PROGRESS AND PLANS OF NATIONAL NANOTECHNOLOGY INITIATIVE (NNI) AGENCIES

March 2019

National Aeronautics and Space Administration (NASA)[1]

Summary

The National Aeronautics and Space Administration is supporting research and development in nanotechnology to address NASA mission needs in aeronautics and space exploration. Nanotechnology R&D efforts include a combination of in-house activities, grants, and contracts that are focused in areas such as the development of advanced lightweight and multifunctional materials to reduce vehicle mass and improve performance; new materials to improve the performance of power generation and storage systems; advanced catalysts and membranes for more efficient air and water purification systems for long-duration human exploration missions; and new materials and manufacturing methods to produce low-power and compact sensors to detect chemical and biological species for astronaut health management and robotic exploration. Such efforts include a combination of theoretical and experimental research. NASA also supports the education and training of the next generation of scientists and engineers through a variety of programs ranging from internships for undergraduates and high school students, graduate fellowships such as the Space Technology Research Fellowships, and postdoctoral fellowships, as well as the continued development of faculty through Space Technology Early Career Awards and other activities.

Plans and Priorities by Program Component Area (PCA)

PCA 1. Nanotechnology Signature Initiatives and Grand Challenges

1a. Nanomanufacturing NSI

NASA continues to invest in efforts to improve the strength of carbon nanotube reinforced composites for use in lightweight, durable aircraft and spacecraft. Super-lightweight Aerospace Composites,[2] a project initiated in fiscal year (FY) 2018 under the Space Technology Mission Directorate (STMD) Game Changing Development Program, is focused on the development of high-strength carbon nanotube reinforcements for polymeric composites. This project is a collaboration between NASA, Nanocomp Technologies, and San Diego Composites to produce, at a large scale, carbon nanotube reinforcements with nearly three times the specific tensile strength of state-of-the-art carbon nanotube fibers and utilize them to fabricate polymeric composites with more than double the specific tensile strength of today's carbon nanotube fiber-reinforced composites. The project will demonstrate these advanced composites in cryogenic propellant tanks and other components for use in nuclear thermal propulsion systems for future NASA space exploration missions.

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[2] https://www.nasa.gov/feature/langley/nasa-looking-to-tiny-technology-for-big-payoffs

Under a public/private partnership funded under an STMD Tipping Point Project, NASA is collaborating with Northrop Grumman Innovation Systems (formerly Orbital ATK) to develop carbon nanotube-based vibration-damping structural composites for launch vehicle structures. These composites could eliminate or reduce the need for acoustic blankets and their associated parasitic weight.

1e. Water NSI

NASA is interested in the development of reliable, low maintenance, low-power methods for the purification of water for use in long-duration human exploration missions. Of particular interest are technologies that are not susceptible to biofouling. Under a Phase I SBIR, Sweetsense, Inc., in collaboration with Rice University, the University of Colorado, and Portland State University, is designing and demonstrating a "Nanophotonic Capillary Distiller," a capillary-based water recovery system.[3] This system utilizes a gold nanoparticle-enhanced pasteurization process to purify urine wastewater without the need for toxic oxidizing pretreatment chemicals. This project is managed out of the NASA Glenn Research Center.

NASA is also collaborating with the National Science Foundation (NSF)-funded Nanosystems Engineering Research Center for Nanotechnology Enabled Water Treatment (NEWT) at Rice University. The NASA Johnson Space Center (JSC) is interested in nanophotocatalysts, membrane nanotechnology, and nano-adsorbents currently under development by NEWT researchers for their potential applications in spacecraft water treatment and recovery for long-duration human space exploration.

PCA 2. Foundational Research

The Ultra-strong Composites by Design (US-COMP) NASA Space Technology Research Institute,[4] led by Michigan Technological University, is a collaboration between investigators at eleven universities, industry, NASA, and the Air Force Research Laboratory. This five-year, $15 million institute is focused on the development of the fundamental understanding to enable the design of carbon nanotube reinforcements and composites with mechanical properties that significantly exceed those of state-of-the-art aerospace-grade carbon fiber reinforced composites. To meet this goal, US-COMP is exploring optimized carbon nanotube material synthesis techniques, advanced composite processing methods, computational tools, and test methods.

