OCEAN EXPLORATION: DIVING TO NEW DEPTHS AND DISCOVERIES

HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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Appendix II: Additional Material for the Record

OCEAN EXPLORATION: DIVING TO NEW DEPTHS AND DISCOVERIES

WEDNESDAY, JUNE 5 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 9:15 a.m., in room 2318 of the Rayburn House Office Building, Hon. Lizzie Fletcher [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

"Ocean Exploration: Diving to New Depths and Discoveries"

Wednesday, June 5, 2019
9:00 a.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of this hearing is to discuss the state and importance of U.S. ocean exploration, ongoing research, scientific discoveries and applications, technological innovations, research gaps, and the future of the field. The witness panel will provide an opportunity to hear perspectives from many of the major players in U.S. ocean exploration enterprise, which is comprised of federal, commercial, academic, and non-profit/philanthropic sectors.

WITNESSES

- **Dr. Katy Croff Bell**, Founding Director, Open Ocean Initiative, MIT Media Lab
- **Dr. Carlie Wiener,** Director of Marine Communications, Schmidt Ocean Institute
- **Mr. Steve Barrett**, Senior Vice President Business Development, Oceaneering International
- **Mr. David Lang,** Co-founder, Sofar Ocean Technologies

OVERARCHING QUESTIONS

- How are the roles of each of the sectors in the U.S. ocean exploration enterprise defined?
- What is the state of the enterprise overall, and how can we strengthen the partnerships within it?
- What are the current challenges in the ocean exploration enterprise, i.e. technology development, data sharing, funding, partnerships, etc.?
- What will ocean exploration look like in 10-25 years?
- What are the tools, technologies, and innovations currently used in ocean exploration?
- How can ocean exploration and discoveries benefit society and the economy?
- How is the U.S. ocean exploration enterprise evolving as new technologies emerge and what is the future of the enterprise?
- Where does the U.S. stand globally in ocean exploration and how can we continue to stay on track?
- What are the current policies guiding U.S. ocean exploration?

BACKGROUND

According to the President's Panel for Ocean Exploration in 2000, – a panel of America's finest ocean explorers that was charged to develop the first-ever national strategy for ocean exploration – ocean exploration is defined as "discovery through disciplined, diverse observations and recordings of the findings." It includes observations and documentation of biological, chemical, physical, geological, and archaeological aspects of the ocean in the three dimensions of space and in time.[1] While ocean exploration may often be thought of as exploration of the deep sea, it also includes exploration of mid and surface waters.

The oceans cover 70% of the earth's surface, yet according to the National Oceanic and Atmospheric Administration (NOAA),[2] over 80% of the world's oceans remain unmapped, unobserved, and unexplored and less than 10% have been mapped in some detail (using sonar). Ocean exploration is more than just bottom mapping or discovering wrecks and new marine species; it has also helped us discover cancer-fighting drugs and understand the origins of life. The motivators driving ocean exploration can be diverse, from pure discovery of the unknown, to collecting baseline measurements of ocean chemistry and biology, to searching for biological or mineral resources for extraction. Research can be hypothesis-driven or discovery based.

Ocean exploration has been likened to space exploration, due to space and the subsea both being cold, dark, and inhospitable to human life; however, ocean exploration has not received the same level of public attention or fascination as space exploration. While most Americans know that the U.S. has a national space exploration program (based at the National Aeronautics and Space Administration), most do not know we have a national ocean exploration program (based at NOAA). Remarkably, 12 people have walked on the moon but only four have gone to the deepest part of the ocean, the Mariana Trench. The first time was in 1960 when Jacques Piccard and Don Walsh descended to the deepest part of the ocean, the Challenger Deep in the Mariana Trench, in the *bathyscaphe*[3] Trieste.[4] Ocean exploration experienced a resurgence in popularity in 2012 when "Titanic" film director James Cameron made the first solo dive to the Challenger Deep.[5] The most recent return to the Challenger Deep was in May 2019, when Dallas businessman Victor Vescovo broke Cameron's record for the deepest dive in history, at 10,927 meters (35,853 feet).[6]

Ocean Exploration Enterprise: Public, Private, Academic, Non-Profit Sectors

Given the breadth and scope of modern ocean exploration, it is a largely collaborative endeavor, with involvement from federal, commercial, academic, non-profit/philanthropic, and

[1] Report of the President's Panel for Ocean Exploration, "Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration." 2000. https://oceanexplorer.noaa.gov/about/what-we-do/program-review/presidents-panel-on-ocean-exploration-report.pdf

[2] NOAA, "How much of the ocean have we mapped?" 7/11/18. https://oceanservice.noaa.gov/facts/exploration.html

[3] A submersible vessel with a spherical room for research and observation

[4] http://www.deepseachallenge.com/the-expedition/1960-dive/

[5] https://news.nationalgeographic.com/news/2012/03/120325-james-cameron-mariana-trench-challenger-deepest-returns-science-sub/

[6] https://www.forbes.com/sites/jimclash/2019/05/14/businessman-victor-vescovo-sets-new-world-depth-record-for-mariana-trench-dive/#7ca6c6d5d0b3

international stakeholders. An example of this wide-ranging collaboration was the 2012 *DEEPSEA CHALLENGE* mission down to the Challenger Deep led by James Cameron, which was made possible through an international team of over a hundred scientists, engineers, filmmakers, and many other partners including the National Geographic Society, Alfred P. Sloan Foundation, and Rolex Corporation.[7]

Since the President's Panel for Ocean Exploration Report of 2000, there have been great strides in national ocean exploration. The first and only national ocean exploration program was established in the Ocean Exploration Act of 2009,[8] which designated NOAA as the lead federal agency for ocean exploration and created NOAA's Office of Ocean Exploration and Research (OER). Since its inception, OER has operated at a budget of about $20 million per year, despite the 2000 Presidential Panel for Ocean Exploration recommending funding levels of $75 million per year.[9] Authorization for the 2009 statute lapsed in 2015, but Congress has continued to appropriate funds for OER.

The 2009 statute also called for NOAA to establish federal partnerships in ocean exploration. NOAA's primary federal partners in ocean exploration include the U.S. Geological Survey (USGS), the Bureau of Ocean Energy Management (BOEM), the National Aeronautics and Space Administration (NASA), the U.S. Navy, and the National Science Foundation (NSF). Each agency has slightly different missions. The Office of Naval Research and National Science Foundation conduct hypothesis-driven research, and develop technologies as tools of exploration. For the USGS and BOEM, ocean exploration is motivated by the need to characterize ocean regions for natural resource management.

There are a number of academic institutions engaged in ocean exploration expeditions, technology development, and research. In May 2019, the University of Rhode Island was designated the lead of a new NOAA Cooperative Institute for Ocean Exploration, which will also have membership from the Ocean Exploration Trust, the Woods Hole Oceanographic Institution (WHOI), University of New Hampshire, and University of Southern Mississippi, and will work with NOAA's OER to survey and characterize three billion acres of the U.S.'s coastal and ocean waters within the U.S.'s jurisdiction, called the Exclusive Economic Zone (EEZ), to support the Blue Economy.[10]

Non-profits and philanthropic organizations also play a prominent role in engaging in and supporting ocean exploration, such as the Schmidt Ocean Institute (which operates the R/V *Falkor)*, OceanX, WHOI, the Monterey Bay Aquarium Research Institute, and the Ocean Exploration Trust (which operates the E/V *Nautilus*). The missions of non-profits can be diverse, from pure ocean exploration to public education and outreach, with many doing a mixture of both. For example, the Schmidt Ocean Institute, founded in 2009 by philanthropists Eric and Wendy Schmidt, engages in pure ocean exploration through conducting collaborative research

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[7] http://www.deepseachallenge.com/the-team/

[8] Public Law 111-11; 33 USC 3400 *et al.*

[9] ibid.

[10] NOAA names University of Rhode Island to host new Cooperative Institute for Ocean Exploration. 5/6/19. https://research.noaa.gov/article/ArtMID/587/ArticleID/2449/NOAA-names-University-of-Rhode-Island-to-host-new-cooperative-institute-for-ocean-exploration

and expeditions on R/V *Falkor* and engages with the public on shore via live video feeds from the field.[11]

The commercial sector that supports ocean exploration is growing, with more technology companies building autonomous vehicles and sensors to aid in exploration. There are a range of companies specializing in autonomous surface vehicle construction, such as Saildrone,[12] to underwater vehicles, like OpenROV,[13] Oceaneering International,[14] and Teledyne Marine.[15] These companies cater to a range of scientific and commercial applications. For example, OpenROV has pioneered low-cost ROV designs that have fostered a community of citizen scientists, while Oceaneering International provides ROVs to the oil and gas industry.

The Ocean Exploration Act of 2009 also required NOAA to create a National Forum on Ocean Exploration to establish a national strategy and program of ocean exploration. Since 2013, there have been annual National Ocean Exploration Forums that have brought together hundreds of key members of the ocean exploration enterprise and created a dialogue to encourage partnerships, technology development, and investments to advance the extent, pace, and efficiency of ocean exploration expeditions. While progress has been made in cultivating partnerships within the enterprise, significant potential remains, as noted in the Final Report for the National Ocean Exploration Forum in 2017.[16]

Scientific Discoveries and Emerging Research Needs

Over the last century, ocean exploration has led to many important scientific discoveries, such as the existence of plate tectonics, novel marine species, new sources of energy, pharmaceuticals, better understanding of the origins of life, and the role of the oceans in regulating the earth's climate. The advent of state-of-the-art technologies, such as cheaper DNA sequencing, satellite data, and underwater vehicles, has quickened the pace of discovery in recent years. However with over 80% of the oceans unexplored and an estimated 91% of marine species yet to be described,[17] there is much more to be discovered. The following are some examples of seminal ocean exploration discoveries.

- **Sonar:** The advent of sonar during World War I, and the development of multibeam sonar by the U.S. Navy in the 1960s which uses an array of beams at varying angles to cover larger swaths of ocean floor with greater precision, had led to an increase in knowledge of seafloor topography. To date, only 35% of the U.S. EEZ and Extended Continental Shelf (ECS)[18]

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[11] https://schmidtocean.org/about/strategic-focus-areas/
[12] https://www.saildrone.com/
[13] https://www.sofarocean.com/
[14] https://www.oceaneering.com/
[15] http://www.teledynemarine.com/SitePages/HomePage.aspx
[16] Final report for the National Ocean Exploration Forum 2017. https://oceanexplorer.noaa.gov/national-forum/media/noef-2017-report.pdf

[17] NOAA, "How many species live in the ocean?" 6/25/18. https://oceanservice.noaa.gov/facts/ocean-species.html
[18] A country's seafloor out to 200 nautical miles.
https://www.un.org/Depts/los/clcs_new/continental_shelf_description.htm

have been mapped using sonar.[19] The U.S. EEZ is the largest in the world, covering 11,351,000 square kilometers,[20] with the continental shelf covering 2.2 million square kilometers, while the U.S.'s land mass is 9,147,000 square kilometers.[21] Given that more of the nation is below water than above water, it is important to understand and characterize what is in the U.S. EEZ in order to better manage and conserve our natural resources.

- **Hydrothermal vents:** In 1977, an expedition on the WHOI-operated deep-sea submersible, *Alvin*, discovered hydrothermal vent communities teeming with life at the mid-ocean ridge north of the Galapagos Islands.[22] Living in complete darkness and extreme pressure and temperatures, it was discovered that the basis for this food web is chemosynthetic bacteria that derive energy from compounds being emitted from the hydrothermal vents. These chemosynthetic bacteria are thought to hold secrets to the origins of life on earth and on other planets.

- **Biochemical compounds:** The deep sea is seen as an untapped resource for discovery of drugs derived from biochemical compounds from marine plants and animals. Over the past 30 years, at least 200,000 bioactive compounds have been discovered.[23] For example, marine sponges have been found to contain anticancer and antibiotic properties that are being developed into pharmaceuticals. The promise of developing bio-derived marine compounds into pharmaceuticals, agricultural products, and other products is explored in the National Research Council 2002 report *Marine Biotechnology in the Twenty-First Century.*[24]

- **Human impacts:** Scientists are also learning more about the impacts of humans on the oceans. Scientists have discovered that more than 90% of the excess heat from the atmosphere is stored in the ocean, and that while most is in the top 700 meters, a portion of heat gets stored in the deep ocean.[25] Measurements in the deep ocean revealed that the global warming "hiatus" from 1998 to 2013 was actually due to redistribution of heat content in the oceans.[26] Plastic debris has been found in the deep ocean, including in the deepest part of the ocean, as discovered on Vescovo's recent solo dive.[27]

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[19] ibid.
[20] NOAA Ocean Exploration Review Panel's report, "Ocean Exploration's Second Decade." 2012. https://oceanexplorer.noaa.gov/about/what-we-do/program-review/2012-oe-review-report.pdf
[21] https://data.worldbank.org/indicator/ag.lnd.totl.k2
22 https://www.whoi.edu/feature/history-hydrothermal-vents/discovery/1977.html
[23] "Ocean Exploration" highlights from the National Academies reports. 2007. http://nas-sites.org/oceans/files/2012/05/exploration_final.pdf
24 https://www.nap.edu/download/10340
25 https://www.climate.gov/news-features/understanding-climate/climate-change-ocean-heat-content
[26] Cheng, L., et al. 2019. "How fast are the oceans warming?" *Science*. Vol. 363, Issue 6423, pp. 128-129. https://science.sciencemag.org/content/363/6423/128.full
[27] National Geographic, "Plastic proliferates at the bottom of the world's deepest ocean trench." 5/13/19. https://news.nationalgeographic.com/2018/05/plastic-bag-mariana-trench-pollution-science-spd/

Tools and Technology Used in Ocean Exploration

- **Scuba diving:** A more traditional method of ocean exploration, scuba diving technology has evolved greatly over the past two centuries, and still offers advantages to researchers hoping to make discoveries.[28] Divers can directly observe and even manipulate marine ecosystems, an ability which has significantly advanced the fields of marine biology and marine chemistry and has helped uncover archaeological sites and geologic discoveries. For example, in 1982 archaeologist George F. Bass and his team uncovered the world's oldest known shipwreck (circa 14th century B.C.) after more than 20,000 dives off the coast of Turkey. [29]

- **Research Vessels (R/Vs) and Exploration Vessels (E/Vs):** Traditional oceangoing research vessels carry scientists, equipment, and instrumentation from the shore to research sites, collecting data as they travel. They are observation platforms from which explorers deploy divers and submersibles and use onboard computers and navigation systems.[30] Currently, U.S. ships dedicated to ocean exploration include NOAA vessel *Okeanos Explorer*,[31] NSF Ship *Marcus G. Langseth*,[32] Ocean Exploration Trust's E/V *Nautilus*,[33] Schmidt Ocean Institute's R/V *Falkor*,[34] and OceanX's E/V *Alucia*, with the E/V *Alucia 2* on the way.[35]

- **Dredging and Trawling:** Traditionally, scientists collected samples of marine organisms through dredging or trawling methods, which has led to the discovery of thousands of new species but causes damage to benthic ecosystems and results in damaged, distorted specimens.[36] Samplers attached to deep submergence vehicles, or submersibles, have allowed scientists to collect samples without the problems with dredging and trawling.[37]

- **Human-operated vehicles (HOVs):** Submersibles allow scientists to systematically sample and collect intact specimens and watch animal behavior in real time. Submersibles are built to withstand crushing pressures, darkness, and extreme cold at abyssal depths that human divers cannot reach.[38] NOAA OER uses the HOV *Alvin* to carry scientists to 4500 meters of depth.[39]

- **Remotely-operated vehicles (ROVs):** ROVs are robotic vehicles that transmit information to controllers above the water through physical cables. They are equipped with cameras and sensors with data collection capabilities and can reach depths of 3000 meters.[40]

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[28] https://oceanexplorer.noaa.gov/technology/diving/scuba/scuba.html
[29] http://dels.nas.edu/resources/static-assets/osb/miscellaneous/exploration_final.pdf
[30] https://oceanexplorer.noaa.gov/technology/vessels/vessels.html
[31] https://oceanexplorer.noaa.gov/technology/vessels/vessels.html
[32] https://www.ldeo.columbia.edu/research/office-of-marine-operations/langseth
[33] https://www.oceanexplorationtrust.org/nautilus-exploration-program
[34] https://schmidtocean.org/rv-falkor/
[35] http://www.oceanx.org/
[36] http://dels.nas.edu/resources/static-assets/osb/miscellaneous/exploration_final.pdf
[37] https://oceanexplorer.noaa.gov/technology/tools/suction/s_d_sampler.html
[38] https://oceanexplorer.noaa.gov/technology/subs/subs.html
[39] https://oceanexplorer.noaa.gov/technology/subs/alvin/alvin.html
[40] https://www.rigzone.com/training/insight.asp?insight_id=343&c_id=

- **Autonomous underwater vehicles (AUVs) and gliders:** These unmanned underwater vehicles are distinct from ROVs in that they have no physical link to above water controllers. Like ROVs, they carry sensors to collect environmental data. They are much cheaper than fully-equipped research vessels and operate independently of human direction. Gliders can further cut energy costs if they are propelled by gravity and buoyancy.[41]

- **Telepresence:** Developed by NOAA OER, telepresence enables live streaming video, data, and information to be transmitted from ROVs to anywhere in the world in real time. This ability to participate remotely in deep sea exploration is important for education and outreach and helps to involve more scientists directly in missions in real time.[42]

- **Sensors and exploration instruments:** As the oceans are one of the most challenging environments to study, special technologies have been developed to examine its characteristics.[43]
    - Mounted on the bottom of ships, the Acoustic Doppler Current Profiler (ADCP) measures the speed and direction of ocean currents by emitting high frequency sounds that scatter off of moving particles in the water.[44] *Drifters* are floating, sailed data collection devices that also investigate ocean currents.[45]
    - Underwater acoustic monitors like *sonobuoys* and *cabled or autonomous hydrophones* collect sounds in the ocean.[46]
    - Deployed from submersibles, *mechanical arms* and nets like the *"Bushmaster and "Chimneymaster"* collect marine specimens.[47]
    - Water column samplers such as *sondes* and *CTDs (conductivity, temperature, depth)* can record a range of water quality data such as pH, dissolved oxygen, and salinity as often as once every four seconds.[48]
    - *Semipermeable Membrane Devices (SPMDs)* are sampling devices used to monitor trace levels of organic contaminants.[49]
    - *SONAR, or Sound Navigation and Ranging,* is used to find and identify objects in water, and determine water depth.[50]

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[41] https://oceanexplorer.noaa.gov/facts/auv.html
[42] https://oceanexplorer.noaa.gov/technology/commstech/telepresence/telepresence.html
[43] https://oceanexplorer.noaa.gov/technology/tools/tools.html
[44] https://oceanexplorer.noaa.gov/technology/tools/acoust_doppler/acoust_doppler.html
[45] https://oceanexplorer.noaa.gov/technology/tools/drifters/drifters.html
[46] https://oceanexplorer.noaa.gov/technology/tools/acoustics/acoustics.html
[47] https://oceanexplorer.noaa.gov/technology/tools/bushmaster/bushmaster.html
[48] https://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html
[49] https://oceanexplorer.noaa.gov/technology/tools/spmds/spmds.html
[50] https://oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html

Chairwoman FLETCHER. The hearing will come to order. Without objection, the Chair is authorized to declare recess at any time. Good morning, and welcome to today's hearing entitled, "Ocean Exploration: Diving to New Depths and Discoveries." The Committee is holding this hearing at the beginning of World Oceans Month and Capitol Hill Ocean Week to celebrate the oceans, and the wonders that they hold. I would like to welcome and thank all of our witnesses for being here today to discuss the state of our oceans and the importance of ocean exploration to the United States. I want to let the witnesses know that my colleagues and I are going to have to leave for votes around 10 a.m., actually on four bills that address ocean acidification that passed out of this Committee last month, so in order to get to witness testimony and questions as quickly as possible, Ranking Member Marshall and I are going to keep our opening statements short. I request to submit my full statement for the record.

As we've discussed in the Subcommittee this Congress, the oceans are incredibly important for sustaining life on Earth, regulating the Earth's climate, supplying over half the oxygen we breathe, providing a major source of protein for billions of people around the planet, and more. Human health is intricately connected to ocean health. We live on a blue planet. The oceans cover 71 percent of our planet, and yet we've mapped about 15 percent of the sea floor. Human eyes have seen less than 5 percent of it. While we have sent 12 people to the moon, only four have gone to the deepest part of the ocean. The ocean is the Earth's final frontier.

Yesterday we held a hearing on biodiversity laws, and heard about the rapid rate at which the oceans are changing through climate change, ocean acidification, pollution, over-fishing, and more. The clock is ticking. At today's hearing I look forward to a discussion with our distinguished panel of experts, innovators, and explorers on how we can advance the pace of ocean exploration, and dive to deeper depths and discovery for a better future.

I also note that the Science Committee is hosting its first ever Ocean Exploration Expo tomorrow morning at 9:30, which some of our panelists, and many other groups from the ocean exploration community will showcase their cutting edge technology, work, and discoveries. This will be an amazing and fun educational opportunity, and I encourage those who can to attend.

[The prepared statement of Chairwoman Fletcher follows:]

Good morning, and welcome to the Subcommittee on Environment's hearing entitled, "Ocean Exploration: Diving to New Depths and Discoveries." The Committee is holding this hearing at the beginning of World Oceans Month and Capitol Hill Ocean Week, to celebrate the oceans and the wonders that they hold. I would like to welcome and thank all of our witnesses for being here today to discuss the state and importance of ocean exploration to the United States.

As we've discussed in this Subcommittee this Congress, the oceans are incredibly important for sustaining life on earth, regulating the earth's climate, supplying over half of the oxygen we breathe, providing a major source of protein for billions of people around the planet, and more. Human health is intricately connected to ocean health.

We live on a blue planet. The oceans cover 71% of our planet, and yet we have mapped only about 15% of the seafloor. Human eyes have seen less than 5% of it. While we have sent 12 people to the Moon, only four have gone to the deepest part of the ocean. The ocean is earth's final frontier.

Yesterday, we held a hearing on biodiversity loss and heard about the rapid rate at which the oceans are changing—through climate change, ocean acidification, pollution, overfishing, and more. The clock is ticking.

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We know more about the surface of the moon than we do about the seafloor. Like space exploration, ocean exploration has traditionally been a difficult, time-consuming, and expensive endeavor. As Dr. Bell points out in her testimony, at the current rate of ocean exploration - using the gold-standard of oceangoing research vessels equipped with special equipment for mapping and exploration - it would take over 1,000 years and millions of dollars to explore the remaining 85% of the oceans.

As new technologies emerge for exploring the oceans, from underwater drones and smaller and cheaper remotely operated vehicles (ROVs), sensors to measure conditions in harsh ocean environments, to machine learning applications, ocean exploration is experiencing a renaissance. But the U.S. is falling behind in marine innovation, as federal investment in ocean exploration remains relatively small and stagnant, while international investment and innovation in ocean exploration grows. I am glad we are having this hearing to explore ways this Committee can look to legislative solutions to support and enhance U.S. leadership in ocean exploration.

The United States has jurisdiction over more ocean than any other nation, so we have a real leadership role to play in ocean exploration. Our exclusive economic zone covers over 4.3 million square miles, an area larger than the 3.8 million square miles of terrestrial land that make up the U.S. Having information on what's in the U.S.'s waters and seafloor is important for national security, natural resource management, economic health, and cultural identity. We must know what's out there in order to better manage and conserve our resources for generations to come.

Ocean exploration would not be possible without a diverse enterprise of federal, commercial, academic, and non-profit investors and stakeholders. The National Oceanic and Atmospheric Administration is home to the nation's only dedicated federal ocean exploration program. This Committee is interested in learning about how the members of the ocean exploration community work together and how these roles can be better defined and partnerships leveraged to increase the pace, scope, and efficiency of ocean exploration.

We are a nation of explorers, and we must keep exploring and learning about the oceans because our future depends on it.

Chairwoman FLETCHER. I will now recognize Ranking Member Marshall for an opening statement.

Mr. MARSHALL. Thank you for holding this hearing, Chairwoman Fletcher. I want to thank our witnesses for appearing before this Subcommittee and sharing their perspectives. Though we are known more for wheat, cattle, and ethanol production, Kansans are affected every day by our oceans. Weather and climate patterns are one direct impact, but other indirect impacts, such as energy production, international trade routes, shipping our exports, as well as recreation and tourism opportunities affect Kansans daily. All Americans benefit from a better understanding of our oceans, whether we live on a farm in western Kansas, or a coastal community along the ocean.

June is National Ocean Month, and it's fitting we hold this hearing recognizing the importance of researching this part of our planet, which has gone largely unexplored. Over 70 percent of our planet is covered by water, and more than 96 percent of that water is in our oceans. There are more than 13,000 miles of United States coastline, and 3.4 million nautical square miles within our Nation's territorial jurisdiction. However, NOAA (National Oceanic and Atmospheric Administration) estimates that only 35 percent of the ocean water adjacent to the U.S. has been explored with modern technology.

A recent proclamation from the White House notes that our oceans, along with the Great Lakes, generate more than $320 billion in economic activity annually. As part of NOAA's Fiscal Year 1920 budget submission, Acting Administrator Dr. Neil Jacobs named the development of the blue economy one of his top priorities. Having a better understanding of our oceans is an important component of promoting economic development, whether it's ensuring a strong fisheries economy, international trade, recreation and tourism, or energy exploration, we all benefit from ocean exploration.

Scientific research is an important aspect of ocean exploration. We will hear from our witnesses today how discoveries from research conducted related to our oceans can positively impact medical research, cleaner energy production, and even the development of spacesuits. I look forward to hearing from our witnesses how this Committee can help promote research for our oceans.

In January 2018, President Trump signed an executive order to advance ocean-related scientific research, and promote greater coordination between Federal agencies and ocean partnerships. This committee should ensure that universities, private companies, and non-profit groups can continue the mission of increasing our knowledge of our oceans for the benefit of our country. Thank you, Madam Chair, and I yield back.

[The prepared statement of Mr. Marshall follows:]

Thank you for holding this hearing, Chairwoman Fletcher. I want to thank our witnesses for appearing before the Subcommittee and sharing their perspectives.

Though we are known more for wheat and cattle production, Kansans are affected everyday by our oceans. Weather and climate patterns are one direct impact, but other indirect impacts, such as energy production, international trade routes shipping our exports, as well as recreation and tourism opportunities affect Kansans daily. All Americans benefit from a better understanding of our oceans, whether we live on a farm in western Kansas or a coastal community along the Atlantic Ocean.

June is National Ocean Month and it is fitting we hold this hearing recognizing the importance of researching this part of our planet which has gone largely unexplored. Over 70% of our planet is covered by water and more than 96% of that water is in our oceans. There are more than 13,000 miles of U.S. coastline and 3.4 million nautical square miles within our nation's territorial jurisdiction, however NOAA estimates that only 35% of the ocean water adjacent to the U.S. has been explored with modern technology.

A recent proclamation from the White House notes that our oceans, along with the Great Lakes, generate more than $320 billion in economic activity annually. As part of NOAA's FY 20 budget submission, Acting Administrator Dr. Neil Jacobs named the development of the blue economy one of his top priorities. Having a better understanding of our oceans is an important component of promoting economic development. Whether it is ensuring a strong fisheries economy, international trade, recreation and tourism, or energy exploration, we all benefit from ocean exploration.

Scientific research is an important aspect of ocean exploration. We will hear from our witnesses today how discoveries from research conducted related to our oceans can positively impact medical research, cleaner energy production, and even the development of spacesuits.

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Thank you, Madam Chair. I yield back.

Chairwoman FLETCHER. Thank you, Mr. Marshall. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Thank you Chair Fletcher for holding this hearing, and I would also like to welcome our witnesses today.

I am glad to see our Committee so engaged in World Oceans Month and Capitol Hill Ocean Week from our film screening of Chasing Coral yesterday, to today's hearing, to our Ocean Exploration Expo tomorrow morning. We are also moving four bipartisan ocean acidification bills, which passed out of this Committee last month, on the House Floor this morning. The oceans are such a vital part of our national economy and livelihoods, with forty percent of the U.S. population residing in coastal counties that it is only fitting that we celebrate them.

The oceans make up over seventy percent of the surface of our planet, but over eighty percent of the world's oceans remained unmapped. It is commonly said that we know more about the surface of the moon than we do about the sea floor. Ocean exploration is more than just finding ship wrecks and identifying new marine species. It has the potential to answer questions about the origins of life on Earth and beyond. We have barely scratched the surface when it comes to marine discoveries.

I have always considered the Science, Space, and Technology Committee to be the Committee of the future. We have seen our federal investments in research and development lead to great advances in science and technology that have helped the United States to lead in many fields. This Committee should be committed to continuing to promote and enable American excellence in science, technology, and innovation. Ocean exploration is a field that has untold opportunity. But, despite the emergence of new cutting-edge and cost-effective ocean exploration technologies, we are ceding ground to other countries. Congress must be engaged in the next phase of ocean exploration so we can regain American leadership in this field.

In order to be global leaders, we must first understand the state and importance of ocean exploration, which is why today's hearing is so important. The witness panel brings together diverse perspectives of organizations that are at the leading edge of ocean exploration. It is a field that is built upon a foundation of partnerships between public, private, academic, and non-profit sectors. We need to ensure that we are fully leveraging these partnerships to maximize the resources and tools available to us. I am looking forward to our witnesses providing feedback on how these partnerships are working, and how we can address knowledge gaps so that we can continue to make advances in this important.

Chairwoman FLETCHER. And at this time, I would like to introduce our witnesses.

Our first witness, Dr. Katy Croff Bell, is the founding Director of the Open Ocean Initiative, and a research scientist at the MIT Media Lab. Her background is in deep-sea exploration, and since 1999 she has led or participated in more than 25 oceanographic and archaeological projects. In 2001, she was a John A. Knauss Marine Policy Fellow in the NOAA Office of Ocean Exploration. At the Ocean Exploration Trust, she was chief scientist of the Nautilus Exploration Program. Dr. Bell received her B.S. in ocean engineering from MIT, her Master's in maritime archaeology from the University of Southampton, and her Ph.D. in geological oceanography from the University of Rhode Island.

