Space Solutions to Earth's Global Challenges

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Using Space Technology 'Back Home' on our Toughest Challenges:

NASA Technologies and Contributions Towards Sustainability of our Planet

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Abstract

Since its creation 50 years ago, NASA has nurtured partnerships to transfer NASA-developed technologies for public benefit. These benefits have reached throughout the economy and around the globe. NASA's research has not only enhanced our understanding of air and space, but also our understanding of the Earth and how to sustain the Earth and its resources. This paper documents some of the important contributions of NASA's technology to sustainability of our planet, and prospects for future contributions. From using remote-sensing data from satellites, NASA scientists are giving us a better understanding of the causes and effects of global climate change, and NASA technologies have advanced irrigation and crop management techniques for farmers around the world. NASA technologies have been saving lives and improving the quality of life in many ways all over the globe. The paper will provide an overall framework of how NASA is contributing to the sustainability of our planet and improvements to quality of life, as well as some specific recent examples including: the use of a portable water filtration device that is a direct descendant of a technology developed for use on the ISS and space shuttle to provide clean drinking water to people in Pakistan, the Dominican Republic, and Northern Iraq; space suit technologies have been adapted to create a type of weather balloon that have been used as an affordable "satellite" for cell phone coverage in remote parts of Africa; a technique for diffusing landmines with surplus NASA rocket fuel that is saving lives in Kosovo and Jordan; a device originally developed for monitoring astronaut health that is now being used in networks of sensors for monitoring environmental changes, including monitoring water quality in Vietnam and tracking public health information in Ethiopia; the radiant barrier material popularized as the "space blanket" that was shipped in mass quantities to Pakistan after the earthquakes in 2005; and techniques developed for groundwater remediation at Kennedy Space Center's launch sites that have been used to reclaim areas heavily contaminated with solvents and industrial byproducts.

1. Introduction

NASA has a long history of finding applications of space and aeronautics technologies that provide broad public benefits in addition to pushing back boundaries in science and exploration. The basis for NASA's contributions along these lines can be directly traced to the opening declaration of policy and purpose of the National Aeronautics and Space Act that created NASA in 1958 [1], which said "The Congress hereby declares that it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind." The Space Act goes on to say that NASA should "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

NASA's mission in aeronautics and space drives the development of new technology that can provide benefits in many areas. As NASA's Administrator, Mike Griffin stated in his speech to kickoff NASA's 50th Anniversary lecture series, "I do think that there is a very strong link, the strongest possible link between doing the hardest things that human beings do, which is flying in space, and how it benefits the rest of our economy and, indeed, our whole way of life." [2]

Contributing to some of the toughest challenges facing us on planet Earth, particularly those related to sustainability of our home planet, is something that NASA takes very seriously. This connection was highlighted by NASA Deputy Administrator Shana Dale recently at the NASA Future Forum in Seattle [3]:

> *"Sustainability of our Earth permeates NASA's missions. For example, to survive on the Moon's surface we must find ways to create, collect, store and use energy without access to fossil fuels. Other sources of energy must be developed into practical resources that humans can use in extreme environments. As we continue to explore, new sources of energy and the means to deliver it can help to address the pressing demand for energy right here on Earth. Space exploration demands cleaner and more efficient sources of energy that can operate in extreme environments without toxic effects.*
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> *One example of a new and relatively clean energy source offering tremendous potential is solar power. NASA pioneered the use of solar cells in the Apollo Program and continues to push the limits of this technology today, with the solar "wings" that collect the sun's energy for use onboard the International Space Station. Technologies for beaming solar power – moving it from collectors in one place to a remote destination where it may be stored or transferred – hold the promise of a clean and abundant energy source, one that is virtually limitless for as long as the sun endures. The potential impact of these technologies, already being explored by NASA, is so great that we can hardly imagine it, affecting the lives of not only Americans but of every person on the face of the planet.*
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> *In addition to renewable energy sources, space exploration contributes to sustainability in many other ways. In space travel, physical space is limited, weight is critical, and resources are severely constrained. Every watt of energy is accounted for; every cubic liter of air is transported and monitored. Space exploration drives the development of technologies with minimal impact to these tiny ecologies – and, by extension, to the ecology of Planet Earth. These technologies include advanced recycling techniques; treating waste and converting it back into usable resources, as well as new, green power systems. Outposts on the Moon, as well as travel to Mars, will require lighter materials, manufacturing techniques with little waste or pollution, and even better methods of recycling and reuse, contributing to the development of sustainable systems on our own world.*
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> *But perhaps NASA's biggest contribution to sustainability is the development and operation of Earth-observing satellites. Fourteen of those research satellites that peer down on the Earth are in orbit today. These satellites make countless contributions to the understanding of our home planet. They warn us of gathering storms, approaching hurricanes, and shrinking snowcaps. They provide essential information critical to helping us understand our changing environment, showing pollution from factories, and even increasing the productivity of farmers. And we're not done: Another seven Earth science missions are under development at NASA, three of which will launch this year. All in all, NASA invests about $1.5 billion every year in Earth Science."*

