ONR S&T Activities and Opportunities to Support Navy Climate Action 2030

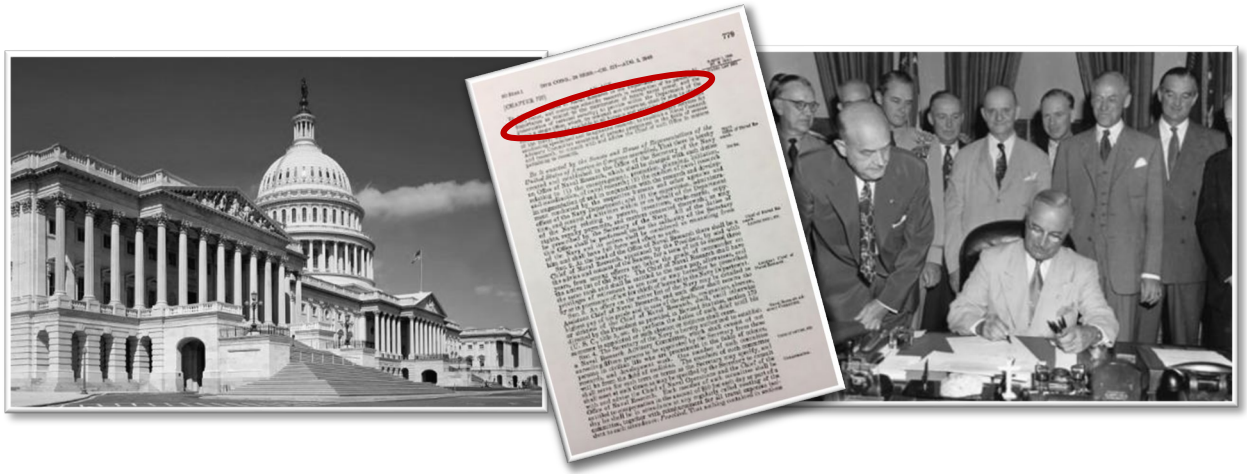
Mark S. Spector, Ph.D.

3 August 2022

Office of Naval Research

Established in 1946 by Public Law 588

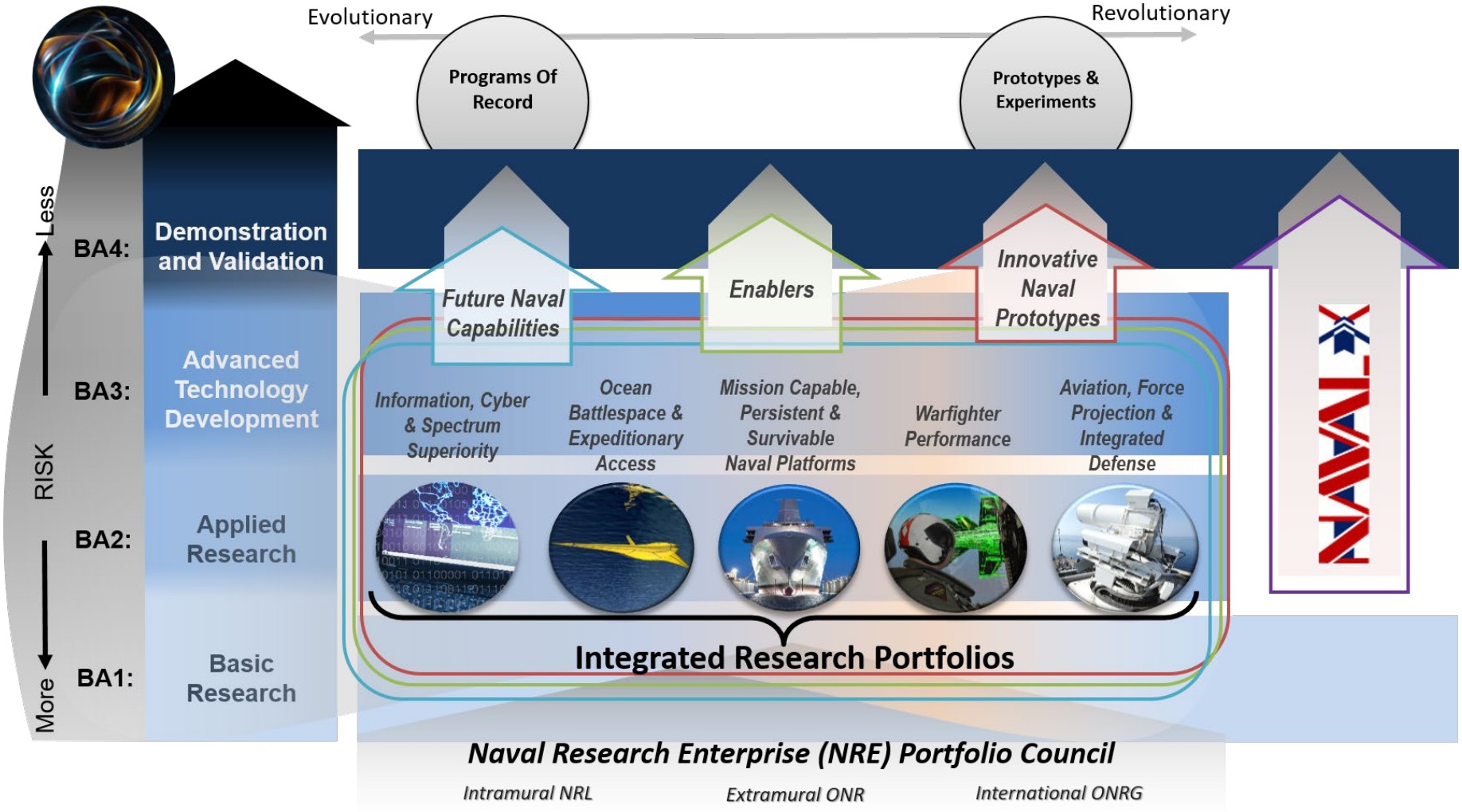
- ***Congress recognizes the value of scientific research.***



"…plan, foster and encourage scientific research in recognition of its paramount importance as related to the maintenance of future naval power, and the preservation of national security…"

- ***Win the current war*** **(direct transition of S&T, FNCs, and workforce)**
- ***Win the future war*** **(scientific research, INPs, and future workforce)**
- ***Full-spectrum warfare*** **(set the pace-lead, extract a cost, change the calculus)**

