



2020s

# ***Navy Decarbonization Research Consortium***

*Advance the  
Technology*

## ***Operational Navy Decarbonization Roadmap and Year 1 Research Agenda***

2030s

*Test and  
Integrate*

***7 Sept 2023***

2040s

*Accelerate  
and Scale*

***Prepared by:  
Naval Postgraduate School  
Energy Academic Group***

2050

# Executive Summary

**DRAFT**

## BLUF:

- Decarbonizing Navy ships requires R&D to enable integration of lower carbon fuels, alternative propulsion systems, efficiency technologies, and carbon capture
- Continued emphasis on demand reduction and efficiency technologies are key to early emission reduction efforts
- ***Navy will only pursue decarbonization measures that maintain or enhance warfighting capability and mission effectiveness***
- Key objectives of this initial effort:
  - Assessed and identified research focus areas for highest potential to enable Navy ship decarbonization
  - Solicited and accepted proposals for Year 1 Research Agenda
  - Developed decarbonization roadmap structure and initial roadmap to guide research and lay the foundation for future efforts
  - Identified key next steps required to advance the research agenda and develop potential technology transition
- Other key points:
  - Majority of current Navy investment supporting decarbonization objectives has been with the goal of increasing combat capability and addressing contested logistics challenges
  - Integrating new technologies on naval platforms is a challenge; decarbonization is a unique challenge
- ***Increased and ongoing collaboration with DOE, DOT and across the Navy is critical to meeting the decarbonization challenge***

# Decarbonization Roadmap

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# Mission Statement & Objective

- Mission Statement
  - The Navy Decarbonization Research Consortium is a public-private collaboration with the goal to advance interdisciplinary research to help the Navy meet the complex challenges of platform decarbonization, with a focus on ships and aircraft.
  - The Consortium will evaluate and identify technologies that show promise for adaptation on naval platforms and accelerate adoption as appropriate.
  
- Objective
  - Establish a consortium of individuals, institutions and companies to address the Navy platform decarbonization challenge, whose membership and structure is adaptable over time
  - Develop a Decarbonization Research Agenda for ONR that includes interdisciplinary research and analysis and research gaps (August 2023)
  - Continue the Consortium to collaborate on research to solve complex problems of platform decarbonization

# Why Decarbonize?

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## IPCC Reporting

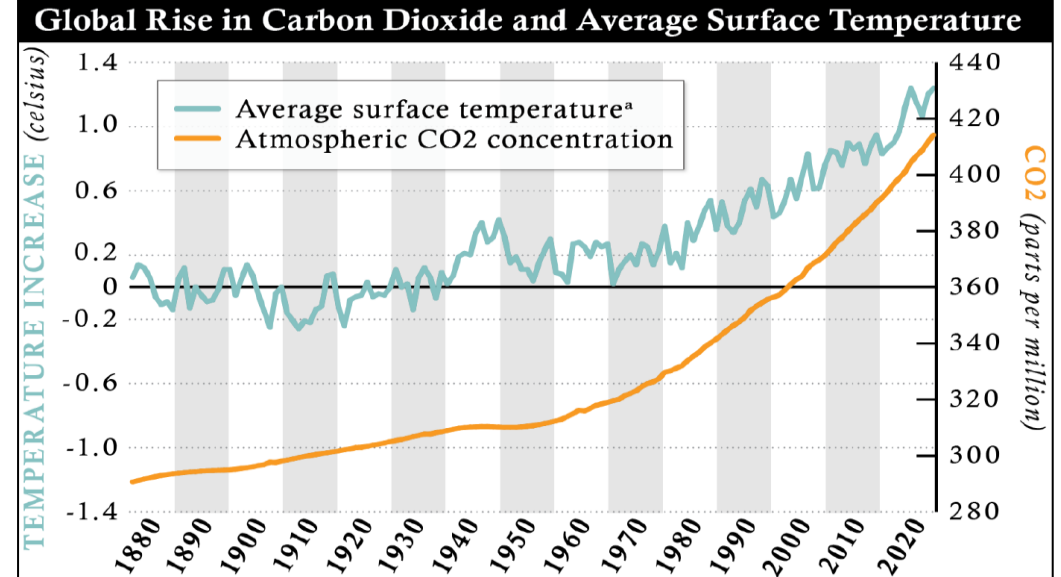
- Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020
- The likelihood of abrupt and irreversible changes and their impacts increase with higher global warming levels
- Limiting human-caused global warming requires net zero CO<sub>2</sub> emissions

