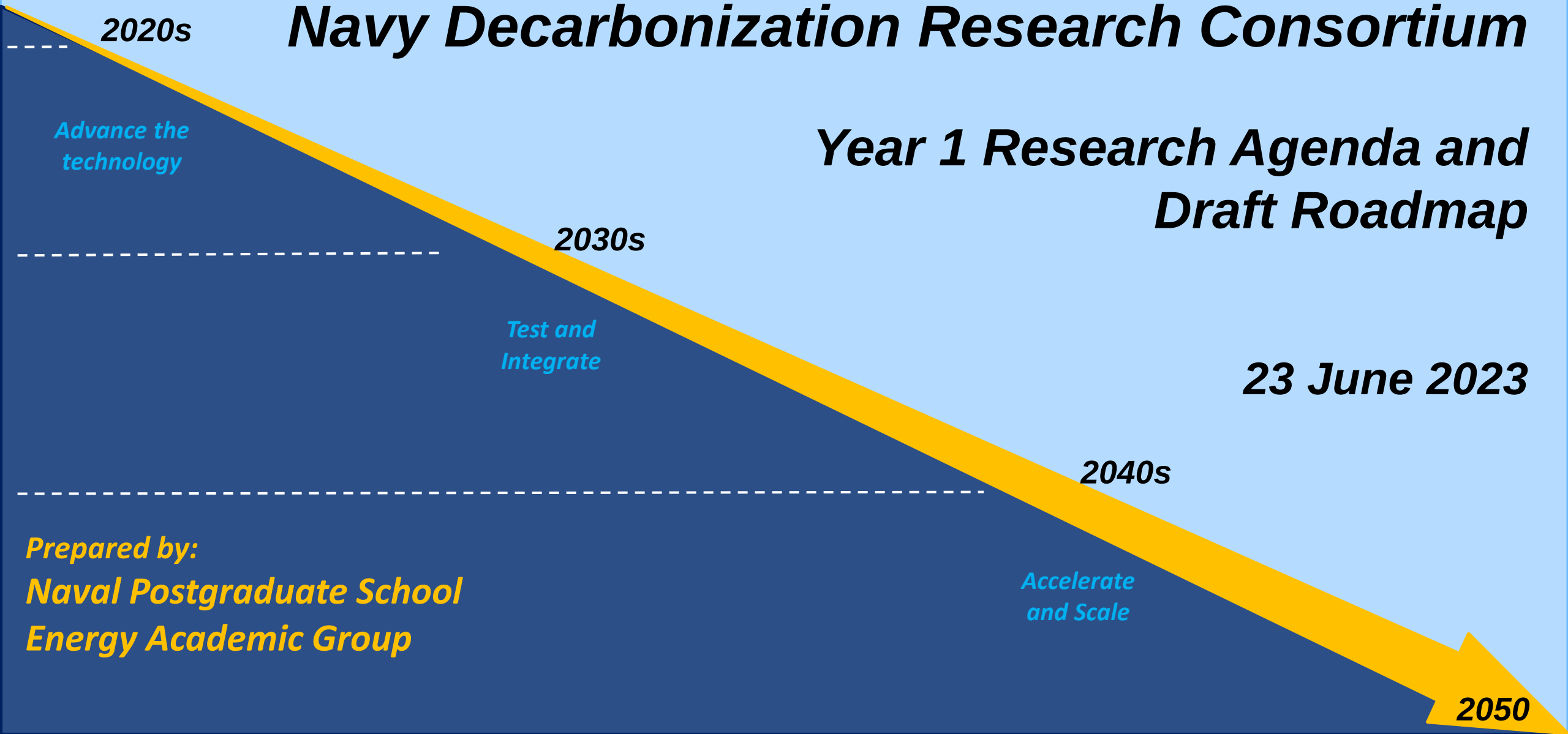
Navy Decarbonization Research Consortium

Year 1 Research Agenda and Draft Roadmap

23 June 2023



Prepared by:
Naval Postgraduate School
Energy Academic Group

Agenda

- Executive Summary
- Mission Statement and Goals
- Key Guidance Documents and Timelines
- Navy Specific Considerations and Constraints
- Research Focus Areas and Cross Cutting Initiatives
- Assessment of Current Activities
- Preliminary Gaps
- Year 1 Research Agenda
- DRAFT Summary Roadmap
- Next Steps

Executive Summary

BLUF: Decarbonization of Navy ships will require significant R&D to enable integration of lower carbon fuels, alternative force composition, and carbon capture, while continued emphasis on demand reduction and efficiency technologies are key to early emission reduction efforts; ***Reducing carbon emissions from ships without degrading warfighting capabilities is a significant challenge***

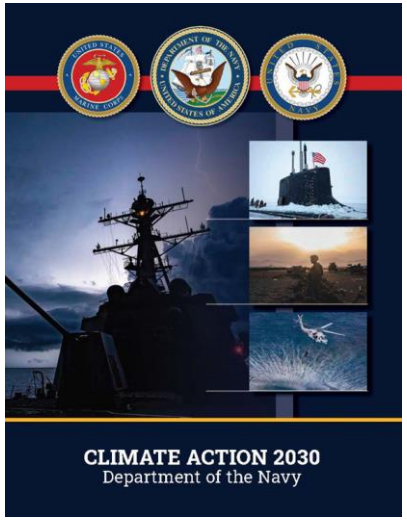
- Key objectives of this initial effort:
  - Assessed focus areas for highest potential to enable *Navy ship* decarbonization
  - Assessed alignment of Navy investment supporting ship decarbonization and identified preliminary gaps
  - Solicited and accepted proposal for Year 1 Research Agenda
  - Developed decarbonization roadmap structure and draft roadmap to guide research and lay the foundation for future efforts
  - Identified key next steps
- Other key points:
  - Integrating new technologies on naval platforms is a challenge
  - Much of Navy investment supporting decarbonization objectives has been with the goal of increasing combat capability and addressing contested logistics challenges; *decarbonization is a unique challenge*
- ***Increased and ongoing collaboration with DOE, DOT and across the Navy is critical to meeting the decarbonization challenge***

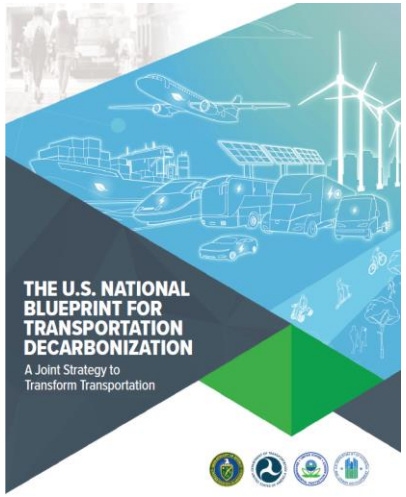
Mission Statement and Goals

- Mission
  - 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.
- Consortium Goals
  - Establish a consortium that includes individuals, institutions and companies necessary to meet platform decarbonization and whose membership and structure is adaptable over time
  - Create 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

Key Guidance Documents and Timelines

Key Guidance Documents





Primary

- EO 14008 – Tackling the Climate Crisis at Home and Abroad (*Jan 2021*)
- EO 14057 – Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability (*Dec 2021*)
- DoD Climate Adaptation Plan (*Sept 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*)
- Summary of World Military Activities (*NPS – 2023*)