Our second witness, Dr. Carlie Wiener, is the Director of Marine Communications at the Schmidt Ocean Institute. Previously she held the position of communications manager for Centers for Ocean Science, Education Excellence, Island Earth, and prior to that she worked as the research and outreach specialist for the Hawaii Institute of Marine Biology, Northwestern Hawaiian Islands Research Partnership, at the University of Hawaii. She also hosted the monthly marine science radio show, All Things Marine, for 6 years. Dr. Wiener received her bachelor's degree in communications, and her master's and doctorate degrees in environmental studies from York University in Toronto, Canada.

Our third witness, Mr. Steve Barrett, is the Senior Vice President of Business Development at Oceaneering International, Inc. Previously he served as senior vice president of Sub-sea Product Lines at Oceaneering International. Mr. Barrett has more than 30 years of experience working in the oil and gas industry, starting in 1980. In 1982, he joined FMCA Technologies, Inc., where he progressed from design engineer to his most recent role as global director of Sub-sea Services. Mr. Barrett holds a B.S. in mechanical engineering from Texas A&M University, and an MBA in finance and entrepreneurship from Rice University.

Our final witness is Mr. David Lang, the co-Founder and Vice President of Business Development and Outreach for Sofar Ocean Technologies. In 2011, Mr. Lang co-founded Open Rove, which pioneered low-cost, underwater drone designs. Open Rove merged with another company in 2019 to form Sofar. Now the mission of the company is to create pervasive sensor networks to understand and monitor ocean environments, and provide critical data for ocean enthusiasts, industry, and conservation. Mr. Lang received his bachelor's of business administration from the University of Wisconsin, Madison.

Each witness will have 5 minutes for their spoken testimony. Your written testimony will be included in the record for the hearing. When you've completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel. And we will begin with Dr. Bell.

TESTIMONY OF DR. KATY CROFF BELL, FOUNDING DIRECTOR, OPEN OCEAN INITIATIVE, MIT MEDIA LAB

Dr. BELL. Chairwoman Fletcher, Ranking Member Marshall, Members of the Environment Subcommittee, and Members of the House Committee on Science, Space, and Technology, thank you for this opportunity to testify on the importance and future of ocean exploration.

The deep ocean, below 200 meters, is the largest ecosystem on our planet, supporting life for every human on Earth. The ocean provides most of the oxygen we breathe, supplies food for billions of people, supports a trillion dollar global ocean economy, nourishes our souls, and astonishes us with its wonders. In turn, we are impacting the deep sea at an unprecedented rate, increasing greenhouse gas emissions, pollution, extraction industries, and more, and yet we only have a rudimentary understanding of the ocean's role in our survival. We are at a critical point where we may be irreparably impacting the deep sea without truly understanding what those impacts may be.

In 2000, an expert panel, led by Dr. Marsha McNutt, published the report of the President's Panel on Ocean Exploration. The distinguished group of academic, industry, and government leaders called for the establishment of a Federal ocean exploration program to map the physical, geological, biological, chemical, and archaeological aspects of the ocean, funded at $75 million a year. Within months the NOAA Office of Ocean Exploration was created, funded at $4 million, and has seen a maximum of $42 million just this year in FY 2019. If high risk research like exploration is underfunded or unstable, agencies will tend to invest in safe bets that result in incremental progress, rather than riskier, but potentially transformative, endeavors that can truly change the future, enhance our understanding of the ocean, and ensure U.S. leadership. Today, deep-sea exploration sits at a crossroads. We could continue making incremental progress, or we could invest in new technologies, research methods, and social systems to transform and accelerate discovery for the 21st century. I believe that America is better served with the latter.

To do so, we must first maximize the efficiency of discovery. Current practices focus on large, ship-based equipment, which affords spectacularly detailed observations, like the ones you see here, but only on hyper-focused spatial and temporal scales, and at a very expensive rate. To try maximize our investment, we should leverage economies of scale to dramatically decrease the cost of sensors and systems by orders of magnitude to significantly increase the amount of area and volume of the ocean that we can explore, develop data systems, standards, archiving, access, and advanced analysis to fully understand data and new scales in an integrated way, and innovate across the spectrum of exploration by applying advances from other industries to ocean challenges, and creating a responsive environment in which to deploy and operationalize new tools to re-establish the United States as a global leader.

Second, we must use these new tools to explore the world's undiscovered places. To be sure, the mandate to explore the entirety of the U.S. exclusive economic zone is a significant challenge, but it is not enough. The ocean does not know boundaries, and it is an incredibly interconnected system, from coastal communities to the high seas, the atmosphere, to the deep-sea trenches. We therefore must view ocean exploration as a global imperative, not a national one, to achieve something greater than we could ever do alone.

And, finally, we must lead a global community of explorers. Traditionally exploration is conducted by those with advanced degrees, and access to costly equipment, limiting the number and diversity of people involved in the enterprise. To fully explore and understand our vast oceans, however, we need to work outside the traditional structures. One strategy for thinking beyond our current model is to build new bridges with communities who have not yet been invited into oceanographic exploration, including underrepresented communities within the U.S., as well as developing countries around the world. Instead of only an elite cadre of academics participating in ocean exploration, limiting the types and amount of work that we can do, we need to nurture new communities, build greater global capacity for exploration, and look for ideas and expertise in unexpected places.

Creating a global program of ocean exploration is ambitious, but imperative, and will yield a significant return on investment, with innumerable benefits to the United States, and the world. To do so, we need to invest in high risk research and development to maximize discovery, explore the world's undiscovered places, and lead a global community of explorers. By undertaking a long-term global strategy of ocean exploration, we will leverage all that we know, and all that we will discover. Thank you very much.

[The prepared statement of Dr. Bell follows:]

Envisioning the Future of Ocean Exploration

Statement of

Katherine L.C. Bell
Founding Director, Open Ocean Initiative, MIT Media Lab
Fellow, National Geographic Society

before the

Subcommittee on Environment
Committee on Science, Space, and Technology
U.S. House of Representatives

5 June 2019

Chairwoman Fletcher, Ranking Member Lucas, members of the Environment Subcommittee, and members of the House Committee on Science, Space, and Technology, thank you for this opportunity to testify on the importance and future of ocean exploration. I am honored to represent two organizations that have led the world in science, innovation, and exploration for more than 130 years, the Massachusetts Institute of Technology and the National Geographic Society.

Founded to accelerate the nation's industrial revolution, MIT is profoundly American. With ingenuity and drive, MIT graduates have invented fundamental technologies, launched new industries, and created millions of American jobs. At the same time, MIT is profoundly global. The MIT community gains tremendous strength as a magnet for talent from around the world. Through teaching, research, and innovation, MIT's exceptional community pursues its mission of service to the nation and the world.

In 1888, the National Geographic Society was founded to "the increase and diffusion of geographic knowledge"; since then, it has become a US-led global leader in science and exploration. Today, it is an impact-driven global nonprofit organization that pushes the boundaries of exploration, furthering understanding of our world and empowering us all to generate solutions for a healthy, more sustainable future for generations to come.

At the nexus of exploration and technology, and with a 20-year career in deep sea exploration, I founded the MIT Media Lab Open Ocean Initiative to work at the intersection of science, technology, art, and society to design and deploy new ways to understand the ocean and connect people to it, empowering a global community of explorers.

Importance of Ocean Exploration

The deep ocean below 200 m is the single largest ecosystem on our planet (Levin et al., 2019), which supports life for every human on earth. The ocean regulates our climate; provides more than half of the oxygen that we breathe; supplies 20% of the average intake of animal protein to 3.1 billion people; holds numerous sources of living, non-living, and cultural resources; and supports a growing $1.5 trillion global ocean economy. In turn, we are impacting the deep sea at an unprecedented rate with increasing greenhouse gas emissions, pollution, extraction industries, noise, and numerous industries are eyeing the deep sea for further industrial development (Mengerink et al., 2014; Packard & Scholin 2018).

And yet, in more than 150 years, we have mapped the shape of less than 15% of the seafloor and human eyes have observed less than 5%. We have only a rudimentary understanding of the ocean's role in our survival on earth and are at a critical point where we may be irreparably impacting the deep sea without truly understanding what those impacts may be.

How is it possible for us to know how to wisely use and protect our planet if we do not know what resources we have, their interactions with each other, and their interactions with humans? We need to know and fully understand our ocean so that we may thrive in harmony with nature now and in perpetuity. We don't have a Plan B.

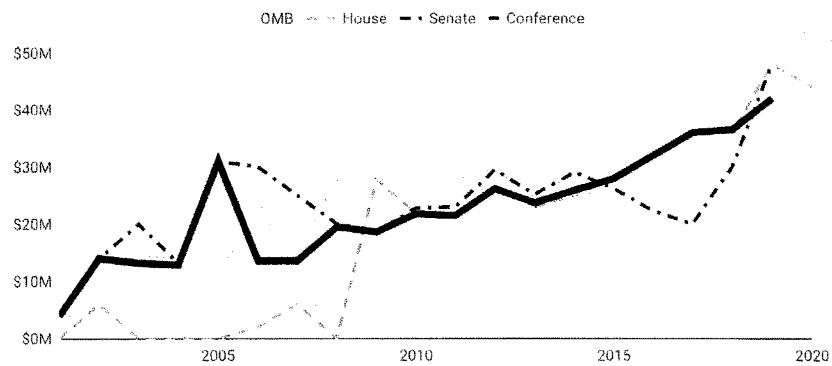
Status of Ocean Exploration

Almost 20 years ago, an expert panel led by Dr. Marcia McNutt was convened on ocean exploration under the Clinton administration. In its Report of the President's Panel for Ocean Exploration the distinguished group of academic, industry, and government leaders called for the establishment of a federal Ocean Exploration Program, funded at $75 million/year with the following objectives (McNutt et al. 2000):

1. Mapping the physical, geological, biological, chemical, and archaeological aspects of the ocean, such that the U.S. knowledge base is capable of supporting the large demand for this information from policy makers, regulators, commercial ventures, researchers, and educators;
2. Exploring ocean dynamics and interactions at new scales, such that our understanding of the complex interactions in the living ocean supports our need for stewardship of this vital component of the planet's life support system;
3. Developing new sensors and systems for ocean exploration, so as to regain U.S. leadership in marine technology; and,
4. Reaching out in new ways to stakeholders, to improve the literacy of learners of all ages with respect to ocean issues.

Such a program was established within NOAA in less than a year, under the administration of President George W. Bush. I was fortunate to have worked in the newly formed NOAA Office of Ocean Exploration in its first year as a John A. Knauss Marine Policy Fellow. In the first year, $4 million was appropriated, and with the exception of 2005, the program has grown linearly since that time but has reached a maximum of only $42 million in 2019 (Figure 1; AIP 2019). This budget history is a far cry from the recommended funding level of $75 million per year recommended in 2001 (roughly equivalent to $108 million in 2019 at level funding).

Figure 1. Budget history of the NOAA Office of Ocean Exploration & Research, 2001-2020 (AIP 2019)



As a result of volatile and insufficient funding, progress in our national program of ocean exploration has been steady, but slow. In a high risk, high reward field like exploration, where we don't know what we might discover when we look in an unexplored region, sufficient, stable funding is necessary to support the enterprise. If, however, funding is meager and unstable, agencies like NOAA will tend to invest in safe bets that will likely result in incremental progress, rather than riskier, but potentially transformative, endeavors that can truly change the future of exploration, enhance our understanding of the ocean, and ensure US leadership in the field.

For example, the technological gold standard of deep sea exploration today is a large vessel equipped with a hull-mounted multibeam echosounder, remotely operated vehicles (ROVs), and satellite telecommunications systems. Assuming a typical exploration vessel spends 800 hours of time per year on the seafloor with an ROV, we will have explored 0.01% of the seabed in one year per ship. At that rate, it will take 10,000+ ship-years to completely view the seafloor, and orders of magnitude longer to characterize the entire volume of the ocean -- once. Even if the fleet of full-time exploration vessels jumped to ten ships, it would still take 1,000+ years to explore the seafloor. In addition, these exploration efforts cost tens of millions of dollars annually and require large ships and equipment, making ocean exploration inaccessible to the vast majority of the population.

While the current operational model plays an important role in current ocean exploration, the vision that is being implemented now is more than 40 years old. Other fields of science have not only kept up with the exponential rate of change of the digital era, but driven it. Ocean science and exploration have, in many ways, been left behind.

Today, deep sea exploration sits at an inflection point. We could continue employing large, expensive assets and making incremental progress in exploration of the deep sea. Or, we could invest in new technologies, research methods, and social systems to transform and accelerate what it means to explore and discover the ocean in the 21st century.

While we have made progress in recent decades, if we are to accelerate the pace of deep sea exploration and maintain global leadership in the field, we must create a new paradigm to increase efficiency and access. Only now, with recent technological breakthroughs across numerous sectors, is it possible to take the current linear growth of exploration and make it exponential. To make gains in ocean exploration, we must invest in three areas: (1) **Maximizing** efficiency of discovery; (2) **Exploring** the world's undiscovered places; and, (3) **Leading** a global community of explorers.

Maximizing Efficiency of Discovery

Current best practices focus on ship-based equipment, which afford spectacularly-detailed mapping, exploration, visualization, and sampling, but only on a hyper-focused spatial scale with restricted temporal access. It also defines a very high price point, and caps the area-per-volume-explorable-per-year. In addition, despite the exploration community's growing expertise with setting exploration targets, there are certainly times when hundreds of thousands of dollars could have been more strategically-focused on other areas, since many key questions do not need the fine-grained observations that large ships and ROVs afford. In other words, what if we could maximize the efficiency of discovery by using smaller tools and platforms for preliminary exploration, and then use the larger ships to follow-up on identified targets with the full suite of best-available technology? And beyond the process of data collection, are we truly maximizing use of the data that we collect through advanced analysis techniques?

Toward a Spectrum of Exploration

Exploiting technological developments from outside the field now allows us to tackle many existing and emerging research priorities with low-cost, low-bandwidth, distributed swarms of sensors and platforms. On the one hand, this requires a radical rethink of what data we actually need to extract from the ocean, and on the other, it requires a radical rethink of what a platform looks like, how we deploy them, and how we recover data in an environmentally responsible way. In terms of data needs, high definition video and samples from the entire pelagic and benthic ocean are the ideal, but the reality is that a strategic, focused approach to a suite of standardized metrics would vastly improve our overall understanding, and help to guide future exploration with more fine-grained tools. Some of these metrics could include biomass tallies, environmental DNA (eDNA), CTD, oxygen, visual imagery, and collection of specimens. Platforms must evolve to be efficient and have longevity, but must simultaneously have high retrieval rates, installation-permanence, and/or low environmental impact. New systems must achieve high-tech functionality without compromising environmental integrity.

In many ways, the US is already a leader in marine innovation for ocean exploration. Take for example, the fact that the first autonomous underwater vehicle (AUV) company in the world, Bluefin Robotics, spun out of MIT Sea Grant in 1997; or the winning Shell Ocean Discovery XPRIZE for Advancements in Autonomous Ocean Exploration team, announced last week, was led by a US-based team; or start-up marine tech companies like Saildrone or SofarOcean are beginning to make inroads at making the industry more innovative and nimble.

But in many ways, we are starting to fall behind. Of the 6 leading AUV companies in the world, half are US-owned, and foreign companies are starting to outpace US players in terms of sales growth; in addition, Asia is starting to see increasing results in investment in this space. Furthermore, many marine technology companies primarily support the offshore energy and defense markets, driving up costs for sensors and other systems so high that it is impossible for scientists to explore as efficiently and effectively as we need. Given recent advances made in terms of economies of scale in electronics, robotics, and sensors, the time is right to not only support the invention of new technologies for deep sea exploration, but also nimble, responsive models to support academic-public-private partnerships to operationalize of them.

Big Ocean, Big Data

Ninety percent of the data in the world has been generated in the past two years (Marr 2018), and there is no reason to believe this explosion in data volume will not continue. More than ever, a solid foundation for processing these valuable data is needed so that they can be accessible and usable. There are many platforms for more standard oceanographic metrics, but for the storage, processing, and annotation of computationally expensive visual data that is required for exploration, challenges still remain. As more ocean-going platforms integrate cameras for observation and navigation, platforms such as Seascribe, Squiddle, and the Monterey Bay Aquarium Research Institute's (MBARI) Video Annotation and Reference System have evolved, but still require extensive curation by experts. For example, the recent NOAA CAPSTONE video data was real-time logged by experts on-ship and using telepresence in 2015-2017, but the post-campaign data curation and cross-checking is still underway by a dedicated team of scientists at the University of Hawai'i.

To address the data analysis bottleneck, the MIT Media Lab, MBARI, National Geographic, and CVision AI are using machine learning to develop a new, publicly available, expertly curated, baseline image dataset called FathomNet. We are working together to build and train machine learning algorithms to accelerate the curation and annotation process, such that it will be tractable for large, citizen-science, distributed platforms to collect data that can be made usable in an efficient manner. In short, we are using machine learning to directly accelerate development of modern, intelligent, analysis of underwater visual data that can be used for not only automated tracking and recognition of objects in the deep sea, but also future development of "smart" robots for exploration and science. Given the emergence of high-resolution, cost-effective sensors, platforms, and imaging systems that will be coming online in the immediate future (e.g. Saildrone, 4k, 8k cameras), there is an impending explosion of ocean data. Solutions across a gradient of explorers, platforms, and data types will be required to handle and ultimately understand this deluge of information.

More broadly, there are three areas of opportunity for dealing with big ocean data: using new and emerging data science techniques to explore legacy, current, and future data for better understanding of the ocean across disciplines and industries; using the results of such analysis for the creation of new data-driven tools for exploration, such as curious robots and heads-up data displays to make real-time exploration more efficient; and, visualizing and physicalizing data in new, innovative ways so that we may share results and tell data-driven stories creatively with a broader audience than ever before.

In summary, in terms of technological investments, we must consider:

1. **Leveraging economies of scale** to dramatically decrease the cost of sensors and systems by orders of magnitude to make it possible for us to significantly increase the amount of area and/or volume explored for markedly lower cost than is possible today;
1. **Developing data systems,** standards, archiving, access, and advanced analysis, with consideration for privacy and data rights, to fully understand data being collected so that we may understand ocean dynamics and interactions at new scales in an integrated way;
2. **Innovating across the spectrum of exploration** requires both applying advances from other industries to ocean challenges, and creating a responsive environment in which to deploy and operationalize them to re-establishing the United States as the global leader in marine innovation.

Exploring the world's undiscovered places

The ocean contains 320 million mi^3 of water covering 140 million mi^2 of seafloor across 71% of the planet. Of that, the United States has jurisdiction over 4,382,645 mi^2, the largest Exclusive Economic Zone (EEZ) in the world, and an area larger than that of the terrestrial United States (3,800,000 mi^2). The most robust, comprehensive scientific data from all areas of US waters must be collected, analyzed, and shared to support informed decision-making at all levels of American society for national, economic, homeland, natural resource, and cyber security. To be sure, the mandate to fully explore the entirety of the US EEZ is a significant challenge.

But it is not enough. The ocean does not know boundaries, and it is an incredibly interconnected system, from coastal communities to the high seas; the atmosphere to deep sea trenches. Ocean processes affect every aspect of our lives, and we are now learning that humans in turn affect many aspects of the ocean. Three years after the Fukushima Daiichi nuclear disaster in Japan, radioactive isotopes were found off the west coast of the US (ORO 2019); Atlantic mackerel, which migrate between Canadian and US waters, are in decline, adversely affecting fisheries in the northeast US; and warming waters in the Atlantic are intensifying hurricanes that land on American shores (Witze 2017).

We therefore must view ocean exploration as a global imperative, not a national one. We must come together on an international level, to achieve something greater than we could ever do alone. Other international scientific efforts, like the International Space Station or the Large Hadron Collider at CERN, have achieved amazing results, and we must use these as models for ocean exploration. Furthermore, deep ocean exploration of biological, chemical, geological, archaeological, and physical parameters would greatly benefit numerous international policy-making bodies, initiatives, and agreements that deal with climate, biodiversity, deep seabed mining, fishing, shipping and dumping, and ocean assessment (Levin et al., 2019). These are issues that affect humans around the world, and it would benefit everyone to work together.

Today's hearing is particularly timely because two weeks ago, the International Oceanographic Commission of UNESCO held the first Global Planning Meeting of the UN Decade of Ocean Science for Sustainable Development. The Decade will take place from 2021 to 2030, and is now defining the goals and approaches that a collaborative, international community of scientists, engineers, policymakers, and citizens can undertake over the next ten years to ensure ocean science and technology can support countries around the world "in creating improved conditions for sustainable development of the ocean." The United States is already involved, with four out of nineteen members of the Executive Planning Group representing US organizations, as well as numerous American scientists and policymakers participating in the first meeting. We should The Decade of Ocean Science is a tremendous opportunity to work with an international team that is already working on a strategy for long-term exploration and understanding of the ocean.

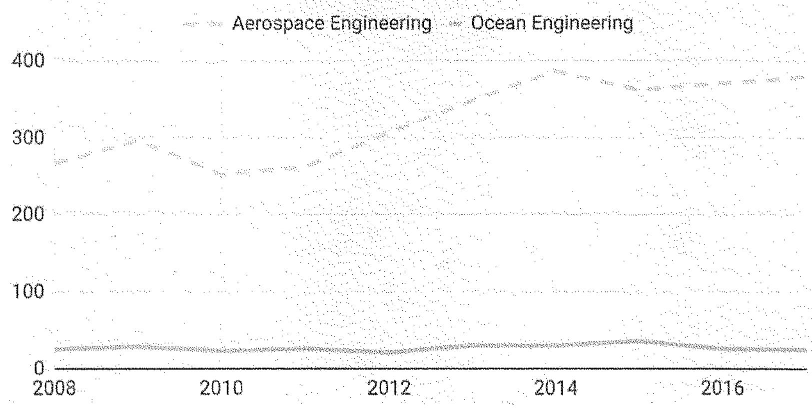
Leading a global community of explorers

Traditionally, exploration is conducted by those with advanced degrees and access to costly equipment. In order to fully explore and understand our vast oceans, however, we need to work outside of the traditional academic structures of science and innovation. One strategy for thinking beyond our current model is to build new bridges with communities who have not yet been invited into oceanographic exploration, including underrepresented communities within the United States, as well as developing countries around the world. Instead of only an elite cadre of academics participating in ocean exploration — which limits the types and amount work we are able to do — we need to nurture new communities, build greater global capacity for exploration, and look for ideas and expertise in unexpected places.

First, however, we must determine whether or not the United States is positioned to lead such a community. To do so, consider the number of students graduating with doctoral degrees as a metric for investing in future leaders as well as diversity in the field (NSF 2018). When considering technical capacity, we see that the number of Ocean Engineers graduating with

PhDs from 2008-2017, the number has not significantly changed (average 27/year); this is in stark contrast to the number of Aerospace, Aeronautical, and Astronautical doctoral recipients, which averages 323/year, more than ten times the number of Ocean Engineers (Figure 2).

Figure 2. Ocean vs Aerospace, Aeronautical, and Astronautical Engineering PhD graduates 2008-2017 (NSF 2018)



As has been demonstrated in numerous studies, as well as recent hearings hosted by this committee, the diversity of a nation's workforce is a key indicator of innovation and success (NASEM 2019). First, I will note that it was challenging to determine how well the US is training graduate level students -- the future leaders of exploration -- due to a lack of data on ocean science, which is often aggregated with other earth sciences. I did find, however, a few notable trends. First, that, on the whole, the gap between male and female earth scientists has narrowed by 8% from 2008 to 2017, with 2017 seeing 45% of graduating earth science PhD being female (Figure 3). From the data available, it is not possible to know what percent is ocean scientists, but this is a positive trend overall for earth sciences generally.

In terms of racial and ethnic diversity, we are also seeing a positive trend. In 2009, doctoral graduates in ocean, marine, and fisheries sciences were 14% non-white, and in 2017, 24% of doctoral graduates were non-white US citizens (Figure 4). While these trends are headed toward seeing a workforce that represents the US population as a whole (USCB 2019), we still have work to do. Female engineering PhDs, for example, are still outnumbered by men in a 3:1 ratio. And while it is encouraging to see that 24% of ocean science PhDs are not white today, we are still lagging behind today's composition of US population, which is 35% non-white. Examining projections of the size and composition of the US population in 2060 shows that we should be aiming for nearly 60% non-white ocean scientists in the next 40 years (Colby & Ortman 2015). The only way to do that is to start investing in the children that are in school, and those who are being born, today.

Figure 3. Female vs Male PhD Graduates in Geosciences, Atmospheric Sciences, and Ocean Sciences (2008-2017) (NSF 2018)

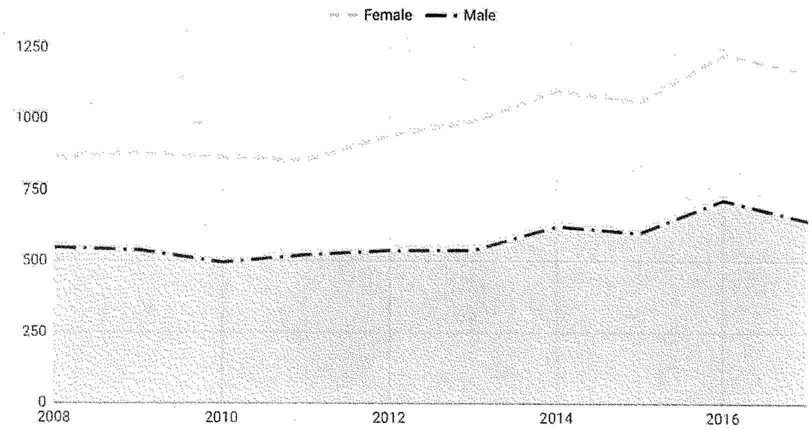
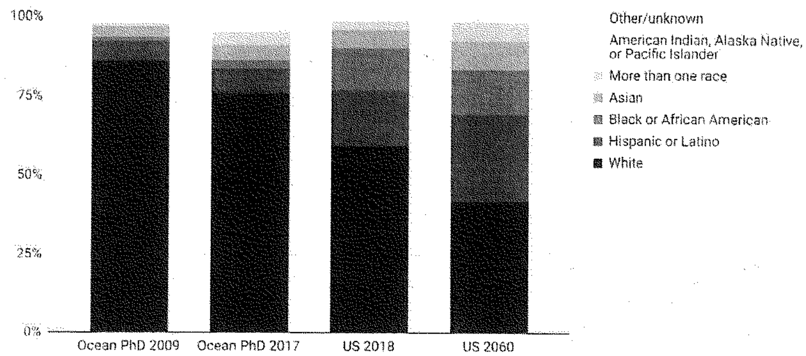


Figure 4. PhD Grads in Ocean, Marine, and Fisheries Sciences 2009-2017 vs US Population 2016-2060 by Race/Ethnicity (NSF 2018, USCB 2019, Colby & Ortman 2015)



To address ocean exploration as a global imperative, we also must consider global capacity. Only ~5% of coastal nations operate 10 or more research vessels, and the United States is the only country in the world that operates vessels of exploration. Academic deep submergence capacity is similarly small. That leaves approximately 95% of coastal nations with little to no ability to explore their own deep waters. This is problematic, not only for those nations to be able to understand and manage their own resources, but also for understanding global connectivity of deep sea systems.

Building an informed appreciation by the global population for ocean discovery is critical. Knowledgeable, responsible citizens purchase, work, and behave differently when rationally-made choices reaffirm beliefs established during early childhood (Kahneman 2011). Continued exposure to ocean discovery will strengthen stewardship and inform decision making – making discovery visible and mainstream will pave the way for a long-term cultural commitment to exploration. In the last 10 years, ocean exploration has entered the public eye through the power of telepresence, and reaches an audience of tens of millions people annually (Raineault et al. 2019). This figure is less than 1% of the global population – more of a niche following than a mainstream one. To create a foundational culture of ocean exploration, we should reach at least 10% of the global population, with a goal of reaching 100%. That is a long way to go.

Early education, continued engagement, and mainstream entertainment can work together to reinforce a connection to the ocean that could result in a global network of individuals, institutions, and industries more responsibly using the bounty of the seas. A populace raised on, near, or deeply invested in the ocean would create a larger pool of knowledgeable employees for the blue economy, and citizens engaging as responsible ocean stewards. To that end, leveraging the tools of mass media such as film and television with ocean-based themes and stories will create beloved characters and fond memories, as well as profit for entertainment industry. Disney's *Moana* is the first animated ocean exploration hero to hit the mainstream, grossing more than $600M worldwide, and the 12th-most profitable release of 2016; *Aquaman* grossed $1.148B worldwide, becoming the highest-grossing film based on DC comics characters, and 21st highest of all time. The time is right to add more ocean characters and role models to the scene.

2018 National Ocean Exploration Forum: All Hands on Deck

In November 2018, I chaired the 2018 National Ocean Exploration Forum at the MIT Media Lab in collaboration with OER to imagine creative new ways to make the ocean so pervasive in modern culture that everyone has a positive association with, and understanding of, the sea. The Media Lab and OER brought together leaders in ocean exploration, industry, entertainment, recreation, art, and design to empower an open, inclusive global community of ocean explorers. Throughout the course of the Forum, we addressed: sparking curiosity in the ocean through play; imagining a bright, optimistic future for the ocean; immersing people in the ocean and bringing the ocean to people; engaging the heart and soul through the creative arts; empowering a global community of ocean explorers; and, connecting people to the ocean and to each other.