ONR Portfolio – Departments

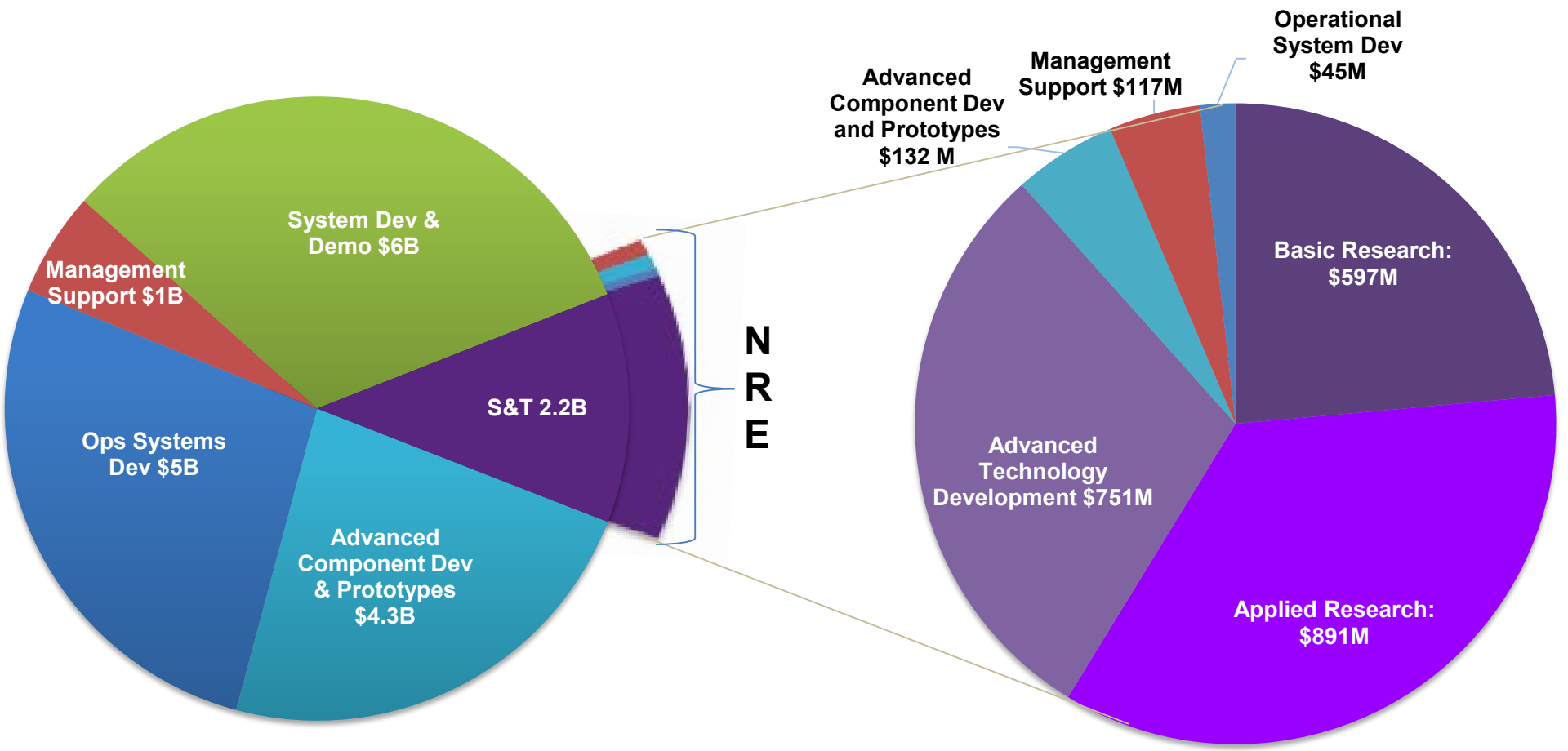


The Portfolio Investment

Relative to FY19 Navy Budget ($194.1B)

FY 19 DoN R&D $18.65B

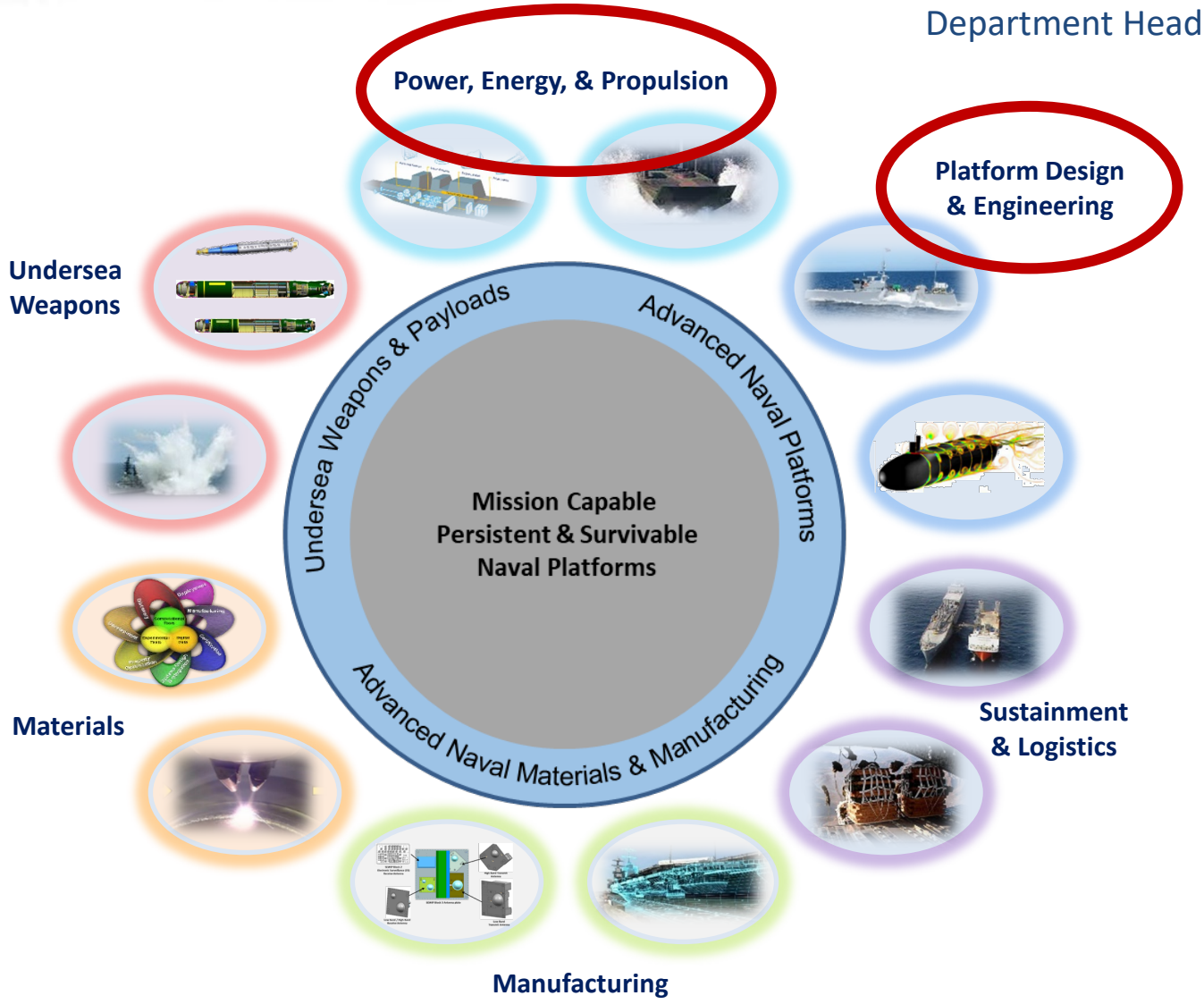
Naval Research Enterprise $2.5B of FY19 R&D Budget