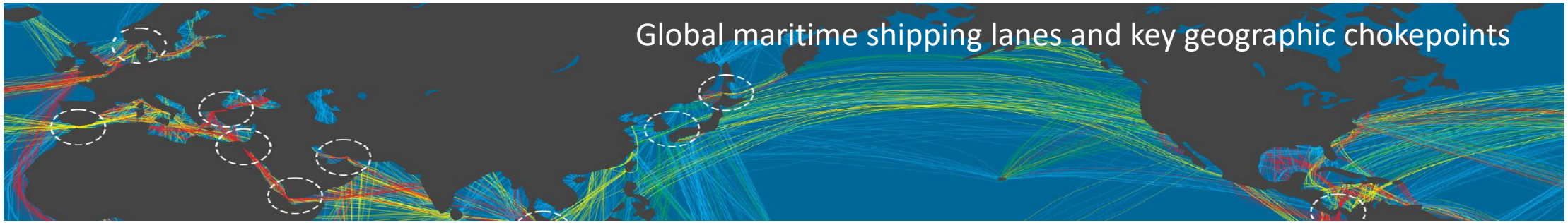
Guidance Document Summary and Timelines

Key Guidance Document	*Target*	2020s	2030s	2040s
EO 14057 & Navy Climate Action 2030	• 100% carbon-free electricity (CFE), including 50% 24/7 CFE • 65% reduction in scope 1 & 2 GHG emissions • Net zero emissions economy-wide		**2030** **2030**	**2050**
US Transportation Decarbonization Blueprint	• 5% of the global deep-sea fleet are capable of using zero-emission fuels • Net zero emissions from international shipping • Reduce aviation emissions by 20% • Net-zero GHG emissions from the U.S. aviation sector • Catalyze the production of: - at least three billion gallons of SAF/year - ~35 billion gallons by 2050		**2030** **2030** **2030**	**2050** **2050** **2050**
IMO GHG Strategy	• Reduce carbon intensity of international shipping by: - At least 40% - Pursue efforts towards 70% • Cut annual GHG emissions by at least half		**2030**	**2050** **2050**
DOE Hydrogen Shot	• Reduce cost of clean hydrogen by 80% to $1 per 1 kg in 1 decade (*1-1-1*)		**2031**	
DOE SAF Grand Challenge	• Scale up domestic production of SAF with a minimum of 50% life cycle GHG reduction (*reflected in Transportation Blueprint above*)		**2030**	**2050**
USAF Climate Action Plan	• Increase operational energy intensity of flying missions by: • Complete successful pilots of drop-in compatible SAF at two operational AF locations, with 10% SAF blend at same or lower cost	5%/**2027** **2026**	7.5%/**2032**	
World Military Activities	• General trend towards net zero by			**2050**

Navy Specific Considerations and Constraints

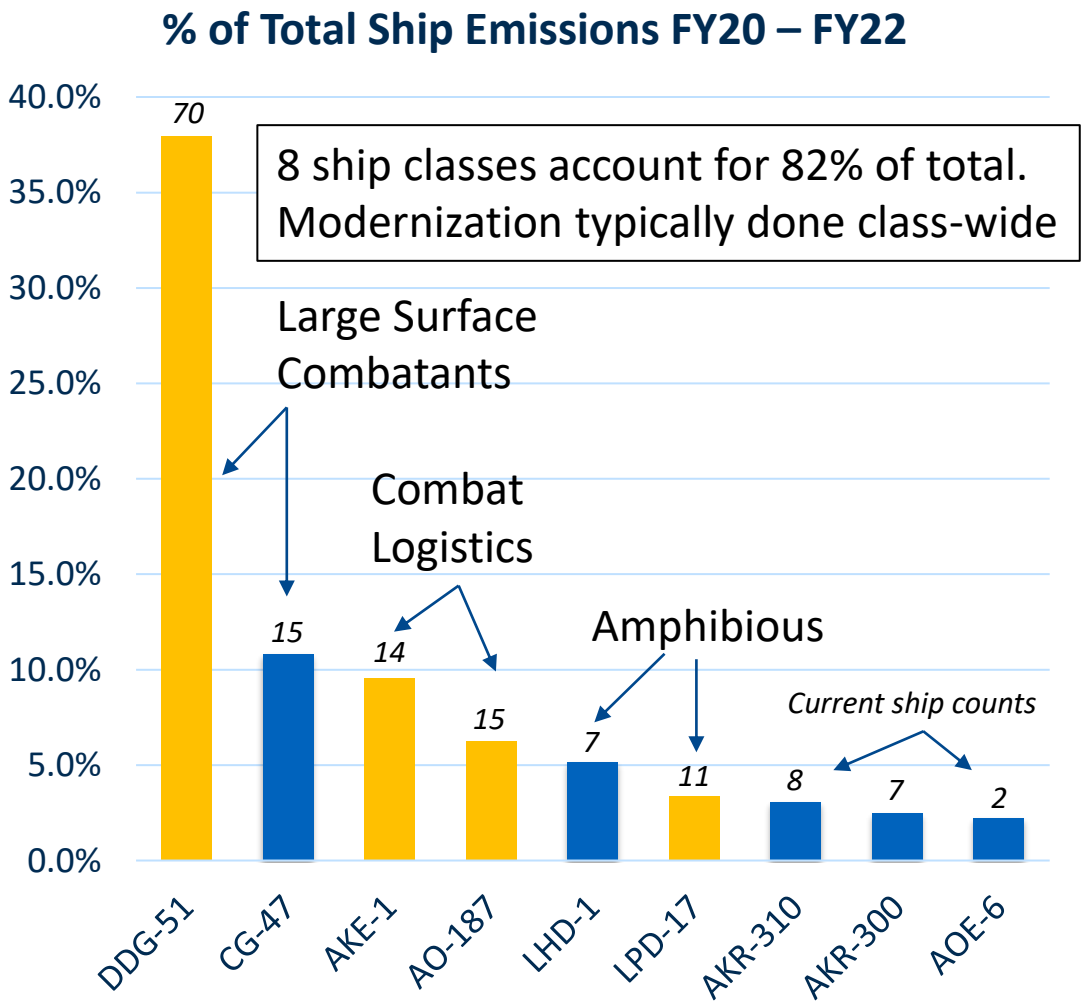
Considerations for Navy Ship Decarbonization

- Navy ships must maintain ability to ***refuel underway*** and at ***remote*** supply depots – we operate ***forward***, ***distributed***, and in ***contested*** environments
  - Unlike commercial maritime, the US Navy trains and operates outside maritime shipping lanes
- Integration of technologies on new and existing ships must meet ***strict standards*** to manage risk to equipment, personnel, and mission
  - Standards for commissioned ships (warships) include MIL-STD and Technical Warrant Reviews and design criteria
  - Standards for Military Sealift Command ships include American Bureau of Shipping
- Space, weight, power, and cooling ***margins are limited*** on platforms designed for maximum combat capability



Global maritime shipping lanes and key geographic chokepoints

Navy Specific Issues –Target Classes



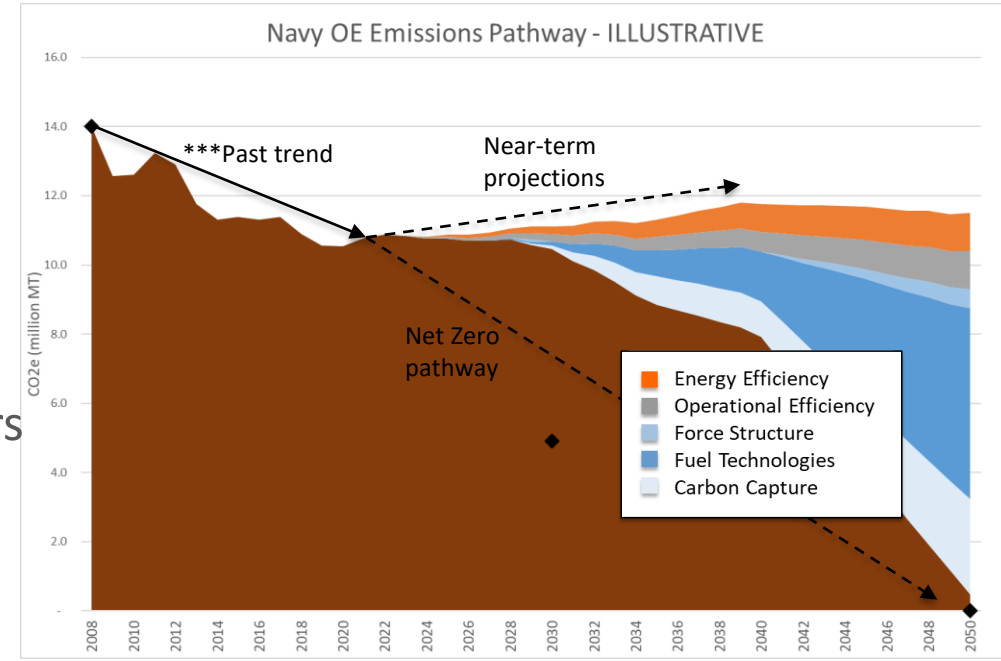
- Existing ships and new designs are powered by conventional gas turbine and diesel engines
- Priority for back-fit are DDG-51, T-AKE, T-AO, and LPD classes, as these platforms will be around past 2050 (30+ year service life)
  - CG-47 class phasing out over next decade, replaced with DDG-51 Class
  - T-AO-187 being replaced with T-AO 205 (Fleet Oilers)
  - Navy adding LPD-17 hulls over next decade
- Adding new small and large surface combatants, logistics ships, small amphibious ships and unmanned surface vessels over next 2 decades
  - FFG 62 - FY23
  - DDG(X) transition ~FY30
  - 89 -149 unmanned platforms by FY45
  - New logistics vessels

