through its potential to conduct suborbital point-to-point travel across Earth. Starship can be used to launch payloads and travelers into space, but below the level of low Earth orbit, then travel across Earth and land at a spaceport on a completely different part of the planet. Though early rocket travel might be both expensive and too turbulent for human passengers, Starship's ability to travel many times to different locations across Earth has great potential to transport cargo at rapid speeds. The reusability of Starship means that the craft could be used like a plane to travel across the planet an indefinite number of times. In the long term, as Starship continues to innovate and provides smoother voyages, crewed suborbital point-to-point travel will be more feasible (***SpaceX projects a flight from New York to Shanghai would take 39 minutes instead of 15 hours by airplane***).[15] The network effects of deploying increasing numbers of Starship systems not only enhances terrestrial travel but also enables rapid flight rates and turnaround times to enable the lowest-cost access to space.

EMPOWERING NATIONAL SECURITY

Starship facilitates the transportation of military systems to orbit, the deployment of proliferated constellations, in-space maneuver, in-space refueling, repositioning between orbits, and long-term operations across strategically relevant locations. If Starship proves capable of point-to-point travel, it will facilitate the rapid transportation of military cargo between distant theaters. The Air Force, recognizing the vast potential of Starship point-to-point travel, recently awarded SpaceX with a $102 million contract to demonstrate these capabilities as part of its Rocket Cargo program.[17]

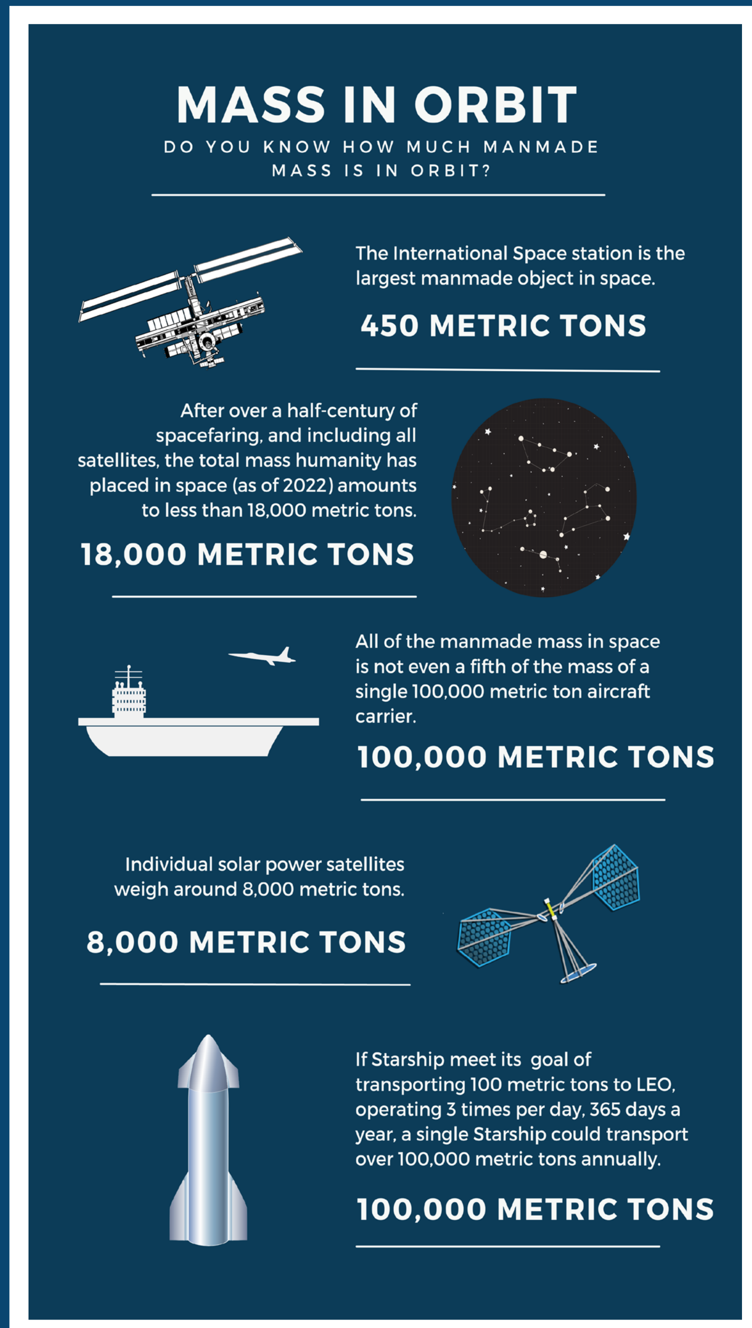
THE COST AND SCALE TO ENABLE ENTIRELY NEW MARKETS

Starship has the ability to revolutionize both terrestrial and extraterrestrial travel, which has important ramifications for space and transportation policy. By increasing the affordability of travel into low Earth orbit, Starship will expand the reach of industry beyond Earth's atmosphere. For example, Starship is already being contracted in the growing space tourism industry. Japanese billionaire Yusaku Maezawa, alongside a crew of eight artists, is currently booked for a circum-Lunar cruise aboard Starship.[18] Starship is set to offer more tourist voyages and expand the space tourism industry.