Naval Platforms (Code 33)

Mission Capable, Persistent, and Survivable

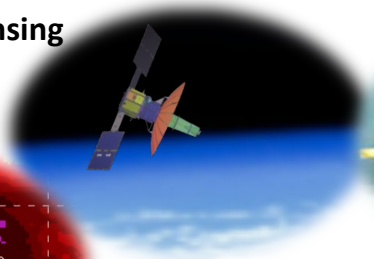
Department Head: Thomas Fu



Ocean Battlespace Sensing and Expeditionary Access Department (Code 32)

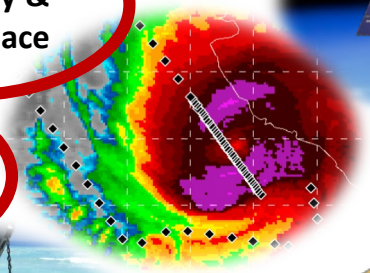
Department Head: Thomas Drake

Remote Sensing

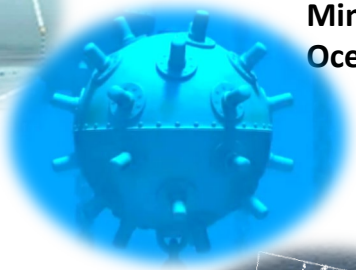


Anti-Submarine Warfare

Marine Meteorology & Space

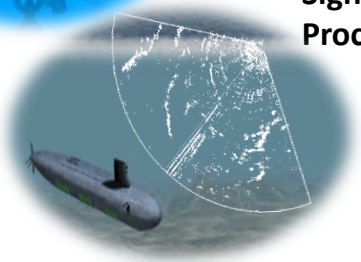


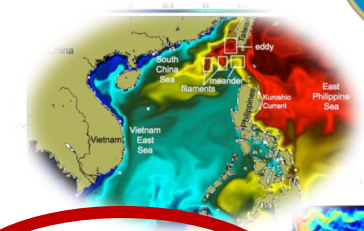
Mine Warfare & Ocean Engineering

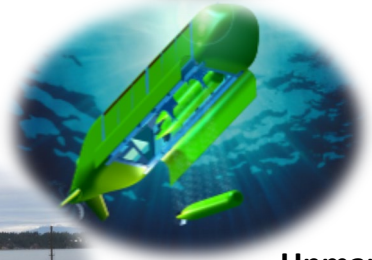


Littoral Geosciences

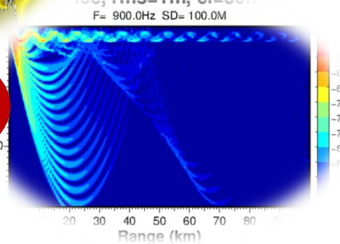
Undersea Signal Processing







Physical Oceanography



Ocean Acoustics (NNR)

Marine Mammals & Biology

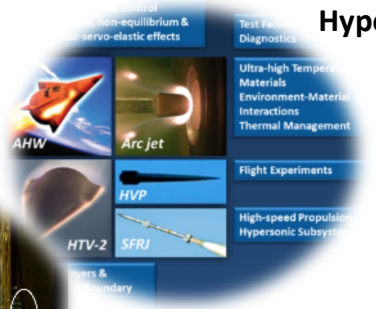
Research Facilities

Unmanned Systems Technology & Autonomy

Aviation, Force Projection and Integrated Defense (Code 35)

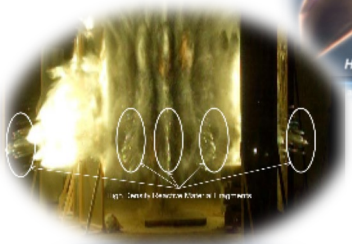
Department Head: Doug Blake

Air Weapons & Hypersonics



Kinetic Weapons

Advanced Energetic Materials



Directed Energy

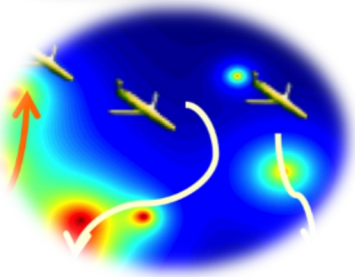
Railgun

Aviation, Force Projection & Integrated Defense (CODE 35)

High Power Microwave

Laser Weapons

Autonomy



Naval Air Platforms

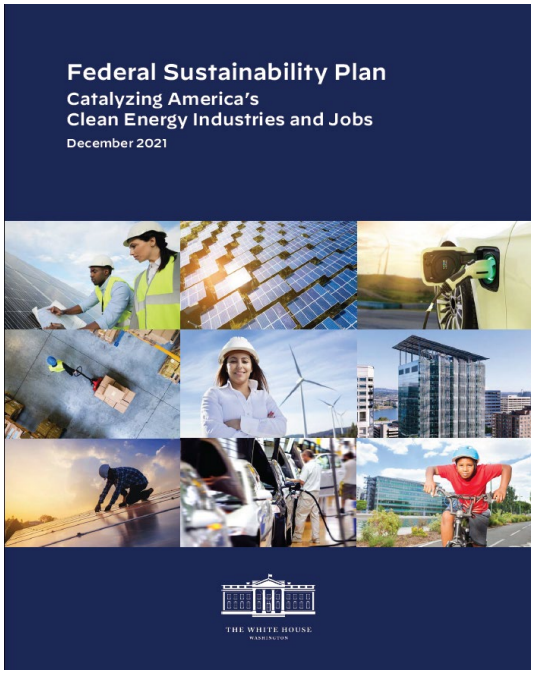
Aerodynamics / Flight Dynamics & Control
Structures & Materials
Power, Propulsion, & Thermal Management

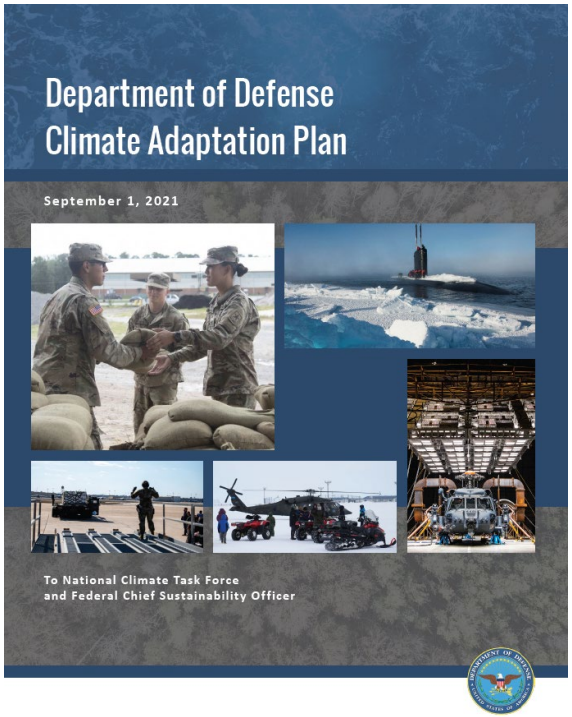
Climate Change S&T is informed by...

