United States Senate Committee on Appropriations
Driving Innovations through Federal Investments
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Written Testimony
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Mr. Chairman and members of the Committee, thank you for the opportunity to provide input for today's hearing reinforcing the importance of Federal investment in basic research as a driver of innovation. I hope this testimony will illustrate that basic research often has lengthy gestation periods and powerful and unanticipated benefits that come in many forms.

Just a small sampling from our institution, Woods Hole Oceanographic Institution (WHOI), speaks volumes about the importance of Federal research to American innovation, prosperity, and competitiveness. Our Institution's history is filled with examples of federally funded research that have made critical contributions to our nation's health, economy, and national defense; that have spawned revolutionary technology and businesses; and that have helped the nation respond more effectively to crises and challenges.

Shortly after WHOI was established in 1930 as a private, nonprofit research institution, a young physicist named Maurice Ewing sent letters to several oil companies. He asked them to support a modest research program to see whether acoustic methods, which had been using to probe terrestrial geological structures, could be adapted to investigate the completely unknown geology of the seafloor.

Ewing later wrote: "This proposal received no support whatever. I was told that work out in the ocean could not possibly be of interest to the shareholder and could not rightfully receive one nickel of the shareholder's money."

This was an era even before the existence of NSF's precursor, the wartime Office of Scientific Research and Development. However, Ewing did receive a $2,000 grant from the Geological Society of America. He and his students came to WHOI to use its new ship, *Atlantis*, which at the time was the only U.S. deep-sea research vessel. They launched novel experiments using sound waves to probe the seafloor.

Huge dividends from initial federal support

To Ewing, the watery part of the ocean was annoying. It was in the way. To study the seafloor, he and his colleagues had to learn how to see *through* it. In the process, they unexpectedly made profound and fundamental discoveries about ocean properties and how sound propagates through seawater. They revealed that the ocean was stratified into layers with different densities, in which sound traveled differently.

Recognizing the potential defense applications of Ewing's work, the Navy, on the eve of war in 1940, began funding basic ocean research that launched a golden era of discovery. One of Ewing's students, Allyn Vine, incorporated their newly gained knowledge to build instruments called bathythermographs. WHOI scientists trained submariners to use them to monitor ocean density layers and escape detection by sonar. It was the first of many applications of this research that saved lives and revolutionized submarine warfare. Ewing and colleagues went on to discover the Sound Fixing and Range (SOFAR) Channel, on which the Navy's Sound Surveillance System, or SOSUS—a backbone of anti-submarine warfare throughout the Cold War—was based.

Research that followed from these beginnings resulted in the late 1960s in the unifying theory of plate tectonics. That research transformed our understanding of how Earth's face—its continents, ocean basins, mountains, and seafloor—is shaped. It offered fundamentally new insights that are being pursued today to mitigate natural hazards such as earthquakes, volcanoes, and tsunamis, as well as a host of other geological phenomena—including significant oil reservoirs beneath the seafloor.

Inquiry to technology to discovery to application

Al Vine remained at Woods Hole and spearheaded deep-submergence technology, including the research sub *Alvin*, which was named after him. Two years after it was completed, *Alvin* was applied to a national emergency, locating a hydrogen bomb that accidentally dropped into the Mediterranean Sea.

In the 1970s, scientists in *Alvin* found seafloor hydrothermal vents. To humanity's utter astonishment, the vents were surrounded by previously unknown organisms sustained not by photosynthesis but chemosynthesis. This discovery, one of the most profound of the 20^{th} century, completely transformed our conceptions of where and how life can exist on this planet and reconfigured our search today for life on other planetary bodies.

Alvin's success spurred WHOI engineers, funded in large part by ONR, NSF, NOAA, and NASA, to develop new generations of deep-submergence technology. These include remotely operated vehicles (ROVs) tethered by fiber-optic cables and free-swimming autonomous underwater vehicles (AUVs). Outfitted with various sensor arrays, these vehicles are now workhorses used for naval activities and national security, as well as by oil exploration, maritime, and other industries. They are used in environmental and fisheries monitoring (including tracking and filming great white sharks), and disaster response. Just three years ago, REMUS vehicles (Remote Environmental Monitoring UnitS), AUVs developed at WHOI, located the wreckage of Air France Flight 447.

Products and businesses from basic research

Chris von Alt and a team of WHOI engineers developed REMUS in the mid 1990s with funds from ONR and NOAA. Navy officials wanted vehicles to assist in searching for explosive mines, a job that at the time was often done by a platoon of divers dragging a long rope parallel to the beach. REMUS was designed to be programmed to "fly" through the depths to continuously take measurements over large areas for many hours at a time, allowing more efficient surveys without putting divers in harm's way.

In 2001, von Alt founded a company called Hydroid to build large numbers of REMUS vehicles for the Navy and later for other clients who realized REMUS' utility. Hydroid now has more than 120 employees and sales in nearly 30 nations worldwide.