Research Focus Areas and Cross Cutting Initiatives

Research Focus Area Development Process

- FY21 DON emissions were ~16.7M MT CO2e
  - ~70% operational, ~30% installations
- While this effort is focused on maritime platform decarbonization, intention is to ensure alignment with broader Navy strategy and pathways
- Roadmap structure was informed by numerous other decarbonization and Net Zero products
  - To ensure alignment with commercial and other government strategies
  - Also identified ROM levels of impact for Navy platforms
- ***Significant reductions in energy use have been realized since 2008, but much of that is attributable to reduced operating hours
  - Energy demand is expected to increase going forward
  - Past trendline is not indicative of future projections

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



Emission Reduction Potential – Select Examples

DNV Alternative Fuels for Naval Vessels White Paper - 2022

FIGURE 3.2

One of the available technologies to decarbonize shipping and its GHG emission reduction potential[6]

LOGISTICS AND DIGITALIZATION	HYDRODYNAMICS	MACHINERY	FUELS AND ENERGY	AFTER TREATMENT MEASURE
Speed reduction Vessel utilization Vessel size Alternative routes	Hull coating Hull-form optimization Air lubrication Cleaning	Machinery improvements Waste-heat recovery Engine de-rating Battery hybridization	LNG, LPG Biofuels Electrification Methanol Ammonia Hydrogen Harvesting from the surroundings	Carbon capture and storage
>20%	5%-15%	5%-20%	0%-100%	>30%

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State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review

Transportation Research Journal – 2017

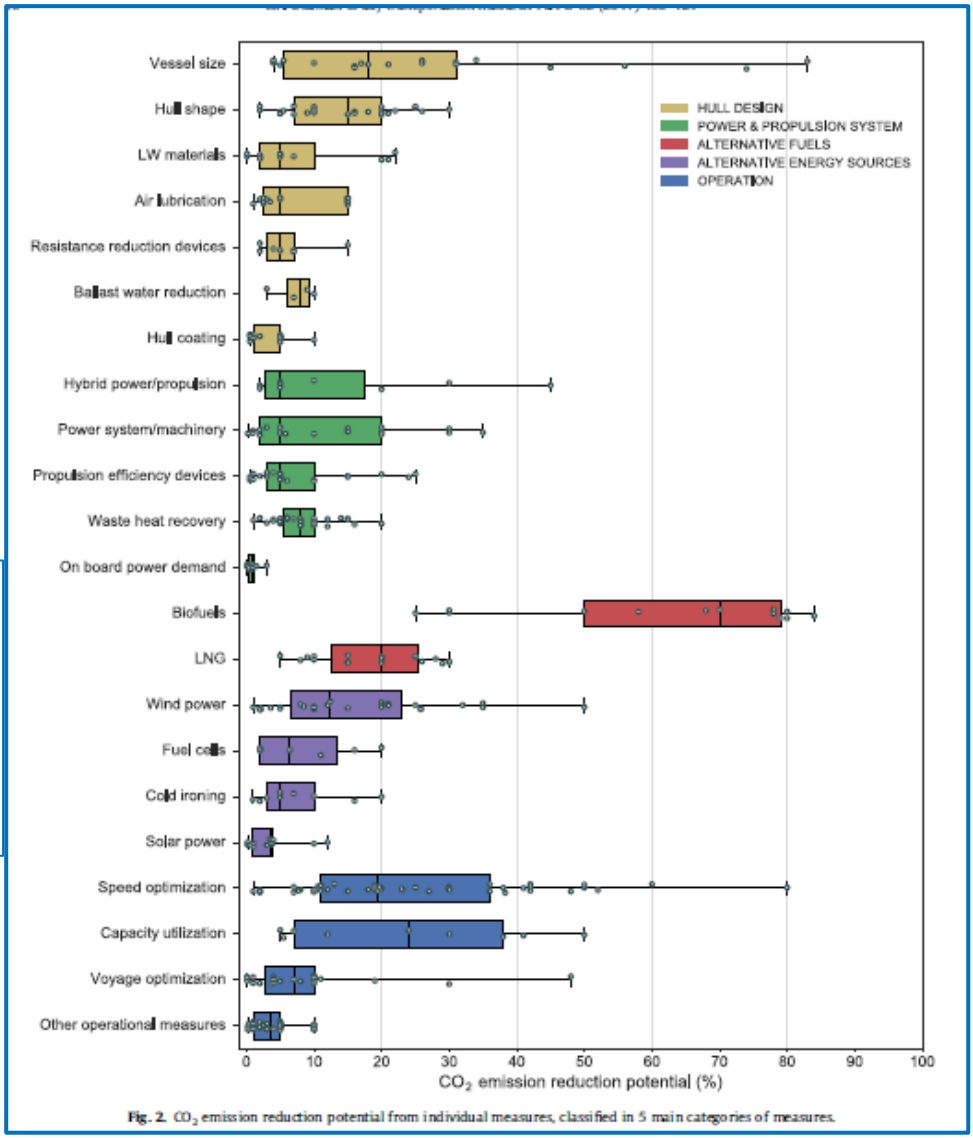
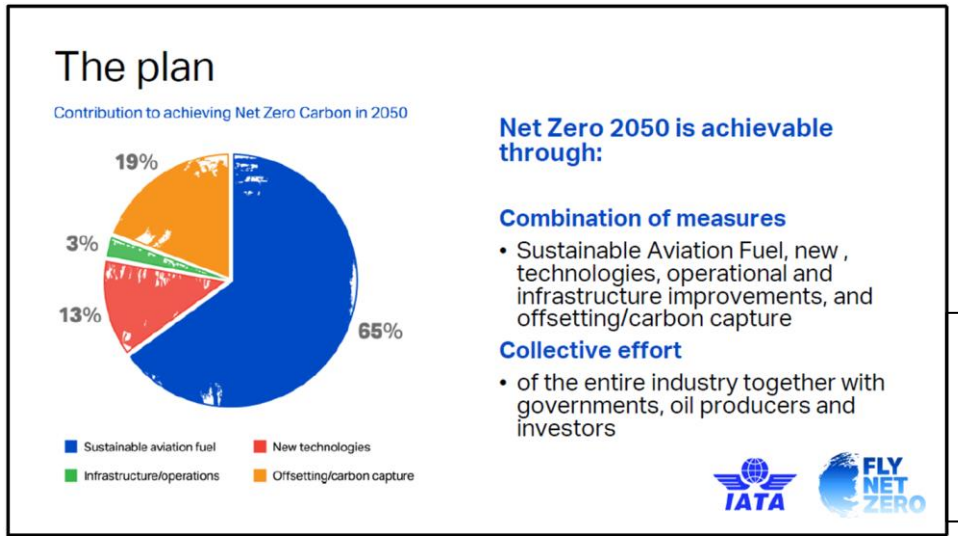
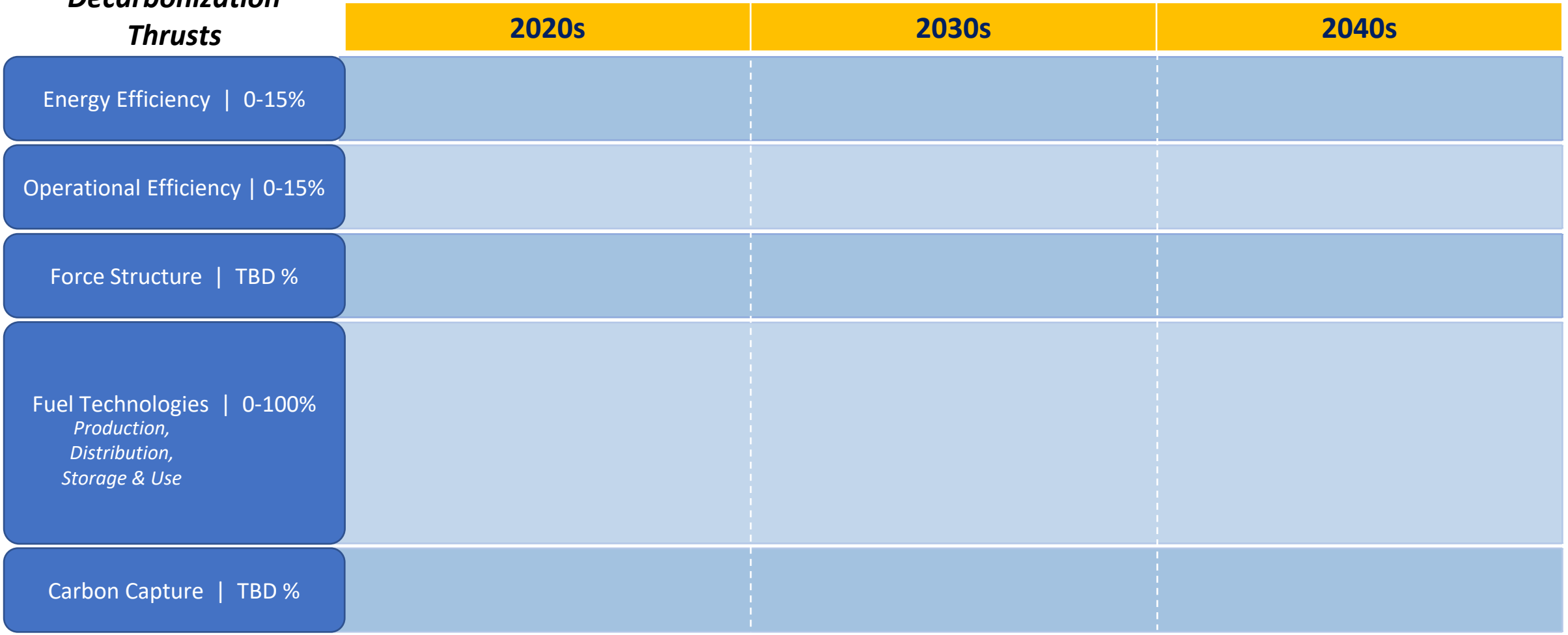


