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5 luminaries give their definitions

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## THE DARK SIDE OF GREEN

From deep sea mining to contrails, decarbonizing aviation presents environmental dilemmas that the industry must still grapple with. **PAGE 24**



**Q&A:** Analyst Riedel on making air taxis mainstream

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PIONEERS  
ON THE MEANING OF

"BUILDING  
THE SPACE  
ECONOMY"



It's a phrase uttered by old-timers, newcomers, entrepreneurs and government officials in the space industry, but what does it mean? Does it refer to people living and working in space, or to today's construction of satellites and rockets on Earth? Is mining asteroids part of the plan? How about orbiting hotels? **Debra Werner** asked five space luminaries to elaborate on what "building the space economy" means to them.

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## SIMON "PETE" WORDEN

Executive director of the Breakthrough Starshot Initiative, established by Stephen Hawking and Yuri Milner in 2016 to develop a fleet of microchip-sized, "ultra-fast light-driven" interstellar probes. A retired U.S. Air Force brigadier general known for bold ideas about the need to expand security measures to support economic expansion into space. A former director of NASA's Ames Research Center in California, Worden holds a Ph.D. in astronomy from the University of Arizona, where he was a research professor.

**"THE SPACE ECONOMY BEGINS WHEN WE START HAVING SUBSTANTIAL OPERATIONS IN CISLUNAR SPACE, WHETHER FOR SECURITY OR ECONOMIC ACTIVITY."**

I wouldn't say we have a space economy yet. When I go to meetings and they talk about all the things they're doing in low-Earth orbit, I think, "Those are just high-flying airplanes." Not that they're not important. In geosynchronous orbit, you're fiddling around in the harbor of the space economy. Maybe you can get fish in the harbor and put booms across the harbor entrance for defense. The space economy begins when you have settlements. You're providing things that came from space to other things in space. I think in a decade, the space economy will just be beginning. It will expand by the middle of the century to the inner solar system and maybe beyond.

The space economy begins when we start having substantial operations in cislunar space, whether for security or economic activity. Within a decade, we're going to start to see settlements on the moon. At that point, the space economy will be bringing something back to the Earth from cislunar space. The initial product is obviously information, but ultimately, there could be other things. First, it will be what resources are there and what competitors might be doing — if there are competitors in cislunar space — whether they're security competitors or economic competitors. An analogy is the Age of Exploration that began in the 1400s. The first thing is just information: What's there?

What are our competitors doing? And then ultimately, are people going to go there? There may be products that are found on the moon that are useful. The initial products will be fuel that comes from water for propulsion and then fuel to support the human habitation on the moon.

Eventually, the resources might come from near-Earth asteroids or comets that are rich in water. After water, I suspect that the next product will be platinum group metals. Today, to get these things that are essential for the terrestrial economy, we have to dig ever deeper into the Earth's crust. Is it cheaper to dig down 5 kilometers or get the stuff in space? It may turn out the moon is important for that too. There was a demonstration many years ago by John Lewis [professor emeritus of planetary science at the University of Arizona's Lunar and Planetary Laboratory]. He had a little vial of lunar regolith that had been brought back from Apollo. He took a magnet over this little glass tube, and you could see these filings jump up. He said that the regolith is not very rich in metals, but it's been hit by micrometeorites, a few percent of which are metal, over billions of years. So, there's a fairly extractable quantity. Those metal fragments are natural alloys of iron, nickel and cobalt, but they will have a certain content of platinum group metals.



## BRENT SHERWOOD

Senior vice president for advanced development programs at Blue Origin, overseeing initiatives including development of the Orbital Reef space station and efforts to establish permanent lunar operations. A pioneer in the field of space architecture, Sherwood led the Jet Propulsion Laboratory Innovation Foundry and developed human and robotic mission concepts for Boeing. An AIAA associate fellow, he holds a master's degree in architecture from Yale University and a master's in aerospace engineering from the University of Maryland.

**T**he space economy centers around continued governmental investment in fundamental exploration and pure research, and hopefully also continued and perhaps increased government investment in basic technologies. Because as you know, the technologies to do amazing things in space are different from the ones that we need on Earth, and there's a high bar to invest in those things. Investment from both domestic agencies and foreign nation agencies should be steady and grow slowly.

On top of that, we want to see multiple wedges, new business segments that start small and have the potential to grow. Some of them will grow much faster than the continued growth of government investment. Then you get to the question, "What is commercial business in space?" A super good example, which we tend to overlook, is telecommunications and Earth remote sensing from geostationary orbit. It was pioneered by governments, but then look at how that mushroomed as a commercial business. A lot more billions of dollars are flowing from private capital into that business than from government sources.

