The Future of the Maritime Industry & Decarbonization

Presenter Name | Month Date, Year

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Overview of Decarbonization

- What is decarbonization & why is it important?
  - Decarbonization refers to the climate change method of mitigation and process to reduce or eliminate carbon dioxide (CO_2) and greenhouse gas (GHG) emissions in the atmosphere.
  - In the shipping industry this involves three key aspects: vessel technology that is energy efficient, operational optimization, and low/zero carbon or carbon neutral fuels. Of these three lowering carbon neutral fuels is the most impactful.
  - To develop decarbonizations equates to mitigating the effects of global warming.
- Current government initiatives
  - U.S. target to be 50-52% reduction of economy-wide GHG pollution from 2005 by 2030.
  - Internation Maritime Organization Goals
  - United Nations Goal 13

Credit: Little Visuals – Nic Jackson

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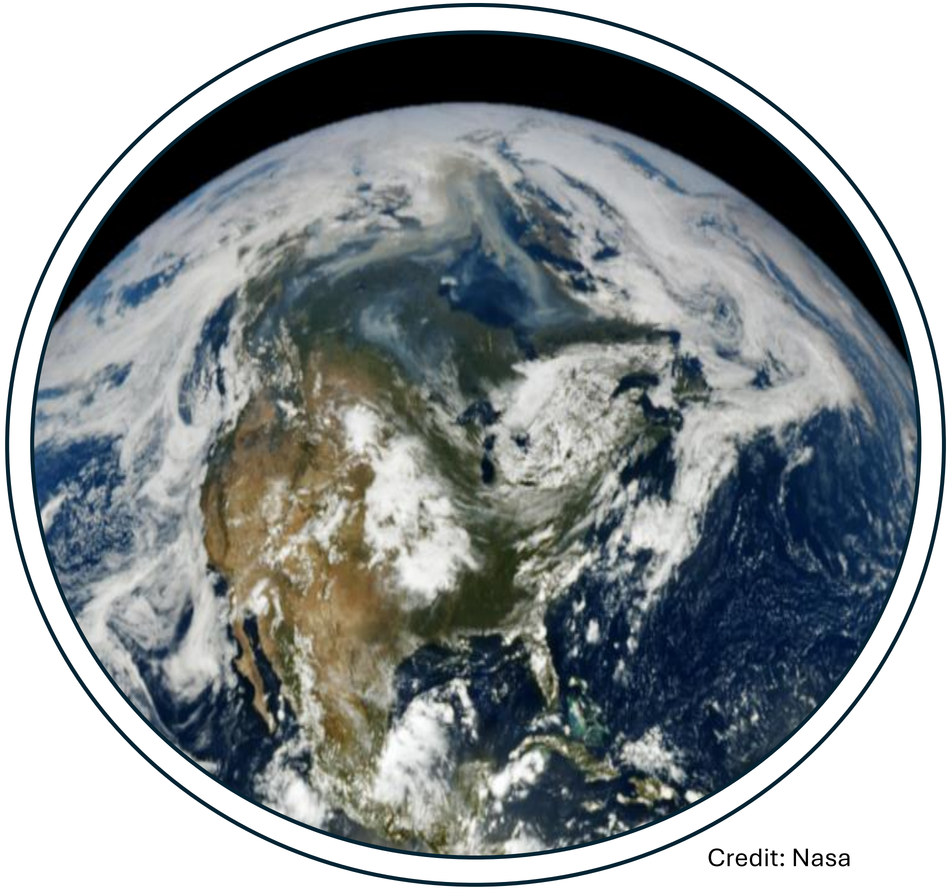
IMO Decarbonization Influence?

Photo: UK Hydrographic Office

- IMO's overarching goal is to minimize GHG emissions from global shipping while urgently seeking to eliminate these emissions as quick as possible. This coincides with a broader strategy which emphasizes a fair and equitable transition.
- The main targets:
  - Reduce CO2 emissions per transport work by 40% (with respect to 2008 levels) by 2030
  - Reduce total annual GHG emissions by 70% by 2040
  - Reach net-zero GHG emissions by or around 2050
- Three-step approach:
  - Short-term (2018-2030)
  - Mid-term (2030-2040)
  - Long-term (2040-2050)

Overview of Decarbonization

- Why are we interested in alternative fuels?
  - Alternative fuels provide many benefits that cannot be visualized by their fossil fuel counter parts.
- Environmental impact
  - Reduce GHG emissions compared to traditional fossil fuels
  - Reduction on any environmental risks such as oil spills when in extraction and transportation phase.
  - Minimize reliance on depleting fossil fuels
  - Key component to climate change mitigation
- Business/economic potential
  - Alternative fuels allow for newer regulatory requirement targets to be met
  - Provide companies with competitive edge which can also attract eco-conscious customers



Credit: Nasa

Overview of Decarbonization

SHORT-TERM (2018-2030)

- Mandatory goal-based technical and operational measures to reduce intensity of international shipping
- Energy Efficiency Design Index (EEDI): encourages the use of energy efficient equipment and engines in new ship designs to produce less pollutions.
- Enhance the Ship Energy Efficiency Management Plan (SEEMP): improves a ship’s energy efficiency while being cost-effective.
- Data collection System (DCS): Requires ships to record/report fuel oil consumption for further energy efficient measures
- Carbon intensity indicator (CII) rating that displays the ship’s operational energy efficiency developing from DCS and SEEMP

MID-TERM (2030-2040)

- Encourage energy transition in the shipping industry, offering the global fleet an incentive while providing a fair and equitable transition for all.
- Incentivizes the use of sustainable low-carbon and zero-carbon fuels in international shipping.
- Involves market-based measures

LONG-TERM (2040-2050)

- Reach Net-zero GHG emissions by 2050 or around
- Adoption of alternative fuels
- Energy efficiency improvements

Short-Term Approach

Alternative Fuels in the Maritime Industry

BIOFUELS

Credit: gratisography

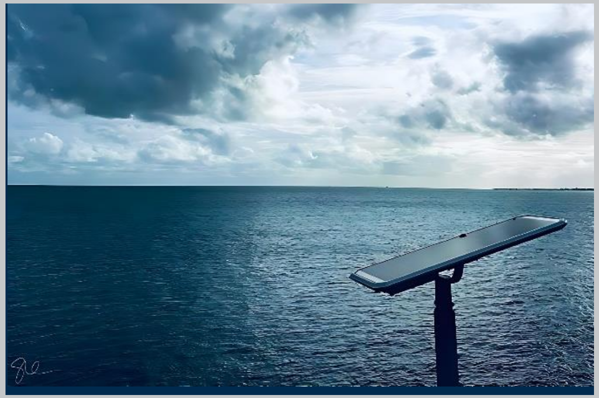
A liquid or gaseous fuel generated by biomass or biowaste.

METHANOL

Credit: Iurii Kovalenko © 123rf.com

A light, volatile, flammable, and toxic liquid alcohol that is commonly used as a solvent, antifreeze, denaturant for ethanol, and in production for various chemicals.

OFFSHORE SOLAR



Credit: Department of Energy

Like onshore counterparts it consists of producing electricity from ocean-based resources. These are solar panels that are mounted on floating structures that are secured to the seabed.

Biofuels - Introduction

Types & Sources

First Generation

These are the most common type of biofuels in production which include:

- Biogas
- Bioethanol
- Biodiesels
- FAME

Next Generation

These are produced from first-generation feedstock or lignocellulose biomass and include:

- Switchgrass
- Trees
- Bushes
- Corn stalks

Future Generation

Recent advancements un biofuel production and include:

- Microbes
- Microalgae

Biofuels – Fuel Production

Production Type 1

Transesterification (biodiesel synthesis)

- Replaces alcohol from esters
- Produces fatty acid methyl esters
- Uses vegetable oils and animal fats
- Prone to hydrolytic and oxidative deterioration

Production Type 2

Thermochemical

- Fast Pyrolysis with Hydrodeoxygenation (FPH)
- Gasification with Fischer-Tropsch Synthesis (GFT)
- Hydrothermal Liquification (HTL) with Hydrodeoxygenation

Production Type 3

Biochemical

- Uses cellulase enzymes for hydrolysis
- Ferments sugars into ethanol
- Recovers unreacted lignin for further conversion
- Less energy required due to no biomass pretreatment
- Needs confirmation for marine fuel standards

Biofuels – Current Uses & Characteristics

Benefits

- Renewable resource
- Minimal modifications needed for existing diesel engines
- Low sulfur content

Characteristics

- Drop-in fuel
- Blends with marine distillate or residual products

Properties

- Greater viscosity then petroleum diesel
- Less viscous drop-in biofuels for HFO improves fuel lubricity
- Higher acid vales when oxidized which can cause potential corrosion
- More susceptible to oxidation degradation
- Higher cloud and pour points than MDO
- Flashpoint: > 93ºC (Pure), 52ºC - 96ºC (Blends), less hazardous
- DOT classification: < 37.8ºC (Flammable), 37.8ºC - 93ºC (combustible)