Many NASA activities, particularly in Earth Science, are specifically intended to address space solutions to Earth's global challenges. In addition, there are also corollary benefits to much of NASA's technology whose development was spurred by other mission focused

applications. When NASA technology is put to use in an application that provides public benefit, but is a different application than what the technology was originally developed for, that new application is referred to as a Spinoff. Each year, NASA publishes 40-50 recent examples of NASA technology being put to public use in the annual *Spinoff* publication. Over 1,500 have been documented and are available and searchable online [4]. The *Spinoff* document is a product of NASA's Innovative Partnerships Program (IPP), reflecting one of the principal roles of IPP – to actively seek out partnerships that transfer NASA technology for application with broad public benefit in health and medicine, transportation, public safety, consumer goods, homes and recreation, environmental and agricultural resources, computer technology, and industrial productivity [5]. Not all of NASA's technologies that contribute to sustainability of the planet are Spinoffs, but many are, including some of the examples in the following discussion.

2. Challenges Addressed by Space Technology

There are numerous NASA activities and technologies making important contributions to sustainability of the planet – far too many to attempt to address them all in this paper. One of the most important and well known is Earth observation and environmental monitoring. NASA develops technologies and spacecraft directly for these purposes, and many papers and briefings at this symposium are discussing various benefits from these activities. This paper will not attempt to duplicate what others are already discussing, but rather seek to summarize some of the applications of space technology that may not be as familiar. These applications are, in large part, not the original purpose of the technology. Rather, they are the application of technologies that had their origins in pushing the envelope in space and aeronautics, but are also being applied to some of the most pressing challenges we are facing here on planet Earth.

To provide some focus and structure rather than simply a long list of contributions, this paper will address four specific challenges – areas where NASA technologies are being put to work and making a real difference around the world. A few recent and representative examples of how this is being accomplished will be summarized for each of the four challenge areas, which are:

- Assistance to Developing Countries,
- Disaster Warning and Relief,
- Environmental Cleanup, and
- Use of Green Technologies.

For each of these challenge areas, several examples will be provided to illustrate how NASA technologies are making contributions towards addressing the challenges. The examples provided are representative, and are not an exhaustive list of NASA contributions. The types of examples for each challenge are summarized in Table 1 below.

Assistance to Developing Countries • Clean Drinking Water • Improved Agriculture • Telemedicine and wireless networks • Improved Environmental Decision Making	**Disaster Warning and Relief** • Earthquake relief • Tsunami Warning • Wildfire Response • Hurricane Warning
Environmental Cleanup • Groundwater Remediation • Land Mine Cleanup • Landfill Cleanup • Oil Spill Cleanup	**Use of Green Technologies** • Aeronautics Technologies • Green Buildings • Encouraging Green Technologies • Solar Power Applications • Paint Stripping • Global Research into Energy and the Environment at NASA (GREEN)

Table 1. There are many examples of how NASA technologies are contributing to the four challenge areas.

3. Assistance to Developing Countries

NASA technologies are making contributions to developing countries in many ways, a few of which will be summarized here. Technologies for clean drinking water have been developed for use on the Space Shuttle and the International Space Station, and are now being used around the world in villages that are suffering from lack of clean water. NASA technology is being used to monitor crop conditions and improve crop yield, and agricultural methods for growing food in space on long duration space missions are being applied to increase the survivability and yield of crops on Earth. Technologies developed to monitor astronaut health for telemedicine on long duration space flight are being used to communicate public health information, and advanced visualization techniques are providing improved environmental decision making in the developing world.