There is a wedge that has started out very small, and I personally believe should be able to grow pretty aggressively: That is tourism. It's still super expensive. The systems aren't as reliable altogether as you'd like for flying private passengers, but reliability and amenities will increase, and costs will continue to come down. There is a large population of high-net-worth individuals in the world who can become the beginning of that tourism market. The way I see it is adventure travel leads to tourism. Adventure travel is climbing Mount Everest. Tourism is taking a cruise ship to the Arctic. Then, eventually maybe I want a condo in space or one-twelfth of a condo in space with 11 other people who also live there for a month of the year, with the best view in the solar system and an

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amazing address and all those things that we know about microgravity.

The question of where people will go in space is very clear to me. However many people travel to Mars, we will have 100 times that many people on the moon. And for every person we have on the moon, we will have 10,000 times that number of people in Earth orbit. The economics simply drive that. I can't make a business case for tourism to Mars or any other business to Mars. It's too far away. It's too expensive. It's too uncertain. NASA hasn't even pioneered it yet for humans. For the moon, I can imagine a time decades from now when there begins to be tourism to the moon the same way we're already seeing tourism in LEO. By the time that happens, there will be lots of tourists in LEO routinely, every few weeks, every month, with some of them staying there for a long period of time.



## CHIARA MANFLETTI

Professor of space propulsion and mobility at the Technical University of Munich, and director and chief operating officer of Neuraspace, a Portuguese company founded in 2020 to help satellite operators dodge debris and other satellites with artificial intelligence. Inaugural president of Portugal Space and a former head of policy and program coordination for the European Space Agency, where she devised ESA's campaign to pay for active debris removal. She holds a Ph.D. in aerospace engineering from Germany's Rhine-Westphalia Technical University of Aachen.

**"HUMANS ARE NOT REALLY SPACEWORTHY. RADIATION, PRESSURE AND A LACK OF GRAVITY ARE PROBLEMS FOR US. WE TRY TO CONQUER SPACE, BUT OUR BODIES ARE NOT QUITE AS FLEXIBLE AS OUR SOULS AND OUR MINDS."**

In the future, the space economy will be totally integrated with the terrestrial economy, with increased dependence of many industries — transport, health care, telecommunications, agriculture, banking — on space resources and services. When I was leading Portugal Space, I had conversations with telecommunication providers. They were so focused on ground infrastructure that they saw space as being in competition. It isn't. It provides services that they can't provide on the ground. When I think about the space economy, it's space no longer being the bubble that is discussed by a very tiny community. I see this bubble breaking, and I see space completely integrated with everything else.

Space infrastructure will become a lot more autonomous, a lot more resilient. Things will be manufactured in space. I'm not sure I believe in asteroid mining for the purpose of taking materials from asteroids and bringing them down to Earth. I'm sure that there will be someone doing it, but for me, it seems a lot more straightforward to take materials in orbits and then use them to make something else in orbit. There will be spacecraft refueling services. Space will become part of our economic sphere of influence more than it is today.

Going further into the future, people will use commercial space stations for producing materials, medicines and all sorts of other things. I think that the robotic side of space exploitation is going to be a lot stronger than the human side for sure. Humans are not really spaceworthy. Radiation, pressure and a lack of gravity are problems for us. We try to conquer space, but our bodies are not quite as flexible as our souls and our minds.

One of the big question marks is how political difficulties that we experience on Earth will have an impact on how the space economy is going to develop. Will it be a truly commercial economy, or is it going to be driven a lot by institutional sovereignty? How much is it going to be driven by ambitions of governments?

I tell my students that the space economy will definitely happen in their lifetimes. Teachers need to pass to their students a message that is optimistic of what the future will bring, so the students channel their energy toward something positive. I also tell them about policy difficulties, so they know what kind of hurdles they will have. But I want them to become the great leaders that we need to make all of this happen sooner rather than later.



## JEFFREY MANBER

President of international space stations for Voyager Space, the Denver company that is developing the Starlab commercial space station. Pioneered commercial space tourism and research as CEO of MirCorp, a private venture that sold research space aboard Russia's Mir space station; managing director of Energia USA, the now defunct U.S. arm of the Russian spacecraft builder; and Nanoracks, which continues to build spaceflight hardware and arrange for experiments on the International Space Station. He holds a bachelor's degree in psychology from Northwestern University.