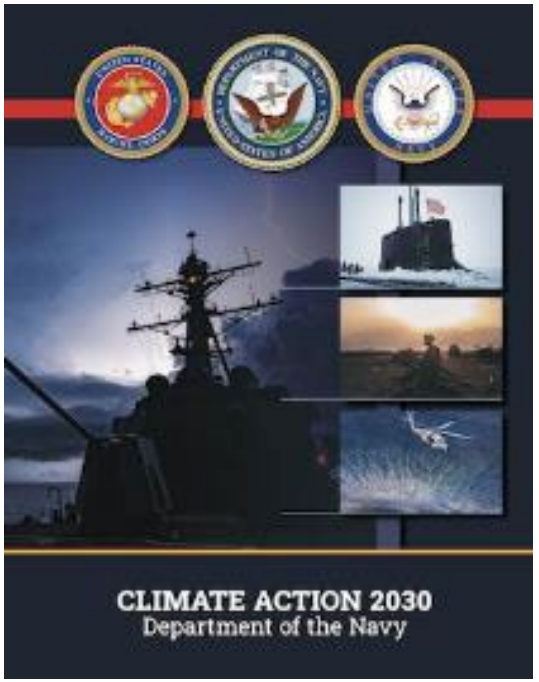
1. Executive Order 14057 (8 Dec 2021) which sets government goals to reduce emissions and catalyze clean energy with the accompanying Federal Sustainability Plan

2. DoD Climate Adaptation Plan (1 Sep 2021) which establishes 5 LOE to ensure that the US military forces retain operational advantage under all conditions

3. DON Climate Action plan (24 May 2022) which mirrors the DoD 5 LOEs to build a Climate Culture, build a resilient force, and reduce climate threat







CLIMATE ACTION 2030

Department of the Navy

Climate-Ready Force

To remain the world's dominant maritime force, the Department of the Navy must adapt to climate change. ***A force that is resilient to climate impacts is more capable, agile and lethal.*** We will enhance our operational capability, resilience, and reduce our climate impacts by aligning our climate actions to ***strengthen maritime dominance, empower our people, and strengthen strategic partnerships.***

Performance Goals

Build Climate Resilience

Ensure that our forces, systems, and facilities can continue to operate effectively and achieve the mission in the face of changing climate conditions, and worsening climate impacts.

Reduce Climate Threat

We must reduce our greenhouse gas emissions and draw greenhouse gases out of the atmosphere, stabilize ecosystems, and achieve, as an enterprise, the nation's commitment to net-zero emissions by 2050.

Ambitious Targets

To achieve net-zero emissions economy-wide by 2050, the Navy and Marine Corps commit to:

- 65% reduction in greenhouse gas emissions department-wide by 2030
- 100% carbon pollution-free electricity by 2030
- 100% zero-emission light-duty vehicle acquisitions by 2027
- 50% reduction in emissions from buildings by 2032
- 50% annual diversion of non-hazardous solid waste from landfills by 2025
- 1 million cars' worth of CO2e drawn down by 2027 through nature-based solutions

Lines of Effort

Our strategy is organized around five lines of effort that are consistent with those laid out in the Department of Defense's (DoD) Climate Adaptation Plan.

1. Climate-informed decision making
2. Train and equip for climate resilience
3. Resilient built and natural infrastructure
4. Supply chain resilience and innovation
5. Enhanced mitigation and adaptation through collaboration

Focus on Resilience

Nature-Based Resilience: Mitigate shoreline erosion, protect mission-critical assets, and improve natural assets that are key to achieving resilient infrastructure and operations.

Energy Resilience: Install cyber-secure microgrids or comparable resilience technology that leverage carbon free power generation and long-duration battery storage.

Climate Change: Three Pillars

- **Mitigation:** Measures to reduce the amount and speed of future climate change by reducing emissions of greenhouse gases or removing carbon dioxide from the atmosphere.
- **Resilience:** The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.
- **Adaptation:** Adjustment in response to a changing environment in order to reduces negative effects.

-DODD 4715.21, Climate Change Adaptation and Resilience.

DON Strategy Lines of Effort:

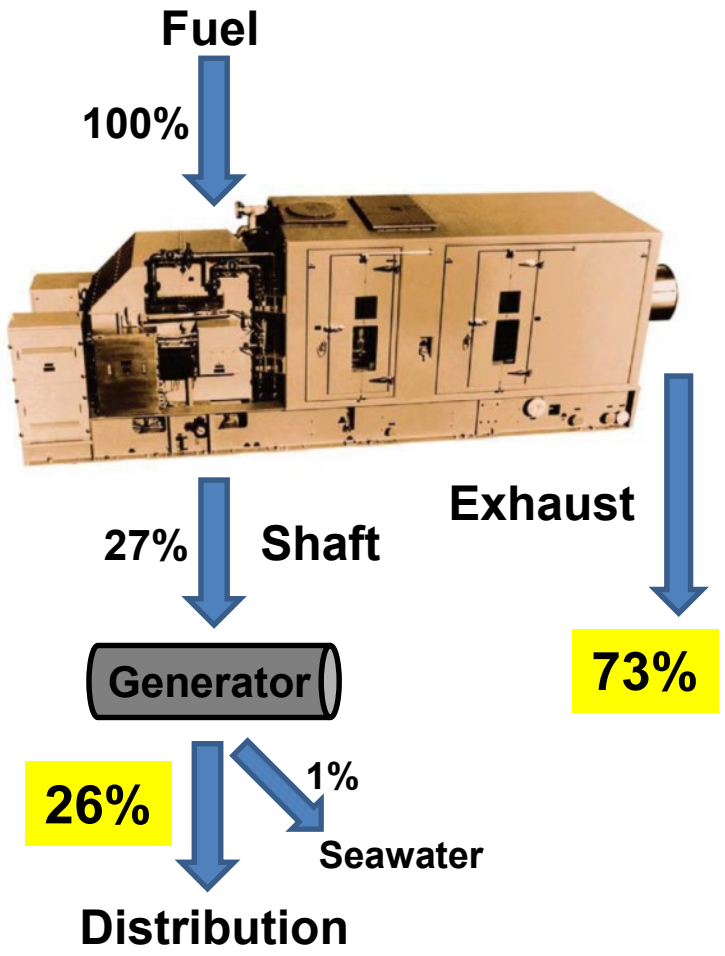
LOE1. Climate Informed Decision Making
LOE2. Train & Equip for Climate Resilience
LOE3. Resilient Built and Natural Infrastructure
LOE4. Supply Chain Resilience and Innovation
LOE5. Enhanced Mitigation and Adaptation Through Collaboration