Clean Drinking Water. According to the United Nations, there are 1.1 billion people, or 18 per cent of the world's population, who lack access to safe drinking water and an estimated 42,000 people die every week from diseases related to low water quality and an absence of adequate sanitation [6]. The major sources of this contaminated water are bacteria, viruses, and cysts. These pathogenic organisms breed in unprotected water and unsanitary conditions. Even cleanup efforts are often thwarted by recontamination of treated water during transportation and storage prior to use.

Contamination of water sources is also a challenge for space explorers. Ensuring clean water on-orbit is critical for safe operations of the Space Shuttle and the International Space Station. To address this problem for NASA, the Microbial Check Valve (MCV) was developed by the Umpqua Research Company of Myrtle Creek, Oregon, with funding from

NASA's Small Business Innovation Research (SBIR) program. MCV technology has been used on every Space Shuttle mission to prevent growth of pathogens in the crew drinking water supply, and is now also the basis for water purification systems now deployed in rural areas and developing countries around the world.

The Water Security Corporation (WSC) of Sparks, Nevada has licensed the MCV technology from Umpqua and now provides MCV-based systems to developing countries where the lack of safe drinking water is a serious health concern. By combining the benefits of chemical adsorption, ion exchange, and ultra-filtration processes, WSC systems can provide safe, healthy, good-tasting water from the most challenging water sources. The technology has been deployed to underdeveloped regions of the world where water sources may be heavily contaminated with bacteria, as described in the examples that follow.

The village of Sabana San Juan has a population of about 300 people and is located in the mountains in the Dominican Republic. The villagers had to travel 5 miles to reach the nearest source of drinkable water. There is a spring that near the village although it is contaminated by herbicides, pesticides, and animal waste. In spite of the contamination, many people used the water. As shown in Figure 1, a WSC water filtration and purification system using MCV technology was delivered an installed by Hermandad, a humanitarian organization. Since there is no electricity, solar panels were installed to power the pump. Now the villagers enjoy safe, clean drinking water and are trained to maintain the system.

Figure 1. Clean water in Sabana San Juan, in the Dominican Republic.

Figure 2. Clean water in Kendala, Iraq.

The organization Concern for Kids has been active in the Kurdish region of Northern Iraq near Kendala, and water has been a key focus of their organization. Many villages have contaminated wells and source water which impact the health of the population and prevent stable growth. Concern for Kids partnered with WSC and engineers from NASA's Marshall Space Flight Center to bring an MCV-based water purification system to service villages in the area, as shown in Figure 2. The system is mounted on a pick up truck with a generator and pump and travels each week from village to village pumping water from the local source in a storage tank to service the village.

MCV-based systems have also been delivered to Pakistan, Thailand, Ukraine, Fiji, Australia, Argentina, Barbados, and Afghanistan.

Improved Agriculture. To conduct research on plant growth in space that could provide a food source for long duration space missions, NASA developed growth chambers that incorporated unique lighting technology, high-efficiency temperature and humidity controls, and automation technology. American Ag-Tec International used this growth chamber as the perfect vehicle for growing minitubers, which serve as nuclear seed stock for potatoes. This allows minitubers to be grown year-round in extreme environmental settings, such as deserts or excessively cold regions. The ability to accelerate the growth cycle of minitubers allows for the introduction of new varieties of potatoes more than three times faster than prior methods. The minitubers enabled by space technology eliminate seasonal and geographical limitations, are more resistant to disease, increase crop yield, and are available for shipment and distribution throughout the world.

NASA's Small Business Technology Transfer (STTR) program funded a hyperspectral crop imaging project to enhance airborne sensing and ground-truth validation for crop inspection. This was done in a partnership between NASA's Goddard Space Flight Center, and SpecTIR LLC, headquartered in Reno, Nevada. In farming, the application of water, pesticides, or fertilizer can be tailored to the needs of crops, based on conditions exposed in hyperspectral imagery. Other areas of application for this technology include pollution and contamination monitoring; wetland and forestry characterization; water quality assessment; oil, gas, and mineral exploration; and submerged aquatic vegetation mapping.

