ENVIRONMENTAL, SOCIAL, AND CORPORATE GOVERNANCE

Scaling life sustainably by streamlining space mobility

April 2025 - version 1.2

STOKE

In his book *Pale Blue Dot: A Vision of the Human Future in Space*, astronomer Carl Sagan challenged us to think beyond our own needs to those of planet Earth. Our planet is, Sagan said, but "a mote of dust suspended in a sunbeam," and it's our responsibility to preserve the only home we've ever known. Development of a vibrant space economy is key to that preservation and to sustainably scaling our civilization.

> *"There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known."* — **Carl Sagan**

Image 1: NASA/JPL-Caltech (modified) — This "Pale Blue Dot" photo of Earth, which was taken by the Voyager 1 spacecraft in 1990, inspired Sagan's book of the same name.

For perspective, it took humans thousands of years to break free from the natural population constraints that exist for all species. Since then, it's taken just a few generations to increase our population by more than an order of magnitude (Figure 1).[1]

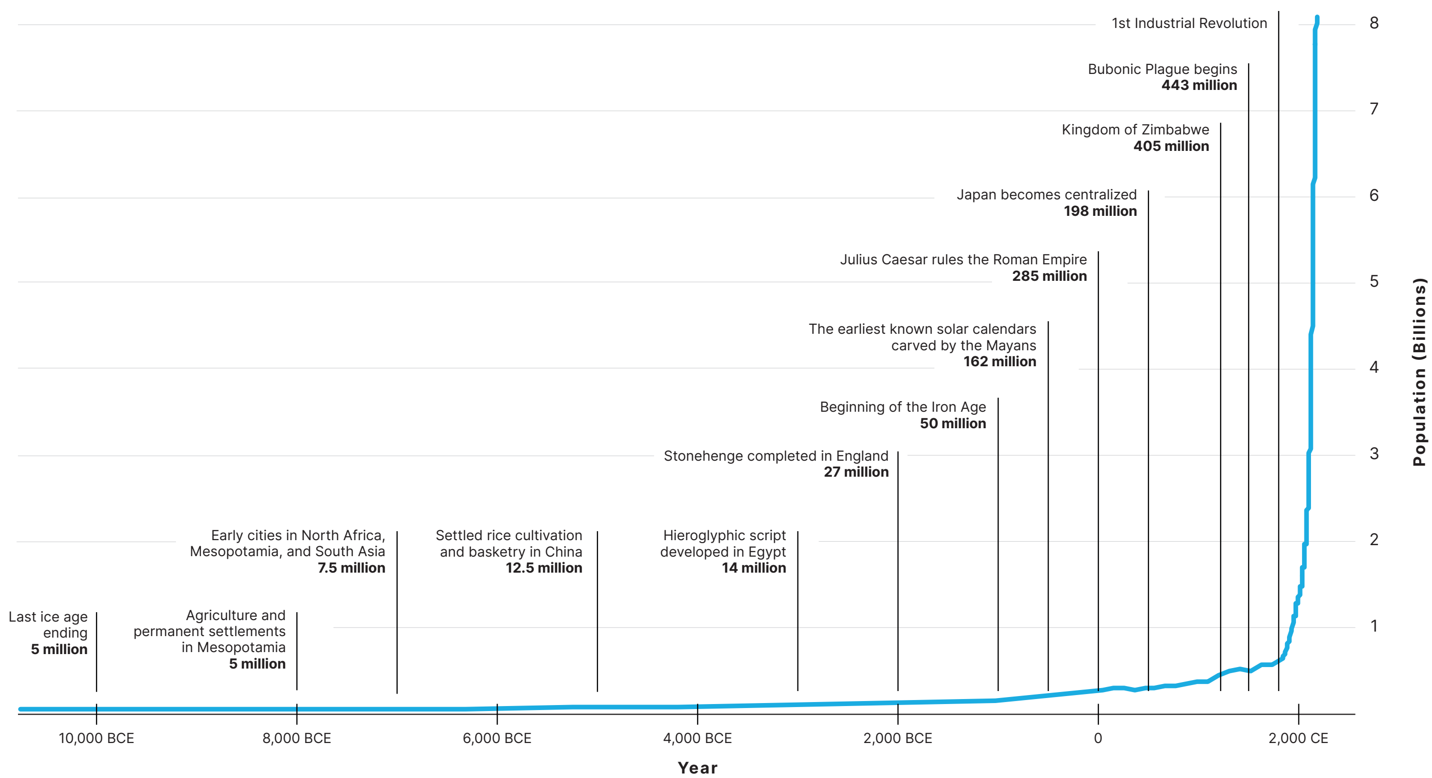

Figure 1: World population began accelerating a 4,000 years ago and has "exploded" in the past 1,000 years. (von Weizsäcker and Wijkman, 2018)

[1] Pengra B. "One planet, how many people? A review of Earth's carrying capacity" (United Nations Environment Programme, 2012).

Prior to 1950, a doubling of the Earth's population would take generations, but recent generations have now seen a tripling. In fact, since 1989, we've been adding more people each year than had ever lived on Earth prior to 500 BCE.

This sudden inflection was triggered by the invention of the modern steam engine, which powered the first industrial revolution and resulted in transformations in agriculture, textiles, manufacturing, materials, transportation, healthcare, and medicine. As Figure 2 shows, energy production has been deeply intertwined with global population ever since, and today our population is at or above the level that most scientists estimate to be the Earth's environmental carrying capacity.[2]