Fig. 2. CO_2 emission reduction potential from individual measures, classified in 5 main categories of measures.



International Air Transport Association Fly Net Zero Strategy – 2021

Decarbonization Roadmap Structure



Research Focus Areas and Cross Cutting Initiatives

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category
Major Thrust Areas	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction
			Propulsion & power generation improvements
			Electrification & hybridization
			Thermal management, WHR
			Demand reduction
			Energy storage
			Lightweight materials
	0% - 15%	Operational Efficiency Improvements	Route optimization
			Plant & speed optimization
			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
			Fuel cell technology
	TBD	Carbon Capture, Use and Storage	Shipboard
			Terrestrial
			Other emissions capture/reduction
Cross-Cutting Initiatives	N/A	Whole ship and system level design considerations	Ship design process
			System level design considerations
	N/A	Ship integration and technology scaling for shipboard use	Ship integration (e.g., retrofit-ability, durability, etc.)
			Scaling for shipboard use
	N/A	Modeling, test sites and demonstration capability	Modeling & data analytics
			Bench scale testing
			Demonstrations & testing
	TBD	Education and Training	Education & training

Assessment of Current Activities

Assessment of Current Investment Activity

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	Navy	DOE	DOT
Major Thrust Areas	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction	◊◊	X	X
			Propulsion & power generation improvements	◊◊◊◊◊	X	
			Electrification & hybridization	◊◊◊	X	X
			Thermal management, WHR	◊◊◊◊	X	
			Demand reduction	◊◊◊◊	X	X
			Energy storage	◊◊◊	X	
			Lightweight materials		X	
	0% - 15%	Operational Efficiency Improvements	Route optimization	◊		
			Plant & speed optimization	◊		
			Trim optimization			
	TBD	Force Structure	Unmanned systems	◊◊		X
			"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-)	◊	X	X
			Non drop-in liquid fuels (ammonia, methanol, etc.)	◊	X	X
			Hydrogen	◊◊	X	X
			Batteries	◊◊◊	X	X
			Nuclear		X	
			Renewable energy	◊◊	X	X
			Fuel cell technology	◊	X	X
	TBD	Carbon Capture, Use and Storage	Shipboard	◊	X	X
			Terrestrial			
			Other emissions capture/reduction	◊		
Cross-Cutting Initiatives	N/A	Whole ship and system level design considerations	Ship design process	◊		
			System level design considerations			
	N/A	Ship integration and technology scaling for shipboard use	Ship integration (e.g., retrofit-ability, durability, etc.)			
			Scaling for shipboard use			
	N/A	Modeling, test sites and demonstration capability	Modeling & data analytics	◊◊		X
			Bench scale testing			
			Demonstrations & testing			
	TBD	Education and Training	Education & training	◊		

Summary of Current Activities – Navy *(1 of 2)*

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	Navy: Summary of Major Efforts
Major Thrust Areas	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction	LCS Stern Flaps; Finlets; Hull Husbandry
			Propulsion & power generation improvements	PA6B Electronic Fuel Injection; Variable Cycle Advance Technology; T-AO 205 Efficient Replacement Engines; Aircraft Turbine Engine Recuperator; Aircraft, Engine Blade Scanning and Coating
			Electrification & hybridization	Integrated Power Systems; Electric Ship Research and Development Consortium (ESRDC); Power Electronics Building Block; Silicon Carbide Power Modules; ESARCA – Electrical Ship Assets
			Thermal management, WHR	Aircraft, Integrated Thermal and Power Management Modelling; Thermal Science and Engineering Program
			Demand reduction	LED Lighting; Efficient Transmit/Receive Integrated Multichip Modules (TRIMMs); Variable Frequency Drives (VFDs)
			Energy storage	Energy Magazine; Energy Storage Flywheel; Electrochemical Materials
			Lightweight materials	
	0% - 15%	Operational Efficiency Improvements	Route optimization	Integrated Climate Weather and Ocean Decision Support; Aerial Refueling Drogue Stabilization
			Plant & speed optimization	Global Energy Information System (GENISYS); Robust Combat Power Control (RCPC); Condition Assessment System
			Trim optimization	
	TBD	Force Structure	Unmanned systems	MQ-25A Unmanned Aerial Refueler; Long Endurance Unmanned Surface Vessel; Robust Unmanned Platform Power System (RUPPS)
			"Single mission optimized" platforms	
			Attritable assets	
			UxV system modeling	

Summary of Current Activities – Navy *(2 of 2)*

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	Navy: Summary of Major Efforts
Major Thrust Areas	0% - 100%	Fuel Technologies Production, Distribution, Storage and/or Use	Blended or drop-in fuels (bio-, renewable-)	Mobility Fuels Program; Service Review of Commercially Approved SAF; Direct Air Capture and Blue Carbon Removal Technology
			Non drop-in liquid fuels (ammonia, methanol, etc.)	Reactor-at-sea, NH3 synthesis, powder catalyst
			Hydrogen	Shipboard Hydrogen R&D; Refueling & Support Package (RASP)
			Batteries	Common Affordable Safe Energy Storage (CASES); Battery Development and Safety; Commercial Advanced Batteries; Battery Commonality; Battery Certification; Large Format Lithium Ion Batteries; COTS Battery Phase II
			Nuclear	
			Renewable energy	Alternative Energy S&T; Subsea & Seabed Warfare (SSW) Energy Harvesting; Biocentric Technology; Ocean Renewable Energy
			Fuel cell technology	H2 Stalker; Microbial Fuel Cells
	TBD	Carbon Capture, Use and Storage	Shipboard	Direct Air Capture and Blue Carbon Removal Technology
			Terrestrial	
			Other emissions capture/reduction	
Cross-Cutting Initiatives	N/A	Whole ship and system level design considerations	Ship design process	
			System level design considerations	
	N/A	Ship integration and technology scaling for shipboard use	Ship integration (e.g., retrofit-ability, durability, etc.)	
			Scaling for shipboard use	
	N/A	Modeling, test sites and demonstration capability	Modeling & data analytics	Theater Energy Model; Modeling & Simulation; Digital Twin Science and Technology
			Bench scale testing	
			Demonstrations & testing	
	TBD	Education and Training	Education & training	Workforce Development