Given how poorly the oceanographic community has historically tackled diversity, we knew we needed a new approach to planning of the 2018 Forum. We intentionally structured the event to enhance diversity and equity, including investing in travel funding for 40 people from around the world who could not otherwise attend the Forum, particularly students, early career scientists, and those from developing countries; demonstrating that representation matters by inviting 57% female and 35% non-white speakers. Finally, we included representatives from mass media and toy industries, such as Disney, LEGO, and the World Surf League, that reach billions of people in a fun and entertaining way; a myriad of opportunities abound with innovative collaborations such as these because it is clear that the oceanographic community cannot reach the global population alone.

My Deep Sea, My Backyard

In parallel, to address the capacity gap between developed and developing countries, the MIT Media Lab is working with colleagues from Boston University, National Geographic Society, Natural History Museum (UK), University of Rhode Island, Inter-American Development Bank, and others to empower citizen explorers in developing island states to explore their own deep-sea backyards using low-cost technologies, while building lasting capacity. This pilot project, called *My Deep Sea, My Backyard* aims to help realize UN Sustainable Development Goal 14 in Kiribati and Trinidad and Tobago; There is interest from colleagues around the world to expand the project to dozens of other countries. Our goal is to enable access to emerging deep-ocean technology that can be used from any platform; and train new scientists, students, and communicators to enable use and dissemination of findings to all stakeholder groups in both underrepresented communities in the U.S. and developing countries around the world.

Working across lines of difference — culture, gender, geography, and industry — requires trust and respect built through a commitment to a shared set of values. We are also doing research on participatory design approaches, and we have been developing this set of Principles for Value-Driven Design, which are being applied to these and other projects focused on enhancing equity, diversity, and innovation in ocean exploration. Participatory approaches to data collection and analysis as well as participatory approaches to technology development, are nascent in the oceanographic community (Glazer 2019). These approaches will allow us to collect and analyze broader datasets, expand the definition of who is considered an explorer, open up future STEM careers for underrepresented people, and help create technologies that have yet to be imagined.

Toward a new Paradigm for Ocean Exploration

Creating a global program of ocean exploration is ambitious, but imperative. Investing in innovative, strategic exploration of our own planet will have a significant return on investment and will result in innumerable benefits to the United States and the world. Most importantly, we must find a balance between ensuring a thriving blue economy with understanding deep sea systems, thus giving us the opportunity to protect the systems on which we rely before they are destroyed. Our very survival on Earth is at stake and there is no time to waste.

The MIT Media Lab Open Ocean Initiative stands ready to serve the nation and the world. We look forward to the opportunity to work with the House Committee on Science, Space, and Technology to create an innovative spectrum of platforms, technology, and people to maximize discovery and under. By undertaking an ambitious, long-term global strategy for ocean exploration, we will leverage all that we already know, and all that we will discover.

Acknowledgements

I would like to acknowledge valuable contributions to this testimony from numerous people, especially Dr. Randi Rotjan of Boston University, as well as: Dr. Allan Adams, MIT; Dr. Diva Amon, Natural History Museum, UK; Dr. Richard Bell, The Nature Conservancy; Dr. Jennifer Chow, MIT Media Lab; Mr. Michael Conathan, Aspen High Seas Institute; Ms. Jessica Cramp, Sharks Pacific; Dr. Jeffrey Drazen, University of Hawaii; Dr. Peter Girguis, Harvard University; Dr. Brian Glazer, University of Hawai'i at Manoa; Ms. Alexis Hope, MIT Media Lab; Dr. Katie Inderbitzen, University of Alaska Fairbanks; Dr. Ayana Johnson, Ocean Collectiv; Dr. Mandy Joye, University of Georgia; Dr. Kakani Katija, Monterey Bay Aquarium Research Institute; Mr. Brian Kennedy, Boston University; Dr. Lisa Levin, Scripps Institution of Oceanography; Mr. Justin Manley, JustInnovation, Inc.; Dr. Jeff Marlow, Harvard University; Dr. Craig McClain, Louisiana Universities Marine Consortium; Dr. Daniel Novy, MIT Media Lab; Mr. Marcus Pearson, Esq., Adventure Scientists; Dr. Shirley Pomponi, Florida Atlantic University; Dr. Stephanie Sharuga, Genwest Systems, Inc./NOAA; Mr. Alan Turchik, National Geographic Society; Dr. Jyotika Virmani, XPRIZE; Dr. Martin Visbeck, GEOMAR Helmholtz Centre for Ocean Research, Germany; Mr. Benjamin Woodward, CVision AI; Dr. Dawn Wright, Environmental Systems Research Institute.

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Dr. Katy Croff Bell

Founding Director, Open Ocean Initiative, MIT Media Lab
Fellow, National Graphic Society

Dr. Katy Croff Bell is the Founding Director of the Open Ocean Initiative at the MIT Media Lab, Fellow at the National Geographic Society, and Founding Member of the Ocean Collectiv. Her research involves developing programs for low-cost, distributed deployment of new and emerging technologies for exploring the ocean and connecting people to it.

Previously, as Vice President of the Ocean Exploration Trust, Dr. Bell led the development of exploration, research, and educational outreach activities for Exploration Vessel *Nautilus*. In that role, she oversaw hundreds of scientists, engineers, educators, and students from more than 30 countries working together to conduct telepresence-enabled expeditions around the world.

Dr. Bell holds an S.B. in ocean engineering from MIT, an M.Sc. in maritime archaeology from the University of Southampton, and a Ph.D. in geological oceanography from the Graduate School of Oceanography at the University of Rhode Island. She was a 2001 John A. Knauss Marine Policy Fellow in the NOAA Office of Ocean Exploration, Chair of the 2018 National Ocean Exploration Forum, and is currently Vice Chair of the Marine Protected Areas Federal Advisory Committee.

Chairwoman FLETCHER. Thank you, Dr. Bell. Dr. Wiener?

TESTIMONY OF DR. CARLIE WIENER, DIRECTOR OF MARINE COMMUNICATIONS, SCHMIDT OCEAN INSTITUTE

Dr. WIENER. Thank you Chair Fletcher, Ranking Member Marshall, and the other distinguished Members of the Committee, for holding this valuable hearing today, and for giving me the esteemed privilege for providing testimony. It is an honor to be here to speak about the deep-sea environment that is not often at the forefront of everyday citizens' thoughts about the ocean. Such vital systems, like deep seamounts, coral reefs, seeps, and other deep systems provide scientific understanding, sharing, and consideration. I thank this Committee for its efforts to facilitate discussion on a national level to address the significance of ocean exploration, and continued need for a collaboration, technology-based research. If you could start the slide, that would be great.

It is my great pleasure to appear before you today in my current capacity as directing communications and outreach for Schmidt Ocean Institute, a 501(c)(3) operating foundation established by Eric and Wendy Schmidt in 2009. Schmidt Ocean Institute is the only philanthropically funded international seagoing facility dedicated to year-round open ocean research, and aims to foster a deep understanding of our ocean by combining advanced science with state-of-the-art technology. In my role I share the exciting discoveries and important research that takes place on the institute's research vessel, Falkor.

A statistic we often hear is that we know more about the far side of the moon than about the ocean, but I personally think that the more important question to highlight here is, why do we know more about the moon than we do about the deep sea? How do we create excitement and passion for the systems that we cannot view from the beach, and bring understanding to the ocean health—about ocean health to America's heartland? Many observe the vastness of the ocean, but few comprehend the scale of the deep sea. However, technology is beginning to change this, not only giving access to these environments for research, but to share this exploration through livestreaming video around the world, technology that continues to advance the state of the ocean science in an area where more focus needs to be allocated, allowing for broader and faster data collection, management, analysis, and open sharing.

As our global ocean changes, we need to be able to capture baseline data for hard-to-reach places, and understand how they will influence shallow environments. Unfortunately, available deep-sea observations are discontinuous, and it is not known how these ecosystems connect to each other, or to the broader ocean food chain. One of the best ways to close this lack of understanding is through multi-disciplinary, multinational partnerships. Schmidt Ocean Institute has endeavored to achieve this through unique collaborations that have had scientific and conservation implications. An example of this is in 2014, high-resolution maps created off of research vessel *Falkor* for the Papahanaumokuakea Marine National Monument. These maps helped to eliminate sea mounts that contributed to justification for expansion of the protected areas. Or of the newly discovered geological formations found in the Pescadero Basin last year that feature upside-down, mirror-like lakes that pool hot fluids. The work at this site will further allow investigation of the geological controls on habitat suitability for different animal communities.

Better data monitoring and capacity will play a central role in improving exploration outcomes. This means not only implementing robust technologies in our own waters of North America, but expanding them globally to remote and developing countries. Robotics systems, coupled with artificial intelligence, can complement existing vessels and platforms. When deployed in groups, autonomous vehicles will improve coverage and cost-efficiency for ocean observations.

Schmidt Ocean Institute has focused on scalable ocean research, offering time at sea for developing and testing of robots, and smart software for autonomous marine surveys. These types of projects allow scientists to make quick and well-informed decisions on how to directly sample and conduct fine-scale surveys. While we still have much to discover here on Earth, scientists are also looking to other oceans in our solar system. In preparation for such endeavors, deep ocean systems can serve as a laboratory to develop and test new technology for use in extraterrestrial exploration.

Ocean exploration lends itself to interactive storytelling and engagement. Outreach programs should not only continue to be supported on a national level, but successful programs must be identified, expanded, and replicated across disciplines and locations. It is important to not just make data and imagery available, but to synthesize these materials for engaging widespread audiences. One example is Schmidt Ocean Institute's Artists at Sea program, that has had many artists participate in science expeditions, and share their art. It is a way to make data approachable, and bring in new audiences to understand the ocean.

The public faces daily messages and negativity surrounding our ocean. During this time of environmental decline, ocean exploration can provide a new narrative, bringing a message of hope by showcasing beautiful and mysterious parts of our ocean that are rarely observed to millions of people. The ocean is changing, but new data, science, and dedicated people can bring a fresh understanding and engagement to the deep sea. Thank you very much for inviting me to testify here today.

[The prepared statement of Dr. Wiener follows:]

Testimony of
Carlie S. Wiener, PhD
Director of Marine Communications, Schmidt Ocean Institute

Hearing on: OCEAN EXPLORATION: DIVING TO NEW DEPTHS AND DISCOVERIES

United States House of Representatives Committee on Science, Space, and Technology
Subcommittee on Environment

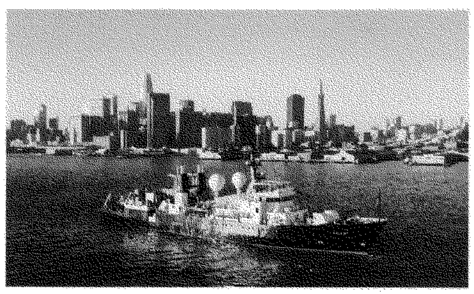
Thank you, Chair Lizzie Fletcher, Ranking Member Roger Marshall and the other distinguished members of the committee, for holding this valuable hearing today and for giving me the esteemed privilege of providing testimony. It is an honor to be here to speak about the wondrous and breathtaking deep-sea environment that is not often at the forefront of everyday citizens' thoughts about the ocean. Such vital systems like deep-seamounts, coral reefs, hydrate seeps, and hydrothermal vents merit scientific understanding, sharing, and consideration. While the focus here today is the deep-sea, we must acknowledge that our ocean is an inextricable component of the system that allows all life to thrive here on Earth. I thank this committee for its efforts to shed light and facilitate discussion on a national level to address the significance of ocean exploration and the continued need for collaborative, technology-based research.

It is my great pleasure to appear before you today in my current capacity directing communications and outreach for Schmidt Ocean Institute, a 501(c)(3) operating foundation established by Eric and Wendy Schmidt in 2009. Schmidt Ocean Institute aims to foster a deeper understanding of our environment by combining advanced science with state-of-the-art technology to achieve lasting results in ocean research, to catalyze sharing of the information, and to communicate this knowledge to audiences around the world. In my role, I share the exciting discoveries and important research that take place on the Institute's operating platform, research vessel *Falkor*.

As the only philanthropically-funded, international seagoing facility dedicated to year-round open ocean research, Schmidt Ocean Institute has positioned itself as a leader and collaborator with both international and U.S. academic institutions, government agencies, and non-governmental organizations. Working with Schmidt Ocean Institute for over five years has allowed me to experience firsthand the important role that science and exploration fulfills in the deep-sea. On every expedition we embark on, something novel is discovered. Whether a new species, seamount, biological or geological interaction, or development in technology; everyday that a research vessel spends at sea, expands our knowledge of the marine environment.

A statistic we often hear is that more is known about the far side of the moon than about the ocean, but I personally think the more important question to highlight is *why* do we know more about the moon than we do about the deep-sea? How do we create the excitement and passion for the systems that we cannot view from the beach, environments not observed by a telescope? How do we engage with citizens outside of the traditional marine and coastal communities to bring understanding of ocean health to America's heartland? Many observe the vastness of the ocean, but few comprehend the scale of the deep-sea.

The ocean is enormously deep, reaching 36,000 feet in its deepest trench. At nearly 7 miles below the surface this dark, cold environment, with crushing pressure appears like it would be inhospitable to life. However, this is not the case. Seemingly otherworldly habitats and uniquely adapted species are found in these secret habitats far away from the shorelines of our coasts. More than 90 percent of ocean habitat exists in the deep-sea, but less than 10 percent has been explored by humans. These difficult environments make deep ocean exploration technically challenging and, until recently, largely beyond human reach. But today, technology has allowed us to not only access these environments for study and research, but to share this exploration through live streaming video around the world to classrooms, aquariums, museums, and even smartphones and mobile devices.



Research vessel *Falkor* sailing into San Francisco, CA. Credit: Josh Edelson.

There are only three U.S.-based entities operating non-commercial deep-sea oceanographic research vessels, outfitted with embedded science work class remotely operated vehicle systems that are dedicated to yearly support of ocean exploration, research, and live at-sea outreach. Schmidt Ocean Institute is one of those organizations with its research vessel *Falkor*. While each vessel and entity has a unique focus, all three have sharpened national efforts to better understand the deep-sea.

As a philanthropic platform, Schmidt Ocean Institute has been able to emphasize high-risk, high-reward innovation in ocean science, robotic systems, and emerging technologies and software. Technology that advances the state of ocean science is an area where more national focus needs to be allocated, allowing for broader and faster data collection, management, analysis, and open sharing. As our global ocean changes, we need to be able to capture baseline data for hard-to-reach places and better understand how they will be affected or adapt to warmer ocean temperatures.

Additionally, we need to advance our understanding of how these deep systems interact and influence shallow environments.

The remaining part of my testimony will be divided into three sections that highlight essential components of ocean exploration. I will first discuss the need to define and measure fundamental ecosystem science in the deep ocean using seafloor maps, sensors, and digital imagery. I will then move to the technology - both existing and needed- that is necessary to accomplish national science obligations, highlighting how the use of such capabilities can be optimized and/or expanded. Last, I will emphasize the importance of sharing these exploration programs with the public and nurturing human connection to the deep-sea.

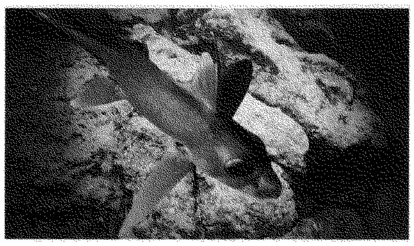
1. OCEAN EXPLORATION AND DEEP-SEA ECOSYSTEM SCIENCE

Ocean exploration is not a new activity; however, past efforts have been limited by capacity, funding, and the availability of technology. Only in recent years have we had the technology to truly invest in detailed assessments, seafloor mapping and characterization of deep-sea environments. Philanthropic endeavors such as Schmidt Ocean Institute have helped to scale capacity and broaden the reach of ocean exploration (see Appendix A). For example, research vessel *Falkor* has contributed more than 1,385 self-funded science days at sea since 2013 and made all of the resulting collected data publicly available. While this effort contributes to our understanding, we are still lacking the data and capacity needed to fully characterize the ocean. Did you know that only about 15 percent of the ocean floor has ever been mapped? Think about that for a second. A simple topographic map is one of the most basic forms of environmental investigation, yet 85% of our ocean remains in obscurity. There are global efforts now underway, such as the United Nations Decade of Ocean Sciences and Seabed 2030 Project, an initiative jointly organized by the Nippon Foundation and the General Bathymetric Chart of the Oceans to encourage more mapping of the seafloor (their goal is a full mapped seabed by 2030). This is one example of the work needed to truly bring our understanding up to date and demonstrates why ocean exploration remains critical for ocean sciences and our nation.

Ocean Exploration and Ecosystem-Based Management

One of the best ways to close this data gap and lack of understanding is through multidisciplinary international collaborations that merge ocean mapping, morphology, geology, microbiology, chemistry, and even education. Schmidt Ocean Institute has endeavored to achieve this, bringing together 165 institutions from 30 different countries over the past six years to explore, collect data, and serve as a catalyst to accelerate the pace of ocean science and technology to innovate, discover, and share. These unique collaborations have led to new discoveries and knowledge that have both scientific and conservation implications.

For example, *Falkor* operated off the coast of Costa Rica earlier this year with collaborators from Temple University, Scripps Institution of Oceanography, and the University of Rhode Island, with the goal of bridging conservation and scientific research. The work expanded knowledge of deep-sea ecosystems in the region and provided justification for possible expansion of Cocos Islands National Park to deep-seamount communities.



Chimaeras found in Costa Rican waters during the January 2019 expedition. Chimaeras are cartilaginous fish, largely confined to deep water.
Credit: Schmidt Ocean Institute.

This was the first survey of seven seamounts in the region, which act as an important migration corridor for the animals. One of the most important contributions science can make right now is to help managers understand how these communities work, to better prepare and assess future changes. The research will support efforts to provide a baseline of the incredible species and found in the deeper ecosystems that do not always attract the attention that they deserve.

During the expedition, four new species of deep-sea corals and six organisms were discovered. Uncovering new species increases our total knowledge about the ocean and how different organisms and systems interact. These discoveries provide an opportunity to unlock information on how our world works and demonstrates that there is still a lot more we can learn about our planet.

In 2014, *Falkor's* high-resolution maps of the Papahanaumokuakea Marine National Monument, northwest of the Hawaiian Islands, helped to illuminate the precious seamounts outside of the existing protected boundaries that led to the discovery of several new species. These efforts contributed to the justification for a significant U.S. government expansion of the protected area. This data collection was a result of Schmidt Ocean Institute making their unique seagoing asset available to U.S. scientists. Using these data, University of Hawaii researchers were able to see, measure, sample, and understand much more than before about the extensive biodiversity of the entire area, not just a small piece of this special area.

Even with the additional mapping of the region, there is still a significant portion that goes uncharacterized, and even more questions about the biology and its genetic connections to the rest of the Pacific. Research vessel *Falkor* will return to the Papahanaumokuakea Marine National Monument this summer to gain insight into the seamount lifeforms and their distribution across the region. This imperative work will provide ocean managers baseline knowledge of the fauna found on the seamounts and how they are connected to the broader central and western Pacific region. The protected waters could be a genetic source for other cobalt-rich regions. The research will also help to better understand the impact of ocean acidification on the formation of deep corals.

This foundational science is the type of work that is needed across the entire Pacific region. Mapping and surveying deep-ocean systems will present a better picture about why ocean species exist in certain places and help scientists and managers to better understand the sensitivity of these ecosystems and migration patterns to changes in ocean climate.

Digitizing Marine Life and Seafloor Habitats

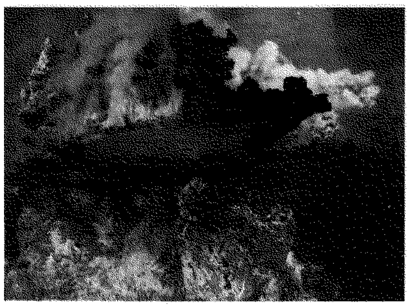
A plethora of submarine activity can be found on the seafloor where heat, water, and gases interact, creating otherworldly ecosystems that host unique organisms and structures. Unfortunately, available observations of these marine habitats are patchy, discontinuous, and scarce; it is not known how these deep-sea ecosystems connect to the broader ocean food chain that supports our commercial fisheries. More quality data is essential to inform effective management. Schmidt Ocean Institute, in collaboration with scientists who sail aboard *Falkor*, is helping to expand the data available through digital characterization of marine habitats and processes for subsequent research, analysis, and open sharing.

Schmidt Ocean Institute's 4500 meter capable remotely operated vehicle (ROV) SuBastian.
Credit: Schmidt Ocean Institute.

Currently, the best way to collect this data is through the use of a remotely operated vehicle (ROV). Schmidt Ocean Institute's ROV SuBastian uses 4K cameras to visually collect and share these remote coral and hydrothermal systems. Using the highest quality resolution of approximately 4,000 pixels allows for crisp lifelike imagery that illuminates ocean habitat as if you were there. Exploratory dives with SuBastian have revealed extraordinary microbial communities, vent systems, and new species. For example, rare animals like the seven-legged octopus were viewed for the fourth time ever this past year, as well as several species not previously known to scientists.

Hydrothermal vents are an expression of submarine volcanism located near areas of tectonic plate movement known as ocean ridges. The vents are part of a globally important process known as sea-floor spreading, which plays a vital part in shaping the surface of our planet. These sites serve as a natural laboratory to document the life cycles of incredible, alien-like organisms and better understand how they survive in extremely challenging environments. The vents are systems of geologic activity where submarine volcanism results in high-temperature venting with unusual chemistry and geology. Ocean exploration should not stop with the species or the vent systems; the interactions between deep and shallow environments is critically important to better appreciate their influence on each other.

Since October of 2018, Schmidt Ocean Institute has participated in three expeditions in the Southern Pescadero Basin, an area off the Gulf of California. Using submarine robotics systems managed from research vessel *Falkor,* the science teams successfully mapped the ocean floor in high resolution leading to the discovery of new hydrothermal vent fields, never seen before species, and unique underwater worlds.



Superheated hydrothermal fluid flows upwards from an underwater volcano 2000 meters below the Gulf of California. Credit: Schmidt Ocean Institute.

At 2,000 meters depth, towering mineral structures (up to 23 meters in height) serve as biological hotspots for life. These newly discovered geological formations feature upside down 'mirror-like' lakes that pool hot fluids (up to 366°C) and create the illusion of looking at a mirror when observing the superheated hydrothermal fluids beneath them. A seemingly inhospitable habitat, with metal-laden minerals and highly sulfidic fluids, yet these sites were teeming with biodiversity. This may be a clue to how life exists in less habitable environments on other planets.

Voyages to the Pescadero Basin are a good reminder of the locations around the world that remain unexplored, yet prove to be important locations for understanding how vent fauna colonize similar sites around the globe. The detailed work at this site will further allow investigation of the geological and geochemical controls on habitat suitability for different animal and microbial communities.

Broader Ocean Impacts

The deep ocean not only supports vent systems and animals, but provides habitat for a wide array of species and works to remove carbon dioxide from the atmosphere. However, a 2017 paper by Sweetman et al. forecast that up to 55 percent of the deep ocean seafloor could be significantly impacted by 2100, starving the animals and microbes that exist. Ecosystem shifts as a result of changing temperature, pH and oxygen levels are predicted to impact these sensitive ecosystems. The situation could be exacerbated by drilling for oil and gas, dumping of pollutants, over-fishing, and deep-sea mining. Little is known about how a changing climate will impact the deep-sea, and more is needed to truly understand these impacts. Ocean exploration is one mechanism for not only characterizing what exists but also for discovering the complex pathways and interactions between biological and physical components of the Earth system. Understanding these pathways and interactions are essential for making projections of the future environment.

What is known is that there is methane stored in ocean sediments, and gas released from the seafloor goes into the ocean. Where this methane goes and how it is transformed in the water ultimately dictates the magnitude of its role. The large flux of methane into the ocean means it may indirectly play a part in the carbon cycle, which is closely linked to Earth's climate. In October of last year, a science team from Harvard University and NASA worked in the Southern California Borderland and showed that methane venting is much more episodic than previously known, changing our assumptions about methane escape from the seafloor.

Several other expeditions have focused on deep-sea methane as well, examining bubbles coming from the sea floor to better understand the gases being emitted and how they travel through the ocean to the atmosphere. Last year, scientists from Woods Hole Oceanographic Institution, while sailing aboard research vessel *Falkor*, examined gas samples with a new bubble capture system that was installed on ROV SuBastian to take chemical measurements of bubble composition. The research illustrated changes in methane from venting locations across a spatial scale and over time. By studying methane bubble concentrations scientists will be able to advance understanding of the biological storage for methane and develop new ways to understand ocean cycles.

Mylar Frozen balloon found in the Pescadero Basin more than two miles below the ocean surface. Credit: Schmidt Ocean Institute.

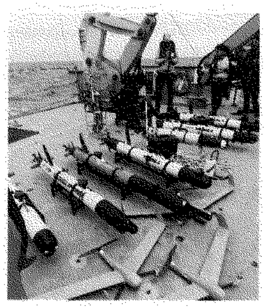
Aside from changing climates, humans are also impacting these exceptional ecosystems. Unfortunately, even in these remote and beautiful environments we have seen an accumulation of trash. During a recent ROV SuBastian dive in the Pescadero Basin at 3,600 meters depth (more than 2 miles), an accumulation of garbage was discovered including fishing nets, deflated Mylar balloons, and even a discarded fully-decorated Christmas tree! Bearing witness to garbage covering our seafloor is becoming more frequent on our ROV SuBastian dives and is a stark juxtaposition to the spectacular mineral structures and biodiversity we find at deep depths.

2. OCEAN EXPLORATION AND TECHNOLOGY

The ocean is far too large to observe with current conventional means. In order to make meaningful advances in ocean exploration research there must be a comprehensive network of agile, resilient, and robust platforms. Ocean managers urgently need swift monitoring and improved tools to track and counter declining ecosystem conditions. Better data and monitoring capacity will play a central role in improving exploration outcomes. This means not only implementing robust technologies in our own waters of North America, but expanding them globally to include remote and developing countries. Robotic systems coupled with artificial intelligence can complement existing vessels and platforms. When deployed in groups, autonomous vehicles will improve coverage and cost-efficiency for making select ocean observations, reducing risk and facilitating high resolution spatially distributed surveys of dynamic marine processes. The following projects provide examples of work to prototype the platforms on which the future of ocean observing can be built.

Scalable Ocean Research with Autonomous Robots and Artificial Intelligence

The ocean is Earth's life support system. To properly conserve this fundamental resource, the ocean's dynamic processes must be observed with higher resolution and coverage in time and space than what is currently possible with dedicated research ships alone. A multi-platform approach with low-cost autonomous vehicles deployed from research vessels in different mediums including underwater, sea surface, and air, can allow for a more comprehensive and complete picture of our oceanic systems. The cost-efficient robotic technologies available now and under development can allow us to achieve the levels of persistence and resolution of observations required for scalable ocean studies in a changing climate.



Multiple autonomous vehicles - aerial and underwater - utilized by scientists and engineers during a 2018 expedition aboard research vessel *Falkor*. Credit: Schmidt Ocean Institute.

Schmidt Ocean Institute has focused on scalable ocean research supporting the use of coordinated robotics from its ship, offering time at sea for both the collection of science and the development and testing of robots and smart software for autonomous marine surveys. Schmidt Ocean Institute is one of the first philanthropically funded exploration vessels to be used as a command center and test platform for the operation of multiple independently-unique vehicles simultaneously, allowing engineers and scientists to refine their techniques. The success of this model should be broadly adopted to accelerate the pace and ability of research for ocean exploration. In 2018, Schmidt Ocean Institute completed several expeditions devoted to developing and testing software that maximized informational contributions of multiple autonomous vehicles to the description of target habitats. The results of this work led to greater mapping, data and characterization efforts.

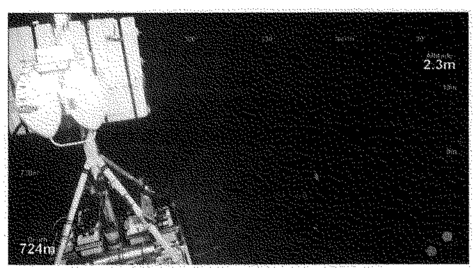
A specific example of this approach took place when a team of international collaborators allowed for coordinated robotic systems to collect over half a million georeferenced images covering 77,453 m^2 of seafloor in U.S. waters. This expedition aboard *Falkor* was an opportunity to test techniques that automate ocean observing. Another Schmidt Ocean Institute expedition used unsupervised learning techniques with 3D reconstruction to analyze 1.3 million seafloor images collected between autonomous unmanned vehicle deployments. As a result, the largest known continuous photogrammetric reconstruction of seafloor mapped at sub-centimeter resolution was created from data collected off the coast of Oregon.

These projects demonstrate how throughput data processing and machine learning can multiply the productivity of ocean exploration. They allowed scientists to make quick and well-informed decisions on how to directly sample and conduct fine scale surveys to study rapidly changing marine habitats that would otherwise be virtually impossible to observe in detail. The resulting work is invaluable in planning operations, including the recovery of seafloor instruments, re-visiting active bubble plumes, and making operation more efficient.

More ocean observations like these are critical to creating actionable science building our nation's ability to understand and manage our ocean resources. The volume of ocean observations is growing at an accelerating pace, but the infrastructure to transmit, store, process, and analyze these data remains in infancy. Thus, even with greater observational capabilities, a substantial amount of development will be required to build systems that facilitate transformation of the data into fact- and science-based ocean management. Many conventional workflows for marine data processing are not automated, inhibiting the productivity of scientists and managers. Strategic focus on projects automating marine data analysis workflows is needed to accelerate the understanding of our rapidly changing marine habitats and multiply the conservation benefits.

Ocean Worlds

While we still have much to discover here on Earth, scientists are also looking to other oceans in our solar system. On Europa, one of Jupiter's moons, geyser-like features shoot more than a hundred miles into the air. If and when humanity takes the plunge into the ocean of another world, we will have to create innovative ways to operate and communicate. In preparation for such endeavors, deep ocean systems are the closest analog on Earth to these other ocean worlds and can serve as a laboratory to develop and test new communication tools and technology for use in extraterrestrial exploration.