Mitigation S&T

- Energy Efficiency
  - Gas Turbine Efficiency
  - Energy Recovery
  - Hybrid Systems
- Low Carbon Technologies
  - Renewable Power Generation
  - Alternative Fuels
  - Carbon Capture
- Low GWP Refrigerants

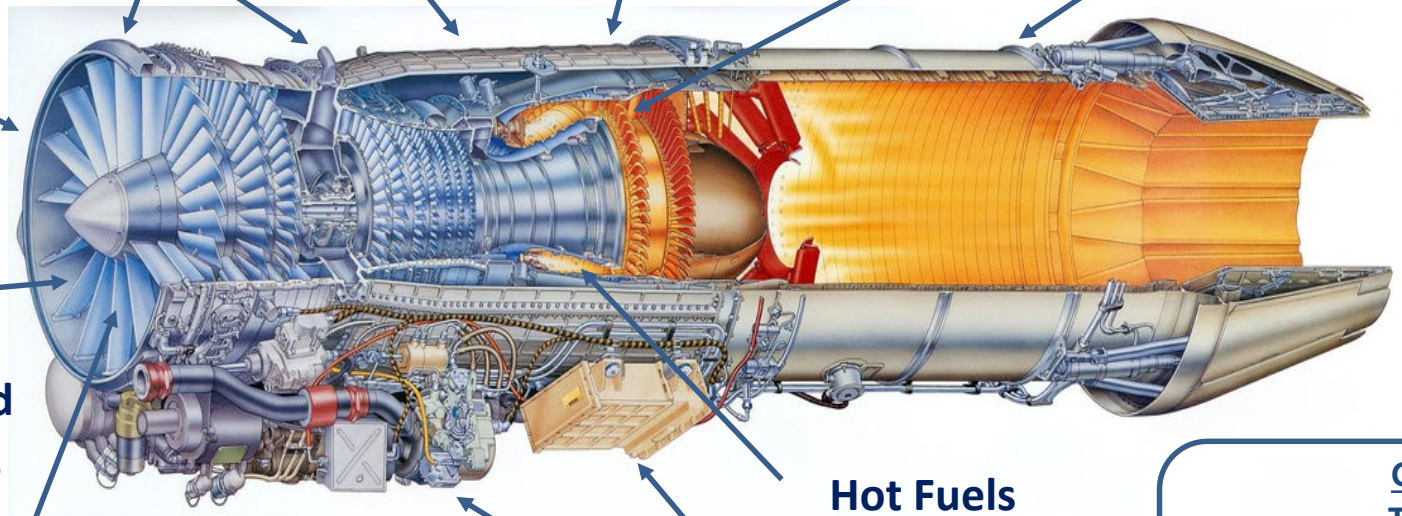
Gas Turbine Efficiency

- Two-thirds of the energy from DoN's fuel is exhausted.
  - By far the largest carbon emission
- Not all 'waste' heat
  - Thermodynamics dictates maximum engine efficiency
- Pathways to improve efficiency
  - Higher temperature operation
  - Combined cycles to increase efficiency
    - Commonly used in commercial power plants to achieve efficiencies up to 65%
    - Come with serious size, weight and integration challenges.



Next Generation Propulsion Enablers

Program Officer: Steven Martens



Goals:
- Thrust ↑
- SFC ↓
- Thermal Capacity ↑
- Weight ↓

Aviation Gas Turbine Programs focused on Reduced Fuel Burn and Weight Reduction

LOE2

Navy Gas Turbine Next Generation Materials Development

Program Officer: Dave Shifler

Problem: Future Shipboard power plant configurations, increased surface combatant loads and operational changes will force the increase of gas turbine operating temperatures that will reduce engine life.

Solution: Provide Navy Gas Turbines with new generation turbine alloys and coatings.

- Enables higher engine load from weapons/sensors
- Enables higher engine temperatures from greater fuel efficient engines and shipboard plant configuration (Hybrid Electric Drive, etc)
- Enables new shipboard plant configuration: Higher power plants with less engines installed

New Turbine Blades & Vanes 20K+ Hours Life Capable

Turbine Vane with Hot Corrosion/ Oxidation: 4300 Hrs

Shipboard Gas Turbine FNC (SW FY19-03)

- New Turbine Single Crystal Alloy w Coatings for Navy Rolls Royce Gas Turbines
- DDG-51 Flt I, II, III, LCS, DDG1000, SSC Platform Applicable
- Demonstration Will Be Completed FY22

Energy Recovery: USN History

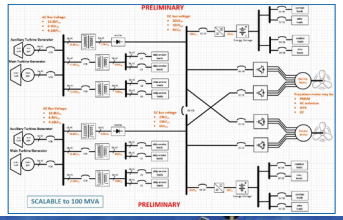
- US Navy has invested over $100M in waste heat recovery developments for shipboard gas turbines from 1960 to the present. The three major programs were:
  - 600 HP Orenda gas turbine for minesweepers (two recuperators per engine)
  - Steam waste heat recovery for DDG-51 (RACER boiler and turbine using LM2500 exhaust heat)
  - 26,250 HP Rolls Royce ICR gas turbine (intercooler and recuperator to recover heat from gas turbine exhaust)
- Each development program was successful in saving large amounts of fuel, but did not finish development or satisfy requirements for the following reasons.
  - Difficult to troubleshoot, maintain and repair
  - Did not meet reliability expectations
    - Thermal fatigue and expansion deformation

The energy recovery heat exchanger presents the greatest technical challenge

Naval Power Systems S&T

Competency Lead: H. Scott Coombe

- Primary goal: Increase the effective use, conversion, storage, distribution, and control of energy to enable integration of future weapons and sensors onto platforms and extend operational reach.
  - *Energy efficiency is a byproduct*
- Major Programs:
  - Power Electronics and Electromagnetics
  - Electrochemical Materials
  - Functional Polymeric and Organic Materials
  - Electric Power Components and Control
  - Power Generation and Energy Storage
  - Thermal Science and Engineering
  - Energy Resiliency
  - Efficient Electromechanical Machinery
  - Materials for Carbon Neutral Energy and Resources
  - Expeditionary Power & Energy
  - Advanced Power Systems for Undersea Applications