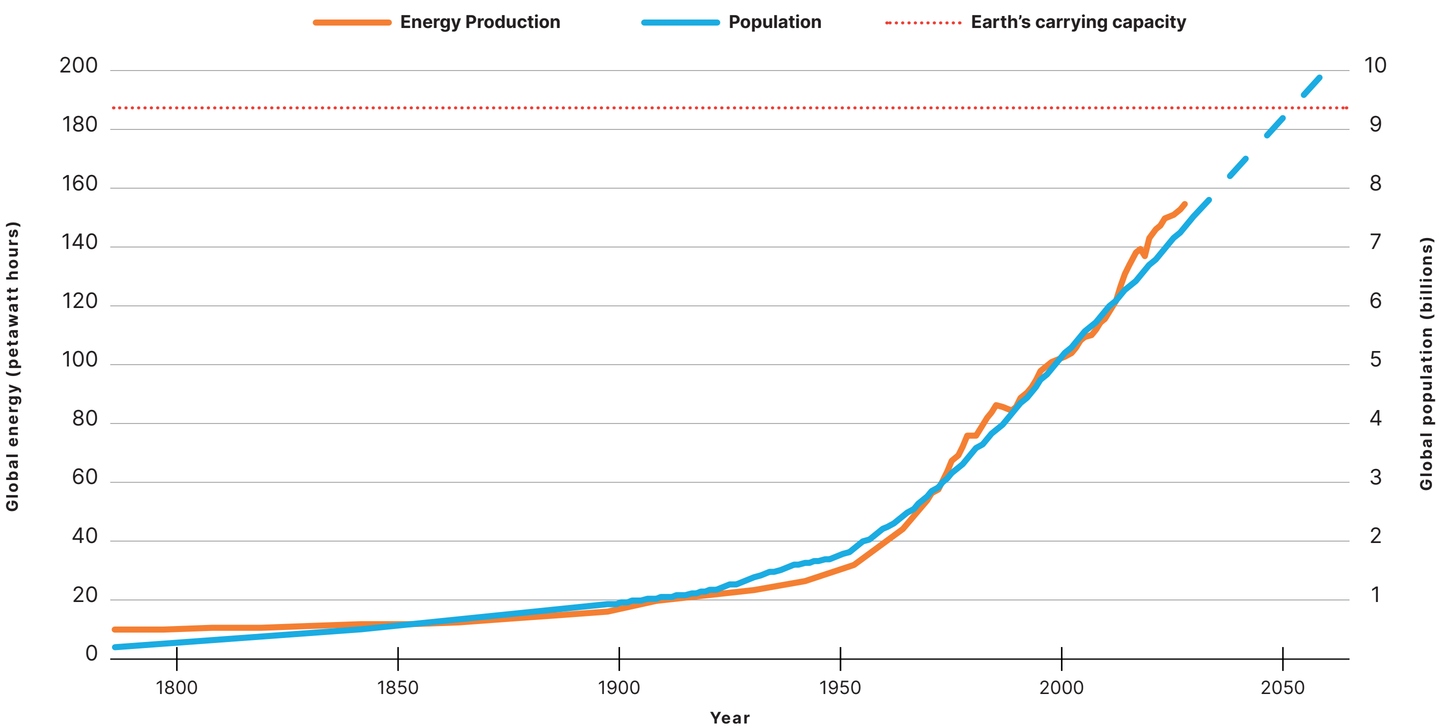

Figure 2: Energy production from 1800 to present day, overlaid with world population, showing a 1:1 correlation. Even if ubiquitous clean energy solutions were found tomorrow, we still face an existential global threat from exploding population.

How do we continue to scale our civilization while also preserving our precious home?

Finding new and sustainable sources of clean energy is obviously paramount, but any solution still leaves us to grapple with acute threats to land cultivation, footprint allocation, water supply, resource extraction, waste disposal, atmospheric composition, and more.

A multipronged approach is required, and the development of a vibrant, sustainable, and scalable space economy will be critical to our survival.

[2] Ibid.

In the near term, Earth observation and monitoring from space will enable us to take greater ownership of the care of our planet. For example:

— Routine, unfettered access to water is essential for all carbon-based life. Climate change stressors coupled with the increased demands of humanity are straining this finite resource. The knowledge obtained from Earth observation sensors enable predictive modeling to address these challenges.[3]

— In order to minimize our current agricultural footprint while supporting the population growth, we must improve the efficiency of our agricultural methods. Space-based Earth observation data provides insights for irrigation management,[4] fertilization, autonomous harvesting, season planning, crop monitoring,[5] livestock tracking, and large-scale fishery maintenance[6] to help minimize agricultural footprints and maximize yields.