## US Intelligence Reporting (US Annual Threat Assessment)

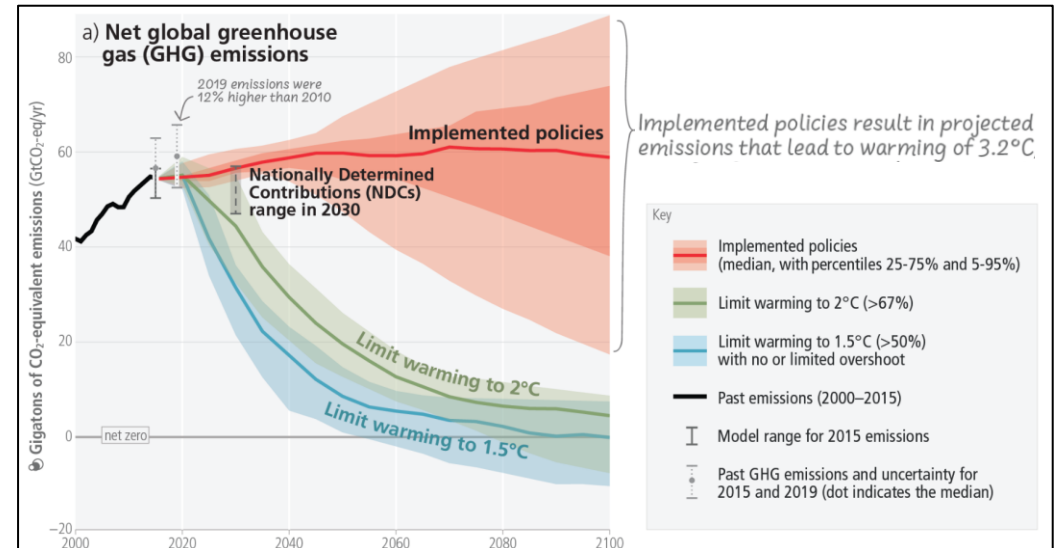
- Climate change will increasingly ***exacerbate risks to U.S. national security*** interests as the physical impacts increase and geopolitical tensions mount about the global response to the challenge

## DoD Climate Risk Analysis

- Climate change presents serious risks***, but DoD, along with the entire U.S. government, as well as our allies and partners, is determined to address this common threat
- The Department will work to prevent, mitigate, and respond to the defense and security risks associated with climate change



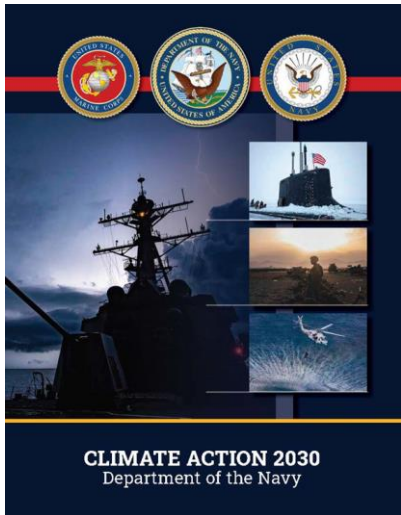
National Intelligence Council report, *Climate Change and International Responses Increasing Challenges to US National Security Through 2040*, 2021



IPCC AR6 Synthesis Report (SYR), 2023

# Directives & Key Guidance Documents

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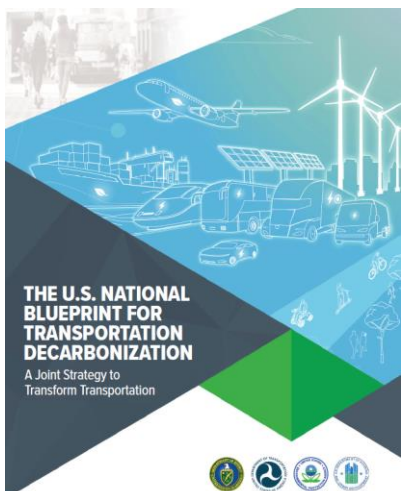


## Primary

- EO 14008 – Tackling the Climate Crisis at Home and Abroad (*Jan 2021*)
- DoD Climate Adaptation Plan (*Sept 2021*)
- DoD Climate Risk Analysis (*Oct 2021*)
- EO 14057 – Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability (*Dec 2021*)
- Federal Sustainability Plan (*Dec 2021*)
- **DoN Climate Action 2030 (*May 2022*)**