Power Electronics & Electromagnetism

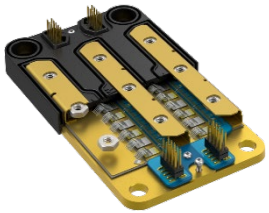
Program Officer: Lynn Petersen

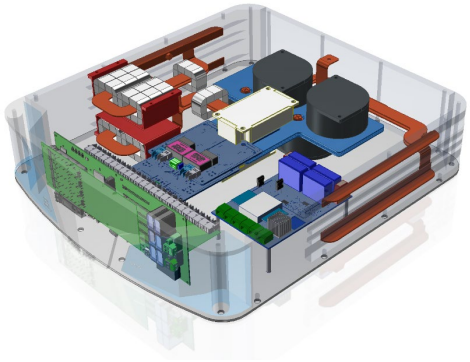
Research Concentration Areas

- Navy and U.S. Marine Corps (USMC) require power systems that meet agility, efficiency, scalability, controllability and security requirements
- Reliability and availability of pulsed and continuous duty, high power and energy, Navy and USMC weapon systems

Research Challenges and Opportunities

- Power electronics devices and electromagnetism: Advanced electromagnetics technologies, computational methods, wide-band-gap materials and devices, theoretical methods for predicting aging of dielectric materials, failure modes…
- Adaptive controls: Provide a leap ahead capability for DoD platforms that utilize distributed machinery systems (resources to loads) by implementing advanced resilient control architectures that operate from a 'systems of systems' perspective, minimizing "human in the loop" reliance
- Machinery controls: New control concepts needed to coordinate all the system elements to provide the high-power to pulse loads while maintaining power quality to all loads and system stability…
- Advanced Power Systems: Developing highly integrated Power Electronic Building Block (PEBB) based converters





Electrochemical Materials

Program Officer: Michele Anderson

Safe energy and power dense generation and storage is crucial to providing operational endurance to warfighters, systems and platforms. The Office of Naval Research Electrochemical Materials Program is focused on developing a fundamental understanding of charge (electron and ion) storage, transport and transfer mechanisms, and applying that knowledge to inform the development of materials, materials architectures and devices that address Navy and Marine Corps application power and energy needs.

Research Concentration Areas

- Enhanced safety and capability batteries and fuel cells are required to improve reliability, efficiency, and resiliency in stand-alone and hybrid systems configurations
- ONR requires Integrated Computational Materials Engineering (ICME) methods that enable physics-based multi-scale modeling of coupled reaction mechanisms that span atomistic to cell and system design levels to accelerate the incorporation of new materials and new materials approaches into devices and systems
- ONR requires new experimental tools that enable in operando and in situ quantitative interrogation of complex electrochemical systems to provide new knowledge about reaction mechanisms and the effects of kinetics and structure
- ONR requires fundamental mechanistic understanding of lithium-ion battery catastrophic failure to move beyond current engineering approaches that do not adequately avoid or mitigate damage to platforms and personnel, particularly for large battery systems

Shipboard Energy Storage

Program Officer: Don Hoffman

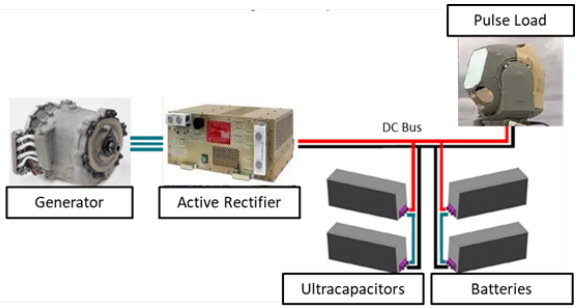
Develop and build hybrid energy storage modules to provide long endurance, high-energy density materials in a small, modular and easily scalable package. This will improve overall platform capability, efficiency, and reliability.

Research Concentration Areas

- Single- and multi-device (flywheels, batteries, capacitors, etc.)
- Safe energy storage systems to enable future, high-power weapons, and sensor systems on legacy and next generation naval vessels.
- High-density, high-cycle life energy storage system based peak shaving operations to provide continuous electric bus stability.

Successfully demonstration High Density Hybrid Energy Storage system in 2021(OSD OECIF program).

Future S&T on kinetic energy storage systems.



Integrated Power & Energy System

IPES ECOSYSTEM

- Virtual Test Bed - Modeling and Sim
  - Univ. of South Carolina
  - NSWCPD
- Lab Scale
  - FSU-CAPS
- NSWCPD
  - LBES
  - ITF

ONR S&T

Compact Power Conversion

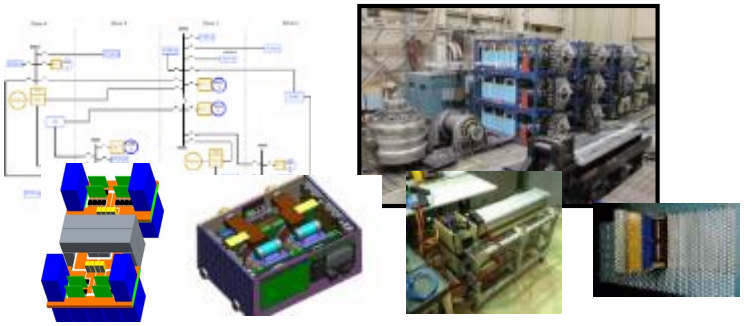
Advanced Circuit Protection

Multifunction Energy Storage

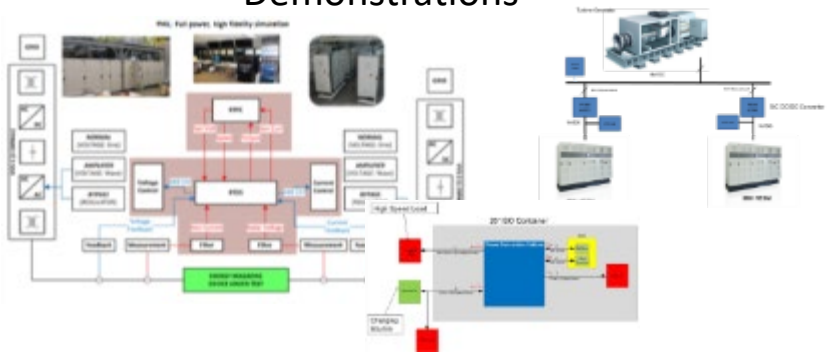
Robust Combat Power Control

IPES Advanced Development Model

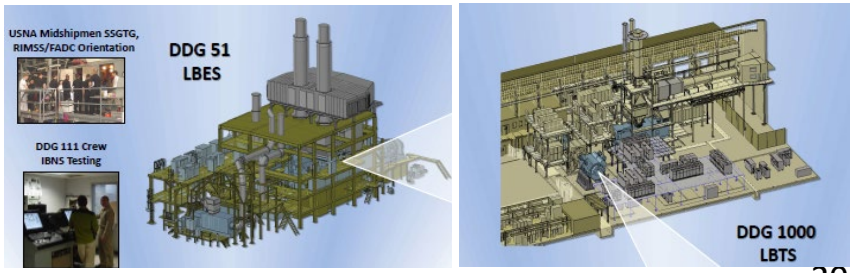
Component Development & Modeling



Reduced Scale Hardware In the Loop Demonstrations



NSWC Land Based Test Sites (LBTS)