Current Uses

- Biodiesel is suitable for marine applications
- Drop-in fuel, largely in road fuel distillates like gasoline and diesel.
- Blends with petroleum products such as:
  - Gasoline
  - Diesel fuel
  - Heating oil
  - Kerosene-type get fuel

Biofuels – Perspectives

Environmental Impacts

- Biodegradable
    - When in contact with water it quickly degrades and disperses
- Until fully degraded these spills can behave like petroleum fuels.
    - Oil sheen
    - Water column toxicity
  - Impacts differ based on biofuel type and blend

Business Implications

- Cost savings in the long run
- Compliance with regulatory standards

Credit: lifeofpix - leeroy

Biofuels – Regulatory Considerations

Storage and Usage

- SOLAS Flashpoint of < 60ºC
- Spill recovery and clean-up standard practices

Fire Safety

- Use of dry chemical, foam, halon, CO2, or water spray for B100
- Isolate from oxidizing agents, heat, and ignition sources

Sustainability

- IMO neutrality verification for sustainable feedstock and energy
  - ISCC scheme

International Standards

- ISO 8217: Products from petroleum, synthetic and renewable sources-Fuels (class F) – Specifications of marine fuels
- ASTM D6751: Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
- EN 14214: FAME Biodiesel Specifications

MARPOL Regulation

- Annex VI Regulation 13: Nitrogen Oxides
- Annex VI Regulation 14: Sulphur Oxides and Particulate Matter
- Annex VI Regulation 18: Fuel Availability and Quality
- Annex VI Regulation 22: Attained Fuel Efficiency Design Index (EEDI)

Biofuels - Commercialization

Feedstocks

- Biomass-based diesel plant feedstocks:
  - Rapeseed oil
  - Soybean oil
  - Palm oil
- Animal feedstocks
  - Rendered beef
  - Poultry litter
  - Other animal fats
- Used cooking oil methyl ester (UCOME)

Availability

- Policy and regulation will increase availability
- Feedstock and fuel will vary depending on location, season, regulatory, and environmental conditions
- The organization of economic co-operation and development and the UN's food and agriculture organization agricultural outlook for 2019-2029 indicates that global biodiesel production is said to increase from 11 billion gallons in 2020 to 12.15 billion gallons in 2029.

Market Influence

- Heavily influenced by agricultural policy which supports economy of farmers, reduce GHG emissions, and reduce energy dependency
- International Renewable Energy Agency (IRENA) estimates that by 2040 biofuels will be more competitive
- Fuel Cost Factors:
  - Feedstock type, geography, regulations, taxes, variability labor costs, and seasonal crop rotation.
  - Key factors: feedstock cultivation, transportation, and densification, storage, and pretreatment processes.

Investment Needs

- Minimal investments needed to modify hoses, filters, seals, and synthetic material components
- Fuel infrastructure needs minor modifications to existing fuel stations and bunkering infrastructure to handle biofuel requirements.

Biofuels – Infrastructure Needs

Vessel Arrangements

- Evaluate fuel storage, fuel treatment system, piping, centrifuges, etc.

Storage Requirements

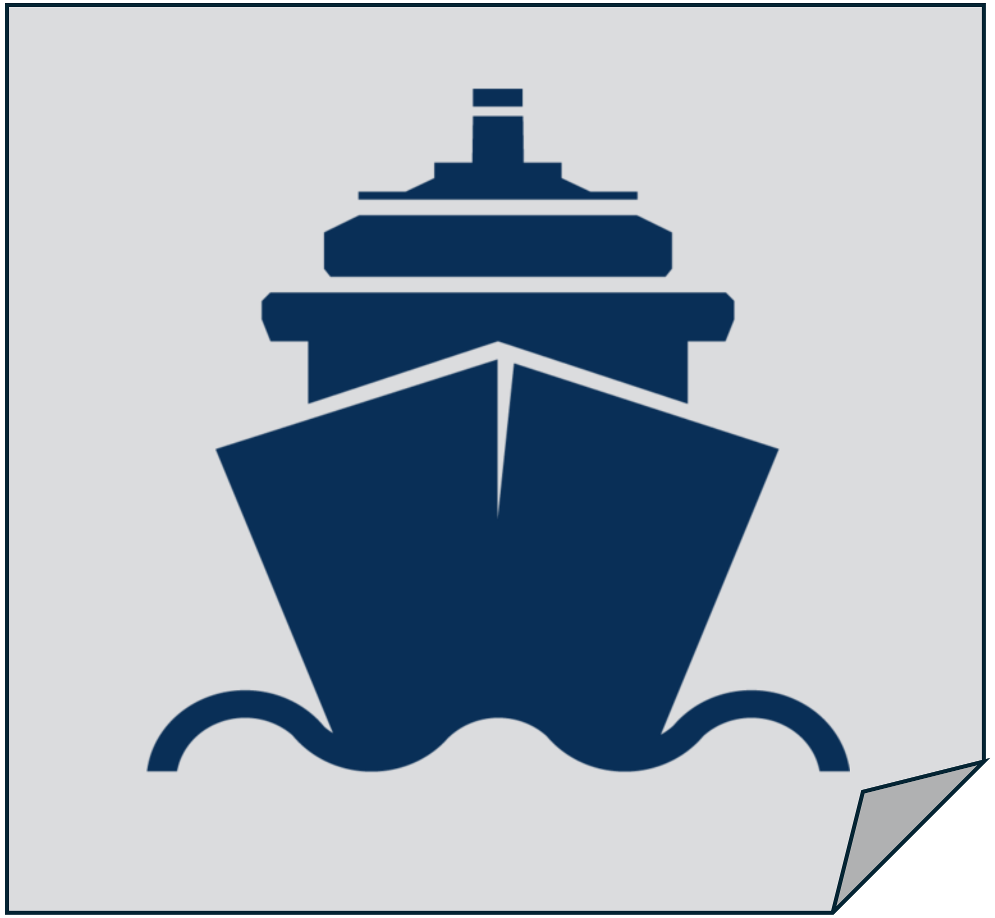
- Increased tank volume for long-distance travel.
- Storage in dark and dry environments
- Temperatures need to be above cloud point

Fuel System Components

- Material for all components are compatible with biodiesel blends.
- Potential addition of high-quality fuel filter systems

Operational and Route Considerations

- Vessel types, engine requirements, and associated cargo operations
- Trade route for the vessel
- Bunkering: location, frequencies, and providers
- Maintenance and repair locations



Biofuels – Limitations & Concerns

Technical and Safety Issues

- Fuel temperature: Range from 10º-15ºC (above cloud point)
  - Improves flow characteristics
  - Reduce clogging
  - Optimize fuel injection, atomization, and combustion in engine cylinders
- Additives are to be regularly tested and monitored for temperature and cloud point properties.
- B100 has a 11% lower energy content than diesel fuel requiring improved combustion performance

Regulation Hurdles

- Compliance with marine fuel standards
- Standards for fire safety protocols
- Regulations provided by IMO, ISO, and MARPOL

Scalability Concerns

- Feedstock availability dependence
- Infrastructure difficulties with larger volume handling
- Economic challenges with scaling up production

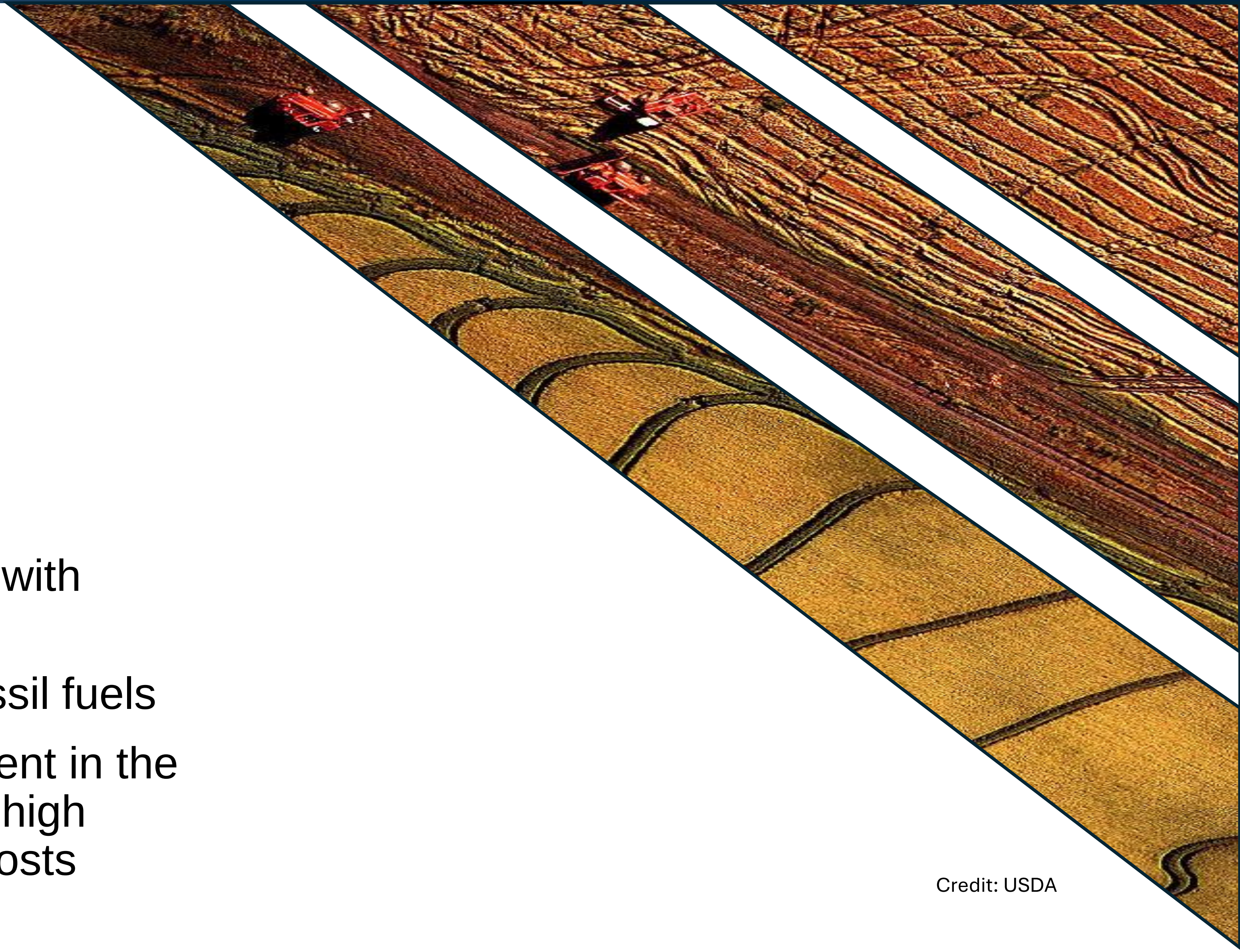
Biofuels – Short- & Long-Term Implications