## Secondary

- **US National Blueprint for Transportation Decarbonization (*Jan 2023*)**
- FAA Aviation Climate Action Plan (*2021*)
- IMO GHG Strategy (*2018*)
- DOE Hydrogen Shot (*June 2021*)
- U.S. National Clean Hydrogen Strategy & Roadmap (*June 2023*)
- Clean Fuels & Products Earthshot (*June 2023*)
- DOE SAF Grand Challenge (*Sept 2022*)
- USAF Climate Action Plan (*Oct 2022*)
- US Army Climate Strategy (*Feb 2022*)
- USCG Climate Framework (*Jan 2023*)
- Summary of World Military Activities (*NPS – 2023*)



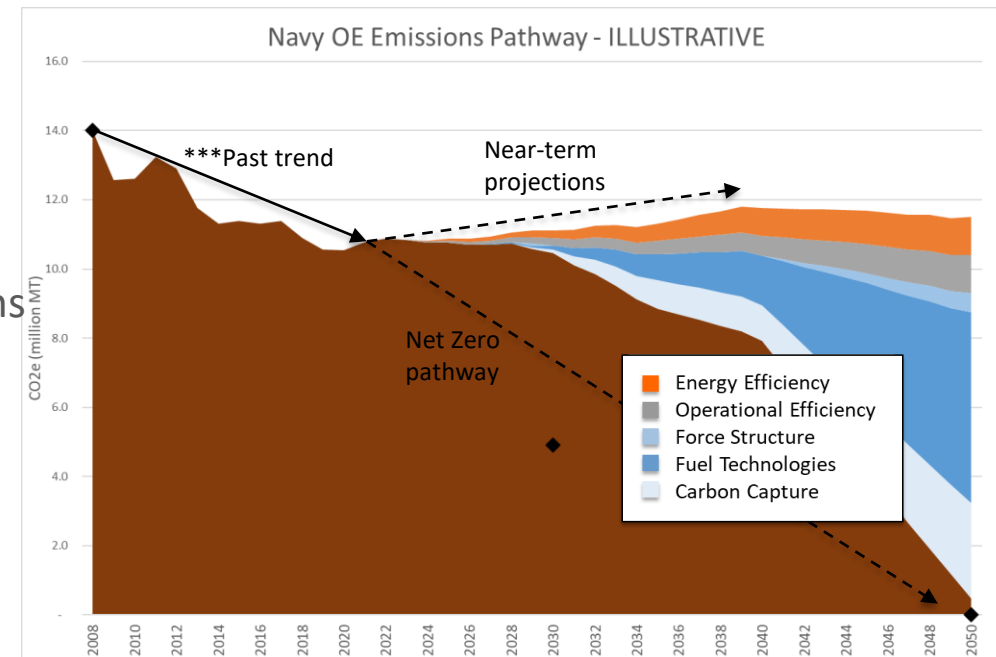


# Navy Emissions & Navy Unique Challenge

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- FY21 DON emissions were ~16.7M MT CO<sub>2</sub>e
  - ~70% operational, ~30% installations
  - Operational emissions ~50/50 split between jet fuel (JP-5) & ship fuel (F-76)
- \*\*\*Significant reductions in energy use have been realized since FY08
  - Majority of reduction is attributable to reduced operating hours & lower speed
  - Energy demand is expected to increase going forward
  - **Past trendline is not indicative of future projections**
- Platforms in-service/in-design today will be in the fleet ***past 2050***, with conventional diesel and gas turbine engines
- ***Energy demand is increasing***, due to growth in new platforms (including ***unmanned*** vessels) and increased onboard energy demand
- Navy ships must maintain ability to ***refuel underway*** and at ***remote*** locations – we operate ***forward, distributed***, and in ***contested*** environments
- Must maintain ***interoperability*** with partners and allies
- Space, weight, power, and cooling ***margins are limited***
- Integration of technologies on new and existing ships must meet ***strict standards*** (MIL-STD and Technical Warrant Reviews)