**"IN THE NEXT DECADE, YOU SHOULD HAVE 10 COMMERCIAL DESTINATIONS WITH AMPLE DOMESTIC AND INTERNATIONAL VEHICLES GOING THERE. YOU WILL ALSO HAVE INTER-ORBIT SPACE TUGS. THE FUTURE IS BRIGHT FOR THE LOW-EARTH ORBIT ECONOMY."**

**T**he coming of age of the low-Earth orbit economy in the next 20 years is going to be a wonderful thing to witness. You have all the ingredients coming together: You have robust transportation to and from low-Earth orbit for cargo. Soon you will have multiple commercial carriers for humans. And equally exciting, you will have multiple destinations. In my view, there will be two to three U.S.-owned commercial space stations. India and China will have space stations. There will be a couple of surprises too: space stations from other sovereign nations and maybe a space station from a consortium of companies. In the next decade, you should have 10 commercial destinations with ample domestic and international vehicles going there. You will also have inter-orbit space tugs. The future is bright for the low-Earth orbit economy. The foundation is being put in place right now.

The first generation of commercial space stations will be driven by the NASA Commercial Lunar Destinations program. Starlab will be focused on research,

biopharmaceuticals, manufacturing, agriculture. We want to offer the astronauts of the International Space Station partners that exist today — unfortunately, except for Russia — and new players access to fantastic state-of-the-art facilities. We have Hilton Hotels as a partner, designing a state-of-the-art habitat so you can live and work comfortably. In the second generation of commercial space stations, NASA will not be the guiding customer. You will see more advances like a robotic platform for very interesting and delicate work. It could be in biomaterials or thin film wafers. You will have a hotel in low-Earth orbit, and you may have a staging ground for exploration of Mars. I see some entrepreneurial efforts coming along with variable gravity. That's wonderful, but it's not the market for today. Not for the next five, six, seven years. We want to exploit the unique environment of space. We're not at a point where we want to duplicate Earth's environment. We want to get those breakthroughs when there's no gravity and finally realize that potential.



## MORIBA JAH

A space environmentalist and chief scientist of Privateer Space, founded in 2021 with Apple co-founder Steve Wozniak to monitor satellites and debris in orbit. A fellow of AIAA and the MacArthur Foundation, Jah is an associate professor of aerospace engineering and engineering mechanics at the University of Texas at Austin. He holds a Ph.D. in aerospace engineering from the University of Colorado, Boulder.

**T**o me, the space economy is just an extension of the economy period. We don't say, "What's the land economy?" or "What's the ocean economy?" It's just the economy. I think labeling it "the space economy" is part of the mistake, because it's not connected. It's like these things are mutually exclusive. Right now, we have critical services and capabilities that are uniquely provided by space: position, navigation and timing, and communications. These robots in the sky we call satellites are already fueling the economy. And looking at how we do space exploration, companies working on the moon, that's just an extension of the economy. I don't consider a space economy to be a disjointed thing. As humanity makes more and more use of space, the economy includes making use of this resource and this orbital ecosystem. It's no different than the economy based on things on land, in the ocean and in the air. Land, ocean, air and space have so many interdependencies. Eliminate any one of these things, and all of a sudden, the economy as a whole breaks down. If we just eliminated satellites, we'd be hosed. That would break the global economy, without question.

As a space environmentalist, I like the idea of circular economies from a waste management perspective, and I like being able to link environmentalism across these different ecosystems to show that space is no different than land, air and ocean. People want to see sustainability and environmentalism happen for space. They need to connect with the rest of humanity that for decades has already been working on waste management and environmentalism in these other ecosystems. Space people tend to be very insular and come up with our own jargon, which is something that doesn't unify; it's divisive. I'm all about unification with the rest of the globe. Why make up terms when we don't have to?

My idea for the space economy is a circular one that focuses first and foremost on the prevention of pollution

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by prioritizing the reuse and recyclability of rockets and satellites. On the rocket side, clearly SpaceX is showing that rockets can be reasonably reusable and recyclable. We have not gotten there on the satellite side. I'm not proposing bringing satellites back to reuse them; I am proposing leaving them on orbit but designing them for reuse and recyclability before you launch them. That would also open up a marketplace for companies that could make use of existing satellites for repurposing them and recycling satellite parts in space. Responsible disposal in space can't keep on meaning abandonment. It can't mean companies disposing of satellites by moving them into an orbit that's sufficiently low to let Mother Nature take care of it. To me, that's abandonment of the objects. It's basically putting the trash on your front lawn and hoping there is a strong enough wind that blows it off. ★