Summary of Current Activities – DOE *(1 of 2)*

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	DOE: Summary of Major Efforts
Major Thrust Areas	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction	EERE – Vehicle Technologies Office: Lightweight and Propulsion Materials; Fuel Efficiency and Emissions EERE: Marine Decarbonization
			Propulsion & power generation improvements	EERE – Vehicle Technologies Office: Lightweight and Propulsion Materials EERE: Marine Decarbonization
			Electrification & hybridization	EERE: Marine Decarbonization EERE – Vehicle Technologies Office: Plug-in Electric Vehicles and Batteries
			Thermal management, WHR	EERE: Advanced Manufacturing and Industrial Decarbonization; Waste Heat Recovery
			Demand reduction	EERE: Advanced Manufacturing and Industrial Decarbonization; Industrial Efficiency and Decarbonization Office
			Energy storage	EERE - Vehicle Technologies Office: Plug-in Electric Vehicles and Batteries; Batteries
			Lightweight materials	EERE – Vehicle Technologies Office: Lightweight and Propulsion Materials
	0% - 15%	Operational Efficiency Improvements	Route optimization	
			Plant & speed optimization	
			Trim optimization	
	TBD	Force Structure	Unmanned systems	
			"Single mission optimized" platforms	
			Attritable assets	
			UxV system modeling	

EERE = Office of Energy Efficiency & Renewable Energy

Summary of Current Activities – DOE *(2 of 2)*

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	DOE: Summary of Major Efforts
Major Thrust Areas	0% - 100%	Fuel Technologies Production, Distribution, Storage and/or Use	Blended or drop-in fuels (bio-, renewable-)	EERE - Bioenergy Technologies Office: Bioenergy Technologies; Transportation Biofuels; Sustainable Marine Fuels; SAF Grand Challenge EERE: Marine Decarbonization EERE - Vehicle Technologies Office: Advanced Engine and Fuels Technologies; Fuel Effects on Advanced Combustion EERE: Clean Fuels & Products Shot
			Non drop-in liquid fuels (ammonia, methanol, etc.)	EERE - Bioenergy Technologies Office: Sustainable Marine fuels EERE - Vehicle Technologies Office; Advanced Engine and Fuels Technologies; Fuel Effects on Advanced Combustion EERE - Hydrogen and Fuel Cell Technologies Office: Novel Hydrogen Carriers – i.e. ammonia or natural gas EERE: Clean Fuels & Products Shot
			Hydrogen	EERE - Hydrogen and Fuel Cell Technologies Office: Hydrogen Shot; U.S. National Hydrogen Strategy and Roadmap; H2@Scale Office of Clean Energy Demonstrations: Regional Clean Hydrogen Hubs EERE - Vehicle Technologies Office: Advanced Engine and Fuels Technologies
			Batteries	EERE - Vehicle Technologies Office: Plug-in Electric Vehicles and Batteries; Batteries
			Nuclear	Office of Nuclear Energy
			Renewable energy	EERE - Bioenergy Technologies Office: Sustainable Maritime Fuels; Marine Decarbonization EERE - Vehicle Technologies Office: Advanced Engine and Fuels Technologies
			Fuel cell technology	EERE - Vehicle Technologies Office: Fuel Effects on Advanced Combustion
	TBD	Carbon Capture, Use and Storage	Shipboard	Office of Fossil Energy and Carbon Management - Office of Carbon Management: Carbon Negative Shot EERE: Marine Decarbonization EERE: Advanced Manufacturing and Industrial Decarbonization; Industrial Efficiency and Decarbonization Office
			Terrestrial	
			Other emissions capture/reduction	

EERE = Office of Energy Efficiency & Renewable Energy

Summary of Current Activities – DOT *(1 of 2)*

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	DOT: Summary of Major Efforts
Major Thrust Areas	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction	Hull Fouling
			Propulsion & power generation improvements	
			Electrification & hybridization	Battery Electric Workboat Technoeconomic Analysis; Battery Electric Tug Boat Demonstration; Battery Electric Ferry Demonstration
			Thermal management, WHR	
			Demand reduction	Emission Reduction Technology - Energy Efficiency White Paper, Energy Efficiency and Decarbonization Technical Guide (2022)
			Energy storage	
			Lightweight materials	
	0% - 15%	Operational Efficiency Improvements	Route optimization	
			Plant & speed optimization	
			Trim optimization	
	TBD	Force Structure	Unmanned systems	Autonomous Systems for Environmental Applications; workboat demonstration of autonomous vs manned for emissions
			"Single mission optimized" platforms	
			Attritable assets	
			UxV system modeling	

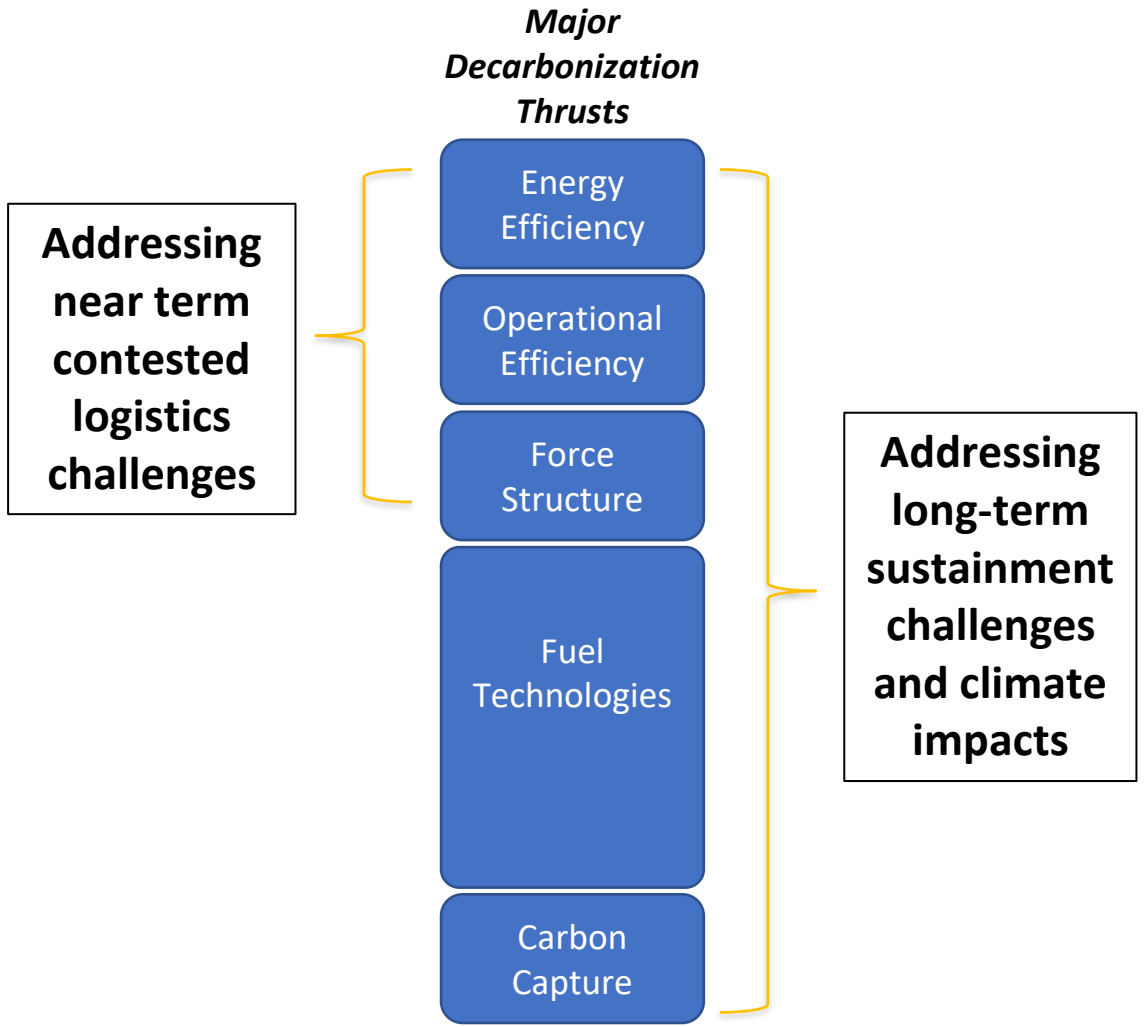
Summary of Current Activities – DOT *(2 of 2)*