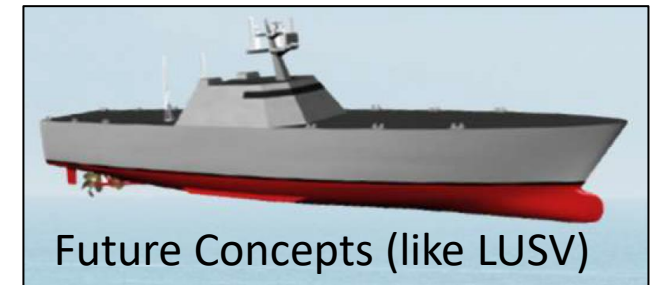
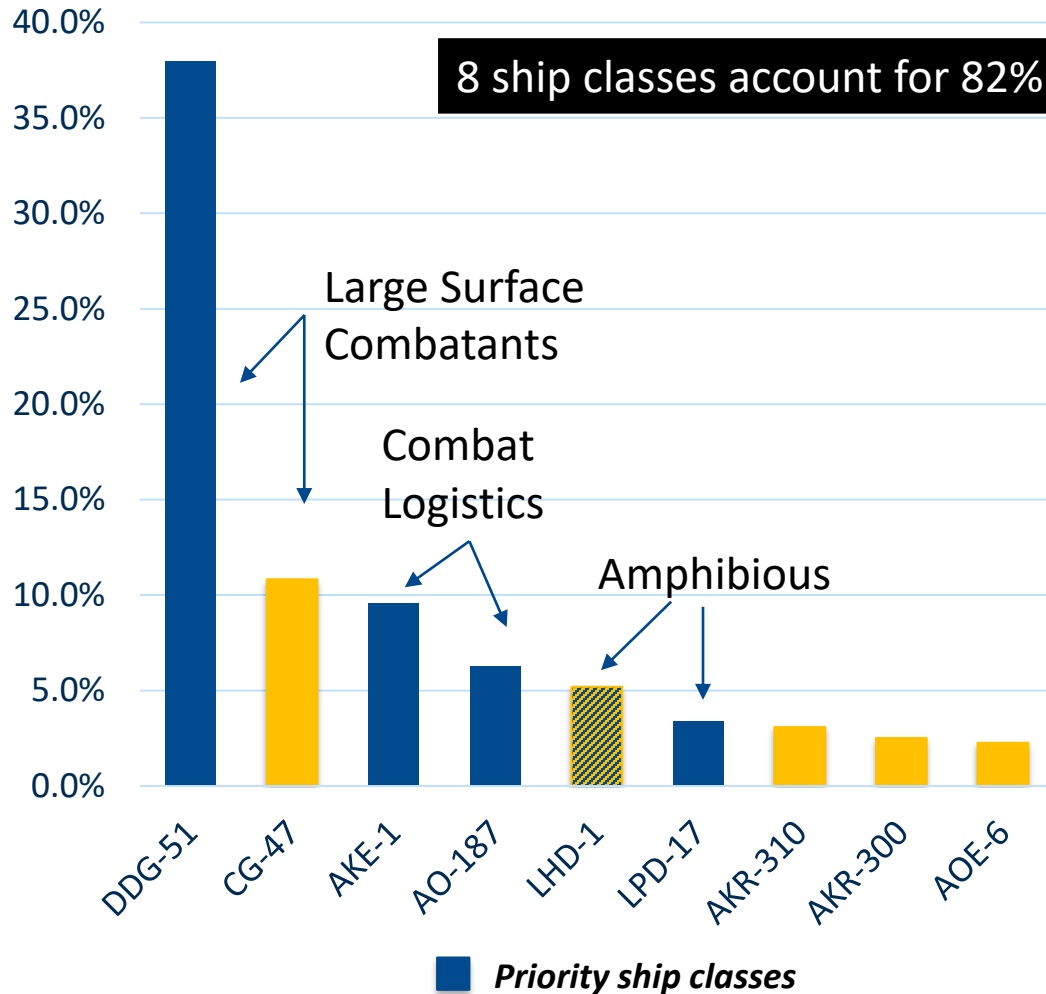
Figure 4.1: DoD Total Energy Consumption as Percent of Federal Total, DoD Total Energy Consumption as Percent OE vs IE, and DoD Service-level Installation Facility Energy Use



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# GHG Emissions by Ship Class: Opportunities for Decarbonization

