One Small Step for Man, One Giant *Mess* for Mankind

“One small step for man, one giant leap for mankind.”

Armstrong’s famous proclamation was certainly right–Apollo 11’s mission to the moon was only child’s play in comparison to the successes of modern space exploration. Although each mission up to date was successful at face value, how great are such accomplishments?

As humanity continues its quest for space exploration, the environmental implications of these endeavors are receiving heightened scrutiny. From space debris due to the egregious amounts of resources consumed, space exploration certainly can’t be considered sustainable. While space travel provides unparalleled opportunities for scientific discovery and technological innovation, its ecological footprint raises significant concerns. Of the multitude of environmentally damaging facets to space travel, the most pressing issue derives from an issue some may find shocking: fuel.

Unsurprisingly, rocket construction is one of, if not the most, unsustainable practices in the space industry. A rocket’s physically large nature necessitates large amounts of sheet metal and other materials, of course, but the most detrimental aspect of construction is the composition of the fuel. Rockets are often composed of 90-95% fuel by weight, much of which is burned during the high-energy phases of lift-off and atmospheric exit. (Infoplease, n.d.). While atmospheric emissions are at the forefront of environmental concerns, the pure consumption of resources also drives emissions.

As it relates to atmospheric emissions, traditional rocket propellants, such as RP-1 (a refined form of kerosene) and hypergolics, release substantial quantities of harmful substances into the atmosphere. These include black carbon (soot), chlorine compounds, and aluminum oxide, which collectively contribute to global warming, ozone layer depletion, and atmospheric pollution (Franklin-Cheung, 2023). Consumption emissions, however, are concentrated in the stratosphere, where their effects persist far longer than surface-level pollutants. For instance, soot particles emitted during launches absorb heat, exacerbating atmospheric warming, while aluminum oxides damage the ozone layer, compounding long-term ecological harm (BBC Science Focus, 2023).

In the quest for sustainability, scientists and engineers are exploring alternatives to conventional rocket fuels. The goal is to develop propellants that minimize emissions while maintaining the high performance required for space missions. Several key criteria guide the development of sustainable fuels, including specific impulse (a measure of fuel efficiency), combustion stability, fuel density, and toxicity (Orbital Today, 2023). One of the most notable advancements in this area is the development of "green propellants," which aim to replace toxic and inefficient fuels with alternatives that have lower environmental impacts. Examples include hydrolox (liquid hydrogen and liquid oxygen), which is widely used but still being improved for efficiency and reduced carbon emissions, and high-performance green propellants (HPGPs) such as ammonium dinitramide-based fuels, which offer lower toxicity and reduced emissions compared to traditional hypergolics like hydrazine. Methalox (methane and liquid oxygen) is another promising alternative, gaining attention for its potential to be manufactured sustainably, especially on other planetary bodies like Mars, where methane can be synthesized in situ (NASA, 2023). Bio-derived fuels, produced from renewable biological sources, also present a compelling option by reducing the carbon footprint of rocket launches while maintaining performance.

The transition to sustainable rocket fuels faces several challenges. High costs of research and development, limited testing facilities, and the stringent performance requirements of space missions all contribute to slow progress. Additionally, private space companies often prioritize cost-efficiency and rapid innovation, which can overlook sustainability considerations. However, these challenges also present opportunities. Collaborative efforts between governmental space agencies, private companies, and research institutions could accelerate the adoption of sustainable fuels. Initiatives like NASA's Green Propellant Infusion Mission (GPIM) have already demonstrated the viability of eco-friendly alternatives, paving the way for broader adoption across the industry (NASA, 2023).

As space exploration accelerates, the environmental costs of conventional rocket propulsion systems are becoming increasingly untenable. Sustainable rocket fuels offer a promising avenue for reducing these impacts, enabling a balance between innovation and ecological responsibility. By investing in research, fostering international collaboration, and implementing robust environmental policies, the space industry can transition toward greener practices. Sustainable fuels are not just an option—they are imperative for ensuring that humanity's reach into the cosmos does not come at the expense of our home planet's ecological stability.

Imperatively, though, such research and investment must happen on all levels of the rocket construction process; we must trivialize the nature of such construction and search for robust solutions for a chance at decreasing emissions. In such a case, one small step towards sustainability can mitigate the giant mess for mankind.

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