NASA scientists are collaborating with the U.S. Department of Agriculture (USDA) and the National Oceanic and Atmospheric Administration (NOAA) to better understand seasonal variability of climate and apply that understanding to agricultural issues. Space provides an ideal vantage point for the measurement of critical parameters for agricultural production, such as water availability, radiation, and vegetation health, over large areas and at low cost. NASA is teaming with the USDA's Foreign Agricultural Service and the National Agricultural Statistics Service to incorporate NASA space-based measurements into models and systems used to monitor and forecast global and domestic agricultural production.

Telemedicine and wireless networks. NASA needs technologies for remote delivery of medical care – or telemedicine – for long-duration spaceflight missions. To help develop those technologies, the National Biocomputation Center was established as a partnership between the Stanford University School of Medicine's Department of Surgery and NASA's Ames Research Center. In early 2005, researchers at the National Biocomputation Center formed a spinoff company, Intelesense Technologies, to use telemedicine sensors for many earthbound applications.

As an example of how this technology is benefiting the developing world, Intelesense is applying this technology in Ethiopia, one of the harshest, driest regions of the world and the third most populated nation in Africa. There, the company is developing a network for communicating public health information from 126 remote medical clinics to 5 corresponding hospitals. The sensors connect all these players with a robust, wireless

infrastructure, in an area where there is no reliable cellular or telecommunications network, and even power supplies are unreliable.

Employing networks of wireless sensors for air, water, weather, and imagery, and then integrating the sensor information with other data sources, Intelesense is applying NASA technology (Figure 3) to help clients better understand how environments and people are linked, monitor and protect natural resources, track emerging infectious diseases like avian influenza (bird flu), predict and adapt to environmental changes, provide for sustainable development, reduce the costs and impacts of natural disasters, and provide an effective and intelligent response to such disasters.

Figure 3. Intelesense is applying NASA technologies to provide environmental, public health, and other data.

Improved Environmental Decision Making. In a recent speech at Calvin College, NASA Administrator Mike Griffin described how NASA is using satellite imagery and advanced visualization technologies to help developing countries in many ways [7]:

> *"NASA is helping the poor countries of Central America with SERVIR (Spanish for "to serve"), a high-tech satellite visualization system that monitors weather and climate, helps to track and combat wildfires, improves land use for city planning and agricultural practices, and helps local officials respond faster to natural disasters. Meteorologists and disaster response experts in Central America use SERVIR to see where rain will fall, where flooding will occur, the location of forest fires, hurricanes, tornadoes and pretty much anything nature can dish out. Most recently, NASA research brought together radar imagery and other satellite data to help the Dominican Republic's government respond to extensive flooding in the wake of Tropical Storm Noel. The SERVIR project along with other acts of kindness and charity by the embedded NASA team has been such a success that one of our researchers, Dan Irwin, actually found himself being nominated to be the mayor for the small town of San Andres, Guatemala. Dan respectfully declined, but he was touched by the vote of confidence. NASA is now working with the State Department, NOAA, and other agencies to help provide capabilities like SERVIR to other regions of the world, like Africa."*

Information on the SERVIR project is available at http://www.servir.net/.

4. Disaster Warning and Relief

NASA capabilities and technologies have been applied in numerous ways for disaster warning and relief, with a few representative examples discussed here. For earthquake relief, two examples describe how NASA technology helped refugees from a major 2005 earthquake in Pakistan. New methods for early warning of Tsunamis will improve warning

reliability which could save lives and reduce false alarms. NASA technologies have helped respond to wildfires, including those that ravaged Southern California last fall. NASA technologies and satellite observations are also improving the accuracy of hurricane warnings.

Earthquake relief. In October 2005, an earthquake registering 7.6 on the Richter scale caused widespread destruction in northern Pakistan, as well as in Afghanistan and northern India. It is estimated that over 79,000 people died, 135,000 people were injured, and 400,000 houses were destroyed. Bakalot, Pakistan, which was devastated by earthquake, had many refugees with no source of clean water other than what was brought in by tankers for months. Water Security Corporation brought an MCV-based water purification system (as described previously) to the site, working with the Al-Khidmat Foundation, a Pakistani relief organization. Water is now gravity fed from a local stream (with contaminated water) to the system, which then purifies the water for the local population, as shown in Figure 4.

Figure 4. Clean water in Bakalot, Pakistan.