**% of Total Ship Emissions FY20 – FY22**

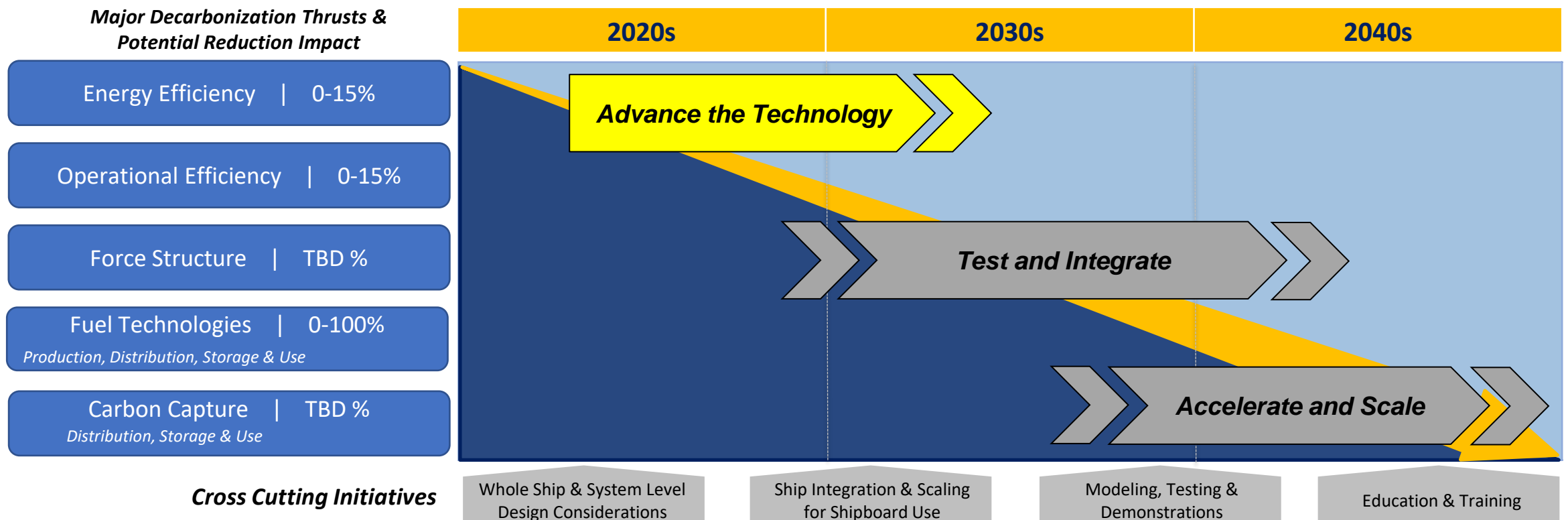




# Decarbonization Thrusts for Navy Operations

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- Current Consortium efforts focused on maritime platform decarbonization
- Roadmap structure was informed by numerous other decarbonization and Net Zero products, to ensure alignment with Navy, other government and commercial strategies
- Consortium identified five (5) major decarbonization thrust areas, supported by four (4) cross-cutting initiatives
  - Also developed Rough Order of Magnitude (ROM) levels of potential emissions reduction impact for Navy platforms



# Decarbonization Thrusts – Detail

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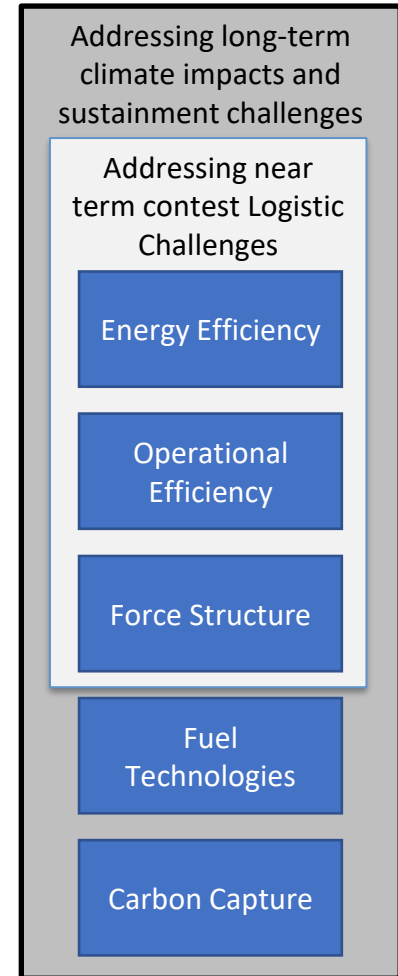
	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category
<b>Major Thrust Areas</b>	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction
			Propulsion & power generation improvements
			Electrification & hybridization
			Thermal management, Waste Heat Recovery (WHR)
			Power demand reduction
			Energy storage
			Lightweight materials
	0% - 15%	Operational Efficiency Improvements	Route optimization
			Plant line-up & speed optimization (single generator ops, etc.)
			Trim optimization
	TBD	Force Structure	Unmanned systems
			"Single mission optimized" platforms
			Attritable assets
			UxV system modeling
	0% - 100%	Fuel Technologies: Production, Distribution, Storage and/or Use	Blended or drop-in fuels (bio-, renewable-)
			Non drop-in liquid fuels (ammonia, methanol, etc.)
			Hydrogen
			Batteries
			Nuclear
			Renewable energy
TBD	Carbon Capture: Distribution, Use and Storage	Shipboard	
		Terrestrial	
		Other emissions capture/reduction (high GWP refrigerants, etc.)	