Power & Energy Science and Technology

Program Officer: **Scott Coombe**

Subsea & Seabed Power:

- Characterization of phenomena in the undersea domain relevant to energy conversion objectives
- Modeling the physics relevant to undersea power and energy production
- Research pathways to enable a future subsea and seabed energy ecosystem to serve future undersea systems and platform power needs
- Understanding energy conversion opportunities throughout the undersea domain, both from an oceanographic geographical domain perspective and from an oceanographic physics perspective
- Understanding the temporal variability of processes that impact harvestable phenomena

Naval Energy Resilience:

- Electrical power intermittency, improved micro-grids, effectively integrating alternative energy sources into a grid, grid security, energy storage, local generation of zero-carbon fuels, and inspection and health monitoring of critical energy infrastructure
- Improving the ability to avoid, prepare for, minimize, adapt to, and recover from anticipated and unanticipated energy disruptions to ensure energy availability and reliability sufficient to provide for mission assurance and readiness, including mission essential operations related to readiness, and to execute or rapidly reestablish mission essential requirements
- Improving the ability of naval platforms around the world to accomplish their missions despite the actions by adversaries or other events to deny, disrupt, exploit, or destroy installation-based capabilities
- Efficient, power dense, practical, and robust energy transduction / solid-state energy conversion approaches for platform energy recovery and prime power applications

Naval Superconducting Science & Technology:

- Alternative (non-superconducting) advanced electrical conductor science and technology
- Conductor science addressing improvement to critical temperatures, critical currents, and performance in magnetic fields
- Exploitation of the many unique characteristics of superconductors to enable transformational and disruptive naval capability
- Superconducting Magnetic Energy Storage (SMES) fundamentals including physics-based modeling of conceptual systems, dynamic behavior and performance, magnetic containment/shielding, and innovations for future energy magazine applications
- Superconducting State Protections including novel cryogenic refrigeration cycles, quench detection and mitigation, vacuum-less insulation approaches, and mechanisms for rapid establishment of superconducting state conditions

Thermal Science and Engineering

Program Officer: Mark Spector

Objective

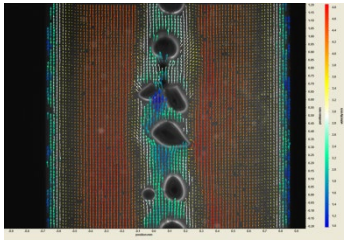
Advance thermal science and technology through fundamental studies of multi-phase heat transfer, fluid dynamics, and nanostructured materials to efficiently acquire, transport, and reject heat and enable higher power density electronic systems.

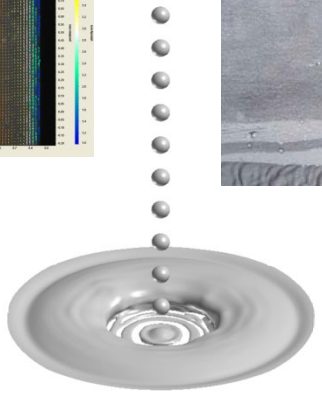
Approach

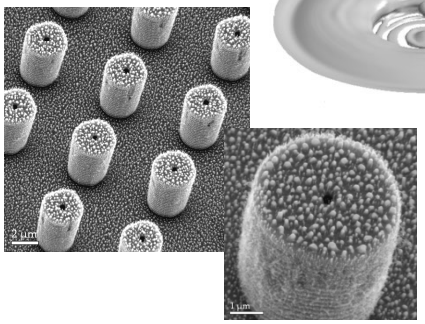
- Develop concepts and models that address cooling and heat transfer at various length scales
- Nanostructured heat transfer surfaces and materials to enhance thermal transport.
- Develop materials with high thermal conductivity and for thermal energy storage
- Topology optimization and additive manufacturing for thermo-fluid applications

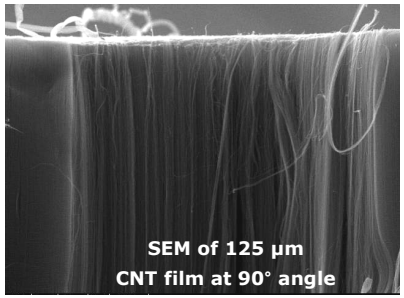
Technical Challenges

- Limited physics-based understanding of evaporative heat transfer
- Two-phase systems often limited by hydrodynamic instabilities and critical heat flux
- Limited materials and fluids available with good thermal properties
- Integral and scalable cooling concepts









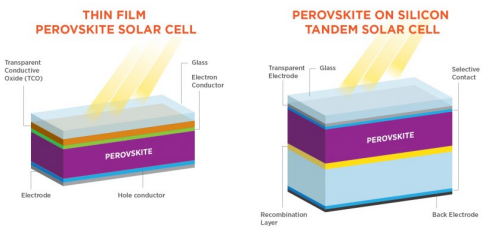
Expeditionary Energy

Program Officer: Joseph Parker

The Expeditionary Energy program seeks breakthrough technologies to support the future of hybrid and expeditionary warfare. The research portfolio is balanced among basic and applied research, and advanced technology development. Investments include disruptive technologies in low-cost photovoltaics, energy scavenging and power generation, energy storage, energy planning and energy-efficient small-scale water purification — all to support the sustainment and logistics of Sailors and Marines deployed in austere environments.