The ABISS lander in action. Credit: Schmidt Ocean Institute.

By working in the deep ocean, we can push the limits of our understanding of existing hardware designs and engineering choices for missions in outer space. Last year Schmidt Ocean Institute hosted four expeditions where software and robotics targeted for space exploration were engineered and tested. One took place off the coast of California deploying NASA's Planetary Science Technology Analogue

Research (PSTAR) funded Autonomous Biogeochemical in situ Sensing System (ABISS) lander. The team from Harvard University and NASA worked together to refine the lander and produce a comprehensive map of the contiguous seeps in the Southern Borderland, reshaping our understanding of connectivity among these habitats.

3. OCEAN EXPLORATION AND REACHING THE PUBLIC

Unique journeys of discovery and exploration in the deep ocean are not fully actualized unless the wonder and scientific value of the work reaches the communities, schools, workplaces, and living rooms that are affected—whether they know it or not—by events in the vast expanse of the deep sea. Being able to share the joy and excitement of discovery and achievement is as critical as the work itself.

Every day we should aim to inspire a passion for the ocean by sharing enthralling footage and bringing the latest in ocean research to people all over the globe. Communicating this work through dedicated outreach programs that target wide audiences is essential to making connections between the public and deep-sea. This especially rings true for communities who have these environments in their backyards, yet have no knowledge or access to them, and to other groups in landlocked regions with no day-to-day tangible connections to the ocean.

Making ocean exploration and marine science accessible to the public, anyone can learn about the research taking place and its effect on their lives. It is important to not just make data and imagery available, but to synthesize them into programs and materials that are useable for engaging a wide spectrum of audiences. Schmidt Ocean Institute makes all of its live dives available in perpetuity on our YouTube channel, and the 4K highlights and weekly expedition videos that have been viewed by more than half a million people. This demonstrates that there is a desire among Americans and the global community to learn more about the ocean—especially the strange and mysterious reaches of the deep ocean. Organizations focused on ocean observation can capitalize on this interest and build momentum for expanding observational efforts. Translating materials into languages other than English can further increase the impact of the resources devoted to exploring the deep sea.

Ocean exploration was once conducted in remote regions where public engagement was next to impossible. This has changed, however, with a growing number of scientists and institutions looking to expand their reach and demonstrate the value of their work. Scientists now connect with local communities, artists, students and scientists using data visualization, technology, and the arts. These mechanisms enable broader understanding of the ocean and offer learners new opportunities to engage and train in ocean sciences. The goal of these efforts is to encourage the public to rethink the way marine science is shared and break down the complexities of ocean research. Ocean exploration lends itself to interactive storytelling and engagement, via a plethora of innovative outreach programs. Such programs should not only continue to be supported on a national level, but successful programs must be identified, expanded, and replicated across different disciplines and locations.

One example of a particularly successful method for engaging the public with ocean science is Schmidt Ocean Institute's Artists-at-Sea program that invites artists to participate in ocean exploration expeditions. The artists interpret and visualize the science conducted through various art forms, which can speak to new audiences making the subject matter approachable and understandable. Projects have ranged from light painting performances, oceanscape resin art, woodworking sculpture, portrait painting, cyanotype prints, and a life-size mural of the *Pseudoliparis swirei* ghost fish. The success of this program has resulted in more than 25 artists sailing, whose 118 pieces of work have been put together in a traveling exhibit that has reached 15 different US venues in 11 different cities including the Aquarium of the Pacific, the International Ocean Film Festival, the America's Cup race, and will open this week at the Michigan Science Center.

Education should be a top priority for ocean exploration programs to encourage student learning with hands-on opportunities and provide experience and career guidance via live engagement. Student participation programs for entry at different age groups is important to developing lifelong connections to the sea. Remote participation with ship-to-shore connections for middle school groups, internships for college students, and direct training and mentoring for graduate and early career scientists are additional ways to engage interested populations.

CONCLUSIONS

The public faces daily messages of negativity surrounding our environment and ocean. During this time of environmental decline, ocean exploration can provide a new narrative, bringing a message of hope. Exploration provides the opportunity to showcase beautiful and mysterious parts of the ocean that are rarely observed to millions of people. The ocean is changing, but new data, science, and dedicated people can bring a fresh understanding and engagement with the deep-sea. Ocean exploration has an opportunity to accelerate this understanding and demonstrate our responsibility to care for the ocean, which remains a critical need for the ocean sciences, as well as our nation.

The House Committee on Science, Space, and Technology can help advance the conversation about how we as a nation can stimulate ocean exploration to advance science, technology, and education. Ocean exploration is critical to better understand the Earth's complex systems, better protect them, and work towards a long-lasting positive connection between humans and the ocean that supports us all, no matter where we live.

We need to leverage economies of scale to decrease the cost of sensors and systems to make them available to more people, to cover more ocean, to build capacity in technology-poor regions, and to protect deep-sea resources where they are vulnerable. Access to emerging technologies is critical in capacity building, but it cannot be just about the technologies. International collaboration and support is needed to address management and protection of global resources. More investment is needed in data standards, archiving, accessibility & analysis, with consideration for data rights. We should look for advances in other industries that can be applied to the greatest challenges in ocean observations; many exciting innovations are happening across technology sectors, such as medical, oil and gas, defense, etc. that could be applied to general ocean exploration and research. Finally, education must remain a top priority for ocean exploration programs, providing programmatic and financial support for student learning and public engagement.

Globally, we can position ocean exploration for high-risk, high-reward, conservation-minded ocean science as evidenced by some of the examples I have shared today. Achievement of these goals can be accelerated by continuing and increasing emphasis on technology development, leveraging innovative platforms for far-reaching communication, and facilitating international collaboration between the best oceanographic scientific minds. I will leave you with a question: What is the greatest difference between Earth—our home—and other planets in our solar system? What do astronomers look for when they search for other planets that might harbor life? The answer is oceans! Our ocean is vitally important to our existence, and life on this planet—not just life in the ocean—is deeply dependent on the state and health of our ocean waters. The more we know about the unexplored depths of the deep sea, and the more we know about how the deep sea interacts with ecological and human systems, the more we will understand how the ocean affects us on the continuum of human experience: from the fish on our dinner plates to the long-term future of our species. The research and development discussed here today is critical for optimal decision making and stewardship of our oceans and to the health, economy, and security of our nation. Chair Fletcher, Ranking Member Marshall, and members and staff of the committee, thank you once again for your invitation to testify here today, and I look forward to answering any questions you may have.

Appendix A: Deep Sea Ocean Exploration Research Expeditions on Research Vessel Falkor

Expedition Title	Year	Lead Principal Investigator	Region/Area	Country of Work	Collaborators	Vehicles
Microbial Mysteries: Linking Microbial Communities and Environmental Drivers	2019	Mandy Joye	Baja Peninsula	Mexico	University of Georgia, Max Planck institute for Marine Microbiology, Harvard University, Coastal Carolina University, Universidad Nacional Autónoma de México,	Remotely Operated Vehicle (ROV) SuBastian, Lander
Costa Rican Deep Sea Connections	2019	Erik Cordes	Costa Rican Shelf	Costa Rica	Temple University, University of Costa Rica (Centro de Investigación en Ciencias del Mar y Limnología), Scripps Institution of Oceanography, University of Rhode Island, California Institute of Technology	ROV SuBastian, ship-towed autonomous vehicle Wire Flyer
New Approaches To Autonomous Exploration At The Costa Rican Shelf Break	2018	Richard Camilli	Costa Rican Shelf	Costa Rica	Woods Hole Oceanographic Institute,Australian Centre for Field Robotics (University of Sydney), National Aeronautics and Space Administration, Massachusetts Institute of Technology, Univeristy of Michigan, University of Athens	ROV SuBastian, Slocum Gliders,
Interdisciplinary Investigation of a New Hydrothermal Vent Field	2018	Robert Zierenberg	Baja Peninsula	Mexico	Monterey Bay Aquarium Research Institute, University of California - Davis, California Institute of Technology, Occidental College, Scripps Institution of Oceanography, Oregon State University, University of Rhode	ROV SuBastian, Autonomous Underwater Vehicle (AUV) D. Allan B (MBARI Mapping AUV)

					Island, Pontifica Universidad Catolica de Chile	
Characterizing Venting and Seepage Along the California Coast	2018	Peter R. Girguis	Coast of Southern California	United States of America	Woods Hole Oceanographic Institute, Harvard University, Texas A&M University, National Science Foundation, National Aeronautics and Space Administration	ROV SuBastian, Autonomous Biogeochemical Instrument for In Situ Studies (ABISS) Lander
Hunting Bubbles: Understanding Plumes of Seafloor Methane	2018	Anna Michel and Scott Wankel	Oregon and Washington Coast	United States of America	Woods Hole Oceanographic Institute, Harvard University, Texas A&M, National Science Foundation, National Aeronautics and Space Administration	ROV SuBastian, ChemYak (Autonomous Surface Vehicle)
Adaptive Robotics at Barkley Canyon and Hydrate Ridge	2018	Blair Thornton	Oregon and Washington Coast	United States of America	University of Southampton, University of Tokyo, Kyushu Institute of Technology, Universitat de les Illes Balears, Tokyo University of Marine Science and Technology, National Oceanography Centre, Australian Centre for Field Robotics, Grey Bits Engineering, Japan Agency for Marine Science and Technolgoy, University of Aberdeen	ROV SuBastian; University of Tokyo AUVs: AE2000f, TUNA-SAND, TUNA-SAND 2
The Seeping Cascadia Margin	2018	Susan Merle	Oregon and Washington Coast	United States of America	Pacific Marine Environmental Laboratory, Oregon State University, Schmidt Marine Technology Partners	None (Onboard multibeam sonar mapping)
Solving Microbial Mysteries with	2018	Andrew Babbin	Coast of Baja Peninsula	Mexico	Standford University, Massachusetts Institute	ROV SuBastain

Autonomous Technology					of Technology (Babbin Laboratory)	
Voyage to the White Shark Café	2018	Barbara Block	Pacific Ocean	United States of America	Standford University, Monterey Bay Aquarium Research Institute, Monterey Bay Aquarium, National Oceanic and Atmospheric Administration, University of Delaware, Saildrone, The Aspen High Seas Initiative (Aspen Institute), The Aquarium of the Pacific, Argos System	ROV SuBastian, Slocum Glider
Underwater Fire: Studying the Submarine Volcanoes of Tonga	2017	Ken Rubin	Tonga Arc Region	Kingdom of Tonga	School of Ocean and Earth Science and Technology (University of Hawai'i at Mānoa), Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, University of Washington, GNS Science, Oregon State University, Point Loma Nazarene University	ROV SuBastian, AUV Sentry
Discovering Deep Sea Corals of the Phoenix Islands	2017	Erik Cordes	Pheonix Islands	Republic of Kiribati	Temple University, Boston University, Woods Hole Oceanographic Institute, Baruch College, National Oceanic and Atmospheric Administration	ROV SuBastain
Searching for Life in the Mariana Back-Arc	2016	David A. Butterfield	Mariana Trench	Pacific Ocean	University of Washington, Oregon State University, National Oceanic and Atmospheric Administration, Pacific	ROV SuBastian

					Marine Environmental Laboratory, Marine Biological Laboratory	
Ecosystem Dynamics of Hydrothermal Vent Communities	2016	Chuck Fisher	Coast of Fiji	Fiji	Columbia University, Harvard University, Pennsylvania State University, Woods Hole Oceanographic Institute	ROV ROPOS
Virtual Vents: The Changing Face of Hydrothermalism Revealed	2016	Tom Kwasnitschka	Coast of Fiji	Fiji	Helmholtz Centre for Ocean Research Kiel (GEOMAR), Memorial University, University of Victoria, Deutsches Forschungszentrum für Künstliche Intelligenz (German Research Center for Artificial Intelligence), University of Ottowa, United States Geological Survey	ROV ROPOS
Hydrothermal Hunt at Mariana	2015	Tamara Baumberger	Mariana Trench	Pacific Ocean	University of Washington, Oregon State University, National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory	AUV Sentry
Magnetic Anomalies at the World's Largest Volcano	2015	William Sager	Coast of Japan	Japan	National Science Foundation, NGS, University of Houston, Texas State Aquarium, CHIBA University	None (Onboard multibeam sonar mapping and magnetometer reading)
Perth Canyon: First Deep Exploration	2015	Malcolm McCulloch	Perth Canyon	Australia	Australian Government, University of Western Australia, Western Australian Museum, Commonwealth Scientific and Industrial Research Organisation, Institute of Marine Science	ROV Comanche

Expanding Mariana Trench Perspectives	2014	Douglas Bartlett	Mariana Trench	United States of America - Guam	National Science Foundation, Scripps, Woods Hole Oceanographic Institute, Prince Albert II of Monaco Foundation, Office of Navel Research Science and Technology, National Aeronautics and Space Administration	Schmidt Ocean Institute Lander (Full Ocean Depth)
Exploring the Mariana Trench	2014	Jeffrey Drazen	Mariana Trench	United States of America - Guam	National Science Foundation, National Oceanic and Atmospheric Administration Fisheries, University of Hawaii, Whitman College, University of Aberdeen, National Institute of Water and Atmospheric Research, Natural Environment Research Council, National Oceanography Centre	Schmidt Ocean Institute Lander (Full Ocean Depth)
The mysteries of Ontong Java	2014	Michael Coffin	Ontong Java Plateau	Kingdom of Tonga	University of Tasmania Institute for Marine and Antarctic Studies, Australian Government, Natural Environment Research Council	n/a
The Iron Eaters of Loihi Seamount	2014	Brian Glazer	Loihi Seamount, Hawaii Island	United States of America	University of Hawaiiat Manoa, Woods Hole Oceanographic Institution, Institut Français de Recherche pour l'exploitation de la Mer (IFREMER), University of Minnesota	AUV Sentry
Papahanaumokuakea Monument	2014	Christopher Kelley	Northwestern Hawaiian Islands	United States of America	University of Hawaii, National Oceanic and Atmospheric Administration	N/A

					National Marine Sanctuaries, National Science Foundation, University of British Columbia, University of Sydney	
Axial Seamount	2013	Julie Huber	Axial Seamount, Vancouver Island	Canada	Marine Biological Laboratory, University of Massachusetts, National Science Foundation, Gordon and Betty Moore Foundation, University of Washington, J. Craig Venter Institute	ROV ROPOS
Open Ocean to Inner Sea	2013	Richard Dewey, Maia Hoeberechts	Juan de Fuca Strait and the Salish Sea, Vancouver Island	Canada	Ocean Networks Canada, University of Victoria, Natural Environment Research Council, Canada Foundation for Innovation	ROV ROPOS
Hydrothermal Exploration of the Mid-Cayman Rise	2013	Christopher German	Mid-Cayman Rise, Caribbean Sea	Cayman Islands	Woods Hole Oceanographic Institution	HROV Nereus

Carlie Wiener is the Director of Marine Communications for Schmidt Ocean Institute. In this leadership role, she has drawn international attention to the science completed through the institute's ship-based program, and implemented a communications strategy for the organization. Carlie has more than thirteen years of experience in marine science communications working on strategy, research, community outreach, evaluation, and professional leadership. She received her bachelor's degree magna cum laude in communications and her Master's and Doctorate degree in environmental studies from York University in Toronto, Canada. Her previous research has focused on environmental education, experiential learning, integrating natural and social science for marine management, and marine mammal tourism. Carlie also hosted the monthly marine science radio show, *All Things Marine* for six years, and has taught several courses on communicating ocean sciences and marine science for the public.

Chairwoman FLETCHER. Thank you, Dr. Wiener. Mr. Barrett?

TESTIMONY OF STEVE BARRETT,
SENIOR VICE PRESIDENT, BUSINESS DEVELOPMENT,
OCEANEERING INTERNATIONAL

Mr. BARRETT. Chairwoman Fletcher, Ranking Member Marshall, Members of the Committee, thank you for holding this very timely and important hearing, and for the opportunity to provide one perspective on the future of ocean exploration. I'm very excited to be here today, and to represent Oceaneering International, and to share a seat at this table with some truly incredible co-panelists. Dr. Wiener's tremendous work as Communications Director at Schmidt Ocean Institute, where Schmidt continues to set the bar for getting ocean exploration at the forefront of the public; Dr. Bell's aggressive work to promote ocean exploration as a cornerstone in the field and the academic world, and continues to set the example for others to join and emulate; and David Lang's innovative approach with Open ROV (remotely operated vehicles), and now Sofar Ocean Technologies, and his engagement in ocean exploration and new ideas are bringing a new generation of ocean explorers to our world. Together they are bringing us to new depths and discoveries.

My written submitted remarks focus on how Oceaneering's history of innovation and technology development is helping shape the future of ocean exploration, particularly in the commercial ocean energy services and defense undersea sectors. Oceaneering continues to leverage technology, innovation, and expertise from its maritime, space, and robotics industry portfolios across both the commercial and defense domains to better support current and future of ocean exploration.

Oceaneering has developed state-of-the-art, world-class ROV technologies, and currently is taking those to the next level of all electric, resonant, with remote piloting for extended missions, and building on those breakthrough technologies with our new Freedom vehicle, combining extended electric deployment, work, and hovering capability with remote or autonomy in extended sub-sea survey inspection and maintenance missions.

As Dr. Bell, I think, mentioned deploying assets, working offshore in marine environments is inherently very costly, as is developing new and improved technologies for ocean exploration. Obviously, no sector working alone can achieve all that is needed, and therefore a better collaboration between government agencies, academics, non-profits, and industry should be a priority. Better collaboration could potentially lower the inherent high cost of ocean data acquisition, and expand the footprint of coverage. As Dr. Bell touched on, there must be better ways to leverage the utilization of existing vessels within industry activity, such as transportation, offshore energy services, and fishing, and, with that, we might be able to improve our collective ability to cost-effectively acquire more ocean data.

Finally, to attract our best and brightest young minds who can tackle the technical, cost, data acquisition, and data analytics challenges for ocean exploration, we need to make sure that industry, academia, and government are providing attractive and exciting new opportunities in the areas of ocean exploration. Many current and future technical and collaborative developments across the spectrum of ocean exploration are a key foundation to our collective challenge of reaching new depths and discoveries. Having a robust commercial sector, partnerships, industry, and participants, such as Oceaneering, I believe, can provide a force multiplier that complements the tremendous work of Doctors Wiener and Bell, and of innovative new players in this area, like David Lang of Sofar Ocean Technologies. We all have critical roles to play, and, with your Committee's support, we look forward to our future in supporting ocean exploration. Chairwoman Fletcher, I look forward to engaging in discussion with you and the Committee, and answering any questions that you or your Committee may have.

[The prepared statement of Mr. Barrett follows:]

Steve Barrett
Senior Vice President
Oceaneering International Inc.

Before the
House Committee on Science, Space, and Technology
Environment Subcommittee Hearing

on
"Ocean Exploration: Diving to New Depths and Discoveries"

June 5, 2019

Chairwoman Fletcher, Ranking Member Marshall, and Members of the Committee, thank you for holding this very timely and important hearing, and for the opportunity to provide one perspective on the future of ocean exploration. I am very excited to be here today and to represent the Oceaneering International team, and to share a seat at this table with some truly incredible co-panelists. Dr. Wiener's tremendous work as Communications Director at the Schmidt Ocean Institute continues to set the bar for getting ocean exploration to the forefront of the public. Dr Bell's aggressive work to promote ocean exploration is a cornerstone of our industry and the academic world, and continues to set the example for others to join and emulate. And David Lang's innovative approach with OpenROV and now Sofar Ocean Technologies, and his engagement in ocean exploration and new ideas, are bringing a new generation of ocean explorers to our world. Together, they are bringing us to "new depths and discoveries."

I want to focus my remarks today on how Oceaneering's history of innovation and technology development is helping to shape the future of ocean exploration, particularly in the commercial ocean energy service and defense undersea sectors. My remarks intend to highlight how Oceaneering continues to leverage technology, innovation, and expertise from its maritime, space, and robotics industry portfolios across both the commercial and defense domains to better support current and future ocean exploration. This testimony will include specific examples of current product development and concepts of operation that support and promote sustainability and environmental stewardship of the oceans.

I think Oceaneering's mission – solving the unsolvable, is reflective of the theme of today's hearing. As a partner and collaborator, we strive to connect "what's needed with what's next" to solve the toughest challenges in the toughest environments, in and above our world. Certainly, "diving to new depths and discoveries" is a theme that is central to our core mission and is squarely in our wheelhouse. Our experience and our innovative portfolio of technologies continue to safely and reliably improve performance across the maritime and space domains.

So, what does Oceaneering bring to this table?

It brings over 50 years of rich history supporting ocean exploration and literally "diving to new depths," pushing the limits of ROV and mixed-gas diving technology and capabilities while setting new records. Not only did the forward-looking Oceaneering team bring undersea mobile robotics into the mainstream in the offshore oil and gas industry, but Oceaneering also applied this cutting-edge technology in the commercial and defense ocean search and recovery business.

What began with two professional divers forming a Gulf of Mexico diving company has transformed from a small regional company into a global provider of engineered product and services.

Increasing demands for services, paced by innovation and incremental technological improvements made by a growing cadre of engineers and operators, help fuel the oil and gas industry's exploration and expansion into deeper and deeper depths.

Along the way, Oceaneering has become the builder and operator of the world's largest premiere fleet of work class ROVs for offshore oilfield services – a fleet that has quickly expanded into supporting U.S. Department of Defense undersea maritime operations. The capabilities and versatility of Oceaneering's ROVs were put to the test on the world stage during the 2010 Deepwater Horizon / Macondo oil spill; numerous ROVs were employed to provide critical, real-time, "eyes-on" assessments of the damage and to help facilitate resolution of this crisis.

More recently, Oceaneering has made significant investments to support the offshore renewable energy business to a point where a significant number of our ROV assets are engaged in renewable energy projects. Additionally, this technology, and the concepts of operations, equipment, and expertise have been shared with ocean exploration non-profit organizations, and have been the catalyst for enduring partnerships and ever-expanding ocean exploration.

These partnerships and shared ocean exploration interests have been showcased in numerous high-profile events, including:

- The recovery of the Liberty Bell 7 Space Capsule piloted by astronaut Gus Grissom from over 14,000 feet of water
- The recovery of the CSS Hunley, a Confederate submarine lost off the coast of Charleston, South Carolina, during the Civil War
- Surveying, filming, and often locating historical vessels of interest including the *Titanic*, the German battleship known as the *Bismarck*, the British battleship known as the HMS *Hood*, and numerous other ships and submarines
- Locating and recovering numerous commercial aircraft lost over the ocean, including TWA Flight 800 and Itavia Flight 870
- The record-setting recovery of a U.S. military helicopter in over 16,000 feet of water

Over time, Oceaneering's "solving the unsolvable" approach in the oil and gas industry and defense sectors has been expanded into the commercial sector, government space operations, theme park rides, and robotic solutions industries.

So, what's on the horizon?

Oceaneering's history of innovation, which has enabled work to be accomplished in the most complex and dynamic environments, continues to advance.

Perhaps the most exciting and important innovations have occurred with our remote-operation and autonomous technologies for both propelled ROVs and autonomous underwater vehicles (or AUVs). Innovations in sensor capability, communications, high-density power systems, and advanced software controls have enabled remote ROV oilfield operations to be controlled remotely for over a month at a time. We have developed all electric battery powered work class ROVs that can be deployed subsea for extended periods doing inspection and maintenance work supported on by a communications buoy on the water surface. These innovations and technologies generate the subsea resident and autonomous capabilities that mitigate the needs for support vessel and on-site controls. Later this year, Oceaneering will deploy its new Freedom AUV, which is effectively an undersea deepwater drone, capable of inspection and intervention tasks for subsea assets. Inspecting long subsea pipelines via autonomous missions while incorporating a hovering capability significantly enhances the types and quality of inspections performed. These underwater vehicle developments and innovations expand the availability and capability to perform more regular and more comprehensive under water inspections and interventions that will yield greater assurances for the integrity of offshore assets.

These types of efforts – improved endurance, remote operation of assets, precision control, mitigation of vessel and personnel on station time, and improved asset integrity – all contribute to the broader goal of sustainability and better stewardship of the ocean environment. However, more equipment developments and technological innovations are needed to be able to cost effectively and sustainably deploy under water robots and sensors capable of ocean exploration necessary to dive to new depths and discoveries.

Finally, critical to enabling "Diving to New Depths and Discoveries" will be expanding current relationships and partnerships, and also forging new ones, that will continue to leverage our collective capabilities and strengths. Expanding levels of effort like the NOAA's Ocean Exploration and Research program, along with its live streaming events, will continue to put ocean exploration into our homes, excite our children and encourage the STEM programs that we desperately and ultimately need in order to support our industry.

These exciting developments across the spectrum of ocean exploration are a key foundation to our collective challenge of reaching "new depths and discoveries." Having robust commercial sector partners and participants such as Oceaneering, provides a "force multiplier" that complements the tremendous work of doctors Wiener and Bell, and of innovative new players in this arena like David Lang and Sofar Ocean Technologies. We all have critical roles to play. With your committee's support, we look forward to our future in supporting ocean exploration.

Chairwoman Fletcher, I look forward to an engaging discussion with you and the committee, and to answering any questions that you and your committee may have.

Stephen P. Barrett

Steve has over 35 years of experience in the oil and gas equipment and service industry. For the last fifteen years he has been involved in the subsea deepwater segment of the industry. In 2005 he led a collection of emerging technology businesses within FMC Technologies and later progressively led business areas within subsea production equipment and services on a global basis. Steve joined Oceaneering in 2015 to run the manufactured products and service, technology and rentals businesses as Senior Vice President and now focuses on business development, strategy and technology.

Steve started his professional career designing mining equipment after receiving his bachelor's degree in mechanical engineering from Texas A&M University. He hold several US patents related to oil and gas equipment and is also a graduate of Rice University's Jones School of Business.

Steve has served on the boards of the Energy Education Center, The Offshore Energy Center and Target Hunger and is active in numerous industry organizations including the Petroleum Equipment and Services Association (PESA) and the Society for Underwater Technology. He has been a speaker for Oceanology International, Offshore Energy Center, PESA and Center for Offshore Safety events.

Chairwoman FLETCHER. Thank you, Mr. Barrett. Mr. Lang?

**TESTIMONY OF DAVID LANG,
CO-FOUNDER, SOFAR OCEAN TECHNOLOGIES**

Mr. LANG. Chairwoman Fletcher, Ranking Member Marshall, and Members of the Committee, thank you for this opportunity. I need to start with a disclaimer, I am not a formally trained scientist or engineer. My path to this hearing is unusual, and worth explaining. It begins in an unexpected place, not a graduate school lab in Woods Hole or Monterey, not on a research vessel exploring the high seas, and not on a Navy battleship. It starts in 2011, my friend Eric Stackpole's garage in Cupertino, California. We were both in our mid-20s and underemployed. We were attempting to build an underwater remotely operated vehicle, an ROV, for as cheap as we possible could, using only off-the-shelf parts we could buy on the Internet. Our goal was to use the robot to explore an underwater cave in the Trinity Alps in Northern California, supposedly filled with gold from an abandoned heist during the gold rush. The story was an excuse for us to tinker with new technologies and, honestly, to have a little fun.

After our unsuccessful, but commendable, expedition to find the gold, the project took on a life of its own. The effort was reported on by the *New York Times*, and we were overwhelmed with interest by others who wanted a similar, affordable device. We launched a project on Kickstarter to sell our design as a DIY, build-it-yourself kit, and quickly sold more than we projected. Over the years, we grew out of the garage to become one of the largest volume ROV manufacturers in the world, pioneering new designs, and most recently merging with another company to form Sofar Ocean Technologies. Our community, using our tools, have made important contributions to the understanding of species and ecosystems around the world, and contributed to the education and engagement of thousands of students and young explorers.

We only learned later, during a NOAA-organized meeting with leading ocean scientists and engineers, just how unique our effort had been. The scientists were less impressed with what we built, after all, they already had all of these tools, but in how we went about it, by openly sharing our designs online, crowdfunding our initial startup costs, and, most importantly, engaging a global community of citizen scientists. The experts were bound by constraints, both economic and institutional, that we were not. Our innovation was not a result of genius. It was mostly luck, born of necessity and amateur persistence. Our inexperience, mixed with a rapidly shifting technological landscape, created an opportunity to move the needle on small, low-cost ROVs.

I tell you this long story for context, but also because I think we learned really important lessons, which I submit this Committee could find useful. The first is to remember that the mission of ocean exploration, to illuminate the unknown, carries multiple meanings. It's widely reported, as everyone here has said, what little percentage of the ocean we've explored and characterized. Whether mapping the ocean floor, or studying the varying depths of the water column, there are still vast areas of Earth left to explore, and we should. But there is another responsibility of the ocean exploration enterprise that doesn't get as much attention, how we explore. Part of the process of discovery is the constant search for a better way and a new perspective. This is the technological frontier, and it's as dynamic and full of opportunity as the unexplored places. The emerging fields of robotics and machine learning, the advancements of eDNA and genetic sequencing, and the steady march of Moore's law and increasing connectivity continue to make this fertile ground for experimentation.

We're still at the beginning of applying these technologies to the mission of understanding and monitoring the ocean. Over 10 years ago NOAA made a leap by operationalizing Dr. Bob Ballard and the Ocean Exploration Trust's vision for telepresence, and its potential to scale the effectiveness of a single ship at sea, and that telepresence has completely changed the way we conduct science, engage the public, and inspire the next generation. We need more leaps. Exploration is where we go and how we get there.

The second lesson is that entrepreneurs and startups are an increasingly important part of navigating this technological frontier. Congress would be wise to look at the evolution of NASA (National Aeronautics and Space Administration) over the past decade and hope for a similar ocean renaissance. As a generation of space entrepreneurs took to the cosmos, NASA was able to find commercially competitive contractors to take over launch and other duties, which allowed them to focus their resources on what they do best, going further. As NOAA faces the challenge of managing aging ships and infrastructure, the agency would do well to focus enough of their limited resources on stimulating a vibrant private sector, rather than trying to rebuild everything themselves.