# Assessment of Current Activities & Research Focus Areas

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- Assessment of Current Activities
  - Navy prioritizes investment in efficiency, electrification, and force structure enabling employment and sustainment of combat capabilities
    - Navy investment in lower carbon fuels and carbon capture technologies are primarily focused on fuel generation in theater
  - DOE active across all relevant sectors, funding fuels R&D under several focused projects:
    - SAF Grand Challenge
    - Energy Earthshot – Clean Fuels and Production
    - Zero-Emissions Shipping Mission (ZESM)
  - DOT partnered with DOE on ZESM and is active in maritime decarbonization with a focus on Low Carbon Fuels, Electrification, Energy Efficiency, Carbon Capture, and Green Shipping Corridors
  
- **Year 1 Research Agenda Focus Areas**
  - Use of lower carbon fuels in Navy relevant prime movers
  - Shipboard carbon capture technologies
  - Energy efficiency technologies
  - Modelling and analysis of energy systems, ship design process and systems architecture
  - *Operational Efficiency and Force Structure were not prioritized for Year 1 efforts*

**Major Decarbonization Thrusts**



# Year 1 Research Agenda

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## Fuel Technologies & Carbon Capture

- Collaboration of USC, CSU, PSU, USNA
  - University of South Carolina: Fuel Flexible Gas Turbine Technology Integrated with Exhaust Gas Recirculation and Hydrogen Carrier Fuels
  - Colorado State University: Liquid-Fueled Solar Centaur 40 Gas Turbine Testing with High EGR Fraction to Support Carbon Capture System Integration
  - Penn State University: Fuel Flexible Gas Turbine Technology Integrated with Carbon Capture and Utilization
  - USNA: Working Towards Zero-Carbon Naval Energy Technologies with Midshipmen at the USNA
- University of Wisconsin: Enabling mixing-controlled combustion of low carbon fuels in naval reciprocating engines
- University of Illinois: Sustainable Power for Decarbonization of Naval Vessels

## Energy Efficiency: Electrification & Hybridization

- NSWC Philadelphia: Evaluation of Propulsion Derived Ship Service and Weapons Power to Support Decarbonization

## Cross-Cutting: Modeling - Energy Systems, Ship Design, System Architecture

- Collaboration of GWU, NPS, ABS, USNA
  - George Washington University: Energy Systems Modeling, Prediction, and Planning Tool for Navy Decarbonization Technologies
- NPS: Trade space exploration for climate impact and quality attributes for navy ships
- NPS: High-level system architecture, modeling and performance evaluation of a fleet of green-energy ships producing hydroelectric energy and hydrogen at sea

# Advance the Technology – S&T Evolution

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- Take initial steps towards transitioning solutions onto Navy platforms
  - Identify transition/integration pathway(s) and begin to document as evolution plan
  - Assess and elevate technology readiness level (TRL)
  - Continually assess impacts to decarbonization objectives