Starship will also provide companies with the transportation platform necessary for building and servicing space infrastructure. In addition to launching and deploying satellites into orbit, it can send a human crew or robotics to specific locations to repair or assemble satellites and space stations. This ability to more effectively service space infrastructure will have a profound impact on space-dependent industries, like telecommunications, as well as for the military.

Furthermore, Starship will facilitate the capture and transfer of energy from space to Earth's surface. Space-based solar power has incredible potential to provide a vast source of clean energy for humanity.[19] By positioning panels beyond Earth's atmosphere, space solar arrays can capture direct sunlight with much greater efficiency than ground-based solar power. However, designs for individual solar power satellites weigh around 8,000 metric tons.[20] Thus, space-based solar power will require many launches of material and parts into orbit, as well as in-space servicing, assembly, and manufacturing (ISAM). Starship may serve as an essential platform for deploying space-based solar power arrays due to its ability to conduct many inexpensive launches and to serve as a space station for ISAM.

Figure 7. Mass in Orbit



Source: American Foreign Policy Council

REUSABILITY ENABLES SPACE DEVELOPMENT AT SCALE

Because each Starship is designed for fast turnaround and many reuses, Starship has unprecedented potential to enable the economic development of space at scale, and to be the workhorse transportation system for both cargo and humans. Today, the largest and most massive object in space is the 450-ton International Space Station. After over a half-century of spacefaring, and including all satellites, the total mass humanity has placed in space (as of 2022) amounts to less than 18,000 metric tons.[21] That is not even a fifth of the mass of a single 100,000-ton aircraft carrier. Should Starship meet its founder's goal of transporting 100 metric tons to low Earth orbit, operating three times per day, 365 days a year, ***a single Starship could transport over 100,000 metric tons annually.***[22] ***When 10 Starships are put into operation, over 1 million metric tons can be lifted on a yearly basis***; 100 Starships would be able to lift over 10 million metric tons (the equivalent of 100 aircraft carriers worth of mass) every year (Figure 7).

Besides enabling a Martian city and a more powerful Starlink constellation, a system capable of orbiting 100 aircraft carriers worth of mass every year could lift to orbit the construction materials for 1,250 solar power satellites (each at 8,000 tons) every year, year after year. Each of those 1,250 satellites could supply 2 gigawatts of baseload power to the grid, for a total of 2.5 terawatts of power. The total U.S. electrical generating capacity is only 1.2 terawatts[23] and the total worldwide fossil-fuel-generating capacity is only 4.4 terawatts.[24]

SUMMATION

Starship is a radical new capability that offers the potential to break open U.S. spacefaring and spacepower advantage. It is a true step change with the following benefits:[25]

- ★ Allows super-heavy payloads (100 metric tons) to reach low Earth orbit
- ★ Reusability enables ultra-low cost to low Earth orbit (below $1,000/kg immediately and $100/kg in two to three years)
- ★ Refuelability opens entirely new possibilities for accessing higher orbits and maneuvers
- ★ Provides much lower costs to access the Moon, enabling the United States to accelerate the volume and cadence of its Moon program by 4–40 times on the same taxpayer budget
- ★ Unique design enables access to all rocky bodies in the solar system and supports ambitions to settle Mars
- ★ Giant payload bay (1,000 m^3) and ability to return cargo to Earth after experimentation make it a research and development platform
- ★ Unique landing ability opens the possibility of point-to-point intercontinental transport
- ★ Low cost and high launch cadence open up entirely new markets, including space tourism, circum-Lunar tourism, large private space stations, and solar power satellites
- ★ Reusability enables unprecedented scale to place mass in orbit, rapidly overtaking everything placed in orbit to date

In short, Starship reopens the American frontier and demands that policymakers reconsider the direction, pace, and scale of the United States' space program.

Endnotes

1 The term "Starship Singularity" was coined by Michael Laine.

2 SpaceX Starship, https://www.spacex.com/vehicles/starship/.

3 The exact amount of payload depends on inclination and altitude, but low Earth orbit is generally understood to include altitudes above 80 km up to 2,000 km from Earth.

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[25] SpaceX is quick to caution that, as Starship develops, some of the design specifications, and therefore system operations, can and will change. Due to the nature of SpaceX program development, while the paper is based upon information available today, capabilities will change as the system matures.

Figure Notes

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Figure 7: American Foreign Policy Council.

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Space Policy Review

ABOUT THE SPACE POLICY INITIATIVE

For America, space represents the next great strategic frontier. Yet the United States now faces growing competition in that domain from countries like Russia and China, each of which are developing technologies capable of targeting U.S. space assets. As such, defining a strategy for ensuring space security, sustainability, and commerce needs to be a strategic priority for the U.S. AFPC's top-notch array of experts form a robust team that make a major contribution to crafting space policy by providing policymakers with the ideas and tools they need to chart a course in this emerging domain. For regular insights from space thought leaders tune into SPI's Space Strategy podcast (available at https://anchor.fm/afpcspacepod). SPI co-directors: Richard M. Harrison and Peter A. Garretson

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3. Fostering the acceptance and development of representative institutions and free market economies throughout the world in a manner consistent with the Constitution, the national interest, and the values of the United States.

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