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	DOT: Summary of Major Efforts
Major Thrust Areas	0% - 100%	Fuel Technologies Production, Distribution, Storage and/or Use	Blended or drop-in fuels (bio-, renewable-)	Fuel-related Initiatives - various bio-fuel and bio-diesel reports; Methanol testing on 4-stroke marine engine (ORNL/DOE)
			Non drop-in liquid fuels (ammonia, methanol, etc.)	Emission Reduction Technology - Lifecycle Analysis of the Use of Methanol for Marine Transportation; Ammonia testing on a 4-stroke marine engine (in partnership w/ ORNL & DOE)
			Hydrogen	Fuel Cells - Hydrogen Gas Dispersion Modeling
			Batteries	Hybrid and Batteries; vessel demonstration of battery electric for tug boat and ferry
			Nuclear	
			Renewable energy	Regional studies on future energy options for Great Lakes; California Harbor craft; GOM offshore supply vessels and tugs/tows on the lower Mississippi
			Fuel cell technology	Fuel Cells - SF BREEZE, ZERo/V, etc.
	TBD	Carbon Capture, Use and Storage	Shipboard	Maritime Decarbonization - Carbon Capture and Storage Study; Technoeconomic analysis for Carbon Capture; Engineering design study for carbon capture on tanker
			Terrestrial	
			Other emissions capture/reduction	
Cross-Cutting Initiatives	N/A	Whole ship and system level design considerations	Ship design process	
			System level design considerations	
	N/A	Ship integration and technology scaling for shipboard use	Ship integration (e.g., retrofit-ability, durability, etc.)	
			Scaling for shipboard use	
	N/A	Modeling, test sites and demonstration capability	Modeling & data analytics	GHG emissions calculator for vessels
			Bench scale testing	
			Demonstrations & testing	
	TBD	Education and Training	Education & training	

Preliminary Gaps

Preliminary Gaps

- Significant investment across Navy in energy efficiency, operational efficiency and unmanned systems to address near-term contested logistics challenges
  - Some investment in lower carbon fuels and carbon capture technologies, primarily focused on fuel generation in theater
- Operational Efficiency and Force Structure are not prioritized for this effort focused on maritime platform decarbonization
- Carbon capture technologies and the challenges surrounding the use of lower carbon fuels identified as primary gaps for focus of the Year 1 Research Agenda



Preliminary Gaps

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	Navy	DOE	DOT
Major Thrust Areas	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction	◊◊	X	X
			Propulsion & power generation improvements	◊◊◊◊◊	X	
			Electrification & hybridization	◊◊◊	X	X
			Thermal management, WHR	◊◊◊◊	X	
			Demand reduction	◊◊◊◊	X	X
			Energy storage	◊◊◊	X	
			Lightweight materials		X	
	0% - 15%	Operational Efficiency Improvements	Route optimization	◊		
			Plant & speed optimization	◊		
			Trim optimization			
	TBD	Force Structure	Unmanned systems	◊◊		X
			"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-)	◊	X	X
			Non drop-in liquid fuels (ammonia, methanol, etc.)	◊	X	X
			Hydrogen	◊◊	X	X
			Batteries	◊◊◊	X	X
			Nuclear		X	
			Renewable energy	◊◊	X	X
			Fuel cell technology	◊	X	X
	TBD	Carbon Capture, Use and Storage	Shipboard	◊	X	X
			Terrestrial			
			Other emissions capture/reduction	◊		
Cross-Cutting Initiatives	N/A	Whole ship and system level design considerations	Ship design process	◊		
			System level design considerations			
	N/A	Ship integration and technology scaling for shipboard use	Ship integration (e.g., retrofit-ability, durability, etc.)			
			Scaling for shipboard use			
	N/A	Modeling, test sites and demonstration capability	Modeling & data analytics	◊◊		X
			Bench scale testing			
			Demonstrations & testing			
	TBD	Education and Training	Education & training	◊		

Year 1 Research Agenda

Year 1 Research Agenda

- Collaboration of USC, CSU, PSU, USNA
  - Sang Hee Won (University of South Carolina): Fuel Flexible Gas Turbine Technology Integrated with Exhaust Gas Recirculation and Hydrogen Carrier Fuels
  - Bret Windom (Colorado State University) Liquid-Fueled Solar Centaur 40 Gas Turbine Testing with High EGR Fraction to Support Carbon Capture System Integration
  - Brian Fronk (Penn State University): Fuel Flexible Gas Turbine Technology Integrated with Carbon Capture and Utilization
  - Andrew Smith (USNA): Working Towards Zero-Carbon Naval Energy Technologies with Midshipmen at the USNA
- Collaboration of GWU, NPS, ABS
  - Saniya LeBlanc (George Washington Univ): Energy Systems Modeling, Prediction, and Planning Tool for Navy Decarbonization Technologies
- Ronald Giachetti (NPS): Trade space exploration for climate impact and quality attributes for navy ships
- Marcello Romano (NPS): High-level system architecture, modeling and performance evaluation of a fleet of green-energy ships producing hydroelectric energy and hydrogen at sea
- Sage Kokjohn (Univ of Wisconsin): Enabling mixing-controlled combustion of low carbon fuels in naval reciprocating engines
- Jessica Krogstad (Univ of Illinois): Sustainable Power for Decarbonization of Naval Vessels
- John Heinzel (NSWC Philadelphia): Evaluation of Propulsion Derived Ship Service and Weapons Power to Support Decarbonization

Year 1 Research Agenda - Summary

	Approx Impact to Operational Navy Decarbonization (%)	Category	Sub-Category	USC	CSU	PSU	USNA	GWU	NPS1	NPS2	UWisc	U-Ill	NSWC-Philly
Major Thrust Areas	0% - 15%	Energy Efficiency	Propulsive efficiency improvements & direct drag reduction										
			Propulsion & power generation improvements	X	X	X	X				X	X	X
			Electrification & hybridization					X					X
			Thermal management, WHR		X	X	X					X	
			Demand reduction		X			X					
			Energy storage					X					
			Lightweight materials										
	0% - 15%	Operational Efficiency Improvements	Route optimization		X								
			Plant & speed optimization										X
			Trim optimization										
	TBD	Force Structure	Unmanned systems							X			
			"Single mission optimized" platforms										
			Attritable assets										
			UxV system modeling							X			
	0% - 100%	Fuel Technologies Production, Distribution, Storage and/or Use	Blended or drop-in fuels (bio-, renewable-)	X	X	X	X		X			X	
			Non drop-in liquid fuels (ammonia, methanol, etc.)	X	X	X	X	X	X		X	X	
			Hydrogen		X	X	X	X	X	X		X	
			Batteries					X	X				
			Nuclear										
			Renewable energy				X		X	X			
			Fuel cell technology					X	X				
	TBD	Carbon Capture, Use and Storage	Shipboard		X	X	X					X	
			Terrestrial		X			X				X	
			Other emissions capture/reduction										
Cross-Cutting Initiatives	N/A	Whole ship and system level design considerations	Ship design process						X				
			System level design considerations		X				X			X	
	N/A	Ship integration and technology scaling for shipboard use	Ship integration (e.g., retrofit-ability, durability, etc.)		X						X	X	X
			Scaling for shipboard use		X	X						X	
	N/A	Modeling, test sites and demonstration capability	Modeling & data analytics	X	X		X	X		X	X	X	
			Bench scale testing	X		X	X				X	X	
			Demonstrations & testing		X	X					X	X	X
	TBD	Education and Training	Education & training	X	X	X	X	X		X	X	X	