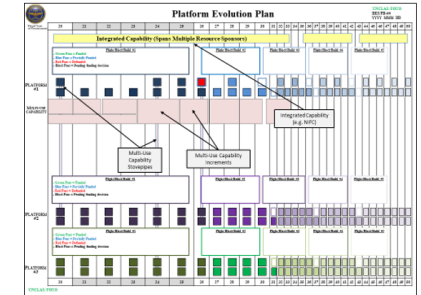
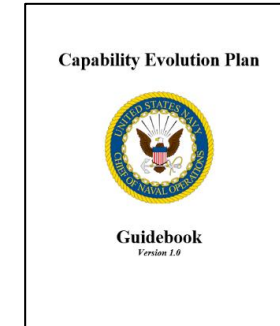
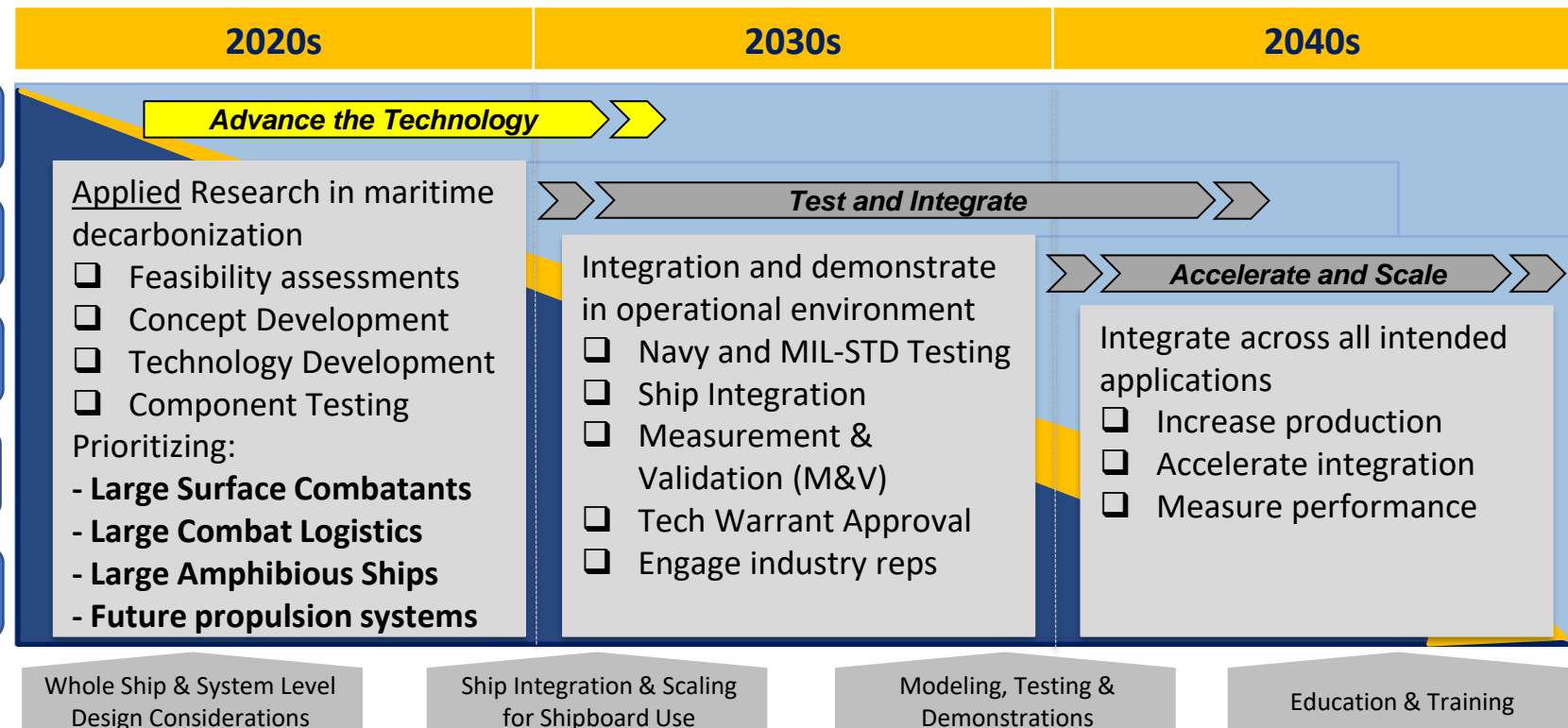


Figure 5. Integrated and Multi-use Capabilities Depiction

### Major Decarbonization Thrusts & Potential Reduction Impact

- Energy Efficiency | 0-15%
- Operational Efficiency | 0-15%
- Force Structure | TBD %
- Fuel Technologies | 0-100%  
*Production, Distribution, Storage & Use*
- Carbon Capture | TBD %  
*Distribution, Storage & Use*

### Cross Cutting Initiatives





# Collaboration Strategy

- Develop and mature a robust collaboration strategy, with six core communities
  - Current Consortium group – foster increased collaboration amongst Consortium members
  - Internal Navy and other DoD – operational energy, climate and resilience constituencies
  - Other USG Agencies – DOE, DOT, ARPA-E and others (e.g. EPA, NOAA, etc.)
  - International partners – NATO, Pacific Islands Partnership, etc.
  - Industry – potentially via the DOT/MARAD U.S. Center for Maritime Innovation (*in work*)
  - Academia – identify leading researchers in other technology areas
  
- Two major goals for collaboration activities are:
  - Better understand ongoing efforts and identify most impactful areas of research to guide and prioritize future years’ research agenda
  - Identify appropriate Navy “role” in various thrust areas, considering:
    - Government-wide approach and R&D portfolios of other partner entities
    - Navy unique requirements that may not otherwise be addressed

# Roadmap – Key Actions

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## Major Decarbonization Thrusts