The last lesson is—we learned is that ocean exploration is for everyone. We all have a stake. This is not just a coastal issue. We were surprised by all of the enthusiasm we received for our project, the citizen scientists who wanted to get involved all over the world. I can do no better than John Steinbeck's call to the sea, published in 1966 in *Popular Science*, which is still as relevant as ever. There is something for everyone in the sea. Incredible beauty for the artist, the excitement and danger of exploration for the brave and restless, an open door for the ingenuity and inventiveness of the clever, a new world for the bored, food for the hungry, and incalculable material wealth for the acquisitive, and all of these in addition to the pure clean wonder of increasing knowledge. Ocean exploration is a cause worth championing, and I hope that you do.

[The prepared statement of Mr. Lang follows:]

A Case for Ocean Exploration

Statement of

David Lang
Co-founder, Sofar Ocean Technologies

before the

Subcommittee on Environment
Committee on Science, Space, and Technology
U.S. House of Representatives

5 June 2019

Chairwoman Fletcher, Ranking Member Lucas, members of the Environment Subcommittee, and members of the House Committee on Science, Space, and Technology, thank you for this opportunity to testify on this important issue.

I need to start with a disclaimer. I am not a formally trained scientist or engineer. My path to this hearing is unusual and worth explaining. It begins in an unexpected place — not a graduate school lab in Woods Hole or Monterey, nor on a research vessel exploring the high seas, and not on a Navy battleship. It starts in 2011 in my friend Eric Stackpole's garage in Cupertino, California. We were both in our mid-twenties and underemployed. We were attempting to build an underwater remotely operated vehicle (ROV) for as cheap as we possible could, using only off-the-shelf parts we could buy on the internet. Our goal was to use the robot to explore an underwater cave in the foothills of the Trinity Alps in Northern California, supposedly filled with gold from an abandoned heist during the gold rush. The story was an excuse for us to tinker with new technologies and, honestly, to have a little fun.

After our unsuccessful but commendable expedition to find the gold, the project took on a life of its own. The effort was reported on by the New York Times and we were overwhelmed with interest by others who wanted a similar, affordable device. We launched a project on Kickstarter to sell our design as a DIY, build-it-yourself kit and quickly sold more than we projected. Over the years, we grew out of the garage to become one of the largest volume ROV manufacturers in the world, pioneering new designs, and most recently merging with another company to form Sofar Ocean Technologies. Our community, using our tools, have made important contributions to the understanding of species and ecosystems around the world, and contributed to the education and engagement of thousands of students and young explorers.

We only learned later, during a NOAA-organized meeting with leading ocean scientists and engineers, just how unique our effort had been. The scientists were less impressed with what we built (after all, they had those tools already), but in how we went about it: by openly sharing our designs online, crowdfunding our initial startup costs and, most importantly, engaging a global community of citizen scientists.

The experts were bound by constraints — both economic and institutional — that we were not. Our innovation was not a result of genius. It was mostly luck, born of necessity and amateur persistence. Our inexperience, mixed with a rapidly shifting technological landscape, created an opportunity to move the needle on small, low-cost ROVs.

I tell you this long story for context, but also because we learned important lessons which I submit this committee could find useful.

The first is to remember that the mission of ocean exploration — to illuminate the unknown — carries multiple meanings. It's widely reported, and I'm certain others here will reiterate, what little percentage of the ocean we've explored and characterized. Whether mapping the ocean floor, or studying the varying depths of the water column, there are still vast areas of earth left to explore. And we should. But there is another responsibility of the ocean exploration enterprise that doesn't get as much attention: *how* we explore. Part of the process of discovery is the constant search for a better way and a new perspective. This is the technological frontier and it's as dynamic and full of opportunity as the unexplored places. The emerging fields of robotics and machine learning, the advancements of eDNA and genetic sequencing, and the steady march of Moore's law and increasing connectivity continue to make this fertile ground for experimentation. We're still at the beginning of applying these technologies to the mission of understanding and monitoring our ocean. Over 10 years ago, NOAA made a leap by operationalizing Dr. Bob Ballard and the Ocean Exploration Trust's vision for telepresence and its potential to scale the effectiveness of a single ship at sea. Telepresence has completely changed the way we conduct science, engage the public and inspire the next generation. We need more leaps. Exploration is where we go *and* how we get there.

The second lesson is that entrepreneurs and startups are an increasingly important part of navigating this technological frontier. Congress would be wise to look at the evolution of NASA over the past decade and hope for a similar ocean renaissance. As a generation of space entrepreneurs took to the cosmos, NASA was able to find commercially competitive contractors to take over launch and other duties, which allowed them to focus their resources on what they do best: going further. As NOAA faces the challenge of managing aging ships and infrastructure, the agency would do well to focus enough of their limited resources on stimulating a vibrant private sector rather than trying to rebuild everything themselves. This will spur more innovation, good for both NOAA and the taxpayer.

The last lesson we learned is that ocean exploration is for everyone. We all have a stake. This is not just a coastal issue. We were surprised by the enthusiasm we received for our project all over the country and world. Citizen scientists are aching to get more involved, hoping for institutions like NOAA to lead them. The future should be built with an architecture for participation.

The issue of ocean exploration, while often distant and out-of-sight, plays an outsized role in the human imagination, and engaging everyone in this mission is critical for our survival. I can do no better than John Steinbeck's call to the sea, published in 1966 in Popular Science and as relevant as ever:

> We must explore our world and then we must farm it and harvest its plant life. We must study, control, herd, and improve the breeds of animals, because we are shortly going to need them. And we must mine the minerals, refine the chemicals to our use. Surely the rewards are beyond anything we can now conceive, and will be increasingly needed in an over-populated and depleting world.
>
> There is something for everyone in the sea—incredible beauty for the artist, the excitement and danger of exploration for the brave and restless, an open door for the ingenuity and inventiveness of the clever, a new world for the bored, food for the hungry, and incalculable material wealth for the acquisitive—and all of these in addition to the pure clean wonder of increasing knowledge.

Ocean exploration is a cause worth championing. I humbly request that you do.

David Lang is an entrepreneur, writer, and a co-founder of Sofar Ocean Technologies. Prior to Sofar, he co-founded OpenROV to create a low-cost underwater drones as well as OpenExplorer, a digital field journal to empower and connect citizen scientists and explorers. His work has been featured in the New York Times, WIRED and National Geographic. His TED Talks have been viewed by millions online. Lang is the author of *Zero to Maker*—part memoir and part guidebook for participating in the growing maker movement. He is also a member of NOAA's Ocean Exploration Advisory Board and a TED Senior Fellow.

Chairwoman FLETCHER. Thank you, Mr. Lang. At this point we'll begin our first round of questions, and I'm going to recognize myself for 5 minutes.

I really enjoyed hearing from all of you, and there are some themes that emerged that all of you have talked about. One, stimulating excitement, and innovation, and interest in this exploration, and two, the partnerships, and so I want to try to touch on both of those, and I have general questions for the panel. As I mentioned in my opening statement, and Dr. Wiener referenced, more people have walked on the moon than the deepest parts of the ocean, and, of course, being from Houston, we are very proud of our history of space exploration and putting man on the moon, but certainly there's a lot of work to do here.

So I loved seeing the pictures of the artists that you had, Dr. Wiener, and I'm wondering of you all can suggest some specific ways that we can excite the public about ocean exploration. To your point, Mr. Lang, about invigorating a whole new group of folks to get out and engage in this process, how can we excite the public about ocean exploration with the same vigor that we've seen, for example, in space? And that's for anyone on the panel who wants to take it. Want to go first, Mr. Lang?

Mr. LANG. I would, yes. I think—when you think about what's happened with space, and why it's received such a renewed excitement, the people who are leading at are entrepreneurs. It's Elon Musk and Jeff Bezos. Those are the first things that come to mind, and I think all of the entrepreneurs who are following their lead. And so I think it's wise to look at that example, at charismatic entrepreneurs, as folks who can help reinvigorate. And I think NASA has done a great job of working with that momentum, and helping to support it.

Chairwoman FLETCHER. Thank you. Anybody else want to weigh in? Dr. Wiener?

Dr. WIENER. I'd like to weigh in as well, thank you. Another point I'd like to make too, in terms of the space/ocean comparison, space has done a really good job of branding itself, and the oceans have—are getting there, but it's a lot more diverse. We've got coral reefs, and shallow waters, and deep sea, and many different ecosystems, and making those connections, I think, is something that needs to be emphasized more, and also reaching those that haven't traditionally been involved in the ocean, so reaching some of our underserved or underrepresented groups that don't have direct access to the ocean, and starting with inspiration at a young age, and following through from K to gray, making sure that we are able to engage all of our public communities in the ocean.

Chairwoman FLETCHER. Thank you, Dr. Wiener. Dr. Bell?

Dr. BELL. Yes, I'd like to go in a slightly different direction and look at media and entertainment. I have no idea what percentage, but I would be willing to bet that a large percentage of people who are in the space industry loved watching Star Trek and Star Wars, and there are many people, Mae Jamison, for example, who cites her experience at NASA because of Nichelle Nichols in Star Trek. And I think that it would be a huge opportunity loss to not look at media and entertainment because of the stories that can be imagined and told about—potentially utopian ocean futures, rather than the dystopian ones that we see every day in the media, to bring it to a much, much larger audience than today we're able to through—and we are reaching tens of millions with telepresence. We are reaching lots and lots of people through citizen science initiatives, but if we actually want to reach billions of people, I think we need to do it with different types of partnerships than we have before.

Chairwoman FLETCHER. Thank you. Well, that touches on sort of the second area that I wanted to go to, and, knowing that I have limited time, maybe I can just segue over to talk a little bit about the existing partnerships, and how we can strengthen the existing partnerships amongst government, academia, industry that you all have referenced. How can we strengthen those to leverage the available ocean exploration tools? I think, Mr. Barrett, you talked a little bit about that, and resources in the future, and then how can we kind of broaden that to reach your objective, Dr. Bell, of widening interest? Maybe, Mr. Barrett, could you talk about that a little bit more?

Mr. BARRETT. I think one of the challenges for industry and commercial enterprises like oceaneering is investment, and investment in new technology comes with inherent risks. And often we invest in new technologies because we have a clear line of sight to our customer's needs, and how we would commercialize toward those needs. I think a better line of sight to a broader spectrum of technological needs that apply to ocean exploration, in the academic sense, and in the scientific sense, and the vision going forward could be very useful to commercial enterprise to shape better how they view and justify technical investments, technology investments.

I think the other piece that—it seems to me that the collaboration around the vast numbers of oceangoing vessels, and how they could be utilized to capture more data on a regular basis is something that should be explored more fully. It'll take a platform, and forums, and better opportunities to engage with those enterprises to do it, but it seems like an opportunity to me.

Chairwoman FLETCHER. Thank you, Mr. Barrett, and I see that I have gone over my allotted time, so I will now recognize Ranking Member Marshall for 5 minutes.

Mr. MARSHALL. OK. Thank you, Chairwoman. I want to talk a little bit about globally, some of the global challenges that we have. In particular, I'm always interested to know if our scientists are talking to scientists from other countries, specifically China, India, Russia, Japan, Brazil. Is there any interaction between what we're doing and some folks from there? Have any of the four of you had interaction with scientists from other groups working on solving this problem that we have together? This is a world challenge, obviously. Dr. Bell does.

Dr. BELL. Definitely. Yes, working with Nautilus for many years, we've worked in—all over the Mediterranean region, and so therefore working with scientists from all of those countries. And one really exciting opportunity coming up is the U.N. Decade of Ocean Science for Sustainable Development, which is sort of being—ideas are coming together right now to launch for 2021 to 2030, and I think that's a huge opportunity to work with like-minded scientists from all over the world.

Mr. MARSHALL. Will China and Russia participate in that?

Dr. BELL. I believe that there were—there were scientists from China at the first global planning meeting that was just held 2 weeks ago in Denmark. I don't know if Russia was represented there. But the—that was just the first planning meeting, and regional meetings are being planned for the next year or so——

Mr. MARSHALL. India, Brazil, would they most likely be there?

Dr. BELL. I would have to check.

Mr. MARSHALL. Is there anything that we can do to promote those relationships and work on this challenge together?

Dr. BELL. Absolutely. There are several members of the executive planning group for the U.N. Decade that are from the U.S., Craig McLean, most notably, who's the acting chief scientist of NOAA, so I would definitely talk to him first about who from those countries have been represented so far, and who might be in the future. There will be several regional planning meetings coming up in the next year, and I believe that Brazil might be one of the hosts of those. But I'd be happy to get back to you.

Mr. MARSHALL. Anybody else with interaction with other scientists? Mr. Barrett?

Mr. BARRETT. No. Ours really is through—we're a global company, but our interaction is always through our customers, traditionally, in the global stage.

Mr. MARSHALL. OK. All right.

Dr. WIENER. I just wanted to add to the remarks from Dr. Bell that there's also the Seabed 2030 Project, which is an initiative from the Nippon Foundation in Japan, and it's a global initiative to try and map the entire ocean sea floor by 2030, and so that's another opportunity to engage and collaborate with the nations that you've mentioned. Schmidt Ocean Institute also looks to international collaborations, and we have hosted many scientists from multiple countries collaboratively on our research vessel for different projects, including some of the countries that you had mentioned.

Mr. MARSHALL. OK. So certainly my learning curve on oceanography right now is like this, and I'm back here, so forgive me if this is an ignorant question, but as I think about the function of the ocean, removing carbon gases, and then restoring oxygen from all the plankton that we have around the world, is that all done in the top 10 or 20 meters of water? Are there plants down lower that are doing that as well, in your research?

Dr. BELL. So the actual photosynthesis that's happening is being done in the top layers, where sunlight can penetrate through the water, but the ocean circulates, on a global level, from sea surface down to deep water, so it's a very interconnected system. I am not an expert in that particular field, but the carbon dioxide that's being used by plants is happening in the top layers.

Mr. MARSHALL. So are there any innovation opportunities down deeper to help promote that photosynthesis that's going on above? And I think you were staring to go in that direction a little bit.

Dr. BELL. Do you want—I have one interesting fact about whales, that whale defecation actually is a huge input of carbon to those systems to support plankton, which then are the basis of, for example, fisheries, and other—it's a very——

Mr. MARSHALL. I hope they're not releasing——

Dr. BELL. It's a killer system.

Mr. MARSHALL [continuing]. Any methane gas. OK. Dr. Wiener, go ahead.

Dr. WIENER. I just wanted to add to that, that we still don't fully understand those relationships, and that is why exploration and research is so important, is to better characterize these very specific—not—sorry, to better characterize how these interactions take place, and looking at these small ecosystem relationships, and how they are interconnected.

Mr. MARSHALL. OK—anyone else?

Mr. LANG. I would add its—the perspective of someone who's also relatively new to the ocean exploration enterprise, and ocean science, and the thing that was most surprising to me over the past decade has been realizing just how little we know, and how much we're actually at the beginning of starting to understand these kind of systems, and how much progress——

Mr. MARSHALL. I need to yield back, but I think we keep the goal in mind, if our goal is to innovate, as opposed to just researching for researching, so I yield back.

Chairwoman FLETCHER. Thank you, Mr. Marshall. And, before we move on, I would also like to mention that we received two letters of support for this hearing, and ocean exploration, from OceanX and Woods Hole Oceanographic Institution that I will submit for the record. And, with that, I'd like to recognize Mr. Lamb for 5 minutes.

Mr. LAMB. Thank you, Madam Chair. Mr. Lang, I was very interested in what you said about—as NOAA makes decisions going forward about the use of its resources, sort of where we direct those investments, and how they can take advantage of the energy of young entrepreneurs, and folks in the private sector, while also kind of doing the core mission that you benefit from. Because you highlighted telepresence in your testimony, and that was sort of a NOAA-led innovation, as I understand it. So could you may just go into a little more detail about, in your experience, what you saw as the strengths of NOAA, like, the things that only NOAA could've done, and the things that you think could be sort of more efficiently built upon by people in your situation?

Mr. LANG. Yes, absolutely. So I think the biggest thing that—the biggest opportunity is in terms of autonomy and distributed systems. I think the costs of sensors and compute is going down, connectivity is continuing to increase. I know SpaceX just launched their Starlink system. Connectivity is going to change dramatically in the next few years, and the way that we do—the way that we actually collect that data could be done in a much more distributed manner. And you—there's a number of startups working in this area, and it's a really tricky interface right now to work with NOAA. It's a—it's—there's a lot of hurdles, and a lot of—it's unclear what the interface actually is, and I think that's the big opportunity, is to create——

Mr. LAMB. Are those technical hurdles, like they don't have the systems to make the data interact with each other, or is it more regulatory, or cultural, or could——

Mr. LANG. I would say it's cultural. I think the way that—how fast a startup moves—you think about the way that we're able to raise capital, and the timelines that we're working on, in, like, months and years, rather than the way that kind of the NOAA grant process works, is more on an academic schedule, which is actually really a tough way to work for smaller companies like ours. It's easier for bigger companies, who have those kinds of cycles, but it's trickier for a group like ours. I think the, you know, the Department of Defense, with their DIU (Defense Innovation Unit), has kind of—has started to make headway into trying to figure out a way to interface with these companies, but it's still a problem worth solving.

Mr. LAMB. OK. And the advancements in your space, can you just kind of describe what you expect to see in the next few years, as far as these, you know, just these underwater drones, for lack of a better term? I mean, are we talking sort of pure data gathering, are we talking, like, actual expiration of, you know, species, and testing to determine if we could get, you know, anti-inflammatory drugs or anything out of them? Tell me just kind of where we are.

Mr. LANG. Yes. So these are our ROVs right here. I mean, this is orders of magnitude smaller and cheaper than what's existed before. I think we're going to continue to see the miniaturization and the autonomous potential. I think there's a ton happening with positioning sensors that's going to open up a lot. The way that eDNA is—become a way to actually sense what's in the environment. I think you look at how cheap genetic sequencing is getting, that we're going to have an opportunity characterize these environments in a completely revolutionary way.

Mr. LAMB. So you think we're not that far away from the ability, for example, for one of your sensors to actually sequence a genome underwater, and send that data back to the surface?

Mr. LANG. I don't know if one of—the in situ genetic sequencing is not something—I don't know how close we are to that exactly, because you've got to understand, everything—as fast as that's moving on land, doing that in situ underwater is really hard.

Mr. LAMB. Right.

Mr. LANG. But I would say, when you look at, like, from a systems perspective, and the way that we've been able to engage this global community of citizen scientists, there's a huge opportunity to engage people in a different way. And there was just—the—in 2016 the *Citizen Science Act*, I forget the precise name of it, but—allowed that data to be used for scientific research purposes, and for government research purposes. So there is kind of some precedent to start thinking about these systems in new ways, these data collection systems.

Mr. LAMB. Thank you. I yield back.

Chairwoman FLETCHER. Thank you very much, Mr. Lamb. I will now recognize Mr. Babin for 5 minutes.

Mr. BABIN. Thank you very much, Madam Chair, appreciate it. And thank you, witnesses, for being here. We really appreciate your testimony. In addition to serving on this Subcommittee, I also serve as the Ranking Member on the Space and Aeronautics Subcommittee, and I have the privilege of representing Johnson Space Center back home in Houston. And, with that in mind, I'd like to ask a couple of questions about ocean exploration, and how this field is often closely tied with technologies that are used in space exploration as well. And so, Mr. Barrett, I'll start with you.

Oceaneering has engaged in extensive research and development as part of its core business of energy exploration. And, for many years, Oceaneering has been involved in the space industry, and is currently working with NASA on the next generation spacesuit. How did your work in ocean exploration contribute to the spacesuit development, and what lessons learned from ocean exploration have helped you in spacesuit development as well?

Mr. BARRETT. Congressman Babin, that's a great question. It's a—such a natural adjacency to take technology and methods that were developed in a harsh environment underwater, and then use those in a harsh environment that includes the vacuum of space. And so the way that man interacts with that environment, though—whether it's a spacesuit, or through a diving suit, there are tremendous learnings and applications that were deployed.

We mostly do work underwater in our diving and in our ROV business, and the way you do work through automation, through tool position, through the use and design of the tools, as well as the visibility and the inherent challenges of mobility and dexterity, it's a natural adjacency for us. And it even carries into the Neutral Buoyancy Lab, which we operate the divers for the Neutral Buoyancy Lab, so—to simulate working in space, it's a natural to do that underwater, and make the astronaut neutrally buoyant so he can practice his—I think they call it EVAs, his extra vehicle activity, over and over until it's very routine and very precise, so——

Mr. BABIN. Which is more hostile, underwater or space?

Mr. BARRETT. Well, in some ways underwater. When I first——

Mr. BABIN [continuing]. I thought.

Mr. BARRETT [continuing]. Joined the sub-sea business, and we were completing—helping our customers complete wells in 10,000 feet of water, the difference is, you know, a vacuum has a pressure differential of one atmosphere. In 10,000 feet of water, you've got pressures of 5,000 psi, so in some ways the ocean depths can be—I will say as hostile, or more hostile.

Mr. BABIN. Right. That does not surprise me. Thank you very much. And, Dr. Wiener, I wanted to ask you, I serve as the Ranking Member of Space and Aeronautics. As I see it, I was fascinated to read how the Schmidt Institute had worked with NASA on the development and testing of hardware in preparation of future deep space missions by utilizing the depths of the ocean, that's similar to the Neutral Buoyancy Lab. How is this partnership between NASA and the institution initiated? And, following up on that, what have been the benefits for each side in this partnership?

Dr. WIENER. Thank you for your question. We've been working with scientists in the research community who work with NASA on development of technologies. There are similar goals there between ocean exploration and space exploration. An example is the Abyss Lander. This was recently used on research vessel *Falkor* in 2018, with Dr. Peter Girguis from Harvard, and some of the technologies that they were using on this lander are to test and see how things work on this lander that could also be used in space.

Additionally, other technologies have been looked at with other scientists on Falkor, in terms of remote capabilities, and being able to talk to the technologies, or the robotics, that you're using, and using AI to make decisions when they're away from—let's say the mothership, whether that's a vessel or a spaceship. Thank you.

Mr. BABIN. Fascinating. Thank you very much, and I yield back, Madam Chair.

Chairwoman FLETCHER. Thank you, Mr. Babin. And, as you all can hear from the bells, votes have just been called, as I mentioned at the beginning of our hearing, so we're going to stand in recess for probably about 15 minutes. I believe we just have one vote on the floor. But we're going to recess, and then we'll come back. Thank you.

[Whereupon, at 10:04 a.m., the Subcommittee recessed, to reconvene at 10:39 a.m. the same day.]

Chairwoman FLETCHER. The hearing will come to order. We are now reconvening our hearing. Thank you to the witnesses for your patience, and we were in the process of taking questions from Committee Members, so I believe at this time I will now recognize Mr. Tonko for 5 minutes.

Mr. TONKO. Thank you, Madam Chairwoman, and thank you for holding this hearing in honor of World Oceans Week. Our oceans hold so much promise, from understanding the origins of life, to offering new medicines, to the enhancing of opportunities to learn and excite new students, and, of course, providing for the thrill of exploration and innovation. The evidence undeniably shows that climate change is hurting our oceans, and the trend will only get worse with inaction. As a Committee, the promise of our oceans should motivate us to push forward in addressing the challenges of climate change.

In 1962, President Kennedy gave his famous moon shot speech in support of the Apollo program. In less than 10 years NASA landed a person on the moon, proving that incredible achievements in science and technology can come about in a relatively short amount of time. So for each and every one of our witnesses, is there a need for an ocean exploration moon shot, and if so, what should it aim to achieve? Maybe we'll start with you, Dr. Bell?

Dr. BELL. That's an excellent question. I think that absolutely yes there should be an ocean moon shot. What exactly it should be I think should be a broader discussion. But looking at exploring some percentage of the ocean by 2030, 2040, would be ambitious, but yet feasible. What that percentage is, maybe 30 percent, I don't know, but I think that it's definitely something that would galvanize the United States behind a common goal, the scientific community, the private community, Federal philanthropic, and would provide some sort of end goal that we can accomplish together.

Mr. TONKO. Thank you. Dr. Wiener?

Dr. WIENER. Yes. I echo Katy's comment that I do think an ocean shot or moon shot would be a very helpful and important initiative. Having a common goal, whether it's mapping the sea floor, or working together to really focus in efforts on working on technology advancement to be able to characterize the ocean in a more persistent and low cost way I think would be another way that we could really help make dramatic improvements.

Mr. TONKO. Thank you. Mr. Barrett?

Mr. BARRETT. Yes. Just building a little bit—we talked a little earlier about inspiring the best, brightest minds, the entrepreneurs, the students, to enter the field, and I think a moon shot, quote/unquote, a very tangible, exciting goal that could spur more collaboration, get people really excited. I do believe that it's no one sector of government alone, or industry, or—I think it has to be the kind of goal that people could really wrap around across all the sectors. I think it'd be fantastic.

Mr. TONKO. Thank you. And Mr. Lang?

Mr. LANG. I think the moon shot works really well in space, and I think—I like Elon's goal of going to Mars as being an invigorating motivator for space. When I think about oceans, I think of Jacques Cousteau, and the example that he set. And, to me, the biggest challenge facing our oceans is not plastic pollution or ocean acidification, it's getting more people to care. And I think the biggest challenge is that, and, in order to do that, I look to Cousteau, really, as the model we should try and emulate.

And he's known for, obviously, his media, as Katy said, as an important part of this, but he also co-invented the aqualung. He invented SCUBA diving. And I think we need to think about these kind of new technologies that give everyone that ability to actually participate in this whole process. And I think NOAA in particular has an incredible opportunity to lead that engagement process.

Mr. TONKO. Quite a point. And with that field of ocean exploration, how is it evolving with the development of new technologies? Anyone?

Mr. BARRETT. I highlighted a few, but I think with the work that Mr. Lang is doing, I think it's going to evolve around how do we get more, you know, more devices collecting data, mapping. It's going to be about power management. There's going to be new technologies needed for communications and autonomy. To deploy these assets, sensors, sub-sea for an extended period of time, it's going to take some new technology to be able to deliver the power, probably from the surface, or recharging these types of things. And I think there's a lot of opportunity—and I think the connectivity is a big enabler for everybody as we get more communication power distributed across the oceans.

Mr. TONKO. And Dr. Bell?

Dr. BELL. Yes, and another thing that we need to consider is also the scale on which we do it. So this—everybody has a supercomputer in their pocket now because millions of these devices are made. There's more computing power in this than all the computers combined that put men on the moon. So if we actually want to explore the entire ocean, or some significant part of it, we need to dramatically bring down the costs of systems, sensors, and the data analysis. People can't sit there after an expedition and review every second of every bit of video that has been collected. We need to be using advanced algorithms, machine learning, computer vision, to be able to deal with the amount of information that will be coming in.

Mr. TONKO. Thank you. My time has expired, but I just want to share with Mr. Lang that—earlier you mentioned the *Citizen Scientist Act*. I'm very proud to have sponsored that legislation, and even more proud that it's been recently signed into law, so thank you, and let's go forward with science. Thank you. I yield back.

Chairwoman FLETCHER. Thank you, Mr. Tonko. I'll now recognize Mr. Gonzalez for 5 minutes.

Mr. GONZALEZ. Thank you, Madam Chair, and thank you to the witnesses for your patience and attention today. Turning first to Dr. Bell, in your written testimony you mentioned ocean science compared to other fields of science, has been largely left behind by the digital era. Help me understand that a little bit. How much of that is sort of the scope of the problem, or the scope of the research that we're trying to do itself, versus workforce, versus just general interest? Kind of just flesh that out for me a little bit.

Dr. BELL. So one of the challenges, again, is just the fact that the tools that we're using today are so large and custom-built. Everybody redesigns a pressure housing for every different vehicle that is being created. And so if we're able to take advantage of, for example, you know, cellphone revolution, the fact that everybody has a computer, bringing down the costs of chips, and all of the over devices that are required to do that, then we can bring down the costs, and significantly increase the amount of area, or volume, that we can explore for the same amount of money eventually.

Mr. GONZALEZ. So why are they custom-built? Because, I mean, that's the, like—right, the custom-built, on premise software versus cloud-based solution question applied to this problem——

Dr. BELL. Sure. I might defer to Mr. Barrett on that one, for Oceaneering.

Mr. BARRETT. The, you know, the marine environment is an extra harsh environment. Things that come in and out of the water are subjected to every aspect of corrosion, and—so you end up with inherent costs associated with equipment, and deployment of that equipment in the offshore environment. And truly the scale—back to the scale, you know, problem, or opportunity, depending on how we do it—the only way to get the cost down is really through scale, through having a volume of equipment, or sensors, or even a volume of—ability to deploy them is going to be the only way, I think, to get the costs down associated with massive ocean exploration.

Mr. GONZALEZ. OK. And then, turning a little bit to workforce, so, Mr. Barrett, you represent a company who has benefited from ocean exploration and research. What can this Committee do to help you continue technology development efforts, and how challenging is it to find a well trained workforce in this field?

Mr. BARRETT. I think our company is pretty well positioned to find the workforce, but I do believe that this Committee could, you know, further support STEM (science, technology, engineering, and mathematics) education, particularly as it relates to ocean and ocean sciences. We, I think, previously highlighted the need to get more people engaged, more entrepreneurs engaged, more public awareness so that it is an exciting field to go into.

I think we have to create an infrastructure that provides opportunities, more opportunities, and that comes through companies like ours, that provides opportunities because we're commercially successful. It comes from academia. It comes from non-profits having the funding to be able to provide exciting opportunities, and it comes from the success of entrepreneurs, so I think anything you can do to support those endeavors. And, finally, I would say the collaboration piece again. A platform's more, you know, an easier path to collaborate is another area that I think could help us as a company see the vision and future better so that de-risks our technological investments a little bit.