Short-term

- Reduce GHG emissions
- Agricultural impacts
  - Land resources
  - Price of food
- Increased job opportunity.

Long-Term

- Sustainability improvements along with efficiency improvements
- Supports energy transition from fossil fuels
- Continued research and development in the biofuel sector for efficient process, high production, and lower production costs



Credit: USDA

Methanol - Introduction

Sources & Production

- **Natural Gas**
  - Most common source
  - Three step production process:
    - Synthesis gas (syngas) preparation: Reforming of natural gas with steam through partial oxidation to create syngas (CO, CO2, H2)
    - Methanol synthesis: Using by products of H2 and H2O syngas is converted to methanol
    - Methanol purification/distillation: Removes water from methanol separation using reboiler heat from syngas cooling, which can also produce electricity
  - GHG emissions: higher well-to-tank and well-to-propeller emissions compared to (controversial fuels).
- **Biomass**
  - Feedstock: wood, municipal solid waste, and sewage sludge along with biogas from landfills and wastewater treatment This methanol is considered bio-methanol.
  - Production process:
    - Gasification or pyrolysis: produces syngas when under specific temperature and pressure.
  - GHG-Neutral: carbon released is equal to the amount absorbed by plant matter in its lifetime, however, emissions are present when generating energy for the process.
- **Carbon Dioxide and Hydrogen:**
  - Production Process:
    - Carbon dioxide recovery (CDR): converts excess CO2 from syngas, formed by the steam methane reforming process, and creates more low-carbon methanol.
  - Process developed by Mitsubishi Heavy Industries (MHI)

Methanol– Current Uses & Characteristics

Benefits

- Clean burning: Reduction of SOx and PM emissions
- Easier handling and storage than LNG, hydrogen, and ammonia
- Fewer adoption challenges

Properties

- Highest hydrogen-to-carbon ratio (lowers combustion emissions)
- Specific energy 19,700 kJ/kg (lower than LNG and liquid fuels)
- Requires 2.54x more storage volume
- Lower flame temperature (Reduced NOx formation)
- Life-cycle emissions: NOx and SOx are 45% and 8% of regular fuels
- Suitable for internal combustion engines and fuel cells
- Low flash point (small system modifications)
- Heavier vapor density than air
- Flame characteristics: Low temperature, nearly invisible, no smoke
- Flammable range: 6%-36.5% in air, burns in water mixtures (≥25% methanol)
- Autoignition temperature is 450ºC
- Poisonous to central nervous system

Current Uses

- Methanol-burning Dual Fuel (DF) engines exhibited on a few methanol carriers
- Chemical industry
  - Produces chemicals like formaldehyde and acetic acid.
- Vehicle transportation fuel
- Methanol feedstock production from coal is commercially used in China

Methanol – Perspectives

Environmental Impacts

- Biodegradable in aerobatic and aquatic environments
  - In surface water the half-life is 1-7 days
  - Less harmful/limited damage in spills, apart from carbon being released into marine ecosystems
  - High concentrations will create lethal conditions or alter local marine life
- Burns cleaner reducing CO2 emissions
- Takes part in the food chain as it is naturally consumed by bacteria microbes
- Reduced NOx and PM
- Use as primary fuel results in reduction of CO2 by 10%

Business Implications

- Expected lower operational costs due to the availability of methanol in trade
- Compliance with regulatory standards to help meet carbon reduction goals
- More expensive than low-sulfur marine gas

Credit: lifeofpix – Pierre-Andre

Methanol – Regulatory Considerations

Safety Standards

- NIOSH: IDLH value is 6,000ppm
- OSHA: permissible exposure limit is 200ppm
- Methanex Safety Data Sheet allowable occupational exposure limits is 200 ppm (260mg/m3)

Fire Safety

- Use of alcohol resistant foams to extinguish
- Interim guidelines: IMO MSC.1/Circ.1621 for safe handling and of crew safety

Response Material

- Sorbet materials
- Non-sparking shovels
- Emergency communication devices

PPE For Responders

- Face shields
- Goggles
- Butyl/nitrile gloves
- Chemical-resistant coveralls
- Breathing air provisions

Material and Coating

- Tank interior: use of stainless steel or methanol resistant coatings
- Piping and fittings: avoidance of aluminum and titanium alloys due to increased corrosiveness

System and Equipment Reqs.

- Gas detection: installation of sensitive equipment near leak points, ceilings, and low areas
- Ventilation and relief valves: must be clear adjacent areas to avoid ignition sources
- Electrical equipment must be assigned a T2 surface temperature class
- Tank overflow protection measures to prevent flammable conditions and potential ignition sources

Fire and Explosion Prevention

- IGC and IGF Codes: provide framework for low-flashpoint marine fuels
- IMO interim guide: provide guidelines for ship design, fuel containment, bunkering, fuel supply, fire safety, explosion prevention, hazard area classification, and crew training

Methanol - Commercialization

Supply Chain

- Pre-existing supply chains for methanol fuel are in a good position to supply ships at various ports.
- Available worldwide, with major production in China, United States, and Europe
- As port adopts methanol infrastructure its availability in the marine market increases

Production

- Engine providers include MAN and Wärtsilä offering methanol burning engines
- MAN produces the Two-stroke ME-LGIM system for methanol fuel supply
- Wärstilä's retrofit conversion for methanol utilization (which is a variant of HP DF engine technology) displayed by the Stena Germancia RoPax ferry

Fuel Cost

- Varies based on feedstock prices of natural gas and biomass.
- More expensive then low-sulfur marine gas.

Methanol – Infrastructure Needs

After Treatment Systems

- Needed to reach IMO Tier III emission levels

Fuel Injection

- ME-LGI Concept with booster fuel injector values that raise injection pressures to 550-600 bar

Infrastructure Compatibility

- Usage of pre-existing liquid fuel infrastructure with little conversion

Safety Modifications

- Methanol tank locations along with protection
- Inserting and venting of methanol tanks
- Spill containment
- Vapor and fire detection
- Firefighting measures

Corrosive Nature Considerations

- Appropriate tank coatings, piping, and fixtures
- Use of methanol compatible material (nylon, neoprene, non-butyl rubber)

Spill Response Equipment

- Sorbent materials and non-sparking plastic shovels
- Caution tape/barriers for isolation
- Drum/container for waste material
- Emergency communication devices

Fire Detection and Prevention

- Flame detection equipment (infrared cameras)
- Foaming extinguishing systems
- Robust operational procedures

Additional Measures

- Tank overflow and leak protection
- Assessment of bunkering facilities, containment systems, fuel supply systems, and marine engines
- Adequate ventilation and bunkering systems

Methanol – Limitations & Concerns

Technical and Safety Issues

- Flames burn at low temperatures and are almost invisible with no smoke often going undetected
- Corrosive to certain materials
- Toxicity
  - Poisonous to nervous system
  - Ingestion forms formic acid and formaldehyde. Can lead to blindness, coma, and death
  - Minimum lethal dosage is 10mL while median lethal dosage is 100mL
  - Symptoms can include: headache, vertigo, weakness, nausea, vomiting, inebriation, and death with over exposure
- High vapor concentrations can cause asphyxiation
- Contact with skin causes irritation, dryness, cracking, inflammation, or burns will be observed
- Not fully carbon neutral unless using biomass
  - Methanol feedstock produced from coal negatively impacts GHG emissions
- Low energy content and lower energy storage in tanks on ships
- Challenges for fuel supply, infrastructure, and bunkering remain for its adoption
- Use of nitrogen gas to blanket methanol in moist/salty conditions to prevent corrosion