Energy Efficiency

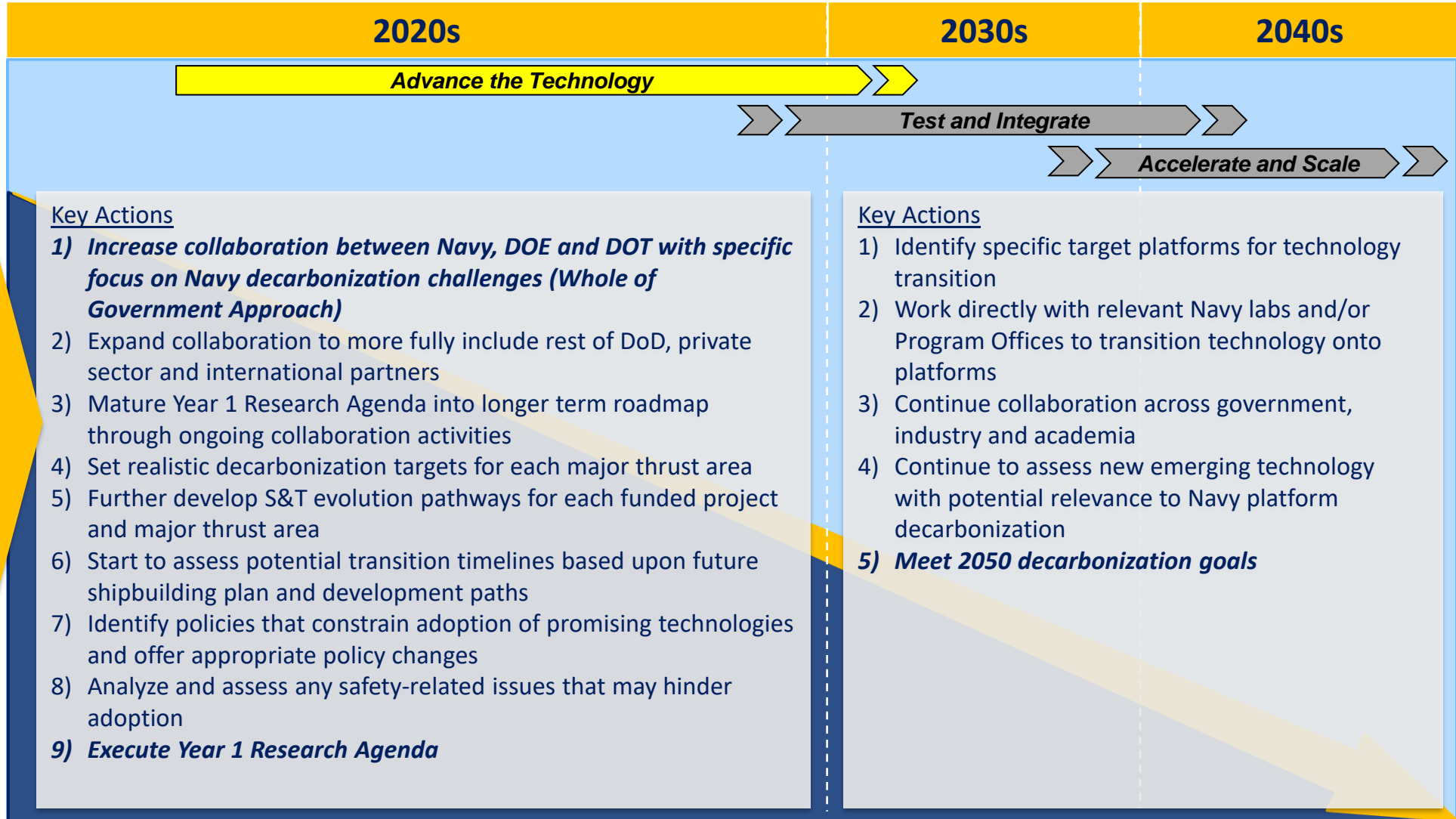
Operational Efficiency

Force Structure

Fuel Technologies

Carbon Capture

Cross Cutting Initiatives



# Next Steps

- Develop and implement Collaboration Strategy with core partners
  - Continue potential research opportunity identification process
- Execute Year 1 Research Agenda
  - Support required Navy-project team collaboration and data collection
  - Develop project specific S&T evolution pathways with each funded research team
- Assess impact of Year 1 research concepts and technologies to overall Navy decarbonization objectives
  - Further develop Roadmap to include more specific targets, as needed
- Align with other roadmap and data collection efforts
  - Work with other efforts to develop methodology to synthesize R&D and project information across technical areas for efficiency, leverage and gap identification purposes
- Explore applying Consortium model and findings to Aircraft
  - Potentially extend to installations at a later date?





# NAVAL POSTGRADUATE SCHOOL

IMMEDIATE IMPACT | FUTURE ADVANTAGE | ENDURING LEADERSHIP

# NPS/Navy Support for Research Project Execution

Research teams expressed desire to get support/help from Navy regarding:

- Access to data and Navy operational context
- Better understanding of the impact of the Navy specific constraints on the research and how these parameters “limit” the trade space; “maximize combat capability” and acceptable trade-offs to that; integration limitations/challenges
- Transition planning and pathways to demonstrate/test and mature research and have it advanced by Navy enterprise
- Continued development towards the Capability Evolution Plan approach, with development of more quantitative targets
- Collaboration between research teams/programs, and collaboration with external partners (DOE, etc.)