Mr. GONZALEZ. Great. And then, Dr. Bell, you cite research that suggests the number of students pursuing Ph.D.'s in ocean engineering have remained steady, while other fields, such as aerospace engineering, have increased. To what do you attribute that trend, and what are you doing to address this challenge?

Dr. BELL. That's an excellent question. I don't know why that's happening. What am I doing to address it? Well, being involved in STEM education, and sort of broad public engagement in general is definitely one thing I'm doing. Last year, about 6 months ago, I chaired the 2018 Ocean Exploration—National Ocean Exploration Forum at MIT, which was on broadening engagement and participation.

Mr. GONZALEZ. Great. And I didn't mean it to be a personal question, sorry.

Dr. BELL. No.

Mr. GONZALEZ. Maybe let me ask it differently. What, in addition, should we be doing? What should—societal, maybe take that lens on it.

Dr. BELL. Sure. Well, I think that——

Mr. GONZALEZ. Didn't mean to call you out there.

Dr. BELL [continuing]. Looking at different partners in different industries in a different and creative way than we've done it in the past, rolling out yet another ocean curriculum for middle school is not nearly as exciting and engaging as maybe a television show, or a movie, that highlights factual things, but also may have, you know, exciting storytelling behind it. Aquaman, for example, was the highest-grossing DC Comics movie of all time, over a billion dollars brought in at the box office. So, like, there's an appetite for ocean themes, I think.

Mr. GONZALEZ. Great. Well, with the Aquaman reference, I yield back. Thank you.

Chairwoman FLETCHER. Thank you. I will now recognize Mr. Casten for 5 minutes.

Mr. CASTEN. Thank you, Chairwoman Fletcher. Thank you to the panel. I must apologize, I have not seen Aquaman yet. I was really hoping it was a nice pivot there. I want to talk a little bit about climate change. We had a—at our full Committee hearing yesterday, one of the witnesses described how 90 percent of all of the heat that we have generated because of man-made CO_2 emissions has been absorbed by the oceans. Good news it's a lot cooler up here on the land than it would otherwise be. The bad news is that we have that heat absorbed in the part of the Earth that we seem to least understand.

And I want to start with Dr. Bell. How much do we understand about how that heat stratifies at deeper depths, and where are there gaps in our knowledge that you think we should focus on really pushing to understand that stratification of temperature in the ocean?

Dr. BELL. So I'm not an expert, admittedly, in climate change and heat distribution, but my understanding, and I'd like to echo Dr. Wiener's comments earlier, is that we really, truly, don't have a good understanding of ocean systems. We have a pretty high-level understanding, but looking at specific locations—for example, during the break I was speaking with Mr. Barrett about oxygen concentrations, and how they affect their sub-sea equipment, but they didn't know that, while deploying different types of equipment. So we have good—generally good global models, but verifying them with in situ measurements all over the world is something that we really don't have, and don't have a really fine-grained understanding of how that works yet.

Mr. CASTEN. Would any of you care to comment on where the gaps in our knowledge, and where we should be thinking about, from a Science Committee, to fill in those gaps right now?

Dr. WIENER. I also am not an expert on the subject, but, just from working with many of scientists who have come on Falkor to look at this very question, I would say it's not just a matter of looking at heat distribution, but also pH, and oxygen levels, and how those are impacted by temperature changes. The other piece of it that has captured a lot of interest from scientists coming onto Falkor is other gases, like methane, that is stored in the sea floor, and how that methane is transformed in the water, and eventually makes its way to the atmosphere. And that's something else that's been looked at, and would have an impact on climate change.

Mr. CASTEN. So you read my mind on my next question. Mr. Barrett, I think you talked about doing some work with some of your clients on offshore gas development. I'm assuming that was methane hydrates you were referring to?

Mr. BARRETT. Well, no, we haven't been directly involved in mining methane hydrates. I was talking about the more traditional aspects of oil and gas production.

Mr. CASTEN. OK.

Mr. BARRETT. We have—I think we've done some survey work around methane hydrates, but that's not part of our direct business.

Mr. CASTEN. OK. Well, I guess I'd follow up with Dr. Wiener. As we raise these temperatures, there's a ton of these clathrates that are down at depth that we are, I think, all crossing our fingers that are going to stay at depth, given the impact on climate. And it comes back to my question, as we warm up at these deeper levels—and I should understand the thermodynamics better. Is it pressure that keeps them down there, is it temperature that keeps them down there, or is it both? Because the pressure will presumably stay, but, as the temperature goes up, how concerned should we be?

Dr. WIENER. You know, I don't feel like I have the expertise to really answer the depth of concern that we should have. I certainly do think, though, that making sure we have a fundamental understanding of that through baseline studies is critical to—before we progress with anything further.

Mr. CASTEN. OK.

Mr. BARRETT. I can comment a little bit on it. There's a, you know, methane hydrate formation curve that has to do with both temperature and pressure, so at points on that pressure/temperature combination is where hydrates form, so it's a combination of the two. Our company's involved in hydrates that actually form in pipelines sub-sea, and the remediation of those, but not—again, not with those naturally occurring hydrates that are, you know, found on the ocean bottom.

Mr. CASTEN. So with your familiarity on that pressure temperature curve, as I said, the, you know, the pressure at 10, 12 atmospheres is going to stay 10, 12 atmospheres of pressure, but the temperature's going to change. Are there ranges of possible warming that get up to a concerning point where it's just into the gas phase?

Mr. BARRETT. Yes. I mean, there are two ways to bust a hydrate. There's one to increase the temperature, or to reduce the pressure. That's the extent of my knowledge.

Mr. CASTEN. OK. Well, thank you all for letting me geek out for a second, and I yield back the balance of my time.

Chairwoman FLETCHER. Thank you, Mr. Casten. I'll now recognize Mr. Beyer for 5 minutes.

Mr. BEYER. Thank you, Madam Chair, and thank you all very much for being here. The ocean-space dichotomy is fascinating, because this is a panel that loves space, so we thank you for giving us a chance to learn so much more about the deep ocean. Mr. Lang, in some of the printed testimony we had—it'll take 10,000 ship years to completely view the sea floor. And even if we have a full-time exploration of 10 ships, it'll take 1,000 years. That's longer than we probably want it to take. You suggested that maybe NOAA should scale back on its direct investment in ships and infrastructure, and let the private sector take up the slack, and we've certainly watched for years as NOAA has been pushing for ever more congressional investment in its fleet. Can you comment on how likely it is that the private sector will pick up what is now a 10,000-year project?

Mr. LANG. Yes, absolutely. And I, you know, in my involvement on the NOAA Ocean Exploration Advisory Board, I've been involved in some of those conversations, and heard, you know, everyone's aware of the challenge. I think the reality is that if we want to map the ocean floor to the extent we want to, it's going to take distributed autonomous systems. And the good news is these things are getting cheaper, and they're getting smaller, and they're getting more affordable. I think the question is, can we get enough brainpower, and enough people working on innovating in this field, and in that space? And I think the—there has to be more of an economic incentive, a clear economic incentive, to drive the investment, to drive the enthusiasm, of entrepreneurs and technologists.

Mr. BEYER. Which means to say, if you map it all, what economic value is it to entrepreneurs? Or the public?

Mr. LANG. Yes, both, right? There has to be kind of economic mechanisms to underwrite that development, whether that's mapping—but also there does have to be a driver that spurs it. And I, you know, whether that's deep-sea mining, I'm not sure.

Mr. BEYER. OK, great. Thank you. Dr. Bell, you talked about how the six leading autonomous underwater vehicle companies, only half are the U.S. But obviously the U.S. has been the leader in all this ocean research. Where's China? Which also comes up in this Committee a lot.

Dr. BELL. Yes, as this morning. That I don't know. Most of the autonomous vehicle companies that I know of are more in western countries than in China. I do know that there has been a sudden explosion of small ROVs by Chinese companies just, like, in the last 6 months to a year. They——

Mr. BEYER. Is there any reason we need to be threatened by Chinese research, as we are, for example, with Chinese research in AI?

Dr. BELL. I don't know enough to answer that question.

Mr. BEYER.OK. Cool. Well—yes, Mr. Lang?

Mr. LANG. I think what—we can look at what happened with aerial drones. These got smaller, and cheaper. And what we keep talking about are making—getting to economies of scale, and making sure the sensors, and the production, can build these at the scales that we need. And that's something they're very good at, and something that we're not as good at. And it's—we are the—on the front lines of that competition, and I think if you look at aerial drones, you can see how we kind of lost out on that industry because of our inability to engage with smaller entrepreneurs who were just getting going at the same time.

Mr. BEYER. Great. Thank you. I don't know who to address this question to, but the whole discovery of the chemosynthetic bacteria in the deep vents, I guess something that clearly didn't need light to have life, and I don't know how much oxygen is involved in it. What will this help us to understand, in terms of the origins of life? There's a recent book that I just read a review of this morning that talked about how we probably are the only intelligent life in the universe because it's so difficult for life to evolve, and yet here we've had life evolve twice, once in the photosynthetic way and once in the chemosynthetic way. No molecular biologists or geneticists on our panel, are there? All right, let me——

Dr. BELL. Well, I don't know if they evolved separately or not, but there are many ocean scientists who are interested in the origins of life, and are also looking to other ocean worlds. So they're studying the microbiome here on Earth so that they can start to identify what types of things we might find, for example, on Europa, once we're able to drill through the ice and get down through the water. So using the information that we're able to study and understand here on Earth is definitely being used for understanding the sort of broader question of life in the universe.

Mr. BEYER. OK, great. Thank you. And then, an easy question, the *Ocean Exploration Act of 2009* required NOAA to establish a national strategy and program for ocean exploration. Is there such an actual national strategy now that's formalized, that's one paragraph, one sentence, one book? Well, I was looking for it all through the testimony, and I saw a lot of amazing ideas, but no national strategy, per the Act. OK.

Dr. BELL. I don't know if there is one. There was a review—a 10-year review of the office, and a report as a result of that. Has the

OAEB (Ocean Exploration Advisory Board) been a part of a national strategy?

Mr. LANG. That's absolutely a discussion that happens at the OEAB level, is trying to set that priority. And there's an annual or semi-annual conference that happens where they bring people from all sorts of sectors, that we do discuss that. The question that you asked is a good one, is there a paragraph that describes it? And I think that's something that, because none of us can recall it, is—if it exists, it's not well known enough.

Mr. BEYER. Well, I know the Chair of the Subcommittee, so I'm going to talk to her about it, so we'll see. Thank you, Madam Chair. I yield back.

Chairwoman FLETCHER. Thank you, Mr. Beyer. I'd now like to recognize Ms. Bonamici for 5 minutes.

Ms. BONAMICI. Thank you, Chair Fletcher. Thank you all for being here. I just want to start with a follow up to Representative Gonzalez's question about workforce, especially because, Dr. Bell, I saw that you do work at the MIT Media Lab, and more than 5 years ago, John Maeda, who spent 12 years at the MIT Media Lab, who was at the time the president of the Rhode Island School of Design, came here to Capitol Hill to help me launch the bipartisan STEAM Caucus, which integrates arts and design into traditional STEM learning to help, number one, engage more people, especially diversify the workforce at the K–12 level and college level, but also to make sure that people who are entering the STEM fields are getting both halves of their brain educated so we have creativity and innovation in the STEM workforce. So I just wanted to mention that there is a bipartisan congressional STEAM Caucus. I also serve on the Education Committee, and it comes up as well, when we're looking at expanding that workforce, the schools that have taken the STEAM approach are seeing more engagement, and more creativity, and innovation.

So, now starting with, you know, looking at our planet, and Representative Beyer mentioned, you know, the focus on space in this Committee. If you look down from space at the planet, you see blue, fundamentally blue, because the oceans cover more than 70 percent of our planet's surface. And you look at—I mean, this is Oceans Month, and Oceans Week here on Capitol Hill. When you look at the blue economy, and the importance of the oceans for feeding people, and the power of the ocean waves, and the potential for generating clean energy, and so much is dependent on ocean—Representative Casten mentioned the—absorbing the anthropogenic greenhouse gas emissions. There's so much happening. It's fascinating that we still know very little about what's deep in the ocean, compared with what we know about the surface.

So, as we're preparing for the United Nations Decade of Ocean Science for Sustainable Development, and the top priority to map the ocean floor, I'm working with my fellow co-chair of the House Oceans Caucus, Representative Don Young from Alaska, to highlight the importance of improving our ocean data and monitoring efforts. So later this month I'm going to be introducing the House companion to Senator Whitehouse's Bolstering Long Term Understanding and Exploration of the Great Lakes, Oceans, Bays, and Estuaries, it's easier to remember *BLUE GLOBE Act*, and that would rapidly accelerate the collection, management, and dissemination of data on the Great Lakes, oceans, bays, estuaries, and coasts. It also tasks the National Academy of Sciences with assessing the potential for an Advanced Research Projects Agency on oceans, or basically an ARPA-O, because we need to overcome the long-term and high-risk barriers in the development of ocean technology.

So, Dr. Bell, in your testimony, you talk about a data analysis bottleneck. So what are the greatest challenges today in the collection, management, and dissemination of ocean data?

Dr. BELL. Sure. Well, one of the biggest challenges is just the fact that it's so distributed. Everybody has—NOAA has its data, Schmidt has its data, the Ocean Exploration Trust has its data. Everybody has it in distributed ways. And even if they say it's publicly accessible and available, in some cases it can be extremely difficult to get, so just even finding—and that's for somebody who knows where to look, and knows people in those organizations, right? So if anybody doesn't know that, or would just be curious, probably couldn't get the data.

Another one is that we're sort of on the verge right now of truly big ocean data, in comparison to organizations like Google, or other tech companies, which are dealing with very, very large amounts of data. Ocean data really isn't quite big yet, but if we're talking about deploying thousands or millions of different types of sensors all over the world, we're really going to have to figure out how do we actually deal with that data. We're not going to be able to have somebody physically sitting there looking at every second of video, right? So we need to——

Ms. BONAMICI. Right.

Dr. BELL [continuing]. Develop the kinds of algorithms to create automated analysis so that we can pull out that information and understanding so that we can really understand what we're collecting. Because if we start collecting terabytes, petabytes, whatever the correct prefix is——

Ms. BONAMICI. Right.

Dr. BELL [continuing]. We're not going to be able to do it.

Ms. BONAMICI. Want it to be useful.

Dr. BELL. Um-hum.

Ms. BONAMICI. And I want to move on—last Congress, I helped secure funding for the construction of a National Science Foundation regional class vessel. It's going to be operated by Oregon State University. It's called the *Taani*. It comes from the Siletz term meaning offshore, scheduled for delivery in 2021, and it's going to be equipped to conduct some detailed sea floor mapping. The *Taani* is going to help identify geologic structures important in the Cascadia subduction zone earthquakes that could likely trigger a significant tsunami on the Pacific coast.

So, Dr. Wiener, what and why are the scientific benefits of mapping the ocean floor important, and what breakthroughs do you believe will emerge as we expand to sea floor mapping?

Dr. WIENER. Well, it is critically important that we are able to map our sea floor, not only to just understand what's down there, but to better characterize the different environments, and how they connect to each other. There are many—multiple initiatives, as we mentioned earlier today, that are looking to collaborate and bring together all of this mapping data.

There are different scales of mapping data. Whether it's centimeter, sub-resolution scale, which you get from a robotic vehicle, versus multiview mapping, which is a larger—still high resolution, but not in the same focus, and I think both are important to have for our ecosystems. I'd also like to mention that it's wonderful to hear about the STEAM initiative that you're doing, and our Artists at Sea program works with some of the data that's collected to transform it in an artistic way for the public. We actually have an exhibit opening this weekend in Detroit.

Ms. BONAMICI. Terrific. Well, thank you so much. I see my time—Dr. Bell? Could we let Dr. Bell respond?

Chairwoman FLETCHER. Yes.

Ms. BONAMICI. Thank you, Madam Chair.

Dr. BELL. Just a specific example for importance of sea floor mapping, especially for tsunamis, is that you need to know the shape of the sea floor for tsunami models to be accurate, to know how much and—of—the sort of magnitude of run-up will be on coasts, so that is particularly important for tsunami modeling and warning.

Ms. BONAMICI. Right. Which is critical, because we're——

Dr. BELL. Um-hum.

Ms. BONAMICI [continuing]. Overdue for a massive earthquake—thank you. I yield back.

Chairwoman FLETCHER. Thank you, Ms. Bonamici. And, before we bring the hearing to a close, I thought I would just see if I could give each witness about 30 seconds to share with us, if you would like to, what you think Congress could do to support ocean exploration. And maybe we'll start with Dr. Bell, and just run down the line.

Dr. BELL. Sure. I have three things that Congress could do to support ocean exploration. The first is to re-authorize the NOAA Office of Exploration Research, because the Public Law 111–11 expired in 2015. The second would be to create a national or international program to include private, public, academic, and philanthropic partnerships, and not it being solely a Federal agency, but rather a more inclusive one. And also to support sufficient funding for said programs, because, in the last 20 years, it's been pretty unstable, and insufficient to really make true headway on accelerating and transforming the future of exploration.

Chairwoman FLETCHER. Thank you, Dr. Bell. Dr. Wiener, do you have anything to add?

Dr. WIENER. I also have three recommendations that somewhat echo Katy's response, but leveraging economies of scale to decrease the cost of sensors and systems to make them available to more people, to cover more ocean, and to build capacity in technology poor regions, protecting sea resources where they are vulnerable. We should also look to the advances of other industries making exciting innovations across technology sectors, such as the medical, oil and gas, defense, et cetera, industries that could be applied to ocean research. And to position ocean exploration for high-risk, high-reward conservation-minded ocean science.

Chairwoman FLETCHER. Thank you, Dr. Wiener. Mr. Barrett?

Mr. BARRETT. I think they covered it really well. I do believe cost is going to be the area that we really need to focus on, and figuring out ways to leverage what either already exists, or how we build scale into the whole effort, because individual missions are just extremely costly, and, you know, you can't cover 70 percent of the Earth very well that way.

I think I already highlighted the other two, which is certainly the educational aspect. Getting the best and brightest engaged and excited about this field I think is critical. And, finally, I think the way we could collaborate better, and I think a good place for Congress would be to create a vision, and to create some goals, and to create some consensus around where we want to be as a country, and for the world, in terms of understanding the ocean better. I think those types of visionary, you know, from the top, those visionary statements and leadership is really what it takes to, I think, muster the whole effort.

Chairwoman FLETCHER. Thank you, Mr. Barrett. And Mr. Lang?

Mr. LANG. Yes, I agree with all the recommendations listed, including the reauthorization. I—the only thing I would add is that—to remember that ocean exploration is not just where we go, but how we get there, and this endeavor, this national ocean exploration initiative has a real opportunity to pioneer some new strategies in how we go about getting there. And I think, you know, given what space has done, it seems to me that engaging with private companies, and with entrepreneurs, and supporting those visions, is a really good way to do it. So, thank you.

Chairwoman FLETCHER. Thank you very much.

Mr. BEYER. Madam Chair?

Chairwoman FLETCHER. Yes?

Mr. BEYER. May I throw out a 15-second challenge——

Chairwoman FLETCHER. You sure——

Mr. BEYER [continuing]. Please?

Chairwoman FLETCHER [continuing]. Can.

Mr. BEYER. I would like—thinking about our space parallel here, we're getting ready to go to the moon by 2024 and Mars by 2033, I have the bumper sticker on my car. If you can think of the parallel in the deep ocean to going to the moon by 2024 and Mars by 2033, it would help us.

Chairwoman FLETCHER. Yes. That'd be great. Well, I want to——

Dr. BELL [continuing]. Make you a bumper sticker.

Chairwoman FLETCHER. I do want to thank you all for coming this morning, for your testimony, and for your patience while we took a break to vote. I would also like to recognize Ms. Bonamici because, of course, we left our hearing to vote on, and Congress has now passed, in the House, H.R. 1921, the *Ocean Acidification Innovation Act of 2019*, and that was largely due to her great work, and it is the first bill coming out of our Subcommittee through the Science Committee. So I'm very pleased, and we passed several others this morning as well on the floor. So thank you very much for being here with us.

The record from this hearing will remain open for 2 weeks for additional statements from Members, and for any additional questions for the witnesses, but you all are now excused, and the hearing is adjourned. Thank you.

[Whereupon, at 11:14 a.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Katy Croff Bell

Submitted by Chairwoman Eddie Bernice Johnson

1. *During the hearing, the panel was asked if there is a national strategy for ocean exploration, and there didn't seem to be a clear response. Given that there does not seem to be a single national strategy, do you think there should be one? If so, what should it look like and aim to achieve, and who should develop it?*

Following the hearing, I reviewed the NOAA Office of Ocean Exploration and Research (OER) website. The FACA-convened Ocean Exploration Advisory Board (OEAB) has provided strategic guidance over the last four years, but there does not appear to be a single national strategy for ocean exploration. While the office does excellent tactical work, I believe that a national strategy with clear long-term goals would be beneficial for the nation.

The closest existing document to a national strategy is the 2000 Report on the President's Panel on Ocean Exploration, which recommended a national program of exploration and was the impetus for the creation of OER in 2001. Since then, numerous discoveries have been made, new technologies and communication methods have been developed (including telepresence and social media), and new players have emerged, in particular philanthropic organizations. Nearly 20 years since the President's Panel, it is time to assess the current state of the US ocean exploration enterprise, set ambitious goals, and plan a strategy for the future.

The national strategy should aim to achieve the following:

- **Assess the current status of the US ocean exploration enterprise**
  - e.g. including strengths, weaknesses, challenges, and opportunities
- **Define ambitious, long-term (10-20 year) goal(s)**
  - e.g. to "image and characterize 100% of the seabed by 2040"
- **Establish guiding principles for all aspects of the strategy**
  - e.g. ensuring open, collaborative research and operations; intentionally structuring equity; and, approaching the goal with systems over things
- **Establish a governance structure under which to operate**
  - e.g. aim for a structure that encourages the establishment and growth of collective intelligence for the ocean exploration community, such that the people and systems involved act more intelligently -- and equitably -- toward a larger goal than any individual or organization has done before
- **Determine the existing and yet-to-be developed resources needed**
  - e.g. identify the agency/organization that should lead the effort, keeping in mind that it may not yet exist; identify the capabilities that humans, machines, data systems, etc., will be required to meet the goal(s)
- **Create a timeline to achieve intermediate objectives**
  - While a timeline is helpful to maintain momentum, we must also maintain flexibility to change milestones, so long as changes support the overall goal

To undertake the formulation of the national strategy, an independent panel/commission should be convened, much like the 2000 President's Panel, with representatives from the government, academia, industry, philanthropy, media, and others. We should also consider that, given the global nature of the ocean, the strategy should take into account international partnerships and collaboration. And finally, given how much technology is likely to change in the next 10-20 years, the strategy should chart a course toward discovery, but understand that we may not yet know the most direct path to get there.

Submitted by Chair of the Subcommittee on Environment Lizzie Fletcher

1. *At the hearing, a Member asked about the involvement of U.S. scientists with scientists from other countries such as Russia, China, Brazil, Japan, and India in ocean exploration.*
    a. *Given the oceans know no geographic boundaries, how important are international collaborations to exploring the oceans?*
    b. *What are some examples of successful international collaborations?*
    c. *What are the concerns or risks around international collaborations in ocean exploration, such as with data sharing with other countries, and do you have ideas on how to address them?*

International collaborations are fundamental for exploring and understanding all aspects of the ocean, including geological, physical, and biological oceanography, as well as chemistry and human history.

Geological features such as mid-ocean ridges, volcanic island chains, and tectonic plates cross international boundaries, and their effects such as volcanic eruptions, earthquakes, and tsunamis can have impacts around the globe. Volcanic eruptions, for instance, can eject tiny bits of volcanic glass, or tephra, high into the atmosphere, disrupting or even shutting down air traffic, killing people in local proximity, and spewing gases that can alter global weather and climate. The 1815 eruption of Mt Tambora in Indonesia is commonly known as the "Year Without a Summer" because it caused average global temperatures to decrease by approximately 1°F, resulting in major food shortages across the northern hemisphere. Earthquakes can cause tsunamis, which can travel and destroy coastlines and communities thousands of miles from their origin. The 2004 Indian Ocean tsunami, for example, originated in Indonesia, but killed more than 200,000 people around the Indian Ocean. The United States could similarly be impacted by volcanic and/or tectonic activity in the Caribbean, or across the Pacific Ocean, which is very geologically active.

Similarly, water travels around the world, driven by oceanic currents. The movement of water drives global heat distribution, and its understanding is critical for weather and climate prediction. Hurricanes that hit the southeast coast of the United States, for example, begin as tropical depressions off the west coast of Africa. Collaborations with countries such as Morocco, Spain, and Mauritania would be beneficial to better understand, predict, and mitigate the impacts of hurricanes in the United States. Another example of climate- and weather-driving phenomena that affects the US include El Niño in the Pacific Ocean, which is predicted to create a hotter and wetter than normal summer for Washington, DC, in 2019.

Water movement is also important for understanding the reproduction and migration patterns of economically important marine life, such as Atlantic Bluefin Tuna that are known to live and/or spawn across the Caribbean Sea, Gulf of Mexico, and north to Canada. Some individuals have even been shown to migrate across the Atlantic Ocean to/from Europe. We do not, however, have a good understanding of how these and other populations of commercially relevant fish interact with organisms that live, spawn, and thrive across great expanses of seafloor in these regions, nor larger animals such as whales, and all of the interactions between them. Exploration of these, and other regions, on an international level would greatly enhance our understanding of these important ecosystems so that we may more responsibly manage living marine resources today and into the future.

These are just a few examples of the numerous ways understanding natural processes, resources, and hazards far beyond our own Exclusive Economic Zone (EEZ) is critical for US interests, as well as those of our international partners.

Fortunately, there is already interaction between American and international ocean scientists on a regular basis. During the hearing, Dr. Wiener discussed the Seabed 2030 effort to acoustically map the entire seafloor by 2030, led by the Nippon Foundation in Japan and the General Bathymetric Chart of the Ocean (GEBCO), which operates under the joint auspices of the International Hydrographic Organization (IHO) and UNESCO's Intergovernmental Oceanographic Commission (IOC). According to the Seabed 2030 website, the project has "drawn on the experience of some 40 international organizations and networks spread across more than 50 countries," and has now aggregated multibeam bathymetric data of 15% of the world's ocean.

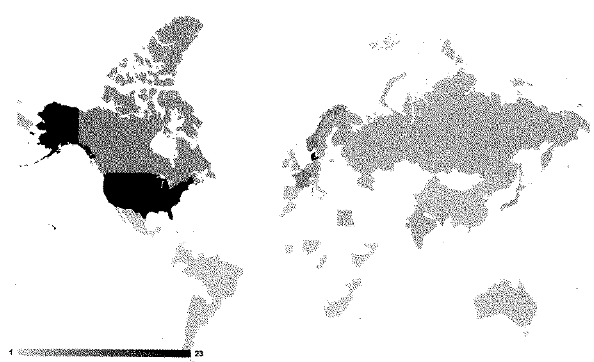


Figure 1. Countries represented at the First Global Planning Meeting of the UN Decade of Ocean Science for Sustainable Development, including Russia, China, Brazil, Japan, and India. Data based on lists of workshop attendees and Executive Planning Group representatives.

During our discussion, I also noted the upcoming Decade of Ocean Science for Sustainable Development, coordinated by the IOC, as an example of a current and upcoming opportunity. Forty-six countries were represented at the First Global Planning Meeting in Denmark in May 2019, including Russia, China, Brazil, Japan and India (Figure 1). A series of 8-10 Regional Workshops are now being organized around the world, the first of which will be held in New Caledonia on July 23-25, 2019, with others anticipated in Japan, Brazil, Italy, Canada, Mexico, and Ecuador in the next 1-2 years.

Another excellent example of successful international oceanographic collaboration is the International Ocean Discovery Program (IODP), which began as the Deep Sea Drilling Project in 1966. "IODP is an international marine research collaboration that explores Earth's history and dynamics using ocean-going research platforms to recover data recorded in seafloor sediments and rocks and to monitor subseafloor environments. IODP depends on facilities funded by three platform providers (NSF, Japan's Ministry of Education, Culture, Sports, Science and Technology, and the European Consortium for Ocean Research Drilling) with financial contributions from five additional partner agencies (China's Ministry of Science and Technology, Korea Institute of Geoscience and Mineral Resources, Australian-New Zealand IODP Consortium, India's Ministry of Earth Science, Brazil's Coordination for Improvement of Higher Education Personnel). Together, these entities represent twenty-three nations whose scientists are selected to staff IODP research expeditions conducted throughout the world's oceans." The twenty-three nations participating in IODP include: Australia, Finland, Japan, Spain, Austria, France. Korea, Sweden, Brazil, Germany, Netherlands, Switzerland, Canada, India, New Zealand, United Kingdom, China, Ireland, Norway, United States of America, Denmark, Italy, and Portugal.

Despite the importance of international collaboration, however, NOAA has seemed to move away from it in recent years. According to the OER Digital Atlas (Figure 2), and my knowledge of OER-sponsored expeditions, since 2001, OER has conducted and/or sponsored 371 cruises around the world, 68% of which were in US waters. If we dig into the details, however, we see that the breakdown of expeditions in US vs non-US waters varies significantly by year, ranging from 11% to 56% of the expeditions in non-US waters.

From 2001 to 2004, OER conducted and/or sponsored 89 cruises, 11-19% of which were in non-US waters. For the next 10 years, from 2005 to 2015, OER became much more international, conducting and/or sponsoring 223 cruises, of which 30-56% were in non-US waters (on the high seas or within EEZs of other countries). In the last 3 years, from 2016-2018, the program has become much more focused on exploration of US waters, conducting and/or sponsoring 62 cruises, 11-21% of which were in non-US waters (Figure 3).