Research Concentration Areas

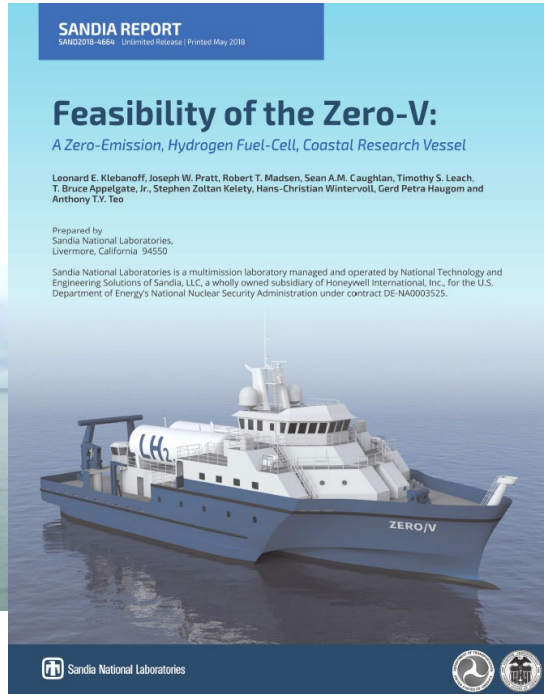
- Scalable energy harvesting and scavenging technologies (mW to kW)
- Next-generation perovskite photovoltaics (applied research, demonstrations and scale-up)
- Hydrogen as an alternative fuel for portable, light-weight applications
- Logistics decision support tools relevant to energy
- Beyond traditional Li-ion batteries for Navy and Marine Corps applications (anionic redox batteries, non-Li chemistries and arctic batteries)
- Electrochemical-based energy efficient water purification at expeditionary scales



Power Case up to 1 kW
Energy Case providing 200 W of H_2
Scalable Architecture

Alt Fuel: Hydrogen

- Green hydrogen, produced from renewable energy, produces no greenhouse gases when burned
  - DOE Hydrogen Shot program seeks to reduce cost of green hydrogen to $1/kg
  - Infrastructure bill contains $9.5B for DOE hydrogen initiatives
- Scripps Institute of Oceanography plans to build a hybrid hydrogen powered research vessel
  - ONR plansto leverage vessel for engineering studies
- GM developing portable electric vehicle recharge stations using H2 fuel cells
  - Potential use on USN installations for vehicle recharge and energy resiliency



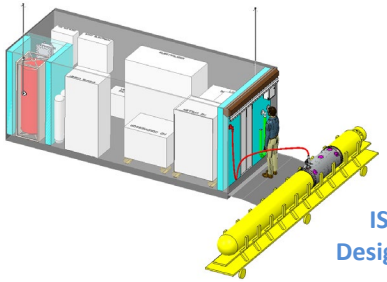
Unmanned Systems Propulsion

Program Officer: Maria Medeiros

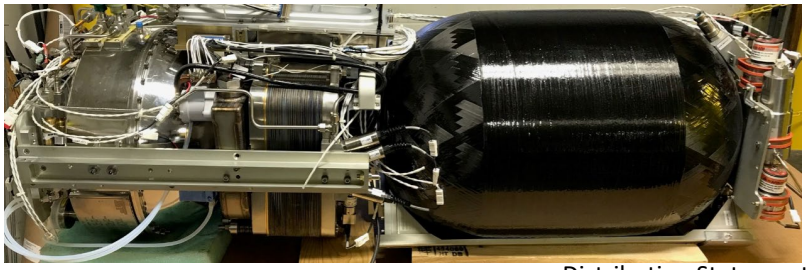
The Advanced Power and Energy for Undersea Applications program aims to develop component, subsystem and system technologies for advanced high-energy density and power density propulsion systems, and enabling increased endurance and reliability in an air-independent environment.

Research Concentration Areas

- Batteries (electrolytes, safety approaches, cathode and anode materials)
- Electrochemical Models
- Engines/motors for underwater applications
- Fuel cells (proton exchange membrane, solid oxide and regenerative)
- Fuels and oxidizers (generation, reformation, storage and delivery technologies and methods)
- Hybrid systems
- Refueling/recharging approaches
- Semi-fuel cells (Al, Mg, Li)
- Thermal power plants



ISO Container Packaged RASP Design for H_2 and O_2 Production, Storage and Delivery



UUV Fuel Cell System for 21" Diameter Hull Using a PEMFC with Gaseous H_2 Fuel and LOX Oxidizer

Low GWP Refrigerants

Program Officer: Mark Spector

- All in-service and future ships use HFC refrigerant chillers
  - R236fa (GWP = 9810) and R134a (GWP 1430)
  - 2021 Consolidated Appropriations Act (Sec. 103) calls for an 85% reduction of HFCs over 15 years
- Evaluating next generation refrigerants with low global warming potential (GWP <750) for use in Navy chillers.
  - New FY22 program
- Evaluating alternative cooling technologies:
  - Magnetic refrigeration
  - Thermoacoustics
  - Thermoelectrics
  - Adsorption/Absorption

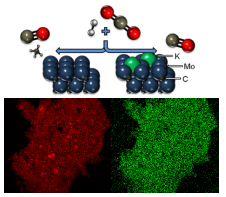
Operational Endurance From Environmental Carbon

Program Officer: Heather Willauer

Develop technology to support sustainable carbon neutral operational energy processes and materials for Navy and USMC needs. The portfolio is balanced among basic and applied research along with advanced technology development to support operational endurance and sustainability.

- Research Concentration Areas
  - Scalable carbon capture technologies
  - Next-generation carbon conversion technologies (basic, applied research, demonstration, and scale-up)
  - Modeling and simulation of reaction pathways
  - Environmental and mission impact simulation
  - Exploitation of energy and material production from environmental carbon in naval environments

Catalyst Mechanisms



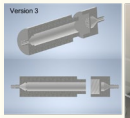
Direct Air Capture & Blue Carbon Removal Technology Program: Roadmap

State of the Art

DOC Prototypes

DAC Prototypes

Fuel Synthesis/Lubes Prototypes



"Proof of Concept" Technology Integration Testing 2022 - 2023

- Solid sorbent efficiencies
- Catalyst efficiencies
- Energy recovery
- Water recovery
- Lighter, deployable blue carbon units
- Electrical efficiencies
- Fuel production
- Fuel evaluation
- Process evaluations

Blue Carbon CO_2/H_2 Capture Skid

Direct Air CO_2/Capture Skid

Gas Processing Skids

Fuel Synthesis Skids 1gpd to 84 gpd

Synthetic Fuel

Scale 2022 - 2023

Engineering and Development Models (EDM) for Integrated 100 gal/day Chemical Process from DAC, DOC, and fuel synthesis technologies

- Determine number and size of chemical units needed to produce 100 gpd of fuel from DOC and DAC CO_2
- Evaluation cost, footprint, and total power requirements
- Determine systems and platform integration
- Determine all system components (Bill of Materials) for integrated synthesis process

Proof of concept and larger scale testing of systems and integrated processes for efficiencies, scaling and deploy ability

Climate Adaptation S&T

- Impact of climate change on military platforms (climate resiliency)
  - Methodologies to assess the impact of climate change on military platforms (sea, land, and air).
  - Science and technology gaps to improve platform resiliency to rapidly changing climate conditions.
- NATO Exploratory Team (AVT-ET-227)

https://www.onr.navy.mil