DRAFT Summary Roadmap

Capability Evolution Plan (CEP) Approach

Capability Evolution Plan

Guidebook

Version 1.0

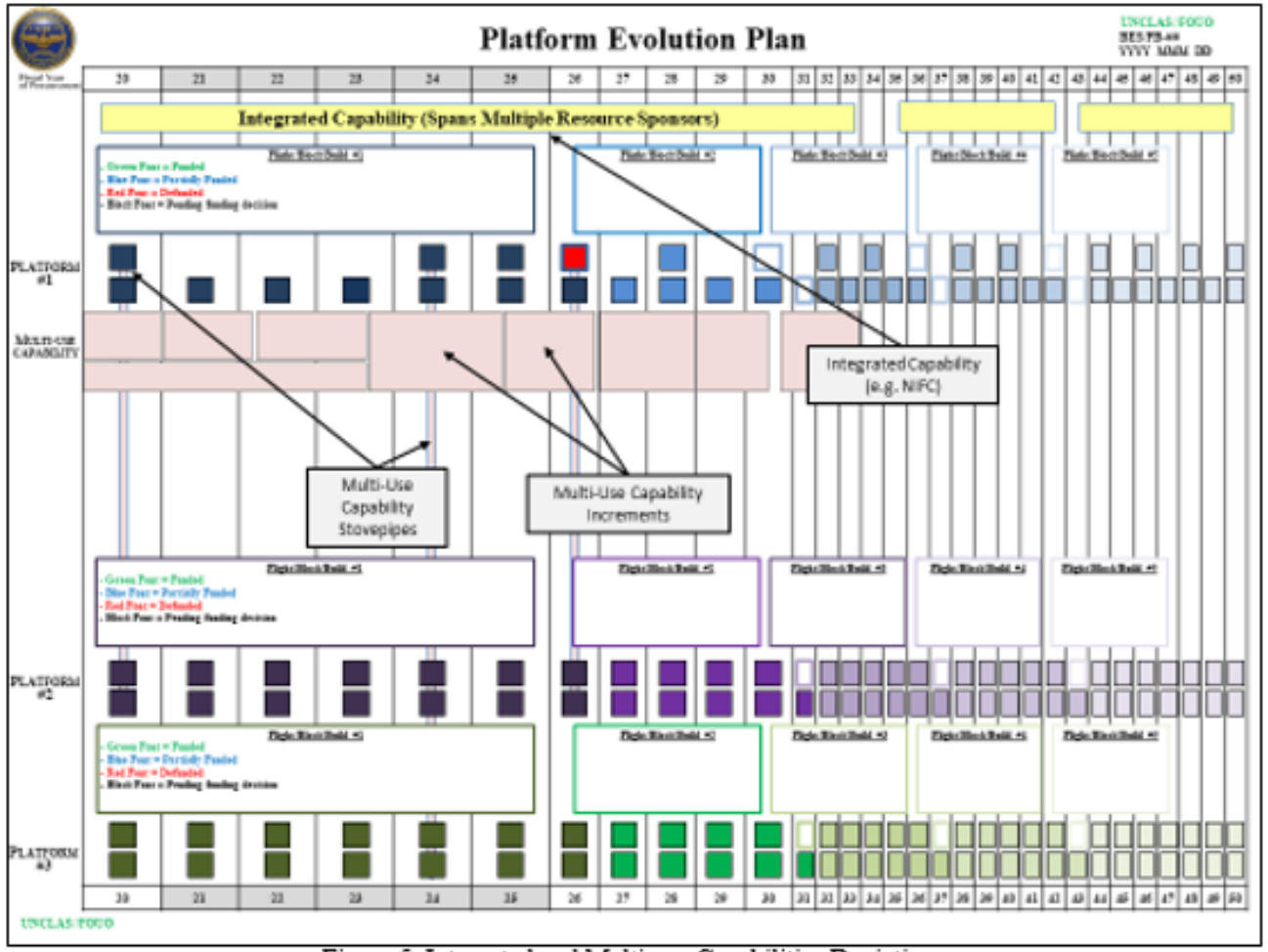
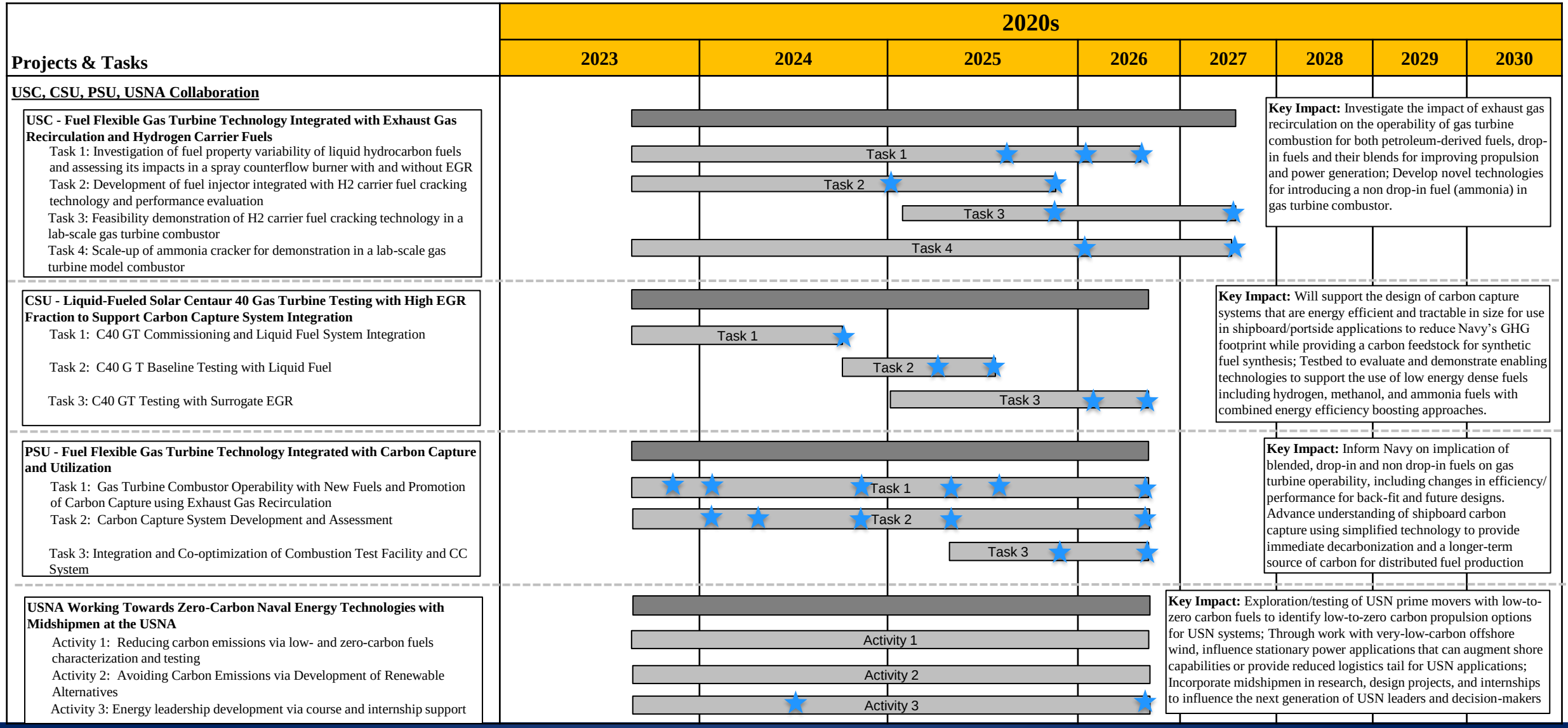