NASA also continues to fund foundational research and the professional development of graduate students and faculty through the Space Technology Research Grants Program. In FY 2018, several new awards were made under the Space Technology Early Career Faculty program to investigate the utilization of graphene and nanoporous materials in the development of batteries capable of operating in extreme cold environments and in the development of metal organic frameworks for advanced CO_2 removal applications. These three-year awards will enable early career faculty to explore new ideas and approaches that are critical to making space travel and exploration more effective, affordable, and sustainable. Under the Space Technology Graduate Fellowship program, awards were made in FY 2018 in enhancing thermal transport in nanocomposites, immunosorbent nanoparticles for life support for deep-space missions, ultrahigh-temperature aerogels, protein-decorated nanoparticle-based sensors, and the synthesis of carbon nanotubes from methane.

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[3] https://sbir.gsfc.nasa.gov/SBIR/abstracts/18/sbir/phase1/SBIR-18-1-H3.01-8183.html

[4] http://us-comp.com/

PCA 3. Nanotechnology-Enabled Applications, Devices, and Systems

NASA is interested in the development of sensor technology to identify biological and chemical species for applications in human and robotic space exploration, including the further development of use of gene sequencing technology in a microgravity environment (see Goal 2 section below). If successful, this technology could enable the identification of microbes, diagnose diseases, and understand crew member health, and could potentially help detect DNA-based life elsewhere in the Universe.

In collaboration with MIT, scientists from NASA's Goddard Space Flight Center are developing a new type of spectrometer based on an innovative quantum dot array (QDA). The QDA replaces prisms and gratings used in conventional spectrometers, which require long path length to achieve high spectral resolution. Due to its low volume, the quantum dot spectrometer is suitable for small satellite missions for a range of science applications, including auroral imaging, mapping of water and hydroxyl in lunar regolith, spectroscopy of the atmosphere or surfaces of planetary bodies such as Venus and Mars, studying volatiles in comet comae, glaciological mapping, and imaging ocean color to understand ocean biogeochemistry and the ecosystem. In addition, this instrument could be utilized by drones to perform chemical analysis for homeland security or military applications. An initial prototype of the sensor has been fabricated and thermal vacuum testing has been conducted on the QDA to demonstrate the stability of QD pixels in a simulated space environment.

Under an FY 2019 Space Technology Early Career Initiative award, researchers at the NASA Goddard Space Flight Center are collaborating with the NSF Center for High Rate Nanomanufacturing at Northeastern University to develop a high sensitivity *in situ* multifunctional wireless sensor platform using an innovative 3D micro- and nanoscale printing approach. The sensor system includes a suite of nanomaterial-based gas, temperature, and pressure sensors, as well as electronics for onboard computation, on-chip heaters, and a wireless communication module—all packaged in a self-contained unit. This platform can provide critical, crosscutting, low-resource breakthroughs applicable to planetary science, heliophysics, and human exploration missions. For instance, the multifunctional platform can detect gases that can fingerprint various biological and abiotic processes on outer planets, moons, and asteroids; quickly pre-screen samples or monitor outgassing of samples during storage for sample-return missions; enhance the time resolution of NASA's thermosphere physics investigations in low-Earth-orbit missions with a sensor network; detect neutral atoms such as atomic oxygen without having to ionize them; and detect leaks of toxic gases in human exploration missions.

Under the In Space Manufacturing Project, NASA Ames researchers are further developing flexible substrate based printed nanosensors for chemical, biological, and radiation detection. Inkjet printing and plasma jet printing have been used to print sensors on various polymer substrates, paper, and cotton. The performance of these sensors has been compared with those previously developed on silicon and silicon carbide and found to have similar sensitivity and detection limits. Printed radiation sensors have been tested for gamma, UV, and x-rays using carbon-based nanomaterials as active layers, providing good sensitivity over a wide range of radiation doses. Machine learning algorithms will be developed in FY 2019 and 2020 to enable the selective identification of various gases and vapors of interest for crew cabin air quality monitoring. The sensors will be integrated with the RFID system under development at NASA JSC.