Regulation Hurdles

- Compliance with marine fuel standards
- Standards for fire safety protocols
- Regulations provided by IMO, ISO, USCG (United States Coast Guard), Maritime Safety Committee (MSC), and MARPOL

Potential Concerns for Scalability

- Feedstock availability dependence
- Meeting global demand

Methanol – Short- & Long-Term Implications

Short-term

- Reduce emissions
  - Reduction of NOx, SOx, and particulate matter
  - Better air quality
- Reduction in GHG emissions which depends on production method (mostly biomass or renewable energy)
- Promotes Infrastructure adaptation and engine compatibility

Long-Term

- Sustainability improvements along with efficiency improvements
- Supports energy transition from fossil fuels
- Continued research and development in the methanol sector for efficient process, high production, and lower production costs
- Development of well-structured regulations for health and safety in production, storage, and use.
- Increased public awareness

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Offshore Solar - Introduction

Sources & Production

- Offshore solar structures use solar radiation, gathering the sunlight to generate electricity
- Existing structures (i.e. oil rigs and wind farms) are mounted with solar panels
- Photovoltaic cells are produced from melted and cut silicone extracted from sand. From here metal conductors are added and once finished these cells can be joined together

Types

Floating Solar Farm

- Involves arrays of such solar panels on floating platforms
- Key components in its structure include solar PV, pontoon, mooring system, inverter, cable, and connections

Hybrid Systems

- Takes advantage of using solar power with other renewable energy sources. These renewable energy sources often include wind and wave.

Integrated Systems

- Utilizes older structures and integrates solar panels on them
- This allows for the utilization of old tools and platforms for more energy production.

Credit: Department of Energy

Offshore Solar – Current Uses & Characteristics

Benefits, Properties & Characteristics

- High energy output during the daylight hours
- In sunny regions there is consistent energy generation. However, there are variations depending on weather conditions
- Durable material able to withstand marine environment
- Integrates with existing marine infrastructure in addition to power management systems

Current Uses

- Piolet projects in Netherlands and Japan
- There are some smaller scale installations on small vessels (usually recreational vessels)

Credit: Department of Energy

Offshore Solar – Perspectives

Environmental Impacts

- Reduction in GHG emissions
- Reduced visual impact when compared to land based solar farms
- Potential for effects on marine life. This can include shading effects on aquatic life
- Risks posed from maintenance and installation activity

Business Implications

- Compliance with regulatory standards to help meet carbon reduction goals
- Business opportunity for manufacturing and maintenance of the solar panels
- Will help to lower emissions cost penalties

Regulatory Considerations

- IMO Standards for GHG emissions
- MARPOL Annex VI
- SOLAS Regulation II-1/41Main Source of electrical power and lighting systems
- Safety protocols for maintenance and installation
- Protocols and safety regulations for energy storage technologies

Offshore Solar – Commercialization

Availability and Market Areas

- Available in regions with high solar irradiance and suitable water
  - i.e. Southeast Asia, Europe, and United States
- There is expansion possibility in coastal areas and islands with limited land

Cost

- High initial capital costs from floats, anchoring, mooring, and plant design
- Lower operation costs than offshore wind

Infrastructure Needs

- Floating platforms and anchoring infrastructure
- Specialized equipment for maintenance and installation
- Management of grid integration systems
- Energy storage technology

Offshore Solar – Limitations & Concerns

Technical and Safety Issues

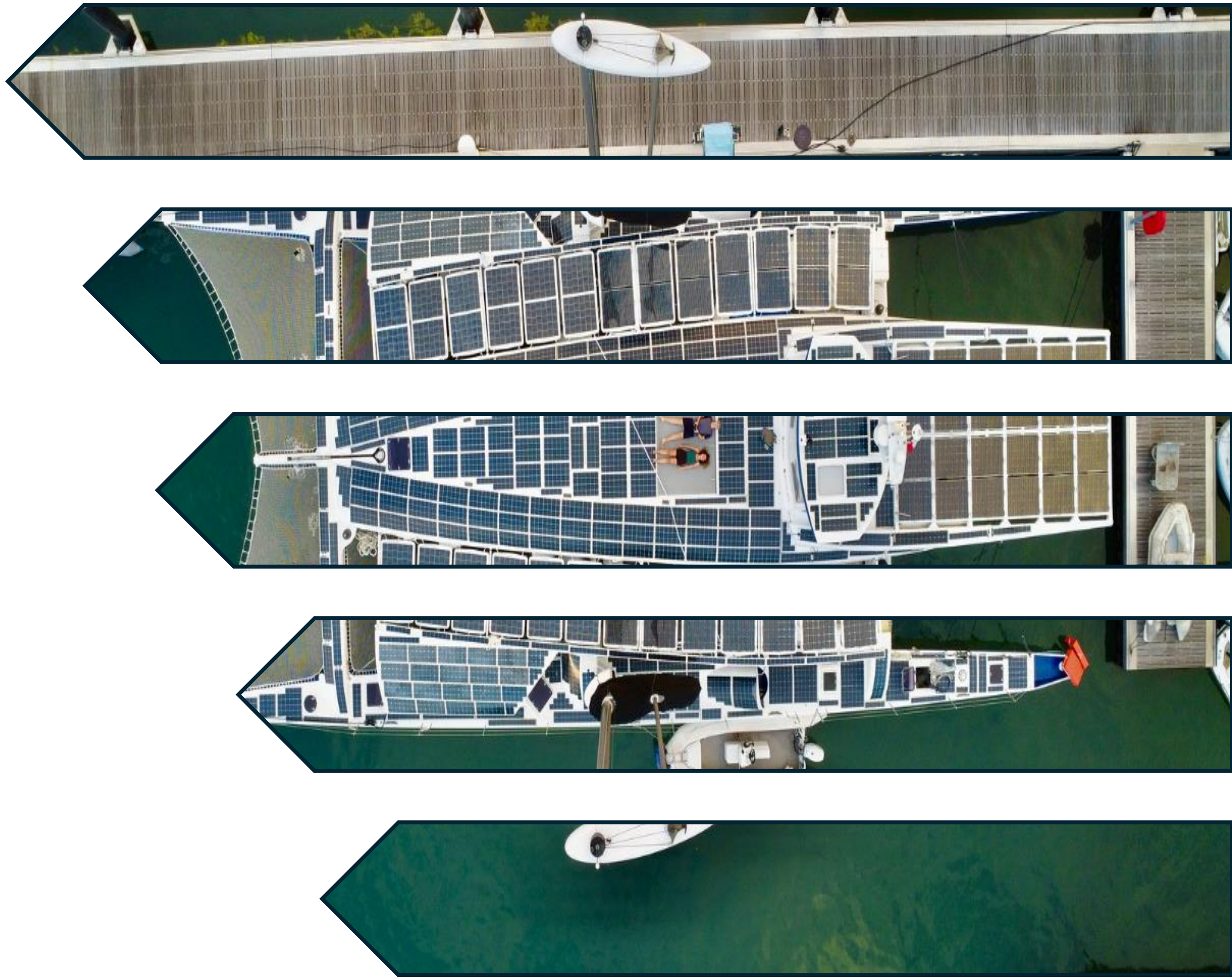
- The harsh marine environment exposure can hinder the solar panels durability and efficiency
- Concerns for installation and maintenance safety in offshore conditions
- Grid connection issues

Regulation Hurdles

- Standards for fire safety protocols
- Regulations provided by IMO, ISO, USCG (United States Coast Guard), Maritime Safety Committee (MSC), and MARPOL

Potential Concerns for Scalability

- High initial costs of installment, infrastructure and deployment
- Technological advancements on efficiency and cost reductions



Credit: Department of Energy

Offshore Solar – Short- & Long-Term Implications

Credit: Department of Energy

Short-term

- Focus on hybrid systems
- Infrastructure development in necessary areas
- New standards
- Compliance with initial GHG goals

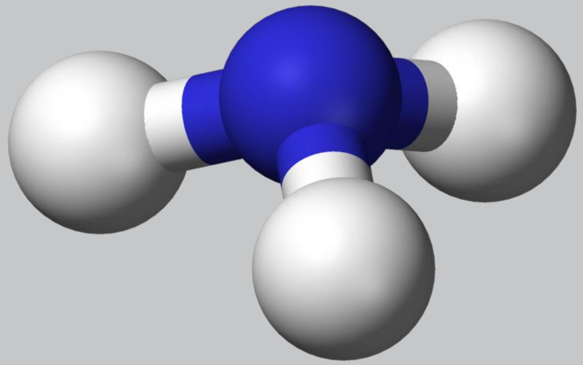
Long-Term

- Sustainability improvements along with efficiency improvements
- Supports energy transition from fossil fuels
- Continues integration and installation in marine energy systems
- Continued research and development in offshore solar sector for efficient process, high production, and lower production costs

Midterm-Term Approach

Alternative Fuels in the Maritime Industry

AMMONIA



Credit: Wikimedia/PD

A colorless gas (NH3) consisting of nitrogen and hydrogen.