Figure 5. Earthquake refugees in Afghanistan keeping warm with 'Space blankets.'

Also in response to these earthquakes, Richard Berger, an avid hiker, was moved by the plight of the people in the remote villages of Pakistan and began a search for products that might help relieve their suffering. He settled on Heatsheets rescue blankets (perhaps better known as 'space blankets') whose mass production was enabled by NASA applications of metallized plastic in the 1960's. In cooperation with a network of small companies, internet fundraising, and in partnership with Mercy Corps, of Portland, Oregon, for distribution, tens of thousands of the reflective emergency blankets were distributed in Pakistan after earthquakes devastated the region, as shown in Figure 5.

Tsunami Warning. New NASA research on tsunamis has yielded an innovative method to improve existing tsunami warning systems [8]. Conventional tsunami warning systems rely on estimates of an earthquake's magnitude to determine whether a large tsunami will be generated. Earthquake magnitude alone is not always a reliable indicator of tsunami potential. The 2004 Indian Ocean quake generated a huge tsunami, while the 2005 Nias

(Indonesia) quake did not, even though both had almost the same magnitude from initial estimates. Between 2005 and 2007, five false tsunami alarms were issued worldwide. Such alarms have negative societal and economic effects.

Researchers at NASA's Jet Propulsion Laboratory, Pasadena, Calif., have demonstrated that real-time data from NASA's network of global positioning system (GPS) stations can detect ground motions preceding tsunamis and reliably estimate a tsunami's destructive potential within minutes, well before it reaches coastal areas. This new method estimates the energy an undersea earthquake transfers to the ocean to generate a tsunami by using data from coastal GPS stations near the epicenter. With these data, ocean floor displacements caused by the earthquake can be inferred. The method could lead to development of more reliable global tsunami warning systems, saving lives and reducing false alarms.

Wildfire Response. In a recent speech at Calvin College, NASA Administrator Mike Griffin described how NASA technologies have been put to use in response to wildfires [7].

> *"Sometimes our contribution is not to create new technologies, but to integrate various existing capabilities in innovative ways. Last fall, NASA used its air and space capabilities to aid Californians during the terrible wildfires that ravaged Southern California. Our Earth-observing satellites helped monitor the spread of those terrible fires. We also sent an unmanned aerial vehicle equipped with unique IR sensors to fly over the fires. The Ikhana UAV, which is operated through a cooperative effort between the Ames and Dryden Research Centers in California, peered through heavy smoke and darkness, found hot spots and flames, and transmitted the sensor information to a computer server at Ames, where it was combined with Google Earth maps and then transmitted to operations centers to provide firefighters a much better understanding of the situation, aiding disaster managers in allocating firefighting resources. The quick turnaround made a difference too. Information gathered from piloted airplanes currently must wait for the aircraft to land before it can be transmitted, while the Ikhana UAV sent the data to fire incident commanders only minutes after acquisition. Eventually and in concert with other agencies, we at NASA hope to have an entire network of sensors which will provide information about natural disasters at every scale, from the ground up to space, aiding responders and hopefully saving lives."*

The Moderate Resolution Imaging Spectroradiometer (MODIS) Land Rapid Response System exemplifies how NASA data are making a difference in planning for and responding to disasters. This system was created to serve the need for quick access to products from the MODIS instrument--onboard NASA's Terra and Aqua satellites--when disaster strikes. NASA collaborates with the University of Maryland, the USDA's Forest Service (USFS), and NOAA to provide firefighters with the most up-to-date maps and satellite images from Terra and Aqua, to help them strategically plan their response. After the fire is under control, land managers can use the information to assist them in planning for rehabilitating the burned area and for protecting water quality in the affected area.

Hurricane Warning. Data from NASA satellite missions make significant contributions in the area of hurricane and flood prediction. NOAA combines satellite-derived estimates of precipitation and wind speed and direction from NASA spacecraft with data from other sources such as hurricane buoys, hurricane hunter aircraft, and air-borne Doppler radar.

Doing so substantially improves the accuracy of forecasts for landfall, track and intensity of hurricanes, and increases the lead-time for warnings for both hurricanes and floods. More accurate forecasts, in turn, enable improved decision-making leading to more enhanced community preparedness for these types of events.