Hydroid is one of 15 spinoff businesses that have emerged from federally funded WHOI research (http://www.whoi.edu/main/affiliated-companies). In the 1970s, WHOI biologist Stanley Watson, conducting fundamental research on bacteria's role in the marine food web, refined and patented a test to detect bacteria in seawater, using an extract from the blood of horseshoe crabs, Limulus amoebocyte lysate (LAL). He realized the medical and commercial potential, creating a company to manufacture the reagent. Associates of Cape Cod, Inc., was the first company to be licensed by the FDA to manufacture LAL to detect the presence of bacterial toxin. LAL is now used worldwide by leading pharmaceutical and medical device companies to ensure the sterility of vaccines, IV fluids, surgical instruments, artificial implants, and countless other drugs and medical devices.

These are not the only unanticipated innovations with enormous societal and commercial value that derived from federally funded basic research on marine life. In 1992 Douglas Prasher at WHOI cloned the gene of a bioluminescent protein from jellyfish called green fluorescent protein, or GFP. A Nobel Prize-winning team developed methods to join the GFP gene to other proteins. The harmless fluorescing tag lets scientists track protein activity in living cells in real time, a technique that has revolutionized scientists' ability to study the inner workings of cells, helping to drive rapid advances in microbiology and the biotech industry.

More recently, WHOI biologists developed an underwater microscope, called the Imaging FlowCytobot, as a basic research tool to photograph plankton on a continuous basis and transmit data back to shore. Placed in the Gulf of Mexico, it unexpectedly detected a toxic harmful algal bloom (HAB) in 2008. The early warning prompted Texas officials to recall shellfish and close down shellfish harvesting, just days before a major regional oyster festival. The technology has been licensed for commercial manufacture to a WHOI spinoff. Last year, NOAA-funded basic research on HABs led to the reopening of shellfish beds off New England, valued at $10 million to $15 million per year, which had been closed since 1990.

Responding to crises

In 2010, research institutions were called into action by federal agencies and BP for another disaster, the Deepwater Horizon oil spill, which occurred at an unprecedented depth of one mile beneath the surface. Decades of federally supported basic research in the deep sea had made WHOI pre-adapted to respond. The technology and expertise used in deep-sea research already existed and could be applied to an unanticipated use.

No proven techniques existed for estimating the flow of oil gushing from the broken riser pipe at such depths. WHOI scientists adapted acoustic instruments and techniques originally used to measure fluids spewing from hydrothermal vents to calculate the flow rate at the broken riser and used this information to determine the total volume of oil spilled during the three-month period before the leak was capped.

A related issue of significant financial importance was to determine precisely how much of the billowy mixture was liquid oil—used in the calculation of penalty cost—versus dissolved natural gas. Accomplishing this required a pristine fluid sample taken directly from the mouth of the gushing riser on the seafloor. WHOI scientists obtained the definitive sample using an isobaric gas-tight sampler, a device developed at WHOI to sample hydrothermal vent fluid and maintain it under pressure, so that dissolved gases could not escape from solution when the sample was brought to the surface.

Additionally, neither the oil industry nor government agencies had expertise in locating the plume of oil and gas that trailed away from Deepwater Horizon into the ocean depths like smoke out of smokestacks. WHOI scientists, however, applied the expertise and technology they acquired in federally funded basic research to find plumes of buoyant hot fluids trailing from hydrothermal vents. Using AUVs and sensors developed for ocean research, our scientists mapped the deep-sea plume from Deepwater Horizon and reported critical water-quality data to federal agencies in near-real time. The same scientists also applied methods derived from basic research to measure minute quantities of chemicals in the ocean to measure the dispersant used in the cleanup. Later, *Alvin* was brought in for focused investigations on the oil spills impacts on deep-water ecosystems.

Innovation on the horizon

Continuing federal funding is supporting new undersea technology development and studies of marine life with therapeutic potential (as well as other disciplines too numerous to mention here). Here are a few examples:

WHOI's Deep Submergence Lab, supported by an NSF grant, has been developing *Nereid*, a hybrid underwater vehicle that can operate in presently inaccessible ocean areas under ice. Outfitted with cameras and acoustic, chemical, and biological sensors, it will operate as an ROV, with direct real-time human supervision, and as an AUV. It's not hard to envision this vehicle's utility to explore and monitor a critical and fast-changing environment, to search for energy resources, and to respond to crises in the polar regions.

There are more microbes in the ocean than stars in the universe; the vast majority, and the chemicals they produce, remain unknown. Our arsenal of antibiotics came from terrestrial microbes, but according to a 2013 report from the Centers for Disease Control, current antibiotics are becoming less effective as bacteria increasingly become resistant to them. With federal support, WHOI scientists are extracting molecules from microbes collected from all over the world's oceans—exploring their therapeutic potential for new antibiotics. They are looking for molecules that block antibiotic resistance mechanisms in pathogenic bacteria, as well as for cures for diseases such as cystic fibrosis.

The NSF annual report from 1952 says, "That which has never been known cannot be foretold, and herein lies the great promise of basic research. … [It] enlarges the realm of the possible." Unconstrained by expected results in the next quarter, and beholden to seek wider benefits for a broader group of shareholders—everyone in this nation—federal funding for basic research is the seed for innovation and continues to enlarge the realm of the possible.