— Earth's complex biodiversity is critical to maintaining our planet's health. Deforestation caused by human activities and uncontrolled fires increases greenhouse gas levels and reduces habitats necessary for biodiversity. Large-scale amounts of ocean plastic and temperature fluctuations have caused an immense decay in the ocean's significant biodiversity. Poaching continues to endanger many species as our extinction list grows longer. Earth observation can support policy changes to curb harmful activities, provide early warning and prevention, and inform emergency responses, policing efforts, and rehabilitation efforts. All of these will help to sustain and revitalize Earth's vibrant biodiversity.[7]

— To understand how and why Earth is changing, it's critical to characterize, monitor, model, and police greenhouse gas emissions. NASA's Orbiting Carbon Observatory (OCO) series of satellites utilizes high-resolution grating spectrometers to separate reflected sunlight and measure greenhouse gases in selected regions.[8] Increasing these capabilities with additional satellites, and advancing sensor technologies through future iterations, will help us develop techniques to mitigate overall atmospheric composition of greenhouse gases.

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[3] Qamer F, Krupnik T, Pandey P, and Ahmad B. "Resource book: Earth observation and climate data analysis for agricultural drought monitoring in South Asia." (South Asia Association for Regional Cooperation Agricultural Centre, 2019).

[4] Aragon B, Ziliani M, Houborg R et al. "CubeSats deliver new insights into agricultural water use at daily and 3 m resolutions" (Scientific Reports 11, 12131, 2021).

[5] Migdall S, Brüggemann L, and Bach H. "Earth observation in agriculture" in: Brünner C, Königsberger G, Mayer H, and Rinner A (eds). "Satellite-based Earth observation" (Springer, Cham, 2018).

[6] Kuenzer C, Ottinger M, Wegmann M, Guo H, et al. "Earth observation satellite sensors for biodiversity monitoring: potentials and bottlenecks" (International Journal of Remote Sensing, 2014).