Figure 5. Integrated and Multi-use Capabilities Depiction

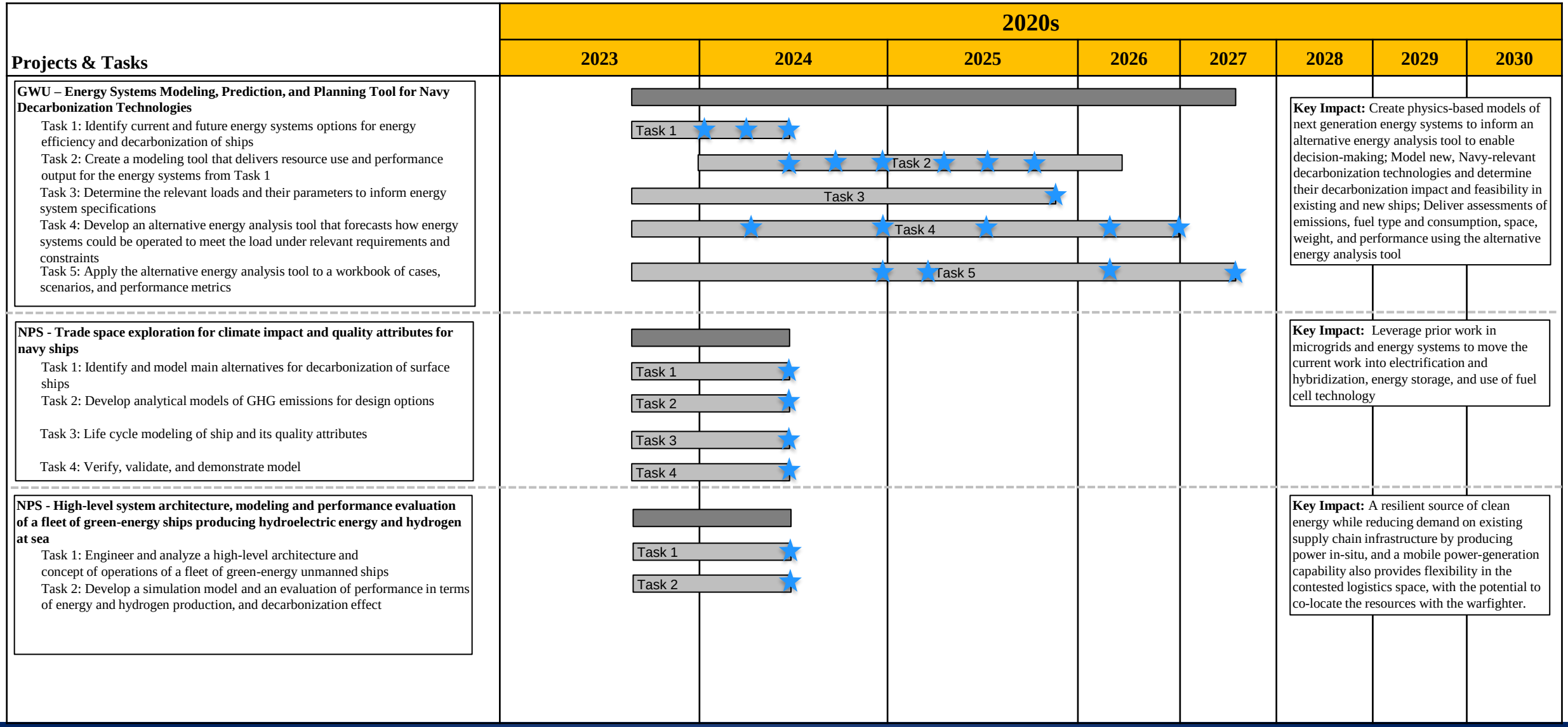
Year 1 Research Agenda - Preliminary CEPs

★ Key milestones



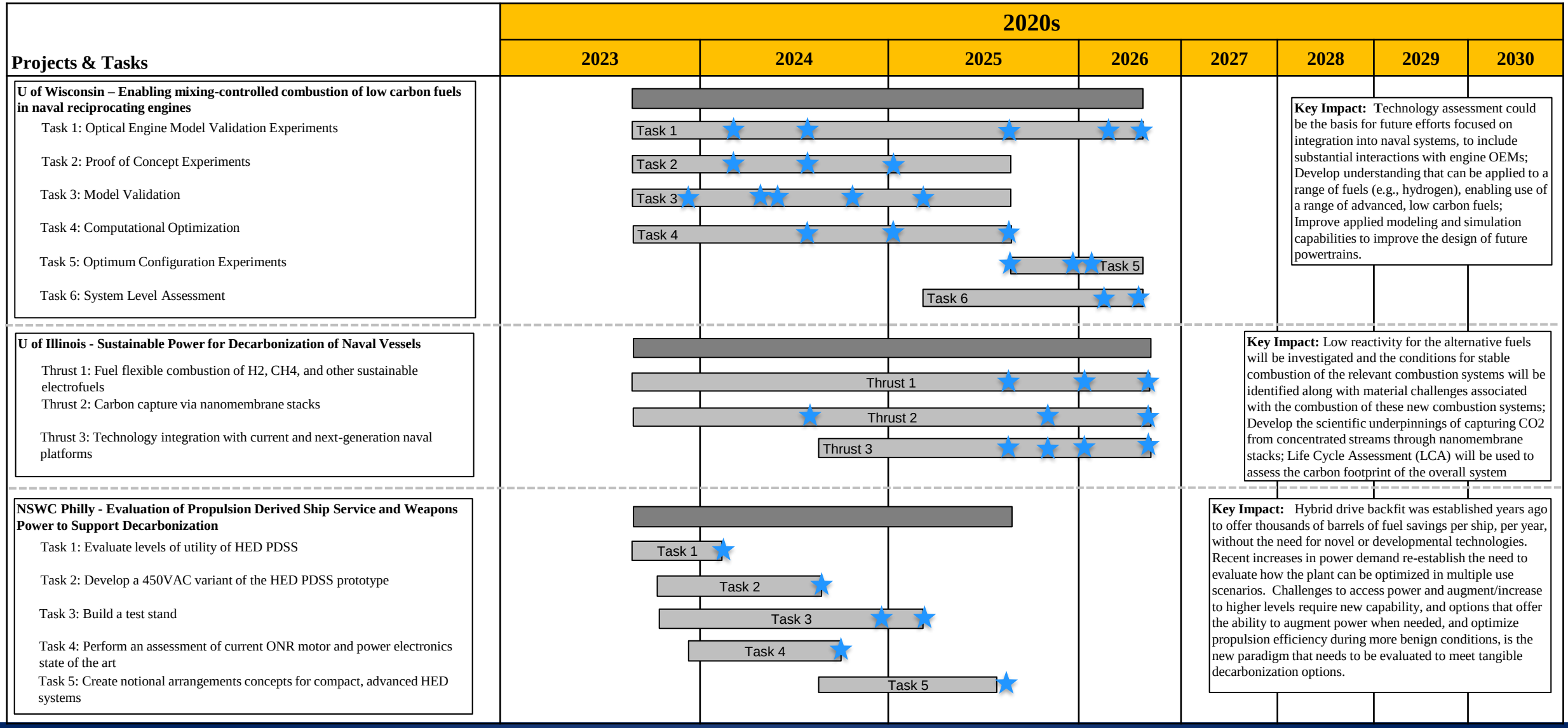
Year 1 Research Agenda - Preliminary CEPs *(cont.)*

★ Key milestones



Year 1 Research Agenda - Preliminary CEPs *(cont.)*

★ Key milestones



DRAFT Summary Roadmap

Major Decarbonization Thrusts

- Energy Efficiency
- Operational Efficiency
- Force Structure
- Fuel Technologies
- Carbon Capture

Cross Cutting Initiatives

2020s	2030s	2040s

Advance the technology ⇨

Test and Integrate ⇨

Accelerate and Scale ⇨

Key Actions

1) Increase collaboration between Navy, DOE and DOT with specific focus on Navy decarbonization challenges (Whole of Government Approach)

2) Expand collaboration to more fully include rest of DoD, private sector and international partners
3) Mature Year 1 Research Agenda into longer term roadmap through ongoing collaboration activities
4) Set realistic decarbonization targets for each major thrust area
5) Further develop Capability Evolution Plans for each major thrust area
6) Start to assess potential transition timelines based upon future shipbuilding plan and development paths
7) Identify policies that constrain adoption of promising technologies and offer appropriate policy changes
8) Analyze and assess any safety-related issues that may hinder adoption

9) Execute Year 1 Research Agenda

Key Actions

1) Identify specific target platforms for technology transition
2) Work directly with relevant Program Offices to transition technology onto platforms
3) Continue collaboration across government, industry and academia
4) Continue to assess new emerging technology with potential relevance to Navy platform decarbonization

5) Meet 2050 decarbonization goals

Next Steps

Next Steps

- Solicit and integrate feedback from ONR leadership and other stakeholders and get concurrence on path forward
- Establish persistent collaboration structure for Navy/DOE/DOT
  - Other DoD and commercial?
- Continue gap identification process and further develop Roadmap and CEPs
- Align with other roadmap and data collection efforts
  - 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 and Installations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