NASA Ames researchers are developing nanoscale vacuum channel transistors (NVCTs) for use on future Europa missions. These are vertical devices with multiple emitters at the bottom facing a common collector at the top and a surround gate for good control of electrostatics. The multiple emitter structure allows an increase in drive current. The output characteristics of devices from both material systems were very good and the performance was not affected when tested for total ionization damage. These NCVTs have been fabricated on a wafer scale on both silicon and silicon carbide substrates. FY 2019 work will involve putting together functional circuits based on NVCTs, and in FY 2020, application demonstrations and redesigns for reliability and long lifetime will be undertaken.

Under a project funded by the Advanced Research Projects Agency-Energy (ARPA-E), NASA Ames researchers are working with Xerox PARC to develop printed sensors for detecting natural gas leaks from gas wells with an accuracy of 1 meter. NASA developed the sensor technology and PARC did the printing and algorithm development for leak detection.

Key Technical Accomplishments by NNI Goal

Goal 1. Advance a World-Class Nanotechnology Research and Development Program

NASA researchers have developed the first-ever fully printed triboelectric nanogenerator (TENG) for scavenging energy from vibration and motion. Among various energy-scavenging technologies, TENG provides the largest power per unit mass. Tens of mW power levels were achieved using a small footprint for powering various physical and chemical sensors. FY 2019 and 2020 work will involve matching the footprint of the TENG to the unused backside of a typical sensor to create a self-powered sensor system, as well as the demonstration of large-scale power generation by combining TENG with wind turbines suitable for use on Mars.

Goal 2. Foster the Transfer of New Technologies into Products for Commercial and Public Benefit

In 2018, NASA initiated the Biomolecule Extraction and Sequencing Technology (BEST) investigation on the International Space Station (ISS) to demonstrate for the first time the use of gene sequencing technology in a microgravity environment. BEST utilizes the Biomolecule Sequence and Genes in Space hardware based on commercially available MinION technology developed by Oxford Nanopore Technologies.

A nano-gold catalyst system has been developed to oxizide carbon monoxide for use in emergency response respirators on the ISS and in future human exploration missions. This catalyst is capable of oxidizing CO into CO_2 at rates more than ten times faster than state-of-the-art CO oxidation catalysts. This system has been certified for use on the ISS and is slated for future use in the Orion spacecraft.

NASA continues its efforts to develop polymer aerogels for use as thermal and electrical insulation and antenna support structures. Under the Convergent Aeronautical Solution's Conformal Lightweight Antenna Systems for Aeronautical Communications Technologies (CLAS-ACT) sub-project, NASA researchers have utilized polymer aerogels as the substrate for conformal antennas for use in beyond-line-of-sight communication for unmanned aerial vehicles (UAVs). Antennas were fabricated in FY 2018 and are in the process of being ground tested. A flight test of the antenna array on a Global Hawk UAV was scheduled for the Spring of 2019. In FY 2018, a new project under NASA's Center Innovation Fund Program was initiated to develop polymer aerogels that are amenable to additive manufacturing processes. Current polymer aerogels have gel times that are not compatible with additive manufacturing. Development of additively manufacturable aerogels would significantly expand the application space for these materials.

Goal 3. Develop and Sustain Educational Resources, a Skilled Workforce, and a Dynamic Infrastructure and Toolset to Advance Nanotechnology

NASA's FY 2018 foundational research also supported the professional development of students and faculty through the Space Technology Research Grants Program, the Space Technology Early Career Faculty program, and the Space Technology Graduate Fellowship program (see PCA 2 section above). These fellowships provide up to four years of support and give students the opportunity to collaborate with NASA scientists and engineers and utilize NASA facilities in their thesis research.

In relation to NASA's Water NSI activities (PCA 1e above), researchers from JSC and NEWT jointly mentored a group of summer students in 2018. One of the student projects involved investigating the use of capacitive deionization (CDI), a selective and reversible method for removing ionic contaminants from water, for potential use in space applications. Students assessed the efficacy of CDI experimental resins, developed by NEWT researchers for removing scaling contaminants from boiler water, for urine processing.