5. Environmental Cleanup

NASA technologies are being put to use in a variety of ways for environmental cleanup, as these representative examples show. Techniques developed to clean up solvents used to clean rocket parts have broad application for groundwater remediation. Land mines are being safely cleaned up using excess rocket propellant from the Shuttle's solid rocket boosters. Land fills are being cleaned up using technology created to purify water on board the Space Station. In addition, NASA technologies led to a new product that effectively cleans oil spills, even in particularly sensitive areas such as coral reefs and mangroves.

Groundwater Remediation. During the early years of the space program, the ground surrounding Launch Complex 34 (LC-34) at Kennedy Space Center was polluted with chlorinated solvents used to clean rocket parts. When released into the ground, these solvents sink through the soil and groundwater until they are contained by a nonpermeable surface such as bedrock. Then, they pool and dissolve into the aquifer into which they were released. Dense nonaqueous phase liquids (DNAPLs) - liquids denser than water dial do not dissolve or mix easily in water - have low solubility, meaning that the pool will continue to contaminate the groundwater for extended periods. It was important for Kennedy to get this site cleaned up, because the Space Center is also a National Wildlife Refuge, home to thousands of shorebirds, endangered sea turtles and eagles, manatees, alligators, and diverse habitats that include brackish marshes and salt water estuaries.

To clean up this Apollo-era mess, Kennedy Space Center and the University of Central Florida partnered to develop a biodegradable environmental cleanup technology – Emulsified Zero-Valent Iron (EZVI). EZVI uses iron particles in an environmentally friendly oil and water base to neutralize toxic chemicals. Other partners in this effort include the U.S. Department of Energy, the U.S. Department of Defense, the U.S. Environmental Protection Agency (EPA), GeoSyntec, Inc., and NASA's Small Business Technology Transfer (STTR) Program. NASA's success in remediating this historic launch site has led to numerous commercial applications through non-exclusive licenses for EZVI to several companies, including Weston Solutions, Inc., and Toxicological and Environmental Associates, Inc. EZVI is now restoring contaminated sites to health in Arkansas, California, Florida, North Carolina, and Texas, as shown in Figure 6. The Environmental Protection Agency (EPA) estimates

Figure 6. EZVI remediation technology in process.

that DNAPLs are present at 60 to 70% of all sites on the Superfund National Priorities List.

Land Mine Cleanup. It is estimated that between 60 and 120 million active land mines are scattered around the world in approximately 70 countries. Every year, 26,000 people, usually women and children, are killed or maimed by a land mine. Two techniques commonly used to disarm mines are a direct, attended operation or a remote operation using high explosives. The direct approach poses considerable risk to the military or humanitarian agency personnel who serve on the detonation teams, as well as to civilians. Remote detonation, which creates a high order detonation of the mine by detonating an explosive charge, can produce shrapnel, which may damage buildings or increase minefield contamination.

Thiokol Propulsion is using NASA's surplus rocket propellant to produce a new flare that destroys land mines safely and easily. The technique, developed by Thiokol in collaboration with DE Technologies, Inc., involves placing a Thiokol-produced flare next to the uncovered land mine. The flare is then ignited using a battery-triggered electric match. Using the solidified rocket fuel as an incendiary, the flare burns a hole in the land mine's case and ignites the explosive contents. With the explosive material burned away, the mine is disarmed and no longer poses a threat.

Through a Memorandum of Agreement between Thiokol and NASA's Marshall Space Flight Center, Thiokol is allowed to make use of scrap Reusable Solid Rocket Motor (RSRM) propellant. Such an arrangement benefits both parties, as NASA is able to reduce propellant waste without negatively impacting the environment, and Thiokol is able to access the materials needed to develop the flare at a low cost. The result is a demining device, which neutralizes land mines in the field without setting off their explosive materials. So far, Thiokol has sold over 700 units for use in the field in Kosovo and Jordan. Thanks to NASA's rocket science, innocent lives will be saved or protected from permanent disabilities.