NUCLEAR

Credit: Nuclear Regulatory Commision

Energy that is released during the process of nuclear fission or fusion.

Ammonia - Introduction

Production Methods

- Ammonia can be produced from renewables or fossil fuels (natural gas as feedstock) using “green” methods like carbon capture and storage or renewable energy.
- According to the United States Geological Survey, worldwide production of ammonia for 2019 was 150 million metric tons. Where this global ammonia capacity is expected to increase by 4% in the next 4 years.

Hydrogen Production

- Reforming methane with steam from hydrocarbon fuels.
- After liquification nitrogen for production is extracted from the air.
- Renewable energy sources can produce hydrogen from electrolysis of water and later synthesized to ammonia.

Haber-Bosch Process

- Combines atmospheric nitrogen with hydrogen to produce ammonia often with the use of a metal catalyst
- Requires high temperatures and pressures

Green Ammonia

- Uses renewable energy sources to electrolyze water and combine it with nitrogen
- Reduces GHG emissions compared to other methods

Ammonia – Current Uses & Characteristics

Benefits, Properties and Characteristics

Storage

- Practical due to energy density and liquification temperature (-77.7ºC)
- 2.4x more volume than petroleum fuels but less than hydrogen
- Industrial storage at -33.6ºC or lower
- Can be stored as liquid at 8.6 bar and 20ºC

Energy

- Higher volumetric energy density than liquefied hydrogen
- Lower re-liquefaction energy than hydrogen or LNG
- Energy storage can come from green sources

Usage

- Used as liquid fuel in engines
- Heat value like methanol
- Suitable for IC engines and fuel cells

Safety

- Narrow flammability range (15.15%-27.35%)
- Autoignition temperature 651ºC
- Low odor threshold (0.037 to 1.0 ppm) for early detection
- Corrosive when introduced to moisture

Reactivity

- High heat of vaporization (1,371 kJ/kg)
- Alkaline reducing agent
- Reacts with acids, halogens, and oxidizing agents

Current Uses

Chemical Industry

- Second most widely used chemical used for fertilizers and pharmaceuticals

Fuel

- Being developed for IC engines and fuel cells
- Serves as a reductant in Selective Catalytic Reduction (SCR) systems
- Liquified Petroleum Gas (LPG) carriers will hold ammonia as cargo
- Very commercially available
- Burned in IC engines (compression ignition with pilot fuel/spark ignition) in 1822 in locomotives and later in WWII used in Belgium as fuel for buses for public transportation.
- Development into the use of ammonia in fuel cells by separating hydrogen out through external reformer or usage in low temperature fuel cell such as polymer electrolyte membrane (PEM) or using directly in high-temperature fuel cell like solid oxide fuel cell (SOFC)

Ammonia – Perspectives

Environmental Impacts

- No CO2 emissions
- Lower NOx emissions compared to the traditional fuels.
  - Dependent on combustion technology
- Reduction in ocean acidification and air pollution
- In a study “ A Preliminary Study on Alternative Ship Propulsion System Fueled by Ammonia: Environmental and Economic Assessments” it was determined that an ammonia fueled ship could lower GHG emission by 83.7 to 92.1% following production methods and propulsion type (Kim et al).
- If a fire does occur there needs to be caution for environmental contamination from diluted water/runoff

Business Implications

- Long-term cost savings
- Compliance with regulatory standards to help meet carbon reduction goals leading to reduced emission penalties
- Investment in developing ammonia production and infrastructure
- Ammonia is a growing market in the sustainable shipping solutions allowing for a potential competitive edge

Ammonia – Regulatory Considerations

IGC Code

- Materials and Design requirements for ammonia containment and design features to minimize exposure
- PPE equipment for safe management
- Strict reporting requirements for production, storage, and use facilities
- Compliance with permissible exposure safety limits

IGF Code

- Ammonia is not permitted, and an amendment would be needed (long-term)
- Discussion with Flag Administration must occur
- Required to meet goals and safety requirements

Risk Assessment Framework

- Preliminary hazard identification study (HAZID) in the design phase
- Risk consideration
  - Loss of function, component damage, fire, explosion, electric shock
  - Equipment of fuel handling, operation control, safety actions, venting, and containment
  - Fire-fighting arrangements for inert fuel lines and purging

Classification Societies

- IACS: Recommendation No. 146 for risk assessment per IGF code
- SOLAS Regulation II-I/55: Requires an engineering analysis submission to flag administration

Land-based Standards

- EPA Chemical Safety Alert: adapts lessons for marine applications
  - Includes training, maintenance, inspection, and ventilation procedures

Environmental and Safety Limits

- IMO NOx limits which controls unburnt ammonia to avoid health hazards and plume formation (2-10 ppm)

Ammonia - Commercialization

Availability and Market Areas

- Production capacity increasing to meet rising demand
- Global supply chains and bunkering infrastructure are being developed
- On going development on production facilities
- Project Movers
  - Wärtsilä four stroke ammonia engine
  - MAN two stroke green-ammonia engine
  - ShipFC Project for vessels to run on ammonia powered fuel cells

Fuel Cost

- Storage costs are decreased by storing at -33.6ºC or lower is preferred rather than pressurization
- Production methods dictate cost competitiveness
- Cost for adapting infrastructure
- Development costs for fuel cells are higher than IC engines
- Costs 3.5-5.2x more than HFO based ships in total life prospective

Ammonia – Infrastructure Needs

Storage

- Cool areas with effective ventilation, away from ignition sources and reactive chemicals (halogens, oxidizers, and acids)
- Refrigeration conditions need pressure and temperature control
- Type C 18 bar tanks remove the need for reliquification equipment
- Tank volume needs to be 2.4x more than that of heavy fuel oil
- Tanks need to follow IGF and IGC codes for distance and safety requirements
- Use resistant material (iron, steel, and specific non-ferrous alloys)
- Incorporates corrosion control to prevent stress corrosion cracking from oxygen exposure

Design Changes

- Larger vessels, reduced cargo space, or more frequent bunkering
- Designs need to be adapted for fuel temperature pressure settings and storage conditions
- Main systems need ammonia fuel containment, ammonia bunkering stations and transfer piping, fuel supply system, boil off gas handing, reliquification, gas valve unit/train, nitrogen generating plant, vent piping systems and masts, and for some ammonia tank types, additional equipment for managing tank temperatures and pressure, deluge systems, personal protective equipment, independent ventilation for ammonia spaces, emergency extraction ventilation and closed fuel systems
- Vent mass location must be 10m from air intake openings and exhaust

Fuel Supply

- Cryogenic/pressurized storage allows for it to be pumped and pressure fed in liquid form
- Needs to adjust to engine fuel demand
- Engines use pilot fuel injection and high-pressure systems minimizing ammonia slip
- Implementation of engine and after treatment solutions for NOx control

Bunkering

- Modify existing infrastructure to better suit ammonia
- Measures to avoid leaks, handle toxicity, and maintain equipment condition

Ammonia – Limitations & Concerns

Technical and Safety Issues

- Toxicity and handling risks
- Requirements for specialized storage and transportation equipment

Regulation Hurdles

- Compliance with marine fuel standards
- Requirements for safety standards and regulations
- Still faces challenges in achieving widespread regulatory approval
- Regulations provided by IMO

Potential concerns for scalability

- Expansion is needed in production and distribution infrastructure needs
- Costs of initial investments may be high and hinder adoption

Ammonia – Short- & Long-Term Implications

Short-term

- Promotes Infrastructure adaptation and engine compatibility
- Expansion of ammonia bunkering facilities
- High initial costs for installation and retrofitting
- Developing of new safety and handling standards
- Development of pilot projects

Long-Term

- Sustainability improvements along with efficiency improvements decreasing costs
- Adoption by shipping companies as vessels increase
- Reduction in GHG
- Supports energy transition from fossil fuels
- Development of an enhanced engine design
- Development of well-structured regulations for health and safety in production, storage, and use.
- Increased public awareness
- Ammonia market growth

© Navigator Gas

Nuclear Maritime Applications

- United States
  - 1940: Research on marine nuclear propulsion
  - 1953: 1st naval test reactor, Mark 1
  - 1955: 1st nuclear submarine, USS Nautilus
  - 1962: U.S. Navy 26 nuclear submarines, 30 under construction
  - 1959: 1st nuclear-powered merchant vessel, N.S. Savannah, Classed by ABS

Current Military Use of Nuclear Power	
US Navy	• 73 Submarines • 11 Aircraft Carriers
Russian Navy	• 21 Submarines • 1 Battlecruiser
China	• 14 Submarines
British Navy	• 10 Submarines
France	• 9 Submarines • 1 Aircraft Carrier
Indian Navy	• 1 Submarine