[7] Ramchandra Pawar P, Shirgaonkar S, and Patil R. "Plastic marine debris: Sources, distribution and impacts on coastal and ocean biodiversity" (Pencil Publication of Biological Sciences-Oceanography, 2016).

[8] Nassar R, Moeini O, Mastrogiacomo J, et al. "Tracking CO2 emission reductions from space: A case study at Europe's largest fossil fuel power plant" (Frontiers in Remote Sensing, 2022).

In the medium and long term, more and more of our human activity will move off of the planet as we seek ways to scale Earth's environmental carrying capacity.[9] In fact, we're already seeing all four major drivers of economic growth move to space: communication, transportation, manufacturing, and energy production. For example:

— In-space manufacturing (ISM) will be required to ensure permanent habitation of orbital and lunar stations. Once realized, ISM will unlock manufacturing techniques unavailable on Earth and provide large manufacturing facilities while minimizing the terrestrial footprint.[10] We are already seeing:

- Companies such as Varda Space Industries demonstrating the benefits of in-space manufacturing in areas such as fiber optics, metallic alloy production, and pharmaceuticals.

- LambdaVision and SpacePharma developing artificial retina replacements and other pharmaceutical applications whose manufacturing scales more economically in space.

- Several research groups pursuing production of full organ transplants[11] and, eventually, production of protein-based foods.[12]

— Space-based solar energy production continues to gain traction and will not only power the burgeoning orbital and lunar economy, but it will begin feeding energy needs on Earth as well.[13]

— Mining of asteroids shows promise in gaining access to rare earth metals and other resources while eliminating the need for mining and production on Earth. AstroForge has created innovative technology enabling the mining of resource-rich asteroids <100m in diameter.

In sum, these developments have both near-term urgency and long-term necessity. A robust space economy must be built in order to place humanity on a path towards sustainable growth. Routine low-cost access to a diverse set of orbits is critical to achieving this goal, provided that it's also done in a way that's scalable and sustainable.

Unfortunately, today's rockets rely on solid rocket boosters and/or fuel-rich kerosene in their engines. This results in radiative forcing — a phenomenon in which more radiation is entering Earth's atmosphere than leaving, causing the atmosphere to heat up. That's 500 times more than that caused by surface and aviation sources on a per kilogram basis.[14] Kerosene engines emit damaging black carbon soot, and as a result, they account for 70% of rocket-based radiative forcing. Solid rockets, which account for 28% of rocket-based radiative forcing, also produce gaseous chlorine and aluminum oxide and deplete the ozone at measurable levels. These approaches need to be phased out as our industry scales or else they will have a significant impact on our delicate upper atmosphere.

[9] Daily G and Ehrlich P. "Population, sustainability, and Earth's carrying capacity" (BioScience, 1992).

[10] Gamota D. "Manufacturing in outer space: not such a far-out idea" (Forbes.com, May 6, 2021).

[11] Sims J. "Why astronauts are printing organs in space" (BBC.com BBC Future, June 2, 2021).

[12] Ní Chúláin A. "Protein made from 'thin air' could be the food of the future for astronauts and may save Earth" (Euronews.com, January 3, 2022).

[13] Clery D. "Space-based solar power is getting serious—can it solve Earth's energy woes?" (Science.org, October 19, 2022).

[14] Ryan R, Marais E, Balhatchet C, and Eastham S. "Impact of rocket launch and space debris air pollutant emissions on stratospheric ozone and global climate" (AGU, Earth's Future, 2021).