Landfill Cleanup. With Small Business Innovation Research (SBIR) funding from NASA's Ames Research Center, Osmotek, Inc., of Corvallis, Oregon, delivered a water purification system that met the stringent criteria for flight aboard the Space Station. During the course of the SBIR work, Osmotek researchers came up with the idea of using their osmosis technique not to produce water for consumption, but to extract water from a waste product. The unit is being used in landfills, where toxic chemicals, or leachate, can be "leached" into a water source that can eventually reach a river or lake. The company's system treats leachate onsite at municipal or industrial landfills by filtering the water and leaving behind the leachate, which can then be solidified into a substance that will not seep into water.

Oil Spill Cleanup. A product known as the Petroleum Remediation Product (PRP) has been invented to clean up environmental hazards such as oil spills using a process called 'bioremediation' (encapsulating live cells). The basic technology behind PRP is thousands of microcapsules—tiny balls of beeswax that contain microorganisms. The product makes use of NASA microencapsulation technology. Work was done at the Jet Propulsion Laboratory (JPL) to demonstrate the feasibility of encapsulating live cells, while technology

developed at the Marshall Space Flight Center for experiments in orbital production of microspheres provides the basic design of the delivery system.

Water cannot penetrate the microcapsule's cell, but oil is absorbed right into the beeswax spheres as they float on the water's surface. This way, the contaminants—chemical compounds that originally come from crude oil such as fuels, motor oils, or petroleum hydrocarbons—are caught before they settle. The microorganisms degrade hydrocarbons (organic 'fat' found in petroleum) by secreting enzymes that transform oil into carbon dioxide and water. These elements are released into the environment leaving residue that is environmentally safe and can be consumed by fish as food. This ecological wonder has been packaged for specific uses to create a variety of different commercial products for such things as maintenance of ship bilges and cleaning and containing areas contaminated by oil products. Use of PRP is especially effective for environmental cleanup in sensitive areas like coral reefs and mangroves.

6. Use of Green Technologies

NASA is undertaking many efforts to improve energy efficiency and reduce environmental impact. This is being done directly in NASA activities as well as through NASA research and technologies. NASA, along with many other Federal Agencies, is only building green buildings now. Aeronautics technologies from NASA continue to reduce aircraft noise and emissions, and even demonstrating "green approaches" for aircraft. NASA technologies are greening products and activities, from solar-powered refrigerators, to the environmentally-friendly stripping of paint from the hulls of ships.

Aeronautics Technologies. In the area of aeronautics, NASA has been investing in changes to both the airspace system and the aircraft that fly within it. NASA is conducting research that would enable significant reductions in noise and emissions. The agency is exploring not only advanced airplane research, but also air traffic management research to develop operational concepts and procedures that would enable increases in capacity two to three times what we have today, while enabling reduced noise impact at airports and improved fuel savings. Recently, research was done that coupled ground-based air traffic control procedures with flight deck automation that resulted in the demonstration of "green approaches" at the San Francisco Airport, enabling optimal fuel burn and, hence, reduced carbon dioxide emissions.

Green Buildings. In 2006, NASA and twenty other federal agencies signed a Memorandum of Understanding that all facilities to be built would at a minimum, meet the U. S. Green Building Council Leadership in Energy and Environmental Design (LEED) Silver rating and strive to meet the LEED Gold rating. Since that time, NASA has achieved LEED certification on three facilities and has 12 others in design or under construction that have or will register for LEED certifications. As one example, NASA recently broke ground on a new green building at the Goddard Space Flight Center in Greenbelt, Md. The Exploration Sciences Building, the space center's first high-performance building, is pursuing a Silver rating through the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program. The three-story, 193,000-square-foot building, the first to be added

to the Goddard complex in over a decade, includes both offices and laboratories. NASA is using over 35 strategies within the LEED rating system to pursue the certification.

Encouraging Green Technologies. *NASA TechBriefs*, which publishes NASA technology available for public use on a monthly basis, recently sponsored the Create the Future design contest to identify and reward the best ideas for new products, and celebrates breakthrough thinking about problems of all kinds. There were six categories, including sustainable technologies, described as products that help reduce dependence on non-renewable energy resources, as well as products designed for other purposes using environmentally friendly materials or manufacturing processes. The winners were just announced and the overall winner, Litroenergy, was from the sustainable technologies category. Litroenergy is a patent pending designed light source material that emits light for 12 plus years without electricity or sun exposure. Steve Stark of MPK CO. of Clayton, Wisconsin, has developed long-life, self-luminous non-toxic micro particles called Litrospheres that emit light continuously for 12 plus years (half-life point) without any exposure to a light or other energy (not effected by cold or heat). This extremely low cost material offers 24/7 light, which can be injection molded or added to paint. Winners will be highlighted in April 2008 in the supplemental issue of *NASA TechBriefs* magazine.

Solar Power Applications. In the midst of developing battery-free, solar-powered refrigeration and air conditioning systems for habitats in space, an engineer at Johnson Space Center acknowledged the need for a comparable solar refrigerator that could operate in conjunction with the simple lighting systems already in place on Earth. As a result, he founded the company Solus Refrigeration, Inc., to take the patented advanced refrigeration technology he co-developed to commercial markets. Now known as SunDanze Refrigeration, Inc., the company produces battery-free, photovoltaic refrigeration systems under a license with NASA, and sells them globally.

The system uses thermal storage for cooling efficiency, with a direct connection between the vapor compression cooling system and the photovoltaic module. This is accomplished by integrating a phase-change material into a well-insulated refrigerator cabinet and developing a microprocessor-based control system that permits the direct connection of a photovoltaic module to a variable-speed compressor. The integration allows for peak power-point tracking and the elimination of batteries (thus, the environmental threat of improper battery disposal is eliminated).

Paint Stripping. A new robotic device that safely strips paint from the hulls of ships without polluting the environment is based on NASA robotics technology. The system, which has received kudos from environmentalist and undersea explorer Jean-Michel Cousteau, could revolutionize paint removal in the shipping industry. This new system consists of an automated robotic device that is magnetized to the ship, a set of high-pressure jet streams, and a controller that helps the robot navigate along the surface of the ship. Using this method, no toxic dust or paint flakes are generated to pollute nearby areas or to be inhaled by system operators. Only water is used in the paint-removal process, and it produces only dried paint chips and clean water. Since a powerful vacuum collects the used water and paint residue, nothing can escape to pollute the environment. The paint is

collected in a container and can then be disposed of safely. Previous stripping methods sandblasted paint from a ship's hull, producing large amounts of toxic airborne dust.

7. Future Prospects

As we look forward to NASA's next 50 years, future achievements will be enabled by new technologies—many perhaps not even imagined today. Technologies now being demonstrated and validated will be put into practice to improve disaster warning and recovery, and new methods will be developed. Additional capabilities will be put to use to continue helping address the challenges of the developing world, and indeed the whole planet. NASA will continue to proactively look for these opportunities and make contributions to the public good that our organic act directs us to do. One ongoing activity that has particularly good potential for identifying new benefits from NASA technology is Global Research into Energy and the Environment at NASA (GREEN).

Led by NASA's Ames Research Center in partnership with Google, a group of NASA and non-NASA scientists, engineers, and educators are known as the GREEN Team. Their goal is to determine how the tools and expertise developed for the exploration of space can be applied to problems on Earth. In addition to NASA's Earth Science programs, they are seeking to identify how technologies and lessons learned from life support, astrobiology, planetary science, systems engineering, and aerodynamics be applied to energy and environmental problems.

To address these issues, inform the NASA community about energy and environmental issues, and create connections between NASA and the energy/clean-tech community, the GREEN Team is conducting a series of events at NASA Ames. These events include lectures by policy makers, scientists, engineers, and philosophers followed by in-depth discussions with an invited audience of critical thinkers. Four events have been hosted at Ames to date, exploring NASA's role in several areas such as research on renewable energy including solar and wind power. There are about 20 active members of the Green Team at Ames, with about 400 researchers at Ames interested in clean technology. There is also interest and participants from other NASA Centers including the chief scientist from NASA's Glenn Research Center, who talked about advanced energy research at Glenn. Through these events, NASA looks to gain an understanding of technology needs in clean energy from industry, how NASA's research can be applied to clean technology applications, and with whom we can collaborate with to leverage our expertise for clean technology applications.

As NASA's Deputy Administrator, Shana Dale, said at the 2nd AIAA Space Exploration Conference on December 5, 2006 [9], "Of course, much of what we gain from exploring and settling the Moon will not be in what we find on it, or in the observations we make from it, but in the scientific and technological progress that will come in the process of doing it. And much of that will have direct economic and health benefits for those of us who remain behind on Earth."

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