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PUTTING SPACE TO WORK

Space activities are moving ahead on many fronts. Steady gains in understanding planetary processes, technology transfer for social applications, and better space science add up to a winning investment for the nations and corporations involved, as well as the planet and the society.

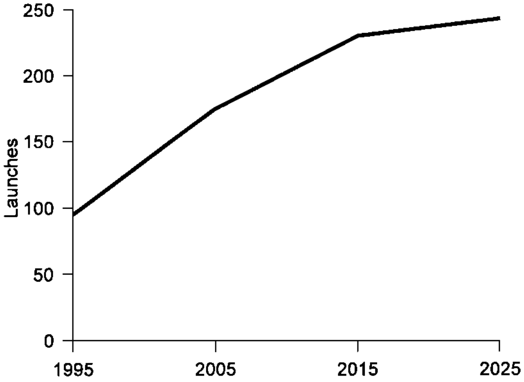
Big space projects, since 2000

International Space Station	Space Plane	Moon Base	Human Expedition to Phobos	Human Expedition to Mars
2013	2017	2020	2024	2030

The big space projects started back with the 400-foot international space station in low Earth orbit completed in 2013. The station provided the stimulus for the R&D that is bearing fruit today. Similarly, it triggered interest and investment in the Moon base, a mostly underground complex of research labs, warehouses, commercial leasing space, and an observatory, which was finished in 2020. The snowball effect continued with a human expedition to Mars' moon Phobos last year, and a planned expedition to Mars in 2030 is being rehearsed on the Moon base. It will follow six robotic missions.

Benefits from space activities are streaming in. Nations no longer use space as a playground for national prestige, but seek concrete scientific and commercial gains from it. Space activities aimed at Earth have provided the most attractive gains. New commercial ventures are forming, new scientific discoveries are being made, and new space technologies are being applied on Earth. The scope of space activities continues to expand. Workers involved in space activities worldwide number in the hundreds of thousands, an order of magnitude increase from the late 20th century. The graph below shows the steady increase in space launches. It has evolved from a specialty to a commodity operation.

World Space Launches: All Earth to Orbit Trips



The overriding feature of the space program, and a exciting side effect, at this quarter century mark is the unprecedented degree of international co-operation. The International Space Agency (ISA) was formed in 2002 as part of the United Nations (UN) family and provides an institutional mechanism for negotiating public and private multinational space projects.

Dealing with global environmental problems set the stage for international space activities. The Montreal Accords on the ozone hole back in 1988 were followed by a ban on ocean dumping in 1998 and international global warming research in 2001. The protocols of these agreements were later adopted by the space community.

A second significant development in space is the flourishing of the commercial sector. Slow progress in commercial space in the 1980s and 1990s dampened hopes that space commerce would ever become a viable industry. At the beginning of the century, with guidance and funding from governments, commercial successes were achieved. The time line below highlights some key commercial events in space.

Timeline of commercial space activities

1997	Earth Observation System
1998	Iridium Satellite Network
2001	Resource Tracking Model
2002	Detection of phytoplankton depletion
2004	Private weather forecasting proliferates
2009	AI robots construct space factory
2015	Biocompatible blood vessels developed
2016	Cancer fighting drug developed
2018	Solar mirrors for light in Alaska
2020	Moon mining begins
2021	Alloy for engines developed
2022	IVHS with global postioning satellite
2024	Solar power satellite for Moon base

International cooperation

Today's cooperation arose from economic necessity. Space activities often lost out to other budget priorities through the 1990s and early 2000s. But international computer and communications networks enabled collaboration among the world's space community and enhanced awareness of the wastefulness of developing redundant programs. These redundancies were addressed by ISA in the 2000s, and the stage was set for multinational projects.

The debate over the U.S. space station *Freedom* in the 1990s provided a clear example of the scope of big space projects being beyond the capabilities of a single nation. Even after scaling down expectations for the station considerably, it was not able to go forward until the project was internationalized. It took the resources of several countries, including all the primary space players—the United States, Japan, Europe, Russia, and China—to get the station in place in 2010. After that accomplishment, discussions about the planned Moon base began with the assumption of international control and cooperation, which enabled it to be constructed relatively quickly. Rather than three programs developing their own shuttles, for example, they collaborated on one and developed other projects with the money saved. It has become clear that the scale and sophistication of space activities is beyond the capabilities of any one nation. The European Space Agency (ESA) model of multiyear funding was adopted by the international space program in 2003. The decline of military missions and transfer of budgets to civilian purposes provided much of the initial funding. Restrictions on international ownership stakes of companies benefiting from the National Aeronautics and Space Administration (NASA) programs were eased. The table below summarizes the strength and weaknesses of the world leaders in space activities. It differs little from the situation 30 years ago, with the exception of the emergence of China as an important member of the space community.

Profile of World Leaders in Space

Countries	Strength	Weakness
United States	Reputation; large, trained, space workforce; thriving commercial sector	Deciding on priorities; reluctant and demanding international player
Russia	Developing scientists; rocket propulsion; space power plants	Still rebuilding the economy
Europe	Launch vehicles	Getting consensus
Japan	Commercial spinoffs for space activities; space robotics; satellites	Commercial interests in space dominate
China	Inexpensive launch capabilities; R&D into new propulsion technologies	Still catching up with the rest of the space community

Competition for the limited space to deploy satellites in low Earth orbit (LEO) also had to be worked out. The problem has been less severe than once forecast, as the size of satellites and other space structures have sharply decreased with continued technological advances in miniaturization, and the recognition that large multimillion- dollar satellites increased the risk of financial ruin. Smaller satellites are easier to launch and present less financial risk. The successful deployment of the Iridium III network of 66 LEO satellites completed in 1998 gave confidence to others that small satellites were as capable as big ones. Extended-lifetime Iridium III satellites are joined by hundreds of satellites in orbit today.

United States

The U.S. space program has regained the credibility it lost with the international space community beginning back before the turn of the century. Political problems hamstrung the U.S. space program. The Cold War mentality of competition and jealous guarding of secrets prevailed a decade after its obvious rationale had expired. The eventual easing of export controls and technology transfer restrictions after the turn of the century was important for big international space projects like the space station, which was able to use technologies once restricted for military reasons.

The eventual warming of the United States to international space cooperation came more from necessity than good will. NASA’s spotty ability to deliver on promises led nations to shop elsewhere for their space needs or meet them domestically. This enabled other nations to close the technology gap with the U.S. program around 2000. The United States today is first among equals in the space community.

High levels of safety that were required following the *Challenger* explosion in 1986 hamstrung rapid progress. Eventually a decision was made, after an extensive series of risk analyses, to make a greater commitment to robotic missions. These missions served as test cases. They proved that the presumed need for multiple redundant systems was excessive. Redundancy was able to be reduced when human spaceflight resumed with testing on the Moon base in preparation for the Mars expedition. The Moon base was built almost totally without human labor, although technicians were at the site.

Russia

Russia’s space program is only now slowly recovering from its fire sale of the 1990s and early 2000s. Desperate for hard currency, the government auctioned off a significant portion of the space program, including hardware and technical experts. The space program was split into different jurisdictions with the dissolution of the Soviet Union, and cooperation among them was difficult. Economic troubles further exacerbated the decline. Although the sale of Russia's space program was often under the guise of international cooperation, desperation was the driver. And the international community took full advantage. Now that relative stability prevails, one can expect a renewed commitment to space by Russia. The government is hinging a great deal of its credibility on the ability to regain prestige through space activities.

Europe

Grandiose plans for European unification in 1992 faltered and only slowly regained momentum following the turn of the century. European Space Agency programs, once a model for cooperation, were a victim of this failure to get along. Dealing with post-Cold War Eastern Europe since the 1990s further diverted attention from space activities. Integrating some of those battered economies into the EC, or in the case of Germany, reunification, took time and money away from space activities.

Europe's position in the space community, however, declined significantly. Even though internal wounds healed, and ESA got back on its feet, much ground had been lost. Europe clearly became, and remains today, a junior partner in international projects. As unification gains momentum, however, many space experts feel it will rise to the top.

Agreements with Japan, which provided much of the funding to revamp ESA, shifted the direction of ESA from developing its own space capability to sharing its expertise and developing niches required by the international community. ESA, for example, remains the world leader in launch capability and has concentrated efforts in that area.

Japan

The Japanese joined the international community's space efforts after much internal political wrangling. Those who argued for Japan becoming the world leader in space technology were only narrowly defeated by those favoring cooperation. The debate over participating in the international space station beginning in 2000 was the turning point. Japan finally signed on in 2005.

Japanese leaders came to the realization that their drive for global technological supremacy had extended beyond the country's limited resources and that Japan simply could not be the world leader in every technological area. Because Japan's position in the space race was far from the top, its leaders decided not to aim for technological supremacy in space, but instead to draw on the resources of other programs that were further advanced. Yet the Japanese have become leaders in space technology areas such as robotics, and Japan is a valuable partner to the international space community.

The Japanese are particularly interested in commercial spinoffs from space ventures. Private industry dictates the government's commitment to space to a much larger extent than in the United States. The nation has been working towards becoming the world leader in the information-based economy for decades. Satellite communications have played an integral part in developing their information infrastructure. Although communications has been the primary driver for Japan's participation in space, research into materials processing, manufacturing, biotechnology, and medicine have been of great interest.

Rather than take on the United States and Europe, partnerships that precluded redundancy and improved overall efficiency were formed, especially after the 2005 decision to join the international space station. The partnership is wary. There is concern in the United States that Japan will take what it has learned from the United States and try to take over the market. On Japan's side, there are questions about the political will and economic capability of the United States to hold up its end of the bargain.

Japan's primary contribution is in space robotics. Autonomous guided vehicles that were developed for factory use have been adapted for navigating the Moon and Mars. Robotic systems repair and maintain space structures, such as platforms, the space station, and probes destined for distant planets. They also perform more mundane housekeeping tasks on space vessels. Expert systems play an important role here. They have developed to the point where they mimic, and in many cases surpass, human capabilities. Low-level learning capabilities are emerging.

Other countries

China, the best of the rest, continues to attract launch business by charging significantly less for commercial satellite launches than is charged by its international counterparts. There are no other significant international or commercial players. Some countries continue to develop domestic space programs for reasons of national prestige, but these are minor programs. Some equatorial countries rent launch sites, because launches are easier near the equator, and others house tracking stations for space activities.

National pride

While the international community plans to go to Mars, Indonesia is now in orbit, having just launched its first domestically manufactured and operated agricultural sensing satellite. Despite the availability of international satellite networks, some countries invest national prestige in developing their own satellite or space program.

Most countries participate in space activities through leasing space aboard international vessels, stations, and bases. Some countries, and, increasingly, large multinational corporations, pay for small pieces of the big international space projects.

Military applications

Military applications in space are evolving from conflict prevention to conflict resolution. Military prospects in space declined as ideas such as the Strategic Defense Initiative (SDI) or Star Wars lost momentum. Funding based on the Cold War fell sharply in the 1990s. The Cold War mentality had set up space as the next battlefield, but today space provides the capability to monitor troop and equipment movements, whereas enforcement takes place on Earth. The 2007 Lima Space Weapons Treaty outlawed weapons in space.

Reigning in international outlaws

The case of Johan Sabini, the international outcast leader of Zaire, appears in textbooks across the world. Despite repeated warnings from UN peacemakers, Sabini invaded neighboring Zambia. Reconnaissance satellites detected his troop movements. Peacemaking troops stopped the invasion, and Sabini was arrested, tried, convicted, and removed from power by the World Court.

The scope of reconnaissance activities is beyond the capacity of one nation. The UN nominally coordinates the multinational peacekeeping observation system. Individual countries own the satellites, and their participation depends on their perception of benefits from drawing on the resources of others. Secrecy concerns have not been satisfactorily resolved. The United States continues to threaten to withdraw from international space projects, citing lax security. These threats have typically been accommodated with granting a greater voice to the United States in decision making.

Satellite reconnaissance provides real-time updates of target or troop movements. Areas with a high probability for conflict are carefully watched. If the reconnaissance detects abnormal patterns, the parties involved are quickly warned. Failure to comply with warnings lead to preventative measures, typically the deployment of UN peacemaking troops.

Reconnaissance satellites have been adapted for nonmilitary operations as well, such as monitoring natural or environmental disasters or other emergency situations. Timely recording of events surrounding the detonation of a nuclear device by terrorists in the Middle East in 2020 helped mitigate the effects of fallout and helped the cleanup.

Technology transfer from military space programs, such as the old SDI was a boon to peaceful applications because it emphasized surveillance and tracking. Spy satellite data was made available for commercial and scientific research. Law enforcement has benefited from surveillance and tracking technologies. The proper balance between monitoring needs and privacy needs, however, is still an issue for governments and the World Court.

Commercialization

Today's thriving commercial space industry has its roots in former U.S. president Ronald Reagan's decision, following the explosion of the space shuttle *Challenger* in 1986, to bar the shuttles from carrying commercial satellites. This encouraged private industry to get into the launch business. Europe's Ariane competed with U.S. companies and won the lion's share of the business in the 1980s and 1990s. Russia and Japan also became competitive. By the 2010s, China made significant inroads by offering cut-rate prices.

Commercial space activities, 1990 and 2025*

1990	2025
satellite communications	satellite communications
launch services	Earth observations
Earth observations	launch services
microgravity research	space robotics
orbital facilities/infrastructure	materials processing

*In order of importance

The competition was fierce in the early stages, as launching capacity far exceeded payloads. Following a shakeout and a gradual growth in demand for launches, a strong industry began to emerge around 2000. Today, governments focus on the big programs, such as space stations, the Moon base, and the manned Mars expedition. Private industry continues to provide launches in addition to activities such as processing, interpreting, and selling data; satellite communications; remote sensing; and materials processing. Private contractors are responsible for carrying out government plans with its oversight.

Profile of U.S. commercial space players

Player	Description	% of market
The space establishment	Origins as NASA and/or military contractors, e.g., Hughes Dynamics	48%
The entrepreneurs	Small start-up venture capitalists that gamble on high-risk, high-potential projects	32%
Business consumers	Companies established within their particular industry seeking to take advantage of potential payoffs from space, but space is not their primary activity	20%

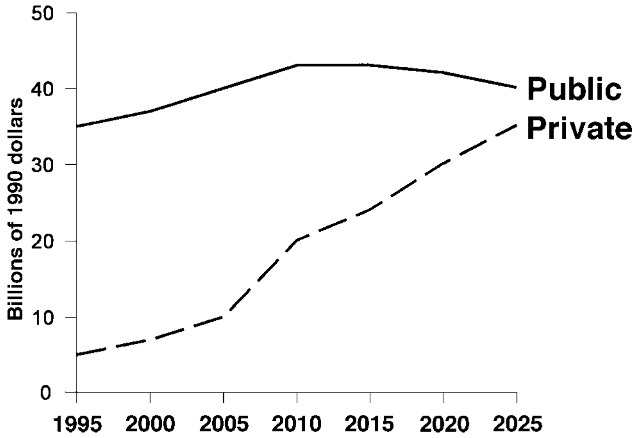
A reasonable balance has been struck between industry risk and reliance on tax dollars for space activities that indirectly benefit society. Since 2010, most governments have turned management of some space activities over to private enterprises. In the United States, for example, government spending has declined slightly since 2010, and private spending over the same period has more than doubled.

What is commercial space?

A commercial space activity in contrast to contract work is defined as a venture where private capital is at risk, where there are existing, or potential, nongovernment customers, where the commercial market ultimately determines the viability of the enterprise, and where primary responsibility and management initiative are with the private sector.

Governments provided the initial investment that stimulated the private sector to get involved. Government commitments to space activities, in the form of start-up incentives, persuaded companies that the risk was worth taking. Government-owned, contractor-operated, joint ventures and consortia arrangements were stepping stones. Joint Endeavor Agreements, which beginning in the late 1980s allowed companies to fund space experiments with free transportation on the shuttle in exchange for sharing the research results, became popular only about 15 years ago. The figure below compares public and private spending over the last 30 years.

Public and Private Space Spending



The remaining seven (down from 17 in the 1990s) Centers for Commercial Development of Space (CCDS), with hundreds of affiliates from industry, academic institutions, and state and federal agencies, received large cash grants of millions of dollars to leverage cash and other kinds of investment. NASA paid the transportation costs to space. When the program began in the 1980s, it was hoped that it would take five years for it to become self-financing. But it was not until 2018 that the centers turned a profit.

Communications satellites, back in the 1980s, were the first space industry to be completely owned and operated by the private sector. Arrangements similar to COMSAT, a private organization to spur the satellite industry, were a model for other commercial sectors. Initially, governments reserved their needs for space launches and other services to native companies. An international agreement in 2003 opened the market, mirroring the global trend toward freer trade.

Partnership between the two sectors is comfortable. Dissemination of data from remote sensing has been private, with government subsidy, since the 1980s, despite its unprofitability until the last few decades. The private sector makes widespread use of the data. Private industry continues to launch the big government programs. The inter-space freight industry, which includes shipping among and between space facilities and specializes in orbital transfer vehicles, docking capabilities, and satellite servicing, continues to grow.

In the 1990s, big players in space diversified into other industries. They believed being totally dependent on space for their existence was too risky. This opened the playing field. There was an influx of military personnel into space occupations around the turn of the century, whose positive impacts have only recently been felt. Small, nimble, entrepreneurial companies foresaw the potential to fill niches and are doing so. These companies came from all across the globe. Some established companies in other industries, such as construction, adapted quickly to being players in the building of the Moon base. Insurance companies are heavy investors in satellite technology. Weather prediction and natural disaster monitoring, for example, can help save them money, so they fund research in this area.

What follows

The benefits of space activities are in three categories: planetary, social, and space science. The table below lists the topics within each category.

Applications of Space Activities

Planetary

pollution tracking and control
natural disaster monitoring
atmospheric research
managing the environment

Space science

advances in astronomy
SETI (the search for extraterrestrial intelligence)
interspace travel
space station
Moon base
planned Mars expedition
prospects for colonies

Social

satellite communications
weather forecasting
crime surveillance and tracking
entertainment opportunities
robots for hazardous duty
energy technology transfer
coordinating transportation
insights into human physiology and psychology
mining
manufacturing and materials processing modules
health, medicine, and pharmaceuticals
crop and fisheries monitoring
solar lighting experiments
systems engineering

Planetary

Space activities continue to improve our understanding of the Earth. Space observations demonstrated the impact of human activities on the atmosphere and the ozone layer in the 1990s. These observations enabled the creation of a strategy to deal with the ozone holes. Corrective actions first involved the banning of chemicals harmful to the ozone layer, completed by 2000. Further research focused on and led to the development of plans to patch the holes by releasing “adhesive” chemicals and synthetic ozone into the atmosphere. Similarly, the identification and beginning of corrective actions for global warming are underway.

Remote sensing applications, such as the now full-blown Earth Observation System (EOS), monitor hundreds of planetary processes such as photosynthetic activity and tides and wind currents and enable an integrated study of the Earth as a planet. Last year, for example, a UN-sponsored program to measure the world’s oxygen supply began. International cooperation in caring for the physical planet is a model for cooperation in other areas. It is indicative of the trend to a totally managed environment. Water, coral reefs, the atmosphere (including global warming and the ozone holes), the polar ice caps, biodiversity, minerals, hazardous waste, landfills, deforestation, and soil are some of the myriad ecosystems of the Earth being monitored from space.

Planetary applications of space activities

- pollution tracking and control
- natural-disaster monitoring
- atmospheric research
- managing the environment

Pollution tracking and control

Pollution tracking and control is a robust industry, accounting for 20% of GDP growth this century. The trend is toward a greater emphasis on control. Knowledge of pollution and its effects has advanced rapidly as a result of years of data collection and interpretation. Analysis is giving way to corrective actions, such as emissions limits, banning of harmful chemicals, and heavy government investment in R&D for alternatives.

Natural-disaster monitoring

Advances in remote sensing and geology enable the prediction of natural disasters, such as earthquakes and hurricanes, weeks, days, or hours in advance. Remote sensing detects ground motion (seismic activity) and maps and monitors undersea faults, greatly improving prediction accuracy. Many natural disasters are now effectively managed, controlled, or prevented. Damage from the Great San Francisco Earthquake of 2018, for example, was held to a minimum thanks to advanced preparations enabled by long- and short-range forecasts that were acted on by government and business.

Policy question

What do government leaders do when informed of a pending natural disaster that they are powerless to do anything about? Do they inform people anyway? Do they say nothing? Leaders have been following a mixed strategy.

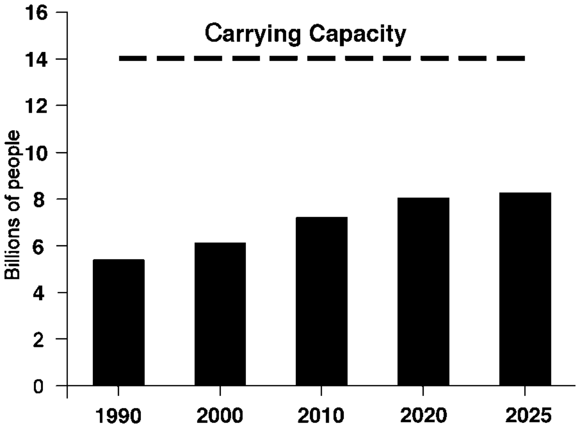
Atmospheric research

Climate change drives a great deal of planetary research. Understanding of upper atmosphere composition and dynamics benefits from this attention. Definitive proof of global warming, derived largely from EOS observations a decade ago, directs lots of funding into enacting plans that have long been sitting on shelves. Interaction between the atmosphere and the oceans has enriched our understanding of hydrology. Satellites and earth probes are supplemented with land observatories.

Managing the environment

Satellites interact with ground-based sensors and microprocessors to create a smart environment and dramatically increase understanding of the planet. Changes can be measured instantaneously. Genetics adds to the capability to manipulate the environment directly or those responses to it. Crops resisting local pests, for example, have been genetically engineered. The effects of genetic manipulation on the environment are closely monitored by environmental groups.

Approaching the Limits: World Population to 1990 to 2025



Diagnosis of the planet's health and monitoring functions are precursors of restoration, maintenance, and planning projects. Environmental engineering is a booming industry. An annual assessment of the health of the planet, first popularized back in the last century by the WorldWatch Institute's *State of the World* reports, is now an international undertaking. WorldWatch now puts out *Restoring the Earth*. The United Nation's *Earth Development Report* draws on a massive database made possible by the EOS a constellation of sensing networks under UN supervision.

WorldWatch Institute
Restoring the Earth, 2023

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This database is the foundation for global environmental management. It is eagerly tapped by the public and private sectors, as well as individual citizens. For example, what urban planner today would not take advantage of the mass of knowledge about potential hazards, estimated carrying capacity, and estimated growth potential?

An interesting development in planetary management was the flourishing of the 3Rs (recycling, reclamation, and remanufacturing). Their evolution can be traced to the institutionalization of the sustainability concept in the 1990s. This triggered discussion of 3Rs practices. Recycling received the early emphasis. Gradually, the three came to be considered together. Today 40% of materials in the United States are recycled, 30% are reclaimed or remanufactured, and 30% are either burned or buried.

The primary enabling capability for the 3Rs was the assembly of the Resource Tracking Model, an offshoot of the EOS, which provided the first reliable quantified estimates of the planet's carrying capacity. Although they are incredibly complex, early findings were that we are approaching depletion of many important resources. The so-called doomsayers, going back to 1972's *Limits to Growth*, now have evidence to back their arguments in favor of sustainability. Armed with this data, their arguments found an audience, and 3Rs programs sprang up primarily at the local level. Regional programs, with some national support, are now well underway. An international agreement on the 3Rs is currently being negotiated at the Melbourne Waste Minimization Conference.

Social

A second area of space applications includes those applications that directly benefit society, in contrast to planetary applications with indirect benefits. Markets range from communications to the fishing industry, which locates fish by identifying phytoplankton, to shipping, ocean drilling, and industrial environmental monitoring groups.

Satellite communications

Satellite communications networks continue to be the primary economic payoff from space activities. They complement the worldwide, broadband network of networks based on fiber optics. They are particularly useful for remote or sparsely populated areas, where the economics for laying fiber optics are unfavorable. People are able to talk, see, or send information to almost anyone in the world. LEO satellites supplement terrestrial cells to form personal communications networks. Direct broadcast satellites broadcast television programs in remote areas to very small aperture terminals (VSATs) which are small rooftop antennas. They provide personal communications services as well.

Today's satellites use higher frequencies, have more onboard power and processing capabilities, are fully digital, weigh less, are compatible with ground-based broadband digital networks, and use ion propulsion, which is weak on Earth, but is sufficient in frictionless vacuum of space. Intersatellite links, in which information is exchanged by transmitting modulated laser beams rather than the microwaves that were used in the past, are growing. Intelsat, Eutelsat, and Inmarsat are connected in space by laser intersatellite links.

Weather forecasting

Weather satellites combine with aircraft, balloons, ground-based observations, and telecommunications linkages to supercomputer-based modeling, smart databases, real-time data, and graphic displays to deliver unprecedented forecasting accuracy. Today's forecasts have longer time horizons (months and seasons rather than weeks) and shorter time horizons (minutes rather than hours) than those of the previous century.

The limits to forecasting

Incomplete understanding of chaotic systems limits further improvement in weather forecasting accuracy. Chaos theory tells us that even a tiny change in initial conditions can have dramatic effects on the behavior of a chaotic system. Until we learn to map initial conditions better, weather forecasting will remain an imprecise science.

Better characterization of initial conditions of the atmosphere since the 2000s has improved short-term weather forecasts. Private forecasting services delivering detailed, tailored forecasts to corporations have proliferated since then. Advances in meteorology enable the prediction of specific storms with a useful lead time and a finer ability to distinguish among types of weather, such as rain versus hail. Forecasting solar storms, which produce solar flares capable of damaging satellites or other space equipment, has been a growth enterprise. Industries heavily influenced by the weather, such as tourism and agriculture, finance many of the projects that have extended the forecasting envelope.

Crime surveillance and tracking

Satellite tracking and monitoring capabilities, including the ability to detect electronic vehicle identity tags from space has been bad news for criminals. Car theft, once a major crime, has virtually disappeared. Fugitives are more readily tracked down. This is not meant to imply that crime no longer exists, but it has been significantly curtailed.

Many are calling for the use of solar mirrors to blanket high-crime areas at night with light, therefore discouraging criminal activity or aiding law enforcement officials pursuing potential lawbreakers. Opposition to this proposal on civil liberties grounds has been equally vociferous, and it has not yet been tried.

Entertainment opportunities

Rapidly growing interest in space-related entertainment suggests that it will be the fastest-growing segment of the commercial market for space activities over the next few decades. Entrepreneurs have seized on the soaring global growth of the entertainment industry and tapped into space as a novel medium. Movies continue to borrow space themes. Space tours are projected to be a thriving industry within the next 50 years. Plans are already being laid for a globe-circling sightseeing space ship. A huge market awaits virtual reality participation in exploration. Virtual reality spinoffs include training in addition to recreation. It is a routine simulation tool. There are hundreds of space simulation games on computer networks across the world. Space educates as it entertains. Interest in science among school children has risen with each new space achievement.

Robots for hazardous duty

Robots and telerobots performing hazardous duty in space have been adapted for Earth duty such as monitoring fusion experiments, running fission plants, overseeing hazardous waste disposal and conversion, and other dangerous duties. Robots and other automated machinery are commonplace inside and outside the factory in agriculture, building construction, underseas activities, as well as in space.

Breakthroughs in machine sensing and vision after 2000 enabled a much wider range of applications for robots and telerobots. Equally critical have been developments in artificial intelligence (AI), which improve robots' onboard information processing capabilities. As advances in AI have progressed since 2010, use of teleoperation has diminished and fully autonomous AI robotic systems have increased.

Robots are used for satellite retrieval; servicing and maintenance; deploying or assembling large structures such as space platforms, space stations, large antennas, and solar power stations; rescue operations; and in situ exploration and analysis of lunar and planetary terrain. Robots perform more space operations than humans. But the versatility of astronauts and long-term plans for space settlement keep human space exploration alive. The key technological advance has been in sensors, particularly machine vision, as well as onboard and teleoperated intelligence. Computer integration of cells of robots continues to improve. Robots are capable of receiving communications, understanding their environment, formulating and executing plans, and monitoring their operation.

Energy technology transfer

Perhaps the most exciting development in space activities is the experiments with solar power satellites (SPSs), which collect solar energy with large arrays in orbit and convert it to radio waves, which are then beamed to collecting antennas. SPSs are exposed to the sun 99% of the year and receive 10 times as much energy as an earthbound solar station. The rising costs of Earth-based energy stimulated a revisiting of SPS research. The development of supporting infrastructure was crucial. The space station and Moon base provided the platforms for the necessary construction and manufacturing.

Earth energy technologies in space

Photovoltaic efficiencies continue to improve. Today's 50% efficiency is much higher than was thought possible 25 years ago when efficiencies seem stalled in the 30% range. Space experiments are responsible for this breakthrough.

Fuel cells are a supplement to SPSs. They produce water in addition to electricity, invaluable to the Moon base, given the absence of water on the Moon. During the day, solar power breaks down water into hydrogen and oxygen which is stored, and then recombined in fuel cells to produce energy when solar energy is unavailable.

Experiments with nuclear fission in space continue. Nuclear thermal propulsion is promising in that it produces a larger amount of energy from a smaller propellant mass. The disadvantage, at least when human crews are involved, is the mass of shielding required to protect from radiation. Space disposal of radioactive wastes has been proved technologically feasible but is still too expensive and politically unpalatable.

An SPS has been used successfully for power on the Moon base. Advocates are confident that the transition to providing power to Earth on an experimental basis will be made within a decade. Opponents deride the proposal as science fiction fantasy, citing the harmful effects of a powerful energy beam on the environment. Further study will be certainly required before a trial run is allowed.

This new energy source could be critical as there has been a substantial increase in energy demand on Earth. Although *per capita* energy consumption has been declining in World 1, it has risen dramatically in the rest of the world.

Public utilities use remote sensing to monitor energy efficiency of users. Wasteful energy practices are easily detected with heat-sensing infrared devices. Large users are routinely monitored, while plans are being laid to extend coverage to all users.

Cryogenic fuel storage of liquid hydrogen continues to lower boil-off levels. This technology has been proposed for the Mars expeditions, which will require large amounts of fuel storage.

Coordinating transportation

Satellites play a role in monitoring transportation infrastructures as well. The safety of aviation, rail, and highway infrastructures is maintained with the assistance of sensors interacting with satellites. Intelligent vehicle highway systems now dot the landscapes in the United States, Japan, and Europe. Initially, IVHS relied on cellular stations for positioning but now take advantage of the greater accuracy that satellite global positioning systems offer.

Global positioning uses ground-based devices, detecting beacons or ranging signals to triangulate a position, as well as three-dimensional sensing for collision avoidance. Positioning is accurate to within centimeters.

Satellite mapping techniques are continually increasing the real-time information available for applications such as crop or forest status, environmental assessment, energy production, geographic information systems, disaster assessment, and land use planning.

Transportation has improved not only through advances in navigation technology enabled by satellites, but also in technology transfer to avionics. Hypersonic travel, at five times the speed of sound, is now commonplace. Space planes developed in 2020, which can take off horizontally and fly to low Earth orbit, and single-stage, heavy lift rockets are used for launching satellites and other payloads. Proposals to use space planes for rapid intercontinental travel—getting from Europe to the United States in less than two hours—have been stalled by high costs.

Insights into human physiology and psychology

The international space station and Moon base are test beds for the physical and psychological effects of space on humans. Extensive life-support systems for extended stays in space have been developed. As the current human expedition to Mars so far indicates, extended stays in space are possible. The full effects will not be known until the mission returns and detailed debriefings take place.

Understanding of human biology continues to grow with assistance from space research. Microgravity effects, including effects at varying gravity, are much better understood. Conception in microgravity has been successful, although the first birth in space awaits further research. Autonomous and/or robotic systems augment human capabilities in space. Cell research studies, such as aging, anemia, bioprocessing, cell secretion, diabetes, drug delivery, hormone production, immune function, light effects, muscular atrophy, and osteoporosis, are ongoing.

Artificial gravity, created by revolving the space structure, is an effective means to avoid the effects of microgravity. It is now the preferred means of space stays, with microgravity experiments ongoing, but of lesser priority.

The study of human psychology in novel environments continues to be aided by research from the study of astronauts. Critics argue, with justification, that astronauts are not representative of the general population and, therefore, the results are questionable. The rigorous selection process for astronauts, and the intensive training they undergo indeed prepares them in such a way that it is hard to extrapolate the findings to the rest of the population.

Still the findings form a basis from which further study can proceed. As more people become space travelers, findings should become richer. Human factors such as productivity in space and teamwork in extreme environments and conditions have been adapted to hiring practices; cognitive/personality screening; stress measurement, evaluation, and management; and interfaces with sophisticated equipment here on Earth.

Genetic testing determines who is suitable for space travel. Some of the criteria used are response to g-force, heart and metabolic rates, and predisposition to claustrophobia. Genetic manipulation, namely augmentation to better withstand the space environment, is being planned for the next Mars mission.

Mining operations

Mining operations include solar concentrators to melt lunar soil to create glass and other building materials. Mining ilmenite, a mineral made of iron, titanium, and oxygen for rocket fuel on the moon is scheduled to begin next year. Active exploration of mining Helium 3, an abundant source estimated to be capable of providing over 10 times the energy equivalent of fossil fuels remaining on Earth, is ongoing.

Mining advances and lessons from the Earth aid lunar mining and vice versa. Petroleum engineering technology has been modified for lunar mining. Remote sensing and expert systems lend precision to the targeting of lunar resources.

A graduate degree in space geology has become a valuable commodity. It includes mining as well as sample analysis from the Moon, Mars, Venus, and eventually other planetary specimens. Experience in lunar mining will provide the basis for future asteroid harvesting.

Manufacturing and materials processing

Manufacturing in microgravity offers one of the most practical applications of space activity. Its importance is diminishing, however, as new technologies developed on Earth make the microgravity environment less attractive. Space manufacturing modules still dot low Earth orbits. The primary products are those that could not be made on Earth, or could be manufactured to a quality that would be prohibitively expensive to achieve on Earth. Manufacturing techniques on Earth and in space are transferred to and from one another. Automated materials handling and automated storage and retrieval systems have lessons directly applicable to remote operations in space, such as docking vehicles and transferring materials from launch vehicles to a space platform or station or Moon base.

Abundant materials opportunities

Knowledge of how materials interact in microgravity are applied to materials processing on Earth. Processing pure materials such as crystals and microscopic latex spheres for calibration are important for pharmaceuticals and other biologicals, biotechnology, chemicals, and electronics industries. Advanced materials processing, such as powder metallurgy; crystal shaping for electronic optics, detectors, and separators; advanced coating and composites tooling; radiation-resistant materials; fault and damage tolerant, self-healing materials and structures; lightweight and self-assembling structures; and adaptive smart materials, surface coatings, electrodeposition, and polymer projects are routinely employed. The vacuum in space allows for the controlled deposition of thin films by epitaxial growth, which is now a powerful technique for electronic, superconducting, and magnetic materials and devices.

Space provides new materials, as well as new means of materials processing. Materials advances improve space structures. Research is enabling the development of materials in space for space structures. A planned addition to the Moon base, for example, will be made almost entirely of materials indigenous to the Moon. Ceramics are able to withstand extremely high temperatures. Advanced composites are light, strong, stable, temperature-resistant and long-lived. Materials for all space structures are stronger, more tolerant of space conditions, and more intelligent, as they are armed with mechatronic devices and integrated with information and control systems. Lighter launch vehicles increase energy efficiency. Photovoltaic grid materials have boosted energy efficiency to 50%.

Zero gravity offers intriguing possibilities for combining materials which cannot be combined on Earth. Liquids that cannot be mixed due to the effects of gravity can be mixed in microgravity to form new alloys. Applications could include aircraft or even motor vehicle parts that are highly heat resistant and longer-lasting. Commercial ventures are researching the possibilities. The Centers for Commercial Development of Space, with help from NASA, spurred research in this area, until it became self-sustaining. CCDS's first important contribution was in 1986, to the development of the first superconducting materials at temperatures above liquid nitrogen, 77 Kelvin. Experiments in this area led to improved materials for radiation detectors.

Recoverable launch capsules, or commercial experiment transporters, called COMETs, were developed in the 1990s for low Earth orbit experiments. They parachute back inside capsules to Earth. Spacehab, Inc., modules inside the space shuttle, and reusable external launch vehicle tanks boosted into orbit, were used until the new international space station was constructed in 2010.

Astronomical technologies offering markets and generating spinoffs include glasses and lightweight materials, high-tolerance machining and polishing, reflective coatings, wavefront control and intelligent optics, and large-scale computer simulation.

All materials are, of course, designed for recycling, reclamation, and remanufacturing.

Health, medicine, and pharmaceuticals

Space medicine research competes with biotech medical research for R&D dollars. Niche applications for Earth predominate. Most space medicine research focuses on treatments needed for those in space.

The health effects of microgravity have improved our understanding of how the body works. Macromolecular crystallography, the primary technique for determining the three-dimensional atomic arrangements within complicated biological macromolecules, has been essential to understanding the fundamental structure/function relationships that govern biological systems.

Primary applications are in pharmaceuticals—such as the delicate separation of complex, nearly identical substances—drug design, protein engineering, and in the chemical and biotechnology industries. Experiments have helped determine enzymes targeted by acquired immunodeficiency syndrome (AIDS) and cancer researchers.

Cancer treatment from space

A new treatment for cancer resulted from protein crystal growth experiments performed in a microgravity space laboratory that identified structures triggering the destructive growth of cancerous cells and enabled the development of drugs to block them.

Bioprocessing experiments, which form and manipulate biomaterials in microgravity, have been instrumental in developing advanced biocompatible materials formed from the self-assembly and polymerization of proteins and other macromolecules. Applications may include artificial body parts, such as skin, tendons, blood vessels, and corneas, as well as advanced membrane technologies.

Crop and fisheries monitoring

Soil science experiments, as precursors to terraforming, have made significant contributions to developing erosion-resistant soils. These synthetic soils, designed for specific surroundings, are used to restore terrain as well as enhance agriculture. Sensing technology enables the alignment of forestry practices with environmental objectives of forest ecology. In agriculture, production is fine-tuned to meet soil and weather conditions. Remote sensing detects plankton and monitors fish population to prevent disruption of the food chain and overfishing.

Lessons from growing food in difficult space environments have been transferred to growing food in harsh environments on Earth. The use of artificial lighting and new growing media combine with careful genetic manipulation to produce food practically anywhere. Automated plant growth facilities have been developed to grow food in space. They provide oxygen as well as food, remove carbon dioxide, and purify water. These facilities are in use at the space station and the Moon base.

Solar lighting experiments

Solar mirrors bring light to regions once darkened for seasons at a time. Alaska and the Scandinavian countries are pioneering this technology. The effect is similar to a bright moonlit night. Though still experimental—the first large-scale trial was just five years ago—initial response is encouraging. Surveys of the local populations indicate that a majority favors continuing the trials. Some complained of trouble sleeping and that their biological clocks were disrupted. Entrepreneurs are investigating using multiple mirrors in tourist areas to extend the day.

Systems engineering lessons

Space programs continue to pioneer the practice of systems engineering for managing extremely complex systems. Huge computing and data storage needs have been met with advances in computer engineering such as parallel processing, artificial intelligence, neural networks, fuzzy logic, and routing theory. Data storage problems have been abating only within the last five years. Exponential increases in data volumes from the Earth Observing System overwhelmed capacity. The trillion bits of data required 10,000 reels of the old magnetic storage tape. Optical storage technology and magnetic and semiconducting storage, still used today, filled the gap. The long-awaited magnetic bubble or holographic storage technologies are finally being used, albeit on a small scale so far. Three-dimensional interactive images are integrated into computer and information systems, mixing video, graphics, text, sounds, and voice.

Space science

Long the primary purpose of space exploration, in recent years the focus has shifted to more tangible applications as the terrestrial agenda continually squeezed budgets. Yet, space science has prospered despite the shift in emphasis.

Space science applications

- advances in astronomy
- search for extraterrestrial intelligence
- interspace travel
- Moon base
- planned Mars expedition
- prospects for colonies

Creating a separate category does not imply that there are no planetary and social benefits from space science. Our growing understanding of the universe, in particular neighboring planets, improves knowledge about our own planet. Certainly the protective measures we have taken to avoid an asteroid collision are practical.

Advances in the pure science aspects of physiology, materials processing, geology, archeology, robotics, automation, virtual reality, cryogenics, energy, materials, computer and software engineering, information and control systems, and sensors in turn advance commercial prospects. The practical applications of these sciences are discussed in the social applications section of this chapter.

A critical management strategy was the shift from custom-designed space structures and vessels to standard models. This innovation, adopted by the international space community, saved money in times of tight budgets and increased the prospects for interaction among different space programs. It was accomplished only after years of excruciating negotiations.

Advances in astronomy

We know that the universe is roughly 18 billion years old. The origin and evolution of the our solar system is far clearer today than at the turn of the century. In the 1990s the Hubble Telescope, despite its flaws, narrowed the error in the universe's age to +/- two billion years. The new generation of orbital telescopes emerging after 2015 further narrowed the range of error to hundreds of millions of years.

Advances in telescopes

Telescopes are now constructed of space-durable, lighter-weight radiation-resistant materials and coatings with greater thermal dynamic and structural stability. They continue to improve by orders of magnitude each generation, roughly every 20 years. Large, rigid, single mirrors have been replaced by segmented mirrors, multiple-mirror telescopes and interferometers, instruments in which an acoustic, optical, or microwave interference pattern of fringes is formed and used to make precision measurements. Space-based interferometry offers resolutions 10,000 times greater than individual telescopes. Adaptive optics, which correct for atmospheric distortion, are enabling large gains in resolving power and sensitivity.

Astronomy today benefits considerably from being largely outside the Earth's atmosphere, with its haze, fog, and clouds shielding some of the radiation emitted from celestial bodies.

Permanent orbiting observatories are now in various orbits. The profusion of space probes is too large to detail here. Intelligent probes are studying planetary systems, comets, asteroids, quasars, and black holes. Results include thousands of asteroids being identified. They are made of rock, metal alloys, and carbon compounds. The carbon-based ones may be useful for mining. (Space entrepreneurs are already expressing interest.) They could be used to make oil, food, or have water extracted from them. The nature of black holes and quasars has been clarified.

The search for extraterrestrial intelligence

SETI is now an international program built around the hodgepodge effort begun in the United States last century. The name was retained for sentimental reasons. Confirmation of the existence of planets around other stars in 1996 boosted the credibility of SETI researchers arguing for funding. This finding dramatically increases the prospects for detecting intelligent life.

False signal

For a brief week in 2007, the world drew together in marveling over the seeming discovery of intelligent life in the universe. Scientists cautioned against overreaction, but most became so caught up with the possibility that caution was abandoned. A common cause for humanity drew people together. Daily life paused, much as it does in wartime, until scientists identified the signal as false and ruled out intelligent life for now.

Interspace travel

Liquid and solid rocket fuels continue to predominate, despite an extensive menu of alternative launch technologies. Single-stage-to-orbit rockets have predominated since 2000. The alternative technologies are presented in the table below, followed by a more detailed discussion.

Propulsion Technologies

Type	Year Proved	Prospects
Fission: thermal propulsion	2019	Shield technology for manned expeditions has been improved enough to be considered for the Mars expedition
Laser	R&D	R&D in this area has lost out; small-scale research only
Tethers	2001	Experiments ongoing; more practical applications needed
Rail guns	2014	Are used to launch small satellites into low Earth orbit
Ion drives	R&D	Losing favor to solar sails
Solar sails	R&D	Significant long-term potential
Plasma Thrusters	2023	Prototypes are being developed
Antimatter	R&D	Costs still too high

Fission thermal propulsion is under consideration for robotic missions, but the problem of shielding human expeditions has not been resolved. Prospects for fusion are dimming, as long-awaited breakthroughs in fusion energy research have failed to materialize. The old maxim that “commercial fusion is always 50 years away” probably still holds true. Helium 3, which is below the surface of the Moon, is a likely fusion fuel source, if and when the propulsion technology arrives.

Protests by environmental groups have impeded research into laser propulsion. The effects of generating the powerful beam that would be required are not fully understood. Environmental groups have opposed any testing until safety can be assured. This presents a chicken and egg problem, as tests are needed for greater understanding.

Tethers, which conduct electromagnetic energy between two spacecraft (usually from a large vessel to a small probe) got off to an inauspicious start back in the last century, when a NASA tether failed to unravel properly. The feasibility of tethers was demonstrated in 2001, but in this case the technology awaits a market.

An electromagnetic rail gun was deployed on Mauna Kea, Hawaii’s highest mountain in 2019, and in the Ural mountains in Russia last year. In the United States, a bitter struggle over environmental effects postponed the construction of the rail gun for five years. Use so far has been limited, and will be for at least the next few years, to small payloads, such as satellites, and to low Earth orbits. R&D continues into possibilities for expanding use. For instance, plans are underway to deploy a rail gun on the Moon for transporting mining materials back to Earth.

Ion drives and solar sails are exotic technologies competing for the same market. To date, solar sails have received more attention. They are thought to be effective close to the sun, not much further out than Mars. Research favors ion drives for travel beyond Mars, but getting beyond Mars has been a lower priority to date.

Plasma thruster prototypes are under development. They use electrical and magnetic fields to force propellant out of the engine. They are an excellent transition technology, since they are not far removed from liquid and solid fuel rockets currently being used.

The concept of antimatter propulsion, in which the antimatter converts all of its mass to energy, has been proven, but the cost of producing the antimatter is still prohibitive.

Space planes are beginning to find commercial practical applications. Lessons from the composites required for entering and leaving orbit, as well as novel aerodynamic techniques, are being applied in everyday aviation. Space planes take off from conventional runways and exit the atmosphere, rather than being launched. Originally developed for military missions, they are now being proposed for very fast intercontinental travel. A flight from the United States to Japan or Europe could take under two hours on a space plane.

Space travel and space-walking technologies are advancing. Extravehicular activity suits have done away with the requirement that astronauts breathe pure oxygen for hours before walking in space. Robotic orbital transfer vehicles, space tugs, and in-space assembly and construction technologies have reduced the need for human expeditions and space walks.

Space sanitation companies have emerged over the past 10 years to clean up the growing volume of space debris. They are paid by satellite and other space-structure operators to prevent debris from colliding with their equipment. The companies have also taken advantage of salvage opportunities.

Space station

The international space station in low Earth orbit endured lengthy battles over its utility before its completion in 2013. Opponents argued that the cost of the station, now estimated to be $120 billion over its proposed 30-year lifetime, did not justify its expected yields. They argued that smaller-scale projects from which funds were diverted ultimately would have been more useful.

Although commercial benefits clearly did not recoup the investment, it established a space infrastructure with electric power, thermal control, warehousing space, communications, fuel storage, docking capabilities, and interspace transportation. The flight telerobotic servicer for assisting in operations and maintenance of space structures had its trial run on the space station.

These capabilities have led most to conclude that building the station was, on net balance, positive.

The station evolved from being a U.S. facility with some international participation to an international facility with U.S. participation. It supports eight full-time astronauts. The four research modules are divided between the main partners—the United States, Europe, Japan, China, and Russia—and countries or corporations leasing space. The leasing funds pay a significant portion of keeping the station afloat. Optimists expected the station to be self-supporting by now, but it is not, and it does not seem likely to be for at least the next decade.

Preparing for the Moon base and Mars expedition became the primary rationale for its construction. Commercial benefits took a back seat. Plans for an observatory and an Earth observation post were abandoned in the initial design to keep costs down. The observatory was built on the Moon base instead. An Earth observation post was added to the space station in 2022. The space station's previous role as the hub of space activity has been downgraded somewhat as the Moon base assumes that role. It remains, however, an important way station. People visiting the moon base, for example, launch to the space station and transfer into an interorbital vehicle to finish the trip. The station has long been a satellite launch point and service and maintenance center. It refuels space vehicles bound for longer journeys and has been a test bed for experimentation with new forms of space-vehicle propulsion systems. It will have direct responsibility for maintaining the solar power satellites, if they ever produce power for Earth.

Moon base

Scientific experiments, astronomy, and preparations for the expedition to Mars are the base's most important functions. The Moon is being thoroughly probed and sampled to determine its origins and for potential mining operations. Small-scale mining operations began with the completion of the initial stage of the base in 2020. Astronomy from the Moon sharply increases resolution, which is inhibited by the atmosphere on Earth. The effects of microgravity on astronauts for extended periods of time have been studied in preparation for the Mars expedition. The microgravity environment is also used for materials processing research and development.

The Moon base consists of mostly underground modules, which protects inhabitants from the radiation that hits the atmosphereless surface. Fission and photovoltaics supply energy, supplemented by recently deployed solar power satellites. Solar mirrors generate artificial light that eases the monotony of month-long day-night cycles.

Designs for building the base were solicited from the world's leading architects. Civil engineers assist with supporting infrastructure, and a long-term goal is to use moon materials and terraforming experiments to make the base self-sufficient. Although the initial modules were constructed on Earth and launched to the Moon, scientists expect to be able to add on a module with indigenous materials within the next decade.

The Moon base is an ideal way station for deep space travel, as its gravity is one-sixth that of Earth. The expeditions to Mars will include a refueling on the Moon base. The base has been a rehearsal studio for the Mars expedition. The base is supplied from space platforms as well as the international space station.

Planned Mars expedition

The planned expedition to Mars is expected to last two years. The international participants have been debating the means for getting to Mars for the past five years and have yet to decide. Japan, Europe, and China have argued in favor of a novel approach, in which a robotic return vehicle and fuel-processing facility would be launched from the Moon base and precede the astronauts. The astronauts would then arrive in a one-way launch vehicle. The fuel-processing facility would take advantage of the carbon dioxide in Mars's atmosphere to make the fuel necessary for the return trip, which would be loaded into the return vehicle. The United States and Russia prefer nuclear thermal propulsion, which they feel is a more proven approach.

The astronauts will spend months on the surface conducting experiments. A goldmine of scientific information has been gathered. Balloons will be deployed in orbit, to test, and deploy instruments, and two Mars rovers will take soil samples and map the terrain.

A robotic mission last year to Phobos, a Mars moon, has not returned yet but promises to provide valuable data about surface and atmosphere of Mars. Two more robotic missions to Phobos, followed by three to Mars itself, will gather information and lay the groundwork for manned expedition. Robotic rovers provided samples, and other scientific and engineering information useful to the manned expedition.

Prospects for colonies

Plans for space colonies are already being laid by private entrepreneurs. Colonies are not a solution to the population problem at this time or for the foreseeable future. They could be useful as test beds for long-term prospects, but at this time they could be no more than novelties.

Terraforming experiments, which modify conditions to enable human survival, have been undertaken on the international space station. Primitive experiments with creating ecospheres began on Earth in the various biosphere experiments beginning in the 1990s. Although the science was sometimes questionable, and the line between science and entertainment was often breached, the results were helpful. Small-scale terraforming experiments are scheduled on the Moon.

Critical Developments, 1994-2025

Year	**Development**	**Effect**
1998	U.S. space station *Freedom* project scrapped.	Paved way for U.S. participation in international space station.
2000	Chemicals harmful to ozone banned worldwide.	Remote sensing monitors compliance.
2001	Resource Tracking Model developed with assistance of Earth Observation System.	Part of international efforts to assess the planet's carrying capacity.
2002	International Space Agency formed.	Part of the UN system; a forum for negotiations.
2003	European Space Agency multi-year funding model adopted by ISA.	Boost to long-term planning efforts.
2003	International trade agreement opens launch markets.	National space programs no longer reserve launches for native industry.
2005	Japan signs on to international space station project.	Japan decides in favor of international cooperation rather than competition in space.
2007	Lima Space Weapons Treaty signed.	Space is preserved as a weapon-free zone.
2010	U.S. government spending on space levels off; private spending continues to surge.	Commercial ventures becoming increasingly viable.
2013	China launches most payloads of any nation.	China joins the world's space leaders.
2017	ISA and International Red Cross form the International Disaster Tracking Program.	Space-based monitoring to provide advance warning and help coordinate relief efforts.
2025	Pollution tracking and control accounts for 20% of world GDP growth from 2000 to 2025.	Space-based tracking efforts an important commercial application.

Unrealized Hopes and Fears

Event	Potential Effects
SETI discovers intelligent life.	Alters humanity's conception of its role in the universe and boosts the importance of the international space program.
International political movement against space activities emphasizes the need to take care of problems on Earth first.	Loss of political support for space exploration.
Nanotechnology enables nanomachines for application such as flushing astronauts' systems from the effects of microgravity, terraforming, or developing a space suit managed by billions of mechanical nanocomputers.	Enhances technological capabilities available for space activities.
A hostile nation develops space weaponry.	Shifts the use of space from peaceful to military purposes.
Meteoroid demolishes the space station or moon base.	Questions wisdom of manned exploration and leading to greater emphasis on robotic missions.
Economic depression.	Loss of funding for space activities.
UN votes down the use of space surveillance technology, citing invasion of national sovereignty.	Reduces effectiveness of peacemaking operations.
UN collapses.	Disintegration of international cooperation; reemergence of competitive national space programs.
Rocket or satellite crashes to Earth, killing or injuring people.	Loss of support for space activities.
World Court fight over ownership of space as countries lay claim to space above them.	Assigning areas of space becomes divisive, much like disputes over water rights.
Environmental impact statements required for space.	Slowing of space development as impacts are studied.