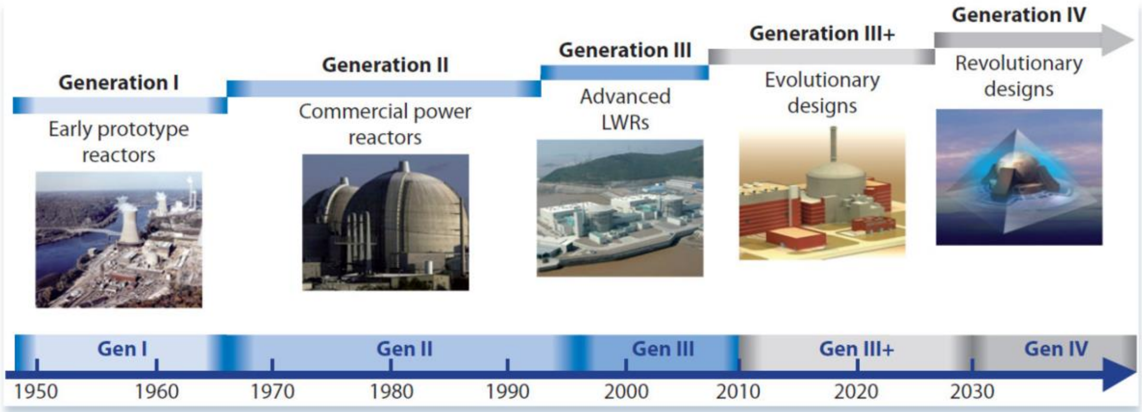
NS (Nuclear Ship) Savannah, enroute to the World's Fair in Seattle, 1962

Credit: US Government - NARA

Generations, Fast and Thermal Reactors

GENERATIONS OF NUCLEAR REACTORS

- Generation I – Early prototypes; Promoted the launch of civil nuclear power.
- Generation II – Focused on economy and reliability. Comprise the majority of worldwide nuclear reactors, requiring active safety measures.
- Generation III – These are normally of Gen II design with additional improvements in safety systems (requires passive system), construction, and efficiency.
- **Generation III+ or Generation IV** – Additional safety improvements from Gen III. Current nuclear development projects



https://www.gen-4.org/gif/jcms/c_196887/gif-r-d-outlook-for-generation-iv-nuclear-energy-systems-2018-update-new-cover

THERMAL REACTORS

- Use “slow” or “thermal” neutrons to maintain fission reaction in the uranium fuel.
- Neutrons are characterized by lower energy, which can be absorbed more easily by an atomic nucleus (neutron activation)
- Thermal reactors require a moderator to slow the neutrons from the fission process.

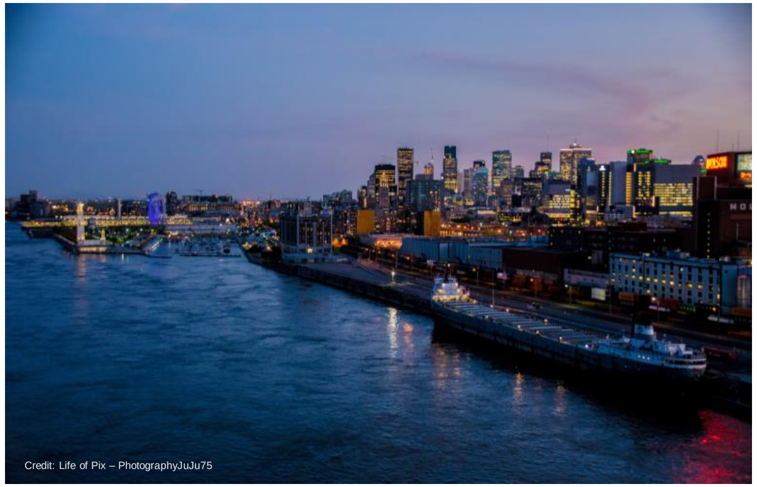
FAST REACTORS

- Use “fast” neutrons characterized by higher energy
- Do not require a moderator
- Sometimes termed ‘breeder’ reactors; capable of generating more fissile products than consumed
- Potential benefits of using used nuclear fuel or other fissile material as fuel (e.g., thorium)

https://en.wikipedia.org/wiki/Fast-neutron_reactor

Nuclear – Maritime Use Cases

Credit: Life of Pix – Leeroy Miller



Credit: Life of Pix – PhotographyJuJu75

Credit: Life of Pix - Leeroy

Land-Based Support

- Electricity for Onshore Power Supply (OPS) to vessels
- Produce marine fuels
- Power marine support infrastructure, shipyards, and ports

Coastal and Offshore Industry

- Floating power barge for grid electricity
- Zero-carbon power for oil and exploration
- Suitable for arrays of microreactors or small modular reactors

Nuclear-Electric Propulsion

- Reactors fitted for high power
- Zero-carbon switch
- Reduce or eliminate bunkering

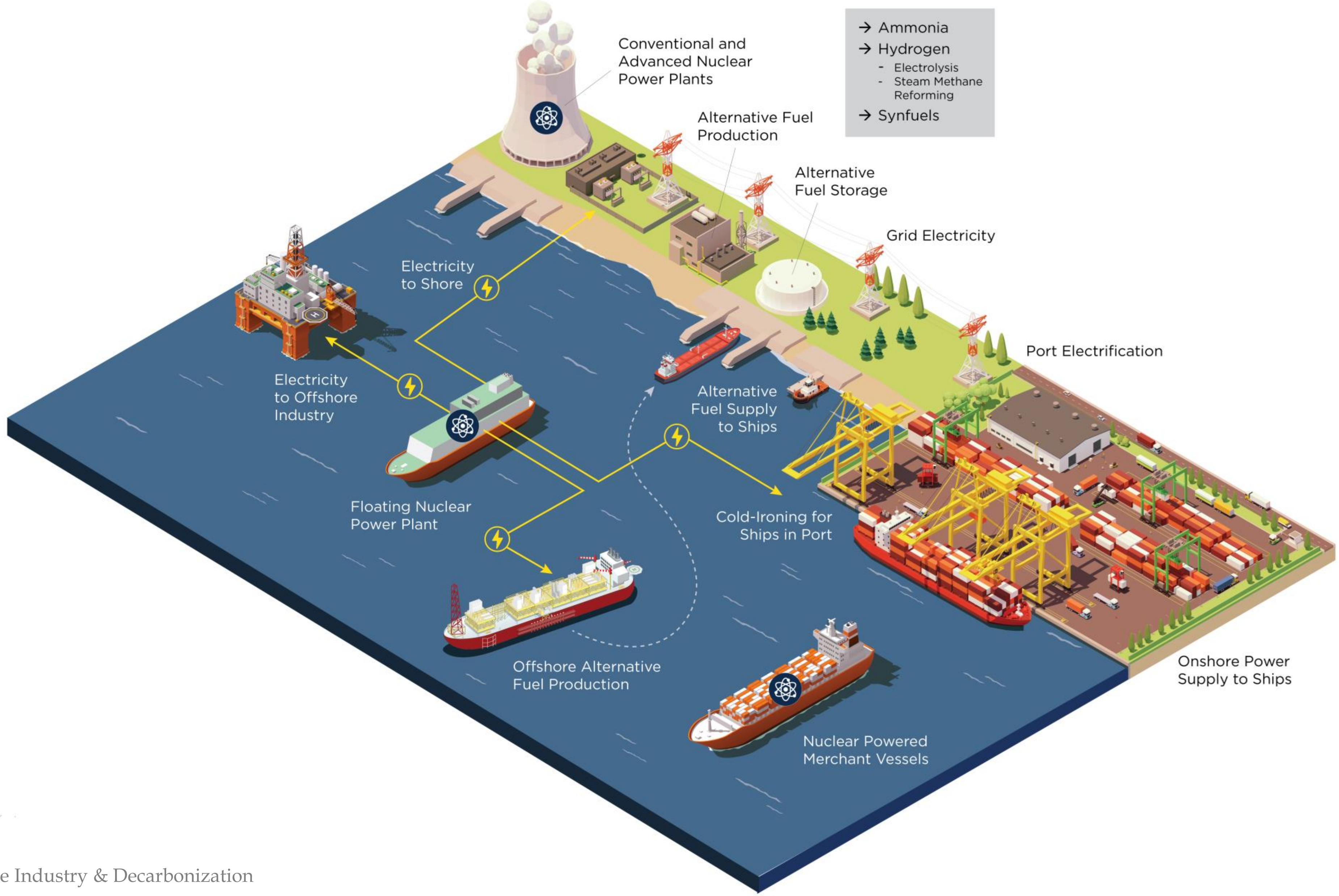
Commercial Nuclear Benefits

The Blue Economy is Suited for Nuclear

- Available space away from population centers or areas with land restrictions
- Readily available water as a heat sink
- Seismic Isolation
- Desalinated/pure water available for hydrogen production from steam methane reforming or electrolysis

Credit: Nuclear Regulatory Commission

Nuclear Maritime Market



Commercial Nuclear Challenges

Safety

- Risk Management
- Safety Management Considerations

Regulatory

- International (IAEA,IMO).
- Flag State.
- Coastal State.

Operational

- Nuclear maintenance at shipyards.
- Terminal considerations.
- Crew training requirements.
- End of life considerations.

Commercial/Social

- Capex requirements for construction.
- Trade location limitations.
- Public perception and acceptance.
- Public/private partnerships.

Safety

- Nuclear power has extensive safety measures
  - Operators are extremely well-trained and well-qualified
    - Operators have federal licenses that take 24 months of classes and tests
    - Operators continue training with a week of classes in the classroom and simulator for every 4-5 weeks worked
    - Operators are certified to be physically and mentally fit and have regular background and criminal history checks
  - Nuclear plants are built to prevent any incidents
    - Multilayer protection is used so no one safety measure is solely relied upon
    - Multiple barriers protect from radiation release
    - Safety measures are redundant to ensure the reactors do not overheat
    - Tests and updates to safety are regularly performed

Credit: John Smallwood

Credit: John Smallwood

https://www.nei.org

Industry Engagement

Marine Nuclear Applications Group (MNAG)

Collaborative consortium meeting regularly to stay up-to-date and educated on developing topics.

“Research hub and resource center that brings together experts from the maritime and nuclear energy sectors to demonstrate advanced nuclear technologies for a range of marine applications.”

Advanced Nuclear & Production Experts Group (ANPEG)

Technical experts investigating the need for nuclear solutions for the clean energy transition.

“A global consortium dedicated to developing low-carbon energy systems based on a “plug-and-play” nuclear microreactor – or Nuclear Battery.”

World Nuclear Transport Institute (WNTI)

Global non-governmental membership organization headquartered in London.

“Collaborate with members to influence regulatory change affecting the transport of nuclear materials.”

Credit: lifeofpix – rawpixel-com

Long-Term Approach

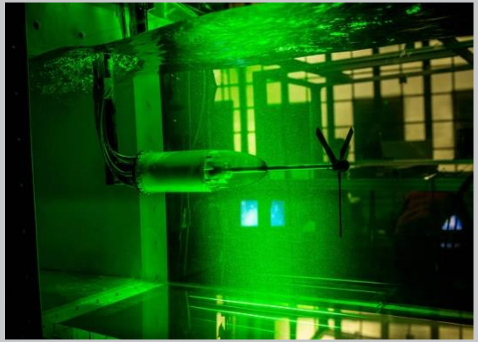
Alternative Fuels in the Maritime Industry

HYDROGEN

Credit: © Elliott Bay Design Group

Odorless, colorless tasteless, and non-toxic highly combustible gas. It is one of the most abundant elements.

TIDAL ENERGY



Credit: Department of Energy

A form of hydropower converting tides and their natural rise and fall into electricity

ELECTRIFICATION

Credit: Kaboompics

Powering systems using electricity rather than fossil fuels

CARBON CAPTURE

Credit: Department of Energy

Process of capturing CO2 that is emitted from powerplants or industrial processes

Hydrogen - Introduction

Types & Sources

- Types of Hydrogen are dependent on the emissions released during production

Brown Hydrogen

- Produced from coal
- Highly carbon-intensive
- Second largest produced hydrogen

Gray Hydrogen

- Most common
- 75% of produced hydrogen is grey
- Produced from natural gas
- Most carbon intensive with 71 kgCO2/MJ H2 for natural gas

Blue Hydrogen

- Produced from fossil fuels
- Uses carbon capture in storage technologies

Green Hydrogen

- Zero Carbon Emissions
- Produced from renewable energy sources through electrolysis
- Around 2% of the global supply
- Can use wind, solar, or nuclear electricity generation

Hydrogen – Fuel Production

- The production of hydrogen is a high energy consumption process consuming around 275 Mtoe or 2% of the world’s energy demand
- Three reformation methods
  - Steam reforming: Water is both an oxidant and source for hydrogen
  - Partial oxidation: Uses oxygen in the air and a catalyst
  - Autothermal reforming: A combination of steam reforming and partial oxidation

Syngas Formation

- Syngas (carbon monoxide and hydrogen) is formed and converted to hydrogen and CO2 with water-gas shift reaction.
- Renewable and sustainability sourced biomass can be used to produce syngas through gasification to reduce carbon intensity of fossil-fuel hydrogen.
- Nuclear plants can make hydrogen from steam reforming of methane or high-temperature thermochemical production.

Electrolysis

- Electrolyzers (like reversed fuel cells) take water and electricity and make hydrogen and oxygen gas.
- Renewable energy can be used to make the electricity making it an electro-fuel with zero carbon impact.

Emerging Processes (Not yet employed)

- High temperature water splitting
- Photobiological water splitting
- Photoelectrochemical water splitting

Hydrogen – Current Uses & Characteristics

Benefits, Properties and Characteristics

- Natural gas occurrence as it is found as a compound of water or methane
- Low density, not maintained by Earth’s gravity
- Flammability is wide ranged and increases with pure oxygen
- Low tank-to-wake emissions impact
- Energy content is highest per mass (120.2 MJ/kg) 2.8x more than MGO
- Volumetric density needs 4x more space than MGO and 2x more than LNG
- Liquification temperature is below -253ºC
- Storage low temperature or high temperature options
- Ability to carry in substances like ammonia and methanol
- Dissipates quickly when leaked
- Can be gas or cryogenic liquid with lowest melting and boiling points except for helium
- Low activation energy, invisible flames, burns at 3.15 m/s
- When exposed to ignition source will either experience
  - Deflagration: Subsonic combustion
  - Denotation: Supersonic combustion (not possible in open air)
- Small size allows dispersion through material causing Hydrogen embrittlement
- No carbon or sulfur emissions

Current Uses

- Chemical production
- Industrial feedstock
- In the U.S. most hydrogen is produced in California, Louisiana, and Texas mainly for the petroleum refining, treating metals, producing ammonia and other chemicals, and processing foods.
- Production of green hydrogen in Chile and Australia
- Used in fuel cells to generate electricity for vehicles and stationary power sources
  - Alkaline Water Electrolysis (AWE)
  - Proton Exchange Membranes (PEM)
- Implemented as supplementary/mixed fuel blend in conventional gas and dual fuel engines
  - Several combustion methods in internal combustion engines

Hydrogen – Perspectives

Environmental Impacts

- Reductions in GHG
- Depending on production and source can have low well to tank or well to wake emissions
- Reduce NOx and particulate matter
- Can use other renewable energy sources

Business Implications

- Long-term cost savings
- Potential for investment in infrastructure, production, and storage
- With its adaption companies can have a leg up in complying with emissions standards and regulations.
- The market for green shipping grows and so does hydrogen

Hydrogen – Regulatory Considerations

AIAA Guide to Safety of Hydrogen and Hydrogen Systems

- Acceptability use for gaseous and liquid hydrogen application for metals and non-metal materials
- May not consider marine or offshore applications

IMO Regulation

- GHG emission reduction strategy MEPC.304(72)
- CCC progress on guides for fuel cell safety on ships
- MSC Resolution MSC.420(97) with liquified hydrogen cargo

ISO Standards

- ISO/TR 15916: Safety considerations and best practices for hydrogen systems
- ISO 11114: Gas cylinder standards for hydrogen

IEC Standards

- IEC 60079 Explosive atmosphere standards
  - Part 10.1 Classification of areas
  - Part 29.2 Gas detectors
- IEC 61892 Standards for electrical installation in offshore units (Part 7 hazardous areas)

NFPA Codes

- NFPA 2: Hydrogen technologies code for storage, use, and handling
- NFPA 55: Compressed gas and cryogenic fluids code

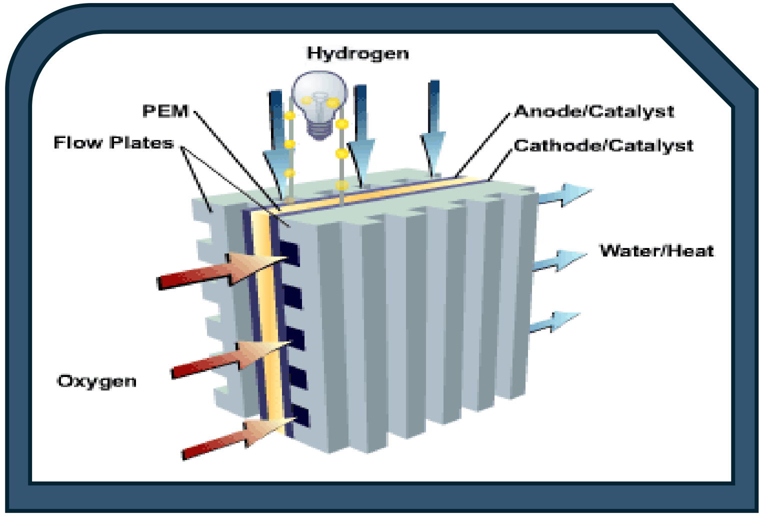
Other Standards

- ANSI/AIAA G-095A-2017 Guide to safety of hydrogen and hydrogen systems
- ASME B31-12 Hydrogen piping and pipelines
- CGA G-5.4 Hydrogen piping systems at user locations
- CGA G-5.5 Hydrogen Vent Systems

Hydrogen - Commercialization

Availability and Market Areas

- Not fully available and may be challenging to acquire
- The global production capacity is in fact growing
- Development of green hydrogen production facilities using renewable resources



Credit: Department of Energy

Fuel Cost

- High fuel costs
- Higher storage costs liquid hydrogen have higher capital costs then LNG bunkering facilities
- Higher costs of dedicated hydrogen pipelines or distribution supply chains
- Potential for lower maintenance costs of fuel cells
- Scaled-up installations of fuel cells and associated hybrid or battery systems are not yet cost competitive when compared with alternative power generation options

Hydrogen – Infrastructure Needs

Safety Measures

- Electric charge protection from ignition from electric charge buildup and sparks
- Deflagration protection by using pressure relief systems, rupture disks, or relief panels
- In hazardous areas there needs to be proper ventilation, hydrogen gas detection, and rated electrical equipment
- For leak detection include strategies to monitor pressure under no gas flow conditions
- Use water spray cooling and insulation to prevent over-pressurization

Storage Requirements

- Pressurized tanks: between 350-750 bar, 2-3x higher than industrial storage
- Insulated pressure vessels used between ambient and cryogenic temperatures and atmospheric and high pressures.
- Cryogenic tanks need thick insulation layers with the possibility to use vacuum insulated Type C tanks
- Selection of appropriate materials and coatings to minimize permeation and hydrogen embrittlement

System Management

- Purging to remove air, oxygen, and other oxidizers from the system
- Proper pressure relief valve arrangements

Operational Procedures

- Successful mechanical ventilation of storage spaces
- Standard procedures for bunkering to consider hydrogen permeation, embrittlement, and material compatibility
- Supply fuel at correct temperatures and pressures
- Emergency procedures including safety operational management plans, equipment failure protocols, and personnel training

Design Consideration

- Engine room change for hydrogen use with battery storage or fuel cells
- Storage systems need to have larger hydrogen tanks and containment systems
- Use of Boil off gas for consumption in fuel cells or engines (reduces wastes)
- On site port availability for constant hydrogen supply

Hydrogen – Limitations & Concerns

Technical and Safety Issues

- Larger storage volumes
- Wide flammability range
- Fuel infrastructure and bunkering investment
- Explosion risk in confined spaces
- Material challenges (i.e. hydrogen embrittlement)
- NOx from burning hydrogen in combustion engines
- Low cryogenic temperature challenges
- At high concentrations it can be an asphyxiant
- Skin contact with cryogenic materials or uninsulated tanks, pipes, or valves cause cold burns or serious skin damage

Regulation Hurdles

- Compliance with IMO and NFPA

Potential concerns for scalability

- High fuel costs
- Lower availability of renewably produced hydrogen

Shutterstock / Audio und werbung

Hydrogen – Short- & Long-Term Implications

Credit: Department of Energy

Short-term

- Short sea shipping
- Early adoption for conscious shipping companies
- Launching of pilot projects in addition to demonstration plants
- Expansion of hydrogen bunkering facilities
- High initial investment costs
- Regulatory compliance with IMO

Long-Term

- Widespread adoption
- Improvements hydrogen production technology and cost reductions
- Reduction in GHG emissions
- Cost-competitive with traditional marine fuels
- Hydrogen market growth

Tidal Energy - Introduction

Production

- Tidal Barrages
  - Like dams
  - Built across tidal rivers, bays, and estuaries forming a tidal basin
  - Turbines are inside the barrage allowing for basin to fill in incoming tides and release with outgoing tides. This allows for electricity generation in both directions
  - Two largest are South Korea and France with 254MW and 240MW capacity
- Tidal Stream Generators
  - Turbines are placed in tidal streams capturing energy from the current where underwater cables transmit to the grid
  - Used with sites that have high tidal velocities created by land constrictions (straits or inlets)
  - Maybe mention MeyGen Project in Scottland 398MW
- Tidal Lagoons
  - Like barrages
  - Man-made retaining walls are used to partially contain large volume of incoming tidal water where embedded turbines capture the energy.
  - Rely on large tidal ranges
  - Can be placed on natural coastlines allowing for continuous power generation
  - Under development in China, North Korea, and the United Kingdom

Tidal Energy – Current Uses & Characteristics

Benefits, Properties & Characteristics

- High energy density
- Constant and more predictable energy output not affected by weather conditions
- Effective in shallow water
- Turbine blades turn slowly
- More powerful than wind energy since water is denser than air
- Clean and renewable
- Low and high tides are easy to predict and often rarely experience unexpected changes

Current Uses

- Projects La Rance, France, Sihwa lake, South Korea generate electricity
- New technology are being tested in places enhancing and reducing costs
- First tidal power station was constructed in 2007 at Strangford Lough in Northern Ireland

Tidal Energy – Perspectives

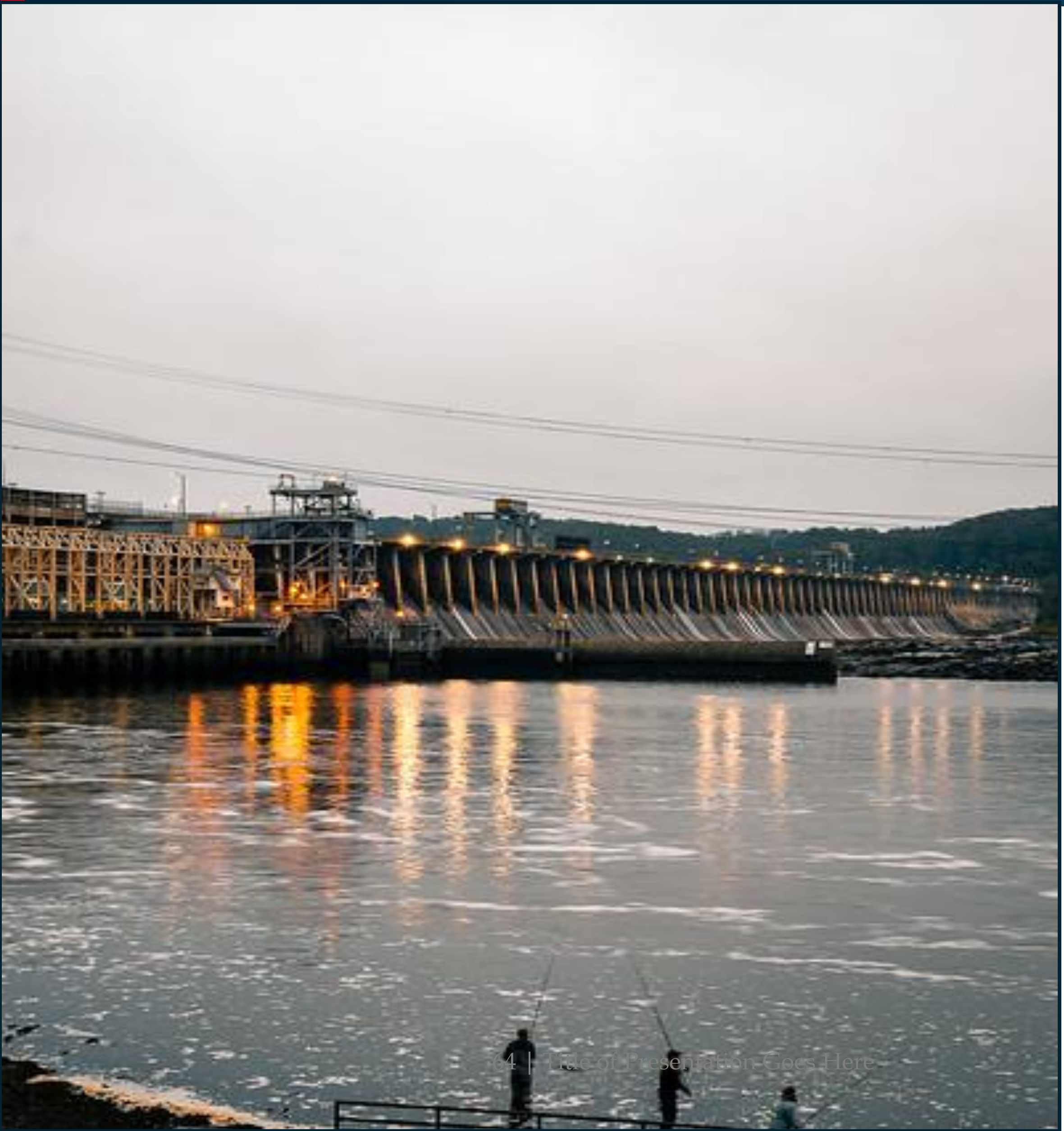
Environmental Impacts

- No GHG gas emissions
- Minimal visual impacts as opposed to wind or solar
- Potential for changes in tidal flow or sediment transport
- Potential noise impacts on marine species which could affect migrations/navigation
- For tidal streams, the turbine blades move slowly so marine life can avoid getting stuck in the system
- Allows for ships to navigate around
- For barrages turbines move quick and marine animals can get caught. Changes in salinity inside tidal lagoon. Additionally, food sources for birds can be limited impacting migration.
- Tidal lagoon impact is minimal with use of natural materials. They also allow for animals to swim around and swim inside

Business Implications

- Low operational costs
- Reduced fuel expenses
- Potