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BWX Technologies, Inc.

Nuclear Reactors for Decarbonized Civil Maritime Transportation

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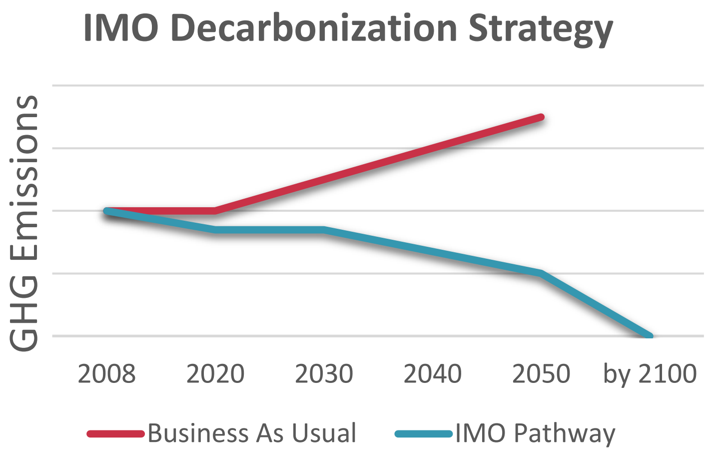
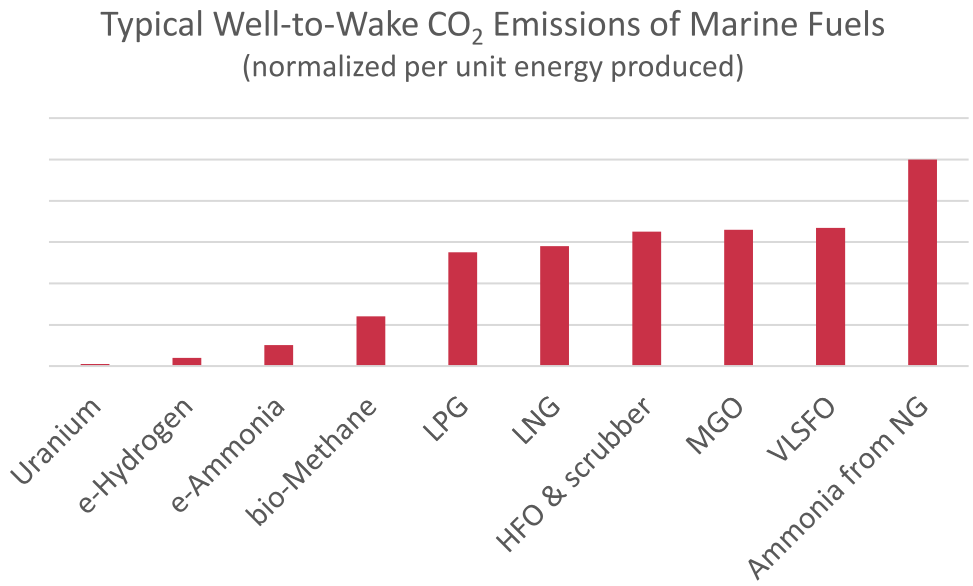
BWXT Advanced Technologies, LLC

Decarbonizing maritime transportation is an extraordinary challenge…





SOLUTION OPTIONS:

1. **e-fuels generated via zero-carbon energy**
2. **On-ship clean energy generation**

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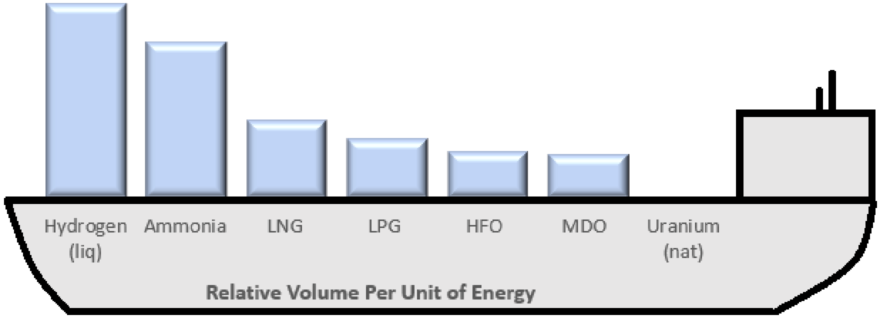
IMO objectives can be achieved with existing nuclear technology!

- Production of e-fuels using nuclear energy
  - Zero-emission
  - High power density needed for sufficient fuel volumes
  - Consider fuel volume and safety



- or, on-board nuclear electric plant
  - Zero-emission, low noise
  - Small footprint
  - Stable operational costs
  - Potential for higher ship speed
  - Ability to redirect electric power to shore
  - Legal and regulatory challenges

BWXT Company Highlights

BWXT is one of the world's most prolific nuclear technology innovation companies and the sole manufacturer of naval nuclear reactors for U.S. submarines and aircraft carriers.

6,600
highly skilled employees

$2.1 billion USD
in 2021 revenues

12
major manufacturing facilities totaling 3.9 million square feet

60+
years manufacturing naval nuclear components and reactors

300+
commercial nuclear steam generators manufactured

1.5 million+
Canada Deuterium Uranium (CANDU) fuel bundles provided

13
U.S. Department of Energy laboratories, environmental cleanup projects and NASA sites

8,000+
fuel elements delivered to U.S. national laboratories, universities and international customers

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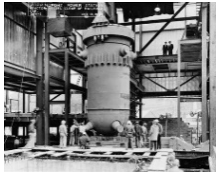
165-Year History of Innovation
75-Year History of Nuclear Technology

1856
Stephen Wilcox patented the water tube boiler

1907
Teddy Roosevelt's Great White Fleet powered by B&W boilers

1946
Awarded first U.S. Navy contract for propulsion systems

1953
Designed and fabricated components for world's first nuclear powered submarine



1956
Manufactured components for first commercial nuclear power plant in the U.S.

1962
Designed and furnished commercial nuclear reactor systems for Indian Point

1966
Initiated design and fabrication of nuclear components for Nimitz-class aircraft carriers

1994
Awarded first major DOE site management and operating contract at Idaho National Engineering and Environmental Laboratory

1997
Awarded first prime contract from DOE

2015
Selected for design and manufacturing contracts for HPR1000 nuclear plant

2017
Awarded NASA Nuclear Thermal Propulsion Reactor Design contract

2018
Announced disruptive medical isotope manufacturing technology

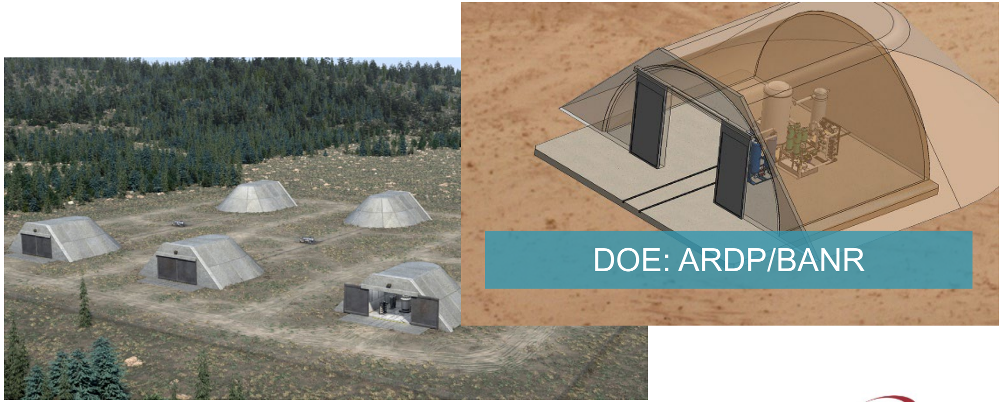
2019
Introduced FDA-approved medical isotope In-111 generic for diagnostic imaging to the U.S. market

2020
Restarted TRISO advanced nuclear fuel manufacturing for future DoD and NASA missions

2020
Awarded DoD contract for mobile nuclear reactor design

NON-NUCLEAR — 1856
NUCLEAR — 1946
1994
BWXT ERA — 2015

Ongoing Projects in BWXT Advanced Technologies



Marine nuclear, even civilian, is not new!

Sevmorput (Rosatom) – 61,000 dwt cargo/icebreaker, 1988-present

NS Savannah (US) – civilian passenger-cargo liner operated from 1962-1965

Reactor technology is continuously improving, but the big catalyst today is the DRIVE FOR DECARBONIZATION

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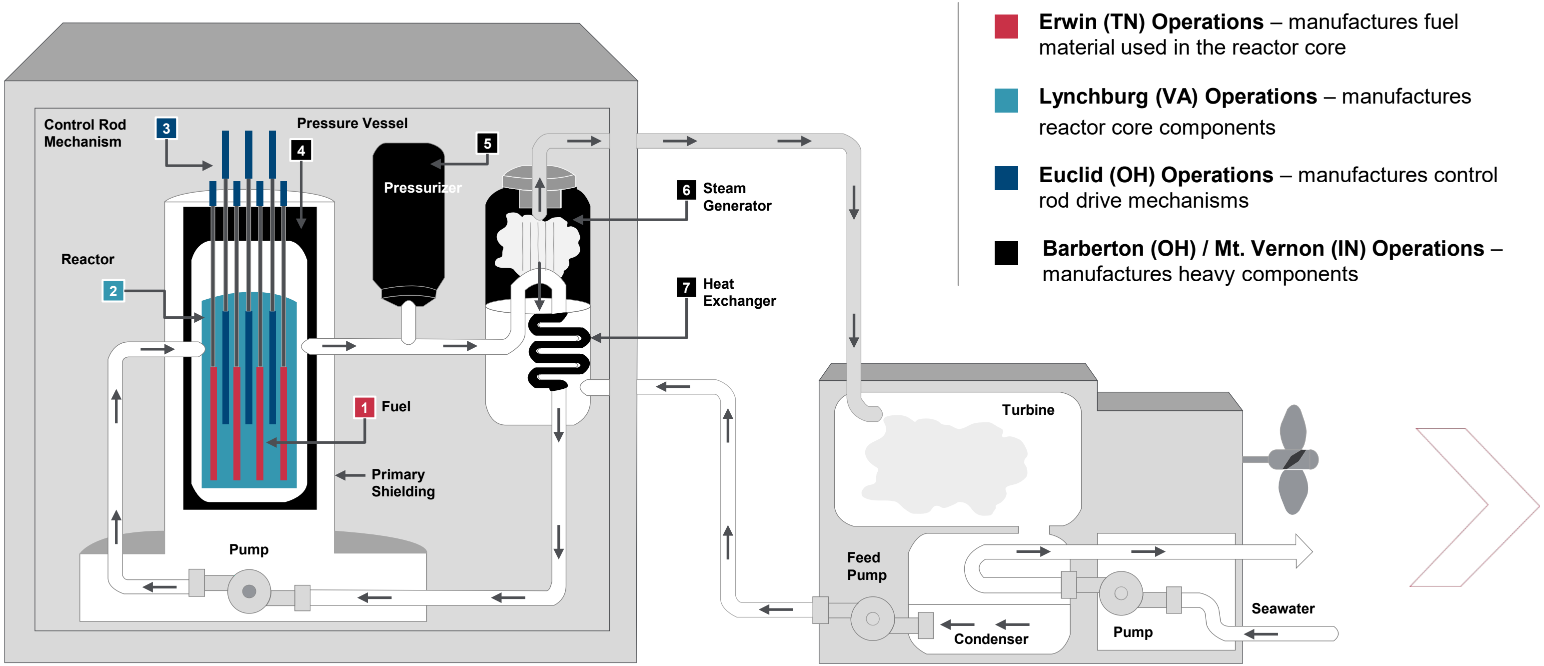
Naval Nuclear Steam Supply System



- **Erwin (TN) Operations** – manufactures fuel material used in the reactor core
- **Lynchburg (VA) Operations** – manufactures reactor core components
- **Euclid (OH) Operations** – manufactures control rod drive mechanisms
- **Barberton (OH) / Mt. Vernon (IN) Operations** – manufactures heavy components

What do we mean by “Nuclear Safety”?

- SUB-CRITICALITY – the ability to “shut down” the self-sustaining nuclear fission reaction
  - Chernobyl disaster exemplifies failure to control nuclear criticality
  - American reactor designs utilize configurations that ensure this type of accident is <u>impossible</u> per the laws of physics; e.g. “negative reactivity feedback”
- DECAY HEAT REMOVAL – the ability to keep reactor components below melting temperatures during fission product decay in a shutdown reactor
  - Three Mile Island & Fukushima exemplify failure to remove decay heat
  - Advanced reactors make use of “passive cooling” concepts
  - In HTGRs like BANR (for example), maximum temperatures possible during accident scenarios remain below the melting points of advanced materials
- RADIATION SHIELDING – minimizing radiation dose during and after operation

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Considerations for commercial maritime nuclear systems

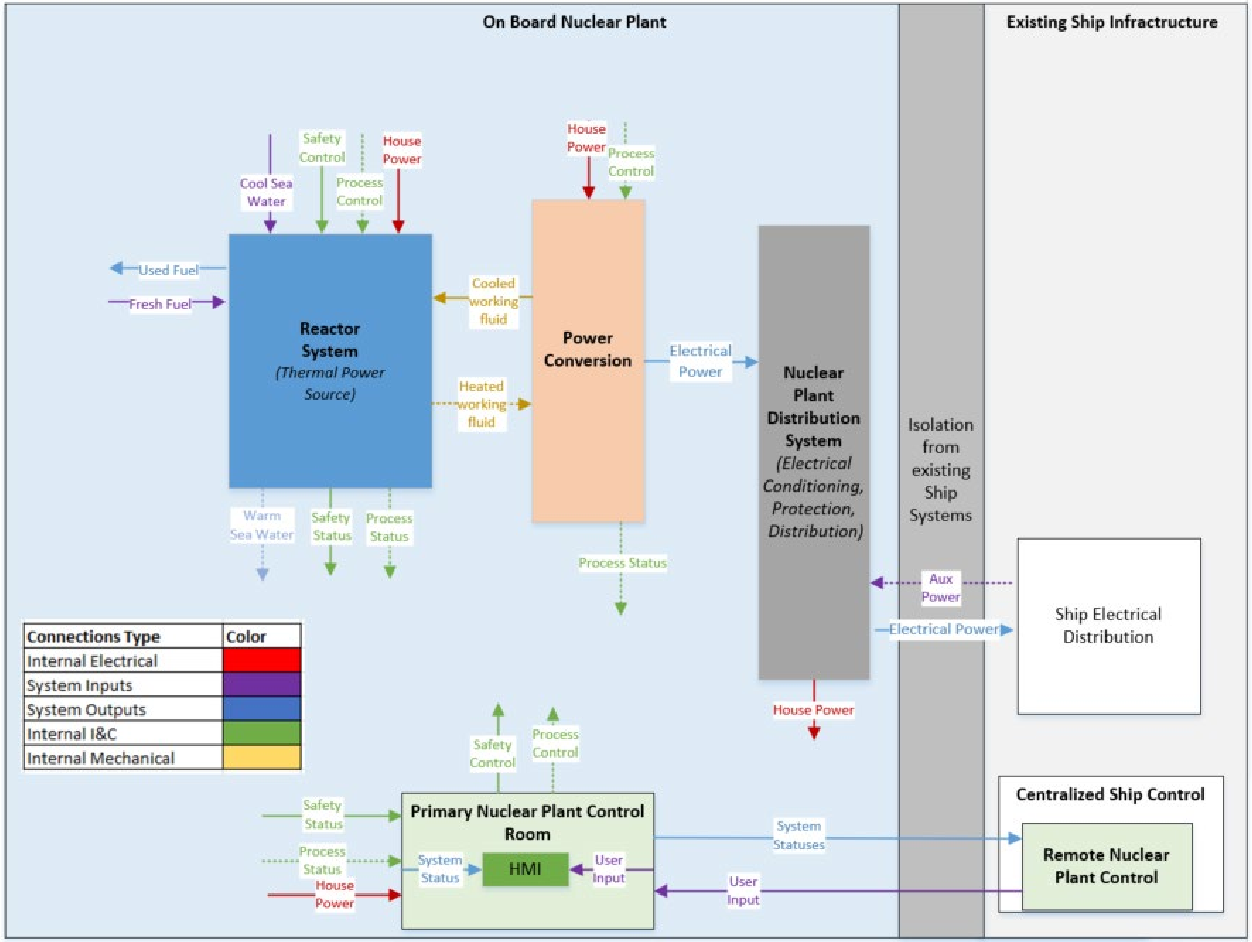
- Many reactor technologies exist, though TRL (Technical Readiness) varies

Mature Technologies			Industry Research Focus Areas	
Pressurized Water Reactor (PWR)	Boiling Water Reactor (BWR)	High Temperature Gas Reactor (HTGR)	Molten Salt Reactor (MSR)	Fusion

- Civil maritime nuclear will likely differ from naval propulsion:
  - Commercial maritime reactors will not utilize HEU fuel (>20% U-235)
  - Commercial maritime nuclear plants will produce power to drive electric motors, rather than direct mechanical propulsion

- Nuclear and wind solutions are not mutually exclusive!

Example System Architecture – On-ship Nuclear Plant



Connections Type	Color
Internal Electrical	
System Inputs	
System Outputs	
Internal I&C	
Internal Mechanical	

The biggest challenges to moving forward are not technical ones!

Regulatory
- Outdated or missing laws
- Jurisdictional questions

Infrastructure
- Reactor handling
- Uranium enrichment

Port Access
- Emergency planning
- Stakeholder education, acceptance

Personnel
- Operators
- Security
- Training programs

Economics
- Capital cost
- Insurance

Waste Mgmt
- Spent fuel removal
- Ship decom.

Tackling these challenges will require close collaboration between industries & their trade groups, and government(s).

For more information on commercial maritime nuclear developments, check out the NRIC Maritime Nuclear Application Group at: https://nric.inl.gov/maritime/

Questions?