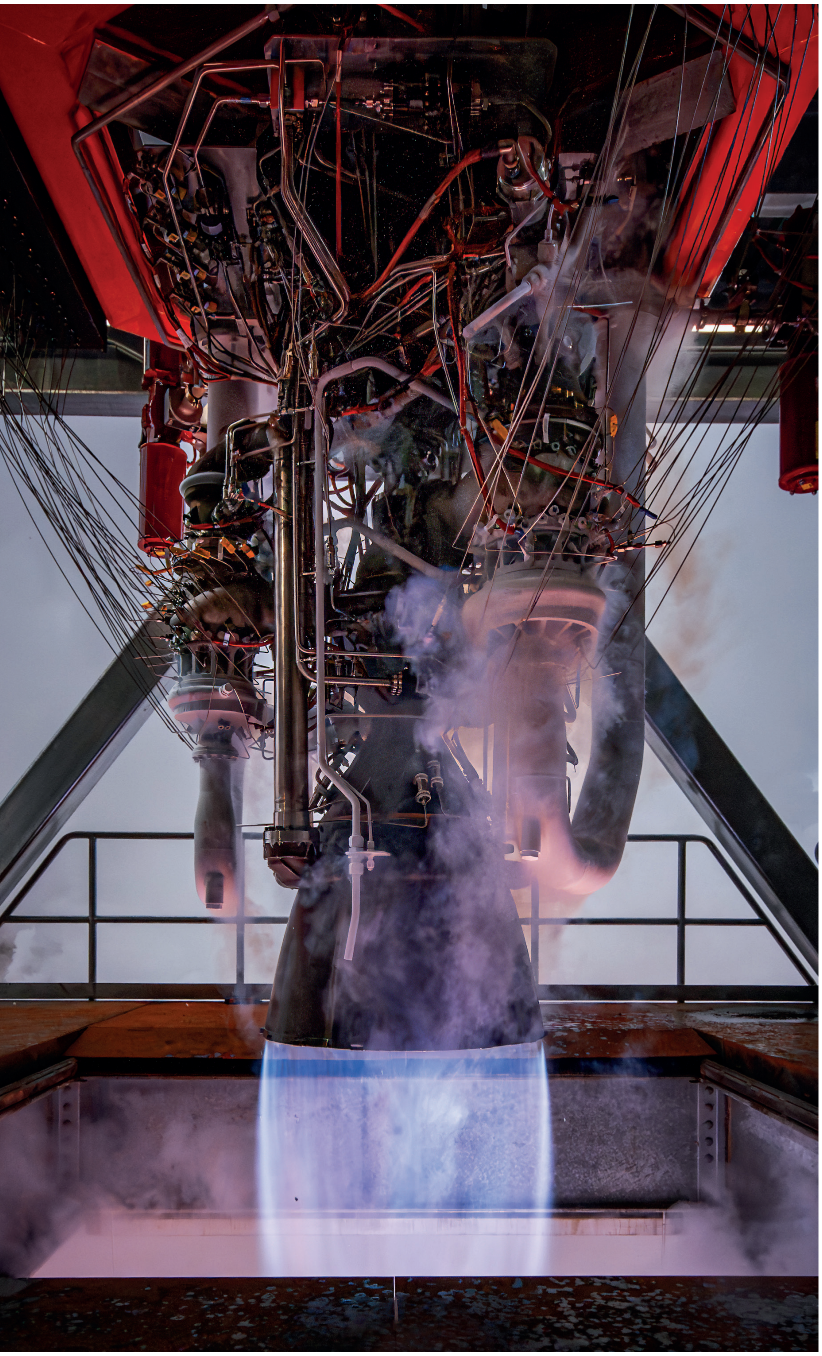

Image 2: Stoke Space's liquid natural gas/liquid oxygen first stage Zenith engine, shown above, and liquid hydrogen/liquid oxygen second stage Andromeda engine both eliminate black carbon emissions — the single most damaging factor in today's orbital launches — and reduce rocket-driven global warming by 98%.

Stoke's high-efficiency rocket engines eliminate these damaging emissions, resulting in a solution that has the lowest environmental impact of any existing or proposed rocket. The liquid natural gas/liquid oxygen first stage and liquid hydrogen/liquid oxygen second stage combine to form the world's most efficient fully reusable rocket. Both fuels are selected to eliminate black carbon emissions, which are by far the most damaging aspect of today's orbital launches. These critical measures will eliminate 98% of the radiative forcing that results from rocket launches.

Stoke was founded with the vision of fostering unlimited human potential — on Earth and in space. A vibrant space economy is critical for the survival and growth of our species. It's vital that we build that economy in a way that's both scalable and sustainable.