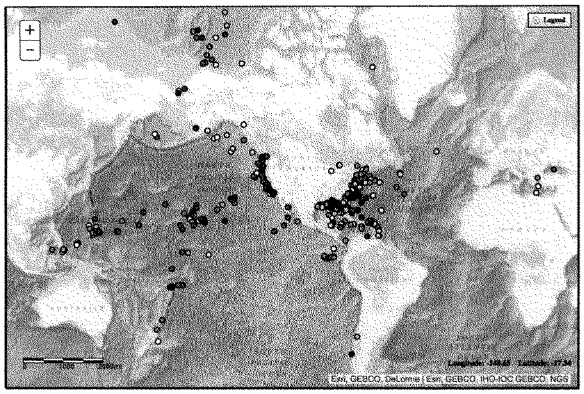


Figure 2. Since 2001, according to the OER Digital Atlas, OER has conducted and/or sponsored 371 cruises around the world, 68% of which were in US waters. Map does not include ~22 cruises conducted by the Ocean Exploration Trust in the Mediterranean, Aegean, and Black Seas.

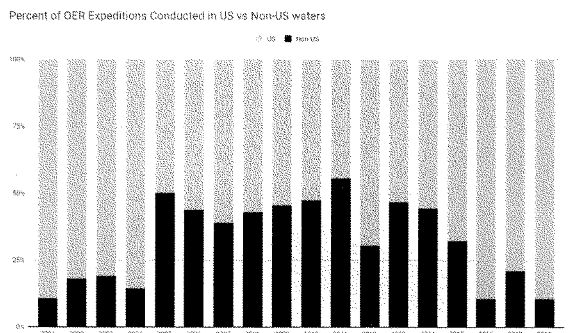


Figure 3. Percent of expeditions conducted and/or sponsored by NOAA OER from 2001 to 2018 in US (yellow) and non-US (blue) waters, according to the OER Digital Atlas.

If we assume that international exploration and collaboration is important for US and global interests, then it would stand to reason that US-led exploration should once again expand to international and other non-US waters, with an emphasis on open, collaborative research. There may be risks in increasing international collaborations, such as allowing other countries access to US-collected data, but I believe that the benefits of collaboration far outweigh the risks. Some of those benefits include the acceleration of data collection, analysis, and understanding about the ocean that can benefit everyone in the world, as well as enhanced strategic relationships with countries that may not have partnered with the US in the past.

2. *In your written testimony and in the hearing, it was brought up that the number of students studying ocean engineering has stagnated while those in other fields such as aeronautical engineering has grown.*
    a. *Can you expand upon what may have contributed to this stagnation?*
    b. *What are the skills needed to advance modern ocean exploration, and how can we build a workforce to achieve it?*

Allow me to begin with a specific case of decline of Ocean Engineering, at my alma mater and current home institution, MIT. As early as 1886, a course in marine engineering was offered at MIT, and due to its popularity, the Department of Naval Architecture was established in 1893. Over more than 110 years, its name changed several times, but its mission remained the same: to offer instruction in the theory and methods of designing, building, and operating marine systems, such as ship design, aeronautics, nuclear propulsion, acoustics, and, most recently, robotics. In 1901, MIT began a special course for the U.S. Navy, extending over three years for the professional training of naval constructors, and supported the Navy and merchant marine throughout its history.

I declared Ocean Engineering as my undergraduate major as a sophomore in 1997, not knowing anything about it other than the fact that I liked both the ocean and engineering. I was often teased by classmates from other departments, wondering *what in the world would I do with a degree in Ocean Engineering*? My class in 2000 graduated two undergraduates. In 2005, the Ocean Engineering Department was merged with Mechanical Engineering. MechE students can still concentrate on ocean research, but it is not a standalone department any longer, and the number of students graduating with a marine engineering focus has dropped precipitously since the department's peak in the 1970-1980s (Figure 4).

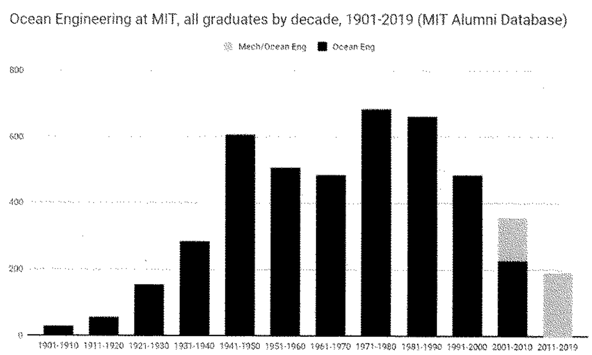


Figure 4. MIT Ocean Engineering graduates, all degrees by decade, show the height of the department occurred between 1941-1990. Blue bars indicate students graduating with any degree (SB, SM, PhD) in Ocean Engineering. Yellow bars indicate students graduating from Mechanical Engineering, with an ocean focus, after the departments were merged in 2005. Students who were admitted under Ocean Engineering pre-2005 were allowed to graduate with that degree title. Number of graduates is approximate; from the MIT Alumni Database.

Why is this occurring? I cannot say definitively, and I am sure that there are numerous factors in play. One very basic reason could be that most of the population does not know that this career option exists. Everyone knows about rocket scientists and astronauts -- even more so now with the new surge in the privatization of space exploration, and the resurgence of such franchises as Star Trek and Star Wars. Perhaps the difference stems from the very public Space Race vs the covert Cold War occurring under the sea in the 1960s, or the magically infinite vastness of space, which evokes feelings of wonder and possibility. Whatever the reason, in more than 20 years in this field, I have met only a handful of people who know what ocean engineering is, let alone any pop culture "hero" that has a background in the field, or a child who expresses interest in wanting to be an ocean engineer or ocean explorer when she grows up. Fact of the matter is: if people don't know what it is, then it won't occur to them to study it, and we need to do something about that if we are to regain and maintain leadership in the field.

The skills needed for the next generation of explorers to advance modern ocean exploration can be broken into three categories: (1) fundamental mathematics, physics, and engineering; (2) knowledge of the environment, including earth science and oceanography; and (3) critical thinking, problem solving, and practical, hands-on skills. Increasingly, given how international the field is (or should be), I also believe that at least an introduction, if not a firm foundation, in international ocean law and policy will also serve the next generation of modern ocean explorers to succeed in the field.

I can hypothesize about many activities that could or should be done to address the dearth of ocean engineers -- from increasing diversity in water sports to producing television shows and films that highlight [diverse] ocean engineers and oceanographers as the heroes of well-written stories. But before we begin speculating, my recommendation would be to commission the National Academy of Sciences to look into the problem in systematic detail, including all potential factors from academics to popular culture; make recommendations for how to address it; and enthusiastically prosecute those recommendations. Given the importance of the ocean for human survival on Earth, we do not have time to waste.

Responses by Dr. Carlie Wiener

During the hearing the panel was asked if there is a national strategy for ocean exploration, and there didn't seem to be a clear response. A) Given that there does not seem to be a single national strategy, do you think there should be one? If so, what should it look like and aim to achieve, and who should develop it?

Yes, there should be a national strategy for ocean exploration. From the great Lewis and Clark expedition, to the U.S. Exploring Expedition thirty years later, to John Wesley Powell's scientific expeditions in the American West, to, more recently, the Apollo missions 50 years ago, and through today, the United States has prospered from opportunities born out of exploration. Exploration should continue to take place and expand to broaden our understanding of the ocean, its resources, and place in Earth's ecological systems. There are multiple ways that exploration will strengthen the United States capabilities including security, science, blue economy, transportation, and better understanding of climate. Exploring the ocean leads to better models, predictions, and connections between systems. The amount of "unknowns" that we still have in regards to 71 percent of our planet's coverage is shocking. We know enough to establish that the ocean is critical to our very survival as humans; however, we do not know enough about how our use impacts this resource and how to wisely manage it for future generations.

With respect to the ocean, the United States has fallen short of other nations, including some of our greatest allies, who have invested heavily in ocean exploration and ocean science. This is an area where the United States should demonstrate leadership and broaden research efforts. An independent group of advisors should be convened similar to the President's Panel on Ocean Exploration, which was the impetus for creating the NOAA Office of Ocean Exploration Research (NOAA OER) in 2001. There seems to be emerging consensus amongst federal, private, and academic partners that such a strategy is needed. The Ocean Exploration Advisory Board has put considerable thought into what legislation for a national program of ocean exploration might include, such as options for councils and other coordinating bodies.

Schmidt Ocean Institute, although pursuing its own mission priorities, would support a national strategy for ocean exploration that aims to pursue scientific knowledge in order to advance basic ecosystem understanding for support of conservation. Consideration for emerging and new technologies, large data management and visualization capabilities, and broad education and outreach should be included in this strategy. NOAA is poised to take leadership on a national strategy, while the private sector including academic institutions, foundations, and nonprofits act as important advisors and partners in development and implementation.

A national strategy should emerge not as a singular mandate; but rather, an organizing strategy that catalyzes progress on multiple fronts. Other considerations could include a priority to characterize all of the "seascapes" within the United States' exclusive economic zones (EEZs) for better understanding and development towards specific strategic reserves. A baseline mapped ecosystem similar to Ecological Marine Ecosystem Units (EMUs) that ESRI, NOAA, USGS, IOC, and others have developed could be extremely useful. It is not too much to say that the future of the United States depends on our ability to manage the rich heritage of our ocean resources and the broader global ocean systems with which they are interconnected.

A national strategy should be designed in the spirit of our race to the moon; engaging the breadth and constancy of the federal government with the competition and ingenuity of the private sector. In every case where the United States has stepped up and pushed for innovation via exploration, our nation has prospered. Our ocean is a great frontier, and one that we must wade into with sensitivity for its fragility and respect for its strength. We should not, however, continue to sit by the shoreside and watch while others lead humankind into the future. It is not just about being the first to explore, but the critical need to understand what we have so that we can manage and use our oceans wisely for the future.

During the hearing there were many comparisons made between deep sea exploration and space exploration. A) What are the connections between the deep sea and space?

There are many connections between the deep sea and space, especially in the human characteristics that are needed to explore both - adventure, ingenuity, risk, and perseverance.

Many of the engineering and human factor design challenges are similar, and ocean and space explorers have much to learn from each other - and do. By working in the deep ocean, we can push the limits of our understanding of existing hardware designs and engineering choices for missions in outer space. There are many challenges that scientists and engineers encounter both in exploration of the deep sea and space, some of these include:

- Latency in communication (in space due to distance - in ocean due to water weakening traditional signal (light, sound) strength).
- Issues in dealing with pressure (in space, a lack of it - underwater, the tremendous weight of the ocean).
- Maximizing battery power (or energy efficiency) after launching a vehicle out of humanity's reach.
- Both require three dimensional coordination/navigation.

Using unmanned robotics have made tremendous advances in both space and underwater exploration. Last year Schmidt Ocean Institute hosted four expeditions where software and robotics targeted for space exploration were engineered and tested (see Table below).

The National Aeronautics and Space Administration (NASA) has just formed a Network for Ocean Worlds to advance comparative studies to characterize Earth and other ocean worlds across their interiors, oceans, and cryospheres; to investigate their habitability; to search for biosignatures, and to understand life—in relevant ocean world analogs and beyond. One of their listed goals is to provide the first opportunity for study between Earth and other planets. The knowledge gained is critical to understanding habitability beyond Earth as well as understanding Earth's ability to sustain life through time.

That said, humankind depends upon the ocean for our very health and existence. The state of our ocean has a direct and immediate impact on our well-being. While supporting exploration of our solar system and the universe is important, does it not make sense to better characterize and understand our own planet at the same time?

Dr. Peter Girguis, Harvard University, offers a great analogy in that exploring space before our own planet is akin to owning a home in which you have never been to the basement. Instead, you hire contractors, surveyors, and many others to study your neighbor's home, all while ignoring your own.

There is no question that the wonders of the deep--whether space or the ocean--awe and inspire us, but we should not forget how much we have to gain. To cite but one example, the strange and wondrous biology of the deep, is rich and diverse. Deep ocean life does not yield just a beautiful image or scientifically interesting sample, it may hold cures for cancer or Alzheimer's, as an example. There is no life that we know of thus far in space. Oceans, in that way, have something unique to offer.

Table: Schmidt Ocean Institute Space-Related Expeditions

Expedition Title	Year	Lead Principal Investigator	Region/Area	Country of Work	Collaborators	Vehicles
Seeking Space Rocks	2019	Mark Fries	Oregon Coast	United States of America	NASA, NOAA Office of National Marine Sanctuaries, Harvard University, Rice University, Case Western Reserve University	ROV SuBastian
New Approaches To Autonomous Exploration At The Costa Rican Shelf Break	2018	Richard Camilli	Costa Rican Shelf	Costa Rica	Woods Hole Oceanographic Institute,Australian Centre for Field Robotics (University of Sydney), National Aeronautics and Space Administration, Massachusetts Institute of Technology, University of Michigan, University of Athens	ROV SuBastian, Slocum Gliders,
Interdisciplinary Investigation of a New Hydrothermal Vent Field	2018	Robert Zierenberg	Baja Peninsula	Mexico	Monterey Bay Aquarium Research Institute, University of California - Davis, California Institute of Technology, Occidental College, Scripps Institution of Oceanography, Oregon State University, University of Rhode Island, Pontifica Universidad Catolica de Chile	ROV SuBastian, Autonomous Underwater Vehicle (AUV) D. Allan B (MBARI Mapping AUV)

Characterizing Venting and Seepage Along the California Coast	2018	Peter R. Girguis	Coast of Southern California	United States of America	Woods Hole Oceanographic Institute, Harvard University, Texas A&M University, National Science Foundation, National Aeronautics and Space Administration	ROV SuBastian, Autonomous Biogeochemical Instrument for In Situ Studies (ABISS) Lander

B) Are there lessons we can take from the success and excitement around space exploration that can be applied to ocean exploration?

Yes. Much of the success of space exploration is due to the human dimension. We are naturally drawn to the excitement of the unknown. We can "see" space in a way that makes it accessible for everyone, and dreams of journeys into space long have been part of our cultural fabric--well before we were able to celebrate astronauts as national heroes with ticker tape parades down Madison Avenue. The space age evolved and accelerated science-fiction/popular culture creating both real/factual and imaginative futures. This model could go a long way in garnering excitement for the ocean, which has not been front and center in global popular culture in recent times.

The initial excitement surrounding space exploration was not just about getting to the moon, it was about competition to be the first and the advancement of technologies at an unprecedented pace. It was about the danger of going into space; watching the steps of exploration take place on the television or radio. How do we get the sense of adventure back? Today, going to the bottom of the ocean, while anything can happen, is relatively safe, internet access allows us to livestream and tweet from the bottom of the ocean, always being connected when we are away.

While connectivity can be vital to teaching people about what is going on and sharing beautiful images, how do we instill a sense of adventure? How do we ignite a passion for our ocean that inspires the public to want to do more? If current technology leaves little to the imagination, perhaps new developments in data science and visualization can help restore the sense of wonder. This could be accomplished by allowing anyone to participate in ocean exploration through immersive environments and advanced visualization tools that help to achieve new scientific breakthroughs. There are rich opportunities to share research results and engage the public in the process. A national ocean exploration strategy can help mobilize the resources and create the opportunities for partnership that will make these opportunities real for all Americans.

During the hearing, many questions were directed from the Committee about other countries. While competitive, space exploration has always been global in perspective. The United States collaborates internationally with academic institutions and governments and today, the space agencies of different nations regularly celebrate the successes of one another. This is not, however, always the case with respect to ocean exploration science. If we are to understand the global ocean, gain access to it for data collection and analysis, or collaborate on high seas issues, international partnerships are essential. The ocean is a fluid system that does not recognize national jurisdiction's. Broader international partnership and data sharing will help to better advance and plan for future changing systems. This has been recognized and is beginning to be considered as part of the United Nations Decade of Ocean Science.

Competition has always been a powerful driver in human history, including exploration. But perhaps it is time for a new paradigm; perhaps we should consider how a national strategy for ocean exploration can set the stage for international collaboration that encourages us to share technology and data with other ocean nations--especially developing nations--to the benefit of us all. The U.S. EEZ is important, but it is a healthy and productive global ocean that is needed now and for the future. Instead of fearing how other countries are advancing their ocean programs, our nation should take leadership with science and engineering excellence and innovation, and re-frame the discussion into how we can advance ocean exploration for the greatest technical and societal benefit globally.

Responses by Mr. Steve Barrett

Subcommittee on the Environment of the House Committee on Science, Space and Technology Hearing *"Ocean Exploration: Diving to New Depths and Discoveries,"* 5 June 2019 Question for the Record response from panel member Steve Barrett representing Oceaneering International Inc..

Question: During the hearing, the panel was asked if there is a national strategy for ocean exploration and there didn't seem to be a clear response. Given that there does not seem to be a single national strategy, do you think there should be one? If so, what should it look like and aim to achieve and who should develop it?

Answer:

Yes, there should be a national strategy for ocean exploration.

The following should be considered as key components to formulation and execution of a national strategy for ocean exploration.

- Should provide clear vision and direction for federal, commercial, academic and non-profit investors and stakeholders to align their respective investments, resources and talent. The vision should emphasize U.S. leadership in the Blue Economy, empowering maritime competitiveness and ocean sustainability.
- Strategy should inform a multi-year plan that provides the architecture for coordination of expenditures and activities.
- Leverage NOAA's Ocean Exploration and Research (OER) Program and National Oceanographic Partnership Program (NOPP) to spur discoveries of new knowledge, advance innovative technology, engage international partners and stimulate current and next generations.
- Congressional enactment of the BLUE GLOBE Act (**B**olstering **L**ong-term **U**nderstanding and **E**xploration of our **G**reat **L**akes, **O**ceans, and **E**stuaries Act) to advance data collection and monitoring by supporting data sharing, accelerating technology development and innovation, growing the future marine workforce, and developing a better understanding of the Blue Economy.
- Proactive congressional leadership to ensure accountability, provide sustained funding and provide the forum for public debate and discussion of critical ocean exploration challenges and opportunities.

Development of the strategy should be led by NOAA in partnership with industry, academia, and non-profit organizations.

Responses by Mr. David Lang

1.a.

The latter part of the question is the first one to answer: who should develop it.

The challenge and opportunity of our ocean-dependent future requires any plans for exploration be tightly coordinated with fisheries management, mineral extraction, marine protected areas, and on and on. We need a National Strategy for the Ocean, not just ocean exploration.

The federal government can and should be that leader, but it would require an audacious vision, an increase in funding, and the institutional structure to focus effort. In my written testimony to the committee, I quoted John Steinbeck's 1966 letter to the editor of Popular Science. I quoted his explanation for *why* we must explore the ocean. That letter also contained a passage about *how* we should structure it:

> "What the exploration of the wet world lacks, and must have to proceed, is organization. Undersea study is split up into a thousand unrelated groups, subjects, plans, duplications, having neither direction nor directors. There is no one to establish the path to be followed and see that it is taken. Our space probes could not have gotten off the ground without NASA, a management for analysis, planning, engineering, and coordinating, having the power to give orders and the money to carry them out. The movement to possess the sea must be given the strength and structure to move."

This level of organization and leadership from the federal level could take several forms. It could be the creation of cabinet position, a Secretary for the Ocean. Or the elevation of NOAA as an agency equivalent of NASA. My personal favorite, and perhaps the boldest vision, is the creation of a government-backed independent agency similar to the National Fish and Wildlife Foundation or United States Institute for Peace. This type of agency would have the freedom to work with industry and non-profit foundations — both increasingly important players in the field — to shape a coherent and bold plan for ocean exploration and stewardship. The rapid advances in technology coupled with the emergence of new philanthropic and entrepreneurial actors make the timing ideal.

The what and the how would follow easily from the who. Start there.

Appendix II

Additional Material for the Record

LETTERS SUBMITTED BY REPRESENTATIVE LIZZIE FLETCHER

OCEANX

STATEMENT FOR THE RECORD PROVIDED BY OCEANX TO THE HOUSE SCIENCE, SPACE AND TECHNOLOGY SUBCOMMITTEE ON THE ENVIRONMENT

JUNE 5, 2019

OceanX appreciates the opportunity to submit our position in support of ocean exploration. OceanX also thanks the House Science, Space and Technology Committee Subcommittee on the Environment for holding today's hearing "Ocean Exploration." We are pleased to see the Committee prioritizing ocean exploration, particularly the state of the U.S. ocean exploration enterprise. The benefits of ocean exploration and discovery are vast and produce tangible advantages by way of technological innovations, species discoveries, and a greater understanding of ocean conditions. But ocean exploration has intangible benefits too, deepening our nation's curiosity for the unknown, our passion for the ocean, and our drive to discover a space few dare explore.

The timing of this hearing is opportune: in the face of rapidly changing global oceans and the ongoing threat of climate change, it is more important than ever before to explore and understand our ocean. What we achieve in ocean exploration in the next 10 years will dictate the future of oceans and humanity for the next century. We rely on the ocean for sustenance, transport, commerce, transportation, and life itself. Though the ocean covers more than 70% of the planet's surface, less than 5% of the ocean has been thoroughly explored. Ocean exploration will contribute global knowledge that will benefit humanity for generations to come.

OceanX is an ocean exploration initiative founded by Ray Dalio and his son Mark Dalio, with a mission to explore the ocean and bring it back to the world. OceanX champions the audacious endeavor of ocean exploration, combining groundbreaking technologies and methods with bold partnerships with those who share our passion for uncovering the ocean's mysteries. Our goal is to cultivate a deep and personal human connection with the ocean and create a global community that is engaged with understanding, enjoying, and protecting our oceans.

Our innovative exploration capabilities include our 56-meter research vessel *Alucia* built to broaden our scientific understanding of the ocean. The ship houses two submersibles (the Triton 3300/3 and the Deep Rover 2), both rated for a max depth of 1,000 meters. *Alucia* also hosts on-site wet and dry labs, scuba equipment, a helicopter, and state-of-the-art media production equipment. For the last seven years, *Alucia* has been exploring the world, housing partners such as Woods Hole Oceanographic Institute, Scripps Institute of Oceanography, the Ocean Research and Conservation Association, the BBC and Sir David Attenborough, National Geographic, and many others.

Technological advances will help us reach new frontiers in exploration. We recently partnered with Woods Hole Oceanographic Institution and NASA's jet Propulsion Laboratory to prototype-test from *Alucia* a small, lightweight autonomous underwater vehicle (AUV) named *Orpheus* designed to withstand the crushing pressure in the hadal zone (6,000-11,000m). The technology *Orpheus* is equipped with can answer fundamental questions about the deepest parts of the ocean, and its design is intended to be replicated to explore outer space.

The discovery of new species is instrumental for development of medicines, materials, understanding of the unique abilities that allow creatures to survive under extreme conditions. Ocean exploration can also help us understand the rarity and diversity of certain areas, and can help managers and policy-makers determine sound marine resource stewardship. Recently, OceanX along with partners at Bloomberg Philanthropies, Woods Hole Oceanographic Institution, University of Connecticut, NASA Jet Propulsion Laboratory, and National Geographic conducted a mission to explore the Northeast Canyons and Seamounts National Marine Monument. The monument is largely unexplored, though is thought to be an incredibly diverse and ecologically sensitive ecosystem supporting deep sea corals, sponges, tuna, sea turtles, sharks, and whales. While using submersibles to dive in the canyons, scientists discovered two new species of deep-sea coral, and new insight into complex patterns of species diversity that defied expectations.

Our hope is that more meaningful partnerships such as this one will elevate what we can achieve toward exploring the oceans.

June 4, 2019

The Honorable Lizzie Fletcher
Chairwoman
Committee on Science, Space, and Technology
Subcommittee on Environment
Rayburn House Office Building
Washington DC 20515

The Honorable Roger Marshall
Ranking Member
Committee on Science, Space, and Technology
Subcommittee on Environment
Rayburn House Office Building
Washington DC 20515

Chairwoman Fletcher and Ranking Member Marshall:

This letter is submitted by Woods Hole Oceanographic Institution with a request for it to be submitted into the June 5, 2019, hearing record: "Ocean Exploration: Diving to New Depths and Discoveries."

A greater understanding and appreciation of our oceans is essential for the well-being of the world's population. For nearly a century, the Woods Hole Oceanographic Institution(WHOI) has pursued a strategy of supporting ocean science discoveries through the integrated design and application of new ocean exploration technology. These discoveries provide wide-ranging benefits, from enhanced maritime security to deep ocean discoveries; from data to support weather forecasting and a better understanding of our changing climate and oceans to aquaculture opportunities; and from oceanic earthquakes, volcanoes, and related natural hazards, to the possibility to discover life on other planets.

The investments being made today in the ocean exploration intellectual, structural, and technological enterprise, and the knowledge being gained as a result of this growing commitment, is strengthening U.S. economic and national security while also helping us understand the physical, biological, chemical, and geological processes hidden from sight under the waves, but which impact our daily lives and our nation's future. Thus, supporting increased access to the sea remains one of WHOI's highest priorities, recognizing that our country's investments in research vessels will be greatly enhanced by engineering and technological advances in instrument and sensor development, and in improving our observation and monitoring capabilities in support of economic, environmental, and national security priorities.

Below we highlight a few strategic ocean exploration and research programs in which WHOI is a leader or partner. It is accompanied by an attached document that describes additional federally supported programs, projects, activities, and infrastructure that are elements of the ocean exploration scientific and technology enterprise.

Cooperative Institute for Ocean Exploration
On May 6, 2019, NOAA announced that WHOI would join a new $94 million consortium led by the University of Rhode Island's Graduate School of Oceanography to support ocean exploration, responsible resource management, improved scientific understanding of the deep sea, and strengthen the nation's Blue Economy. The Cooperative Institute Ocean Exploration (CIOE), comprising five internationally renowned ocean science and technology institutions, will work closely with NOAA's Office of Ocean Exploration and Research (OER) for five years to survey an estimated 3 billion acres of U.S. ocean territory—nearly as much U.S. territory as exists on land.

CIOE's five members—University of Rhode Island, Ocean Exploration Trust, WHOI, University of New Hampshire, and University of Southern Mississippi—will combine their substantial exploration, scientific, technological, and engineering resources and expertise in discovering this largely unexplored "New America." This combined effort will form the front lines of NOAA's efforts to explore and characterize U.S. underwater territory –from the seabed to the surface—in order to support the national Blue Economy, which is expected to double in size and employ at least 40 million people by 2030.

The institute will enhance the capabilities of the NOAA Office Ocean Exploration and Research's two ships of exploration, NOAA's ship *Okeanos Explorer* and exploration vessel *Nautilus* (owned and operated by the Ocean Exploration Trust) to explore the seafloor as well as the mid-water or "Twilight Zone" where 95 percent of all living creatures are found. The Cooperative Institute will also explore the surface of the sea in collaboration with the National Geographic Society, which pioneered the development and use of increasingly sophisticated cameras and drones. https://oceanexplorer.noaa.gov/news/oer-updates/2019/cooperative-institute.html

Ocean Twilight Zone
With the support of the Audacious Project at TED, WHOI has embarked on a journey to explore one of our planet's hidden frontiers—the Ocean Twilight Zone, a vast, globe-spanning, and dimly lit region between about 200 and 1,000 meters (660-3300 feet) beneath the ocean's surface. Understanding of the Twilight Zone is currently limited by its enormous size and lack of easy access, but is driven by the knowledge that commercial fishing fleets are already developing the ability to harvest the region. WHOI's Audacious Project is a pioneering effort at providing a baseling characterization of this vitally important region of the open ocean.

The goal is to address critical gaps in knowledge of this vastly under-studied part of the ocean, including:

- The distribution of biomass and biodiversity within the twilight zone
- Food web linkages within the twilight zone and with other parts of the ocean
- The life histories and behaviors of twilight zone animals
- The role of the twilight zone and its inhabitants in the global carbon cycle

The project will create, expand, and leverage new technologies and novel data assimilation practices to explore the ocean twilight zone, to better understand its importance to other planetary processes, and to ensure sustainable commercial use for the benefit of humanity. A critical part of this effort is to bring science, technology, and society together to accelerate understanding of the twilight zone for use in science-based policies that take into consideration conservation, equitable use, and maintenance of ecosystem services. The aim is to achieve more than scientific discovery—it is to foster more informed ocean stewardship and sustainable human interactions with the ocean and our planet. https://twilightzone.whoi.edu/

Ocean Worlds

The quest for evidence of life on other planets is not new. From the time that humans first understood that Earth itself is but one planet among several orbiting a star that is itself one of many throughout the galaxy, people have gazed at the night sky and wondered what other forms of life might exist beyond our home. Since the 1960s, NASA's astrobiology program has been conducting a careful search for signs of extraterrestrial life. That search has become ever more expansive, venturing well beyond our solar system in an effort to hunt for planets that have astrophysical similarities to Earth in the so-called "Goldilocks Zone" around other stars in the galaxy that could support the presence of liquid water on or below the surface of a planet.

Two NASA missions inside our solar system in only the past 20 years suggested that extraterrestrial life might be present much closer to our home. The Galileo Mission arrived at Jupiter in 1995 and began circling the planet for eight years. The data it sent back provided strong evidence of liquid oceans on three of its moons: Europa, Titan, and Ganymede. More recently and most significantly, the 1997-2017 Cassini Mission to Saturn discovered water-rich gas plumes venting from the icy surface of Saturn's moon Enceladus. Analysis of those plumes suggests Enceladus may have seafloor hydrothermal vents similar to those on Earth that could be providing the necessary energy to sustain existing life.

Together, discoveries from these two missions signal that the search for life beyond Earth has reached a critical new phase. Planetary science and ocean science have begun to converge as it has become clear that multiple planetary bodies within our solar system host saltwater oceans in contact with a rocky, mineral-rich seafloor, just as Earth does. These systems support life on Earth, so why not elsewhere as well?

For both planetary and ocean scientists, these discoveries have reshaped ocean exploration here at home because they strongly suggest that finding life beyond Earth does not require futuristic, science-fiction technologies enabling interstellar space travel. Instead, our most direct path is to continue robotic exploration of the ocean worlds within our own solar system–locations that are not only well within our reach, but that also hold a liquid-ocean environment of a type that today's ocean scientists are already intimately familiar with and that engineers are already accustomed to exploring. This work is facilitating the development and testing of new robotic technologies and software using our planet's ocean as a testbed, allowing us better access to our own poorly explored frontier where new species and process are regularly identified. https://www.nasa.gov/specials/ocean-worlds/ https://oceanworlds.whoi.edu/

HADEX

The Ocean hadal region extends from 6,000 to 11,000 meters (20,000 to 36,000 feet) below the surface and covers a total area of the seafloor that combined may be larger than Australia. It covers the deepest, most remote, and most extreme ocean habitat on Earth. As a result, relatively little is known about what lives in the deepest ocean or how it connects to and interacts with the rest of the ocean and the planet.

Evidence suggests that life below 6,000 meters is surprisingly rich and diverse, despite the harsh conditions, and is fundamentally different from most other life on Earth. Additional exploration is necessary to better understand the strategies that have evolved to permit life to thrive under such conditions, the range of ecosystems existing there, how they function and interrelate, and the role that the hadal zone plays in such critical planetary systems as global carbon and nutrient cycling.

A deeper understanding of the hadal zone also sets the stage for exploration of oceans beyond Earth, on planetary bodies such as Jupiter's moon Europa and Saturn's moon Enceladus, which are known to harbor liquid water oceans beneath a thick crust of ice. Systematic exploration of Earth's hadal regions will not only reveal unique adaptations to extreme conditions that may be present on these ocean worlds, but will also broaden our understanding of the range of conditions capable of supporting life here and, by extension, beyond Earth.

WHOI's HADEX program is built on the successes of the previous HADES initiative and seeks to carry out comprehensive hadal research, exploration, and technology development in partnership with NASA's Jet Propulsion Laboratory. The construction of hadal autonomous vehicle in conjunction with Ocean Worlds initiatives will greatly accelerate discoveries in the hadal zone, fundamentally changing our understanding of life on Earth and elsewhere. https://hadex.whoi.edu/

Ocean Observatories Initiative

The NSF-funded Ocean Observatories Initiative (OOI) is an integrated infrastructure program composed of science-driven platforms and sensor systems measuring physical, chemical, geological, and biological properties and processes from the seafloor to the sea surface at select sites in the coastal, regional, and global ocean. Building on last century's era of ship-based expeditions, recent technological leaps have brought us to a new paradigm in our approach to ocean research—the delivery of a long term observational presence in the ocean.

The OOI network was designed to address critical science-driven questions that provide better understanding and management of our oceans by enhancing our capabilities to observe and address critical issues such as: ecosystem variability, ocean acidification, climate change, and carbon cycling, underwater volcanism, water-column processes, coastal upwelling, air-sea fluxes of heat, and moisture and momentum.

Since becoming operational in 2016, OOI has transformed research of the oceans by integrating multiple scales of distributed marine observations into a comprehensive observing system from key areas of the globe, that allows data to be freely downloaded over the internet in near-real time to scientists, educators, and the general population nationally and internationally. The OOI will continue to deliver data and data products for a 25-year-plus time period with an expandable architecture that meets emerging technical advances in ocean science.

As technological advances continue over the lifetime of the OOI, developments in sensors, computational speed, communication bandwidth, Internet resources, miniaturization, genomic analyses, high-definition imaging, robotics, and data assimilation, modeling, and visualization techniques will continue to open new possibilities for remote scientific inquiry and discovery.

The observatory is funded by the National Science Foundation and is managed and coordinated by the OOI Program Management Office (PMO) at WHOI. https://oceanobservatories.org/

National Deep Submergence Facility
More than half of our planet is covered by water that is at least two miles deep. The National Deep Submergence Facility (NDSF) maintains a world-leading set of underwater vehicles capable of carrying humans or a virtual human presence beneath those waters and down to the seafloor.

The NDSF is sponsored by the National Science Foundation, the Office of Naval Research, and the National Oceanic and Atmospheric Administration, and is hosted at WHOI. Its operation is overseen by the University-National Oceanographic Laboratory System (UNOLS), an organization of 58 academic institutions and national laboratories involved in marine research.

The NDSF operates, maintains, and coordinates the use of three vital deep ocean assets:

- The human-occupied vehicle (HOV) Alvin
- The remotely operated vehicle (ROV) Jason/Medea
- The autonomous underwater vehicle (AUV) Sentry

Whether diving 4,500 meters (14,764 feet) or remaining submerged for several days, these vehicles, working in conjunction with other undersea exploration technologies, offer unique tools to explore the mysteries beneath the ocean's surface. The commitment to advancing undersea technology development supports the work of multiple mission-driven agencies, in addition to simulating interest and excitement in students who are attracted to exploration of the unknown. https://ndsf.whoi.edu/

Conclusion

The expanding ocean exploration scientific enterprise is opening new doors of knowledge, providing us with insights into new drugs, access to food and nutrients, and better understanding of air/sea interactions that influence coastal ecosystem change, impact our daily weather, and drive climate processes. The engineering and technological advances required to address these targets is stimulating development of novel instruments, sensors, and platforms that can be used to support science, national security interests, extraterrestrial exploration, and in the most harsh and forboding regions on Earth and in our solar system. As the NASA Ocean Worlds program demonstrates, for example, it is also helping us investigate our planetary system and the search for life beyond Earth. Finally, this work is also improving our knowledge of the ocean battlespace environment during a period of renewed undersea international focus and competition.

The sheer size of the ocean, and its immense depth, requires continued support of partnerships to allow increased access to this difficult to reach realm that will significantly influence society's health and welfare. While we continue to purse exploration of the universe, we must not overlook the virtually unexplored frontier that covers over 70 percent of our own planet.

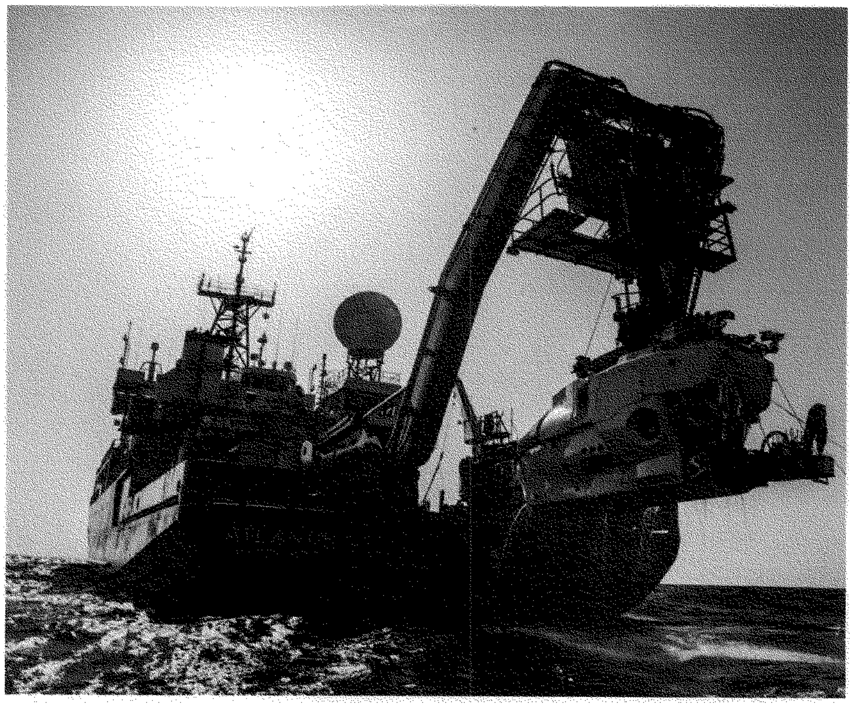
<u>Attachment:</u>
Woods Hole Oceanographic Institution: Understanding an Ocean Planet

Attachment

Understanding an Ocean Planet

The ocean is complex and deeply interconnected to the rest of the planet. As a result, ocean science is increasingly multidisciplinary and requires a constant willingness to test new ideas and new ways of thinking. The Woods Hole Oceanographic Institution (WHOI) is a private, nonprofit research and higher education facility dedicated to the study of all aspects of ocean science and engineering, to the education of future ocean researchers, and to disseminating knowledge to decision-makers and the general public. WHOI was established in 1930 and today, with the help of the National Science Foundation and other partners, it is the largest independent oceanographic research institution in the U.S. During a time of rapid, unprecedented change WHOI scientists, engineers, students, and technicians and are motivated by the opportunity to make a difference by expanding the frontiers of knowledge about the planet and the intersection between humans and the ocean.

Ship Support



Since its founding in 1930, WHOI has supported scientific access to the sea. It currently operates two large research vessels for the oceanographic community: the Global Class R/V *Atlantis*, which is specially outfitted to serve as the support ship for the human-occupied vehicle *Alvin*, and the Ocean Class R/V *Neil Armstrong*, which recently replaced R/V *Knorr* as the primary U.S. research vessel in the North Atlantic. Both ships are owned by the U.S. Navy and operated by WHOI on behalf of the entire oceanographic community as part of the NSF-coordinated UNOLS fleet. In addition to carrying *Alvin*, *Atlantis* also serves as a general oceanographic research vessel capable of enabling advanced scientific expeditions worldwide. It also recently helped locate the voyage data recorder from the cargo ship *El Faro* and assisted with the search for the missing Argentine submarine ARA *San Juan*. *Neil Armstrong* began full operation in 2016 and has since taken up regular servicing of the Irminger Sea and Pioneer Arrays of the Ocean Observatories Initiative, as well as numerous research cruises that require a sophisticated seagoing research platform.

National Facilities

National Deep Submergence Facility (NDSF)

WHOI has operated underwater vehicles for the U.S. oceanographic community since 1964. The fleet of NDSF vehicles includes the human-occupied vehicle *Alvin*, the remotely operated vehicle *Jason*, and the autonomous underwater vehicle *Sentry*. Continual advances in technology and repeated upgrades to the growing and evolving deep-submergence fleet have kept the facility at the forefront of deep-ocean exploration. The expertise developed to support specialized research programs has also demonstrated practical application, as the facility's response to the Deepwater Horizon oil spill in 2010 highlighted. Ongoing developments in vehicle endurance and autonomy, multivehicle operations, and increasing depth capabilities such as the *Alvin* 6,500 meter conversion are designed to meet the increasingly sophisticated scientific objectives of deep-sea researchers and to ensure the facility can offer world-class service to a strong and growing user base for years to come.

National Ocean Science Accelerator Mass Spectrometer (NOSAMS)

The NOSAMS facility was founded in 1991 to measure radiocarbon (cosmogenic 14C) in seawater to trace global ocean circulation. Since then, it has expanded to provide high-resolution dating of a wide variety of earth and ocean science samples for individual researchers, as well as global programs such as WOCE, CLIVAR, and GEOTRACES. Today, the facility makes more than 7,000 measurements per year and is currently focusing on improving precision, automation, and efficiency; processing smaller samples; and directly measuring 14C in carbon dioxide gas.

Northeast National Ion Microprobe Facility (NENIMF)

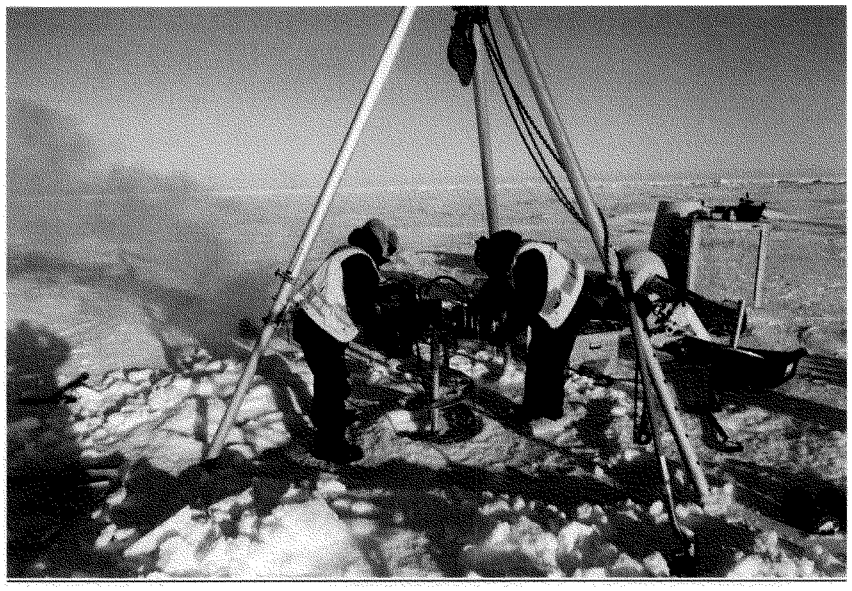
NENIMF was founded in 1996 and specializes in analyzing trace element abundances and isotopic composition of a wide range of geologic and biogenic samples. Its staff has particular expertise in determining magmatic volatiles in silicate glasses and the analysis of biogenic carbonates as recorders of climate and ecosystem change over decadal to orbital timescales. The emphasis on these areas makes NENIMF a unique interdisciplinary resource to the geoscience community with minimal overlap with other ion microprobe facilities.

Changing Arctic

Arctic Inflows

Waters flowing into the Arctic Ocean are fundamental drivers of change across the basin. Clarifying the source, fate, and evolution of these intrusions is critical to understanding the nature and magnitude of the physical, chemical, and biological shifts occurring at an increasing pace throughout the Arctic. Moorings in the Atlantic and Pacific, some in place for much of the past 15 years, monitor intrusions to the Arctic through the Fram Strait and Bering Strait. High-resolution shipboard sampling during cruises to service the moorings adds to the detailed view being formed of how these inflows change over annual and interannual periods.

Ice-Tethered Profilers



The Ice-Tethered Profiler (ITP) was developed to sample the ice-covered Arctic Ocean at high vertical and temporal resolution and over extended time periods and to return data in real-time to researchers around the globe. WHOI maintains the ITP program with North American, European and Asian colleagues, sustaining an array of ITPs and other similar instruments throughout the ice-covered Arctic. Since its inception in 2004, the program has returned more than 80,000 temperature and salinity profiles from the Arctic.

Chukchi-Beaufort System

The interconnected physics and biology of the Arctic Ocean ecosystem may respond dramatically to ongoing and future environmental changes. A better understanding of these complex dynamics and their year-to-year variability is needed to predict how climate change will affect the Arctic ecosystem, including Arctic coastal communities that rely on the marine ecosystem for subsistence. Because Utqiaġvik, Alaska—the largest community on the North Slope—lies at the junction of several ocean regions and downstream of the Pacific-Arctic gateway, the ecosystem of the coastal region nearby may be particularly vulnerable.

Greenland Ice Loss

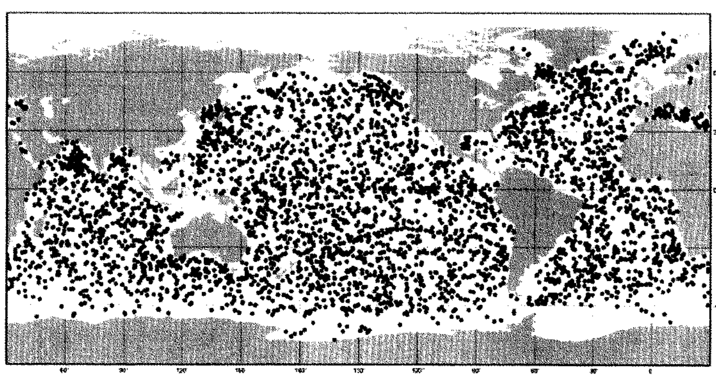
Improved predictions of future ice loss from Greenland are needed to address questions of global concern, including sea-level rise and other changes driven by increasing freshening of the

North Atlantic. However, useful predictions are hampered by limited temporal and spatial observations, as well as a poor understanding of how climate change affects many glacial processes. Observations ranging from the ice sheet surface (including ice cores and geodetic data) to the ice-ocean boundary (including physical and chemical data collected from moorings, helicopter-deployed instruments, and autonomous underwater vehicles) provide the context and constraints needed to improve models of ice loss.

Persistent Observations

Northeast U.S. Shelf Long-term Ecological Research Site (LTER)
The Atlantic Ocean off the Northeast U.S. coast is a complex, highly productive part of the ocean that supports active fisheries and directly affects millions of people. As in other coastal waters, human activities, short-term environmental variability and long-term trends all affect the region's complex food web and may threaten the region's economic viability. The Northeast U.S. shelf (NES) LTER focal site, established in 2017 by NSF, spans the continental shelf, connecting the Martha's Vineyard Coastal Observatory (MVCO) on the inner shelf with the Ocean Observatories Initiative (OOI) Pioneer Array on the outer shelf. Collaborations with scientists at other institutions and federal agencies will extend the studied area over the continental shelf from North Carolina to Maine.

Argo



Argo 3878 Operational Floats December 2017

The NOAA supported global Argo network consists of more than 3,000 autonomous profiling floats deployed by a dozen teams worldwide since 2000. During a typical, four-year mission, each float records and transmits temperature and salinity data across the upper 2,000 meters of the ocean every 10 days. The floats have provided unprecedented access to the global ocean, including the under sampled Southern Hemisphere. Data from the program has supported peer-reviewed publications at a rate of a paper a day and permitted the first calculations of the average global temperature anomaly of the surface ocean.

Ocean Observatories Initiative (OOI)

In 2007, the National Science Foundation launched a $386 million scientific infrastructure program to establish a long-term presence in the ocean: the Ocean Observatories Initiative (OOI). It is the NSF's largest investment in ocean science, consisting of a collection of moored platforms and free-swimming autonomous underwater vehicles positioned in scientifically strategic locations around the world and carrying sensors that collect physical, chemical, geophysical, and biological data from the air-sea interface to the seafloor thousands of feet beneath the surface and over broad spatial and temporal scales. Together, they comprise a vast, oceanographic "telescope" aimed at observing the planet's largest ecosystem and a key driver of weather and climate that helps make our planet habitable.

In 2016, OOI reached a milestone when its network of moorings and vehicles became fully operational. WHOI currently maintains the OOI Coastal and Global Scale Nodes (CGSN), consisting of the Coastal Pioneer Array off the U.S. Northeast coast and two Global Arrays—one each in the Northeast Pacific and North Atlantic. Each array, which WHOI engineers designed and built, operates around the clock, 365 days a year and relays data directly to shore in near real-time. All OOI data is freely available online, giving scientists, policymakers, and the general public an unprecedented, multidimensional look at the inner workings of the ocean.

New Ways of Understanding the Ocean

Ocean Carbon and Biogeochemistry (OCB)

The OCB Program headquartered at WHOI was established in 2006 as one of the major activities of the U.S. Carbon Cycle Science Program. OCB is a coordinating body for the ocean carbon research community and supports a worldwide network of scientists working across disciplines to understand the ocean's role in the global carbon cycle and the response of marine ecosystems and biogeochemical cycles to environmental change.

Lipidomics

Lipids—fat-like biological molecules—can account for as much as 40 percent of organic carbon in the upper ocean. Oceanographers have used lipids for decades to identify microbes in the ocean but have only recently begun to see them as indicators of how microbes adapt to their environment. Expanding the use of lipidomic techniques in oceanography will provide new insights on how microbes respond to environmental change and on how these responses might reflect or impact marine biogeochemical cycles.

Ocean Protein Portal

Proteins are one of the most diverse biomolecules on Earth and they have become a powerful tool to study ecosystem health. However, proteomic datasets are complex and not easily accessed by the oceanographic community. A proposed new Ocean Protein Portal will enable nonexpert users to access these datasets to assess marine environmental function and health and to contribute to the interpretation of global datasets such as GEOTRACES.

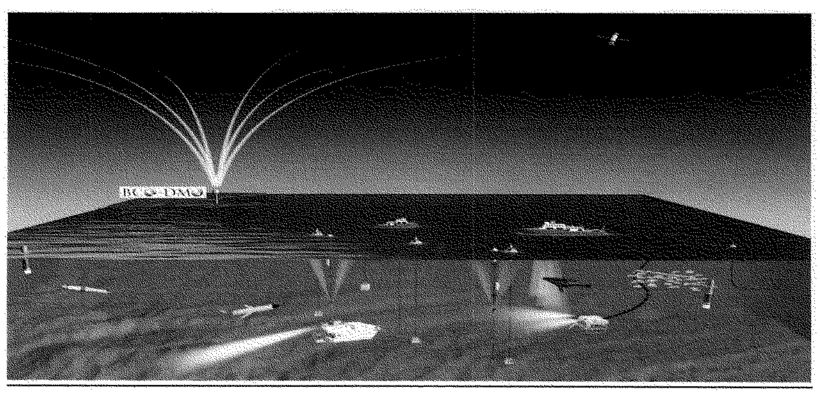
Marine Microbiomes
The ocean contains distinct communities of microbes that inhabit different ecosystems, from individual animals to the open ocean, many of which are critically important to animal and ocean health. Diagnostic techniques developed in health sciences are permitting ocean scientists to address questions that focus on the function of microbial species and how communities change under stress, such as a warming ocean, a bleached reef, or a malnourished whale.

Research Support (NSF funded)

Shipboard Scientific Services Group
Ocean science is deeply reliant on complex, long-duration research expeditions. WHOI Shipboard Scientific Services Group (SSSG) provides technical, scientific, and operational services to all users of ships operated by the Institution. The group consists of seagoing marine technicians and shore-based technical support personnel, who maintain, repair, and assist in cruise planning and the operation of specialized and general-use research equipment. The group also oversees the East Coast Winch Pool and Gravimeter Pool to enable a wide range of sophisticated seagoing research.

Ocean Bottom Seismograph Lab
The Ocean Bottom Seismograph (OBS) Lab was formed in 1975 to develop seafloor instruments that enable imaging the structure of Earth's crust beneath the seafloor and recording earthquakes at tectonic plate boundaries. Since then, the lab has deployed and recovered more than 1,700 ocean bottom seismographs across the globe and played a central role in advancing available technology from a few simple, hydrophone-only instruments to a current fleet of 90 OBSs, including 15-month-capable, combined broadband and strong-motion instruments.

Biological and Chemical Oceanography Data Management Office (BCO-DMO)



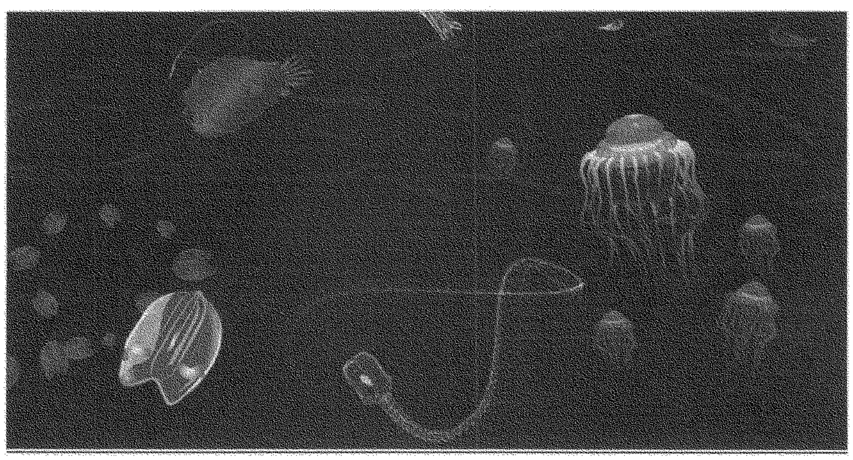
BCO-DMO supports the data management needs of researchers and is funded by the Biological and Chemical Oceanography Programs and the Office of Polar Programs Antarctic Organisms & Ecosystems Program. Its staff works closely with investigators and data contributors to prepare data management plans, consult on data collection, create detailed metadata records necessary for data interpretation and reuse, publicly serve data and metadata, and ensure proper citation and submission to national data centers for archiving. BCO-DMO holdings currently comprise over 9,000 data sets collected from more than 400 instruments and across more than 1,400 parameters—all of which are freely available on the BCO-DMO website.

Seafloor Samples Laboratory

The Seafloor Samples Laboratory contains more than 14,000 marine geological samples, including sediment cores, rock dredges, surface grabs, and samples collected by HOV *Alvin* and ROV *Jason*, all of which are archived, catalogued, and accessible to the scientific community. Current efforts in the lab are focused on improving data management and user retrieval of data, as well as enhancing the lab's imaging capability with a new X-ray fluorescence core scanner and a proposed new CT scanner capable of 3-dimensional reconstructions of sediment and coral cores.

New Technology

Exploring the Midwater



Two new underwater vehicles are being designed to improve access to the vast and under-studied midwater, or mesopelagic. This region from 200 to 1,000 meters depth is where critical parts of Earth's physical, chemical, and biological cycles occur. The autonomous *Mesobot* will follow animals as they trace their daily vertical migrations, follow sinking particles, and collect biogeochemical samples, including environmental DNA. WHOI engineers have also developed a towed platform call *Deep-See*, which carries broadband acoustics, a large-area stereo camera, and a high-resolution holographic camera to detect and image a wide range of different-sized organisms inhabiting the midwater.

Clio
The first underwater vehicle designed specifically to collect both biological and chemical samples from the ocean water column successfully completed sea trials in 2017. The autonomous underwater vehicle *Clio* will support research to better understand the inner workings of the ocean. The vertical-diving *Clio* propels itself to the seafloor and then rises to the surface, filtering water and collecting samples along the way. Shipboard and land-based researchers can use the samples to measure the genetic and functional diversity of marine microorganisms, as well as nutrients that control their diversity on a regional or basinwide scale.

Co-Multi-Robotic Exploration
Direct human exploration of the deep ocean is expensive, dangerous, and hampered by electromagnetic absorption of seawater, leaving the vast majority of the oceans unexplored. New distributed, unsupervised, scene-understanding techniques that can potentially operate under low bandwidth will enable multiple underwater robots and humans to collaboratively explore and map complex ocean environments. Principles learned from developing new control-and-communications techniques will be applicable to deployment of human-robot teams in other harsh environments with similar challenges, such as what might be expected in the aftermath of natural disasters.

Science & Society

Coastlines and Economic Resilience
Coastlines are influenced by a complex set of physical processes further complicated by human responses that are the result of interlocking priorities and decisions. A new set of integrated models aims to better understand the complexities that play out under different geologic processes, climatological variables, development scenarios, legal and regulatory frameworks, and strategies for coastal protection or response. These models should help project how developed coastlines and coastal communities will respond to a range of threats that are the result of changing climate conditions.

Woods Hole Center for Oceans and Human Health (WHCOHH)
WHCOHH was established with joint grants from the NSF and NIH to support an interdisciplinary approach to understanding the multifaceted connections between the ocean

and human health. Scientists from oceanographic, biological, and technical disciplines work together to address these connections. Current Center research questions address fundamental controls on harmful algal blooms (HABs)—"red tide" organisms that pose economic and human health threats—as well as bloom-forecast models that include climatic influences and the neuro-developmental consequences of low-level exposure to algal toxins.

The Search for *El Faro*

Assets of the National Deep Submergence Facility, including the highly experienced teams that manage, maintain, and deploy *Alvin* and *Sentry*, were called upon to assist the National Transportation Safety Board in their investigation of the loss of the cargo ship *El Faro*, which sank in 2015 during Hurricane Joaquin. In relatively short order, the teams surveyed the wreck site and located the ship's voyage data recorder for later recovery, not only bringing closure to the families of those lost, but also helping improve safety for mariners in the future.

Ensuring the Future of Ocean Science

DunkWorks

Innovation today is being driven by more flexible and more accessible methods of manufacturing and testing. These technologies are reducing the cost of failure and increasing the pace of development in many business areas. With support from the Commonwealth of Massachusetts, the WHOI Center for Marine Robotics recently opened DunkWorks, a rapid prototyping and additive manufacturing facility, to help the state's active marine technology sector quickly take designs from concept to application.

Shore-based Infrastructure
Transformative ocean science requires integrated research facilities ashore that can be flexibly configured to meet the needs of large-and small-scale investigations simultaneously. WHOI recently initiated a feasibility study for the redevelopment of its 50-year-old waterfront infrastructure to support the oceanographic community in partnership with NSF, NOAA, the U.S. Navy, and the Commonwealth of Massachusetts. The proposed new waterfront research complex will include a new dock, shore-based and in-water testing facilities, laboratories, work spaces, public access and outreach, and an operations center. It will be designed to adapt to rapidly evolving scientific and technological opportunities, a changing climate, and the growing awareness that the ocean plays a critical role U.S. economic and national security interests.

Expanding Partnerships
Today's research environment requires a wide range and a diverse mix of partnerships to advance the goals of a complex ocean science and engineering portfolio. Fortunately, the Institution's status as a leading non-profit with a long record of success has given it the ability to form partnerships with more than 50 research organizations, as well as with private foundations, NGOs, philanthropists, and public-private entities around the world. These enable WHOI scientists and engineers to take on high-risk projects with the potential to open new avenues of research that, as they mature, fall more directly within the mission of traditional funding agencies. Private partnerships also help develop new technologies that hold the potential to directly benefit the U.S. economy, international competitiveness and national security.

Oceanography 2.0
From its earliest days, the field of ocean science has been driven primarily by incremental advances in technology. But that model is increasingly outmoded, largely as a result of increasing costs and shifting national priorities in the face of ever-tighter budget constraints and the limitations imposed by the tenure system. With support from the Moore Foundation, WHOI is formulating a new vision for ocean science and exploration, one that takes its cues from the small, agile startup businesses and creative "maker spaces" that have sought to disrupt and reimagine conventional wisdom. With this, we envision a research community that is able to adopt new ideas quickly and is focused on big ideas with the potential to transform knowledge about the planet and substantially impact society.

Our Mission
The Woods Hole Oceanographic Institution is dedicated to research and education to advance understanding of the ocean and its interaction with the Earth system, and to communicating this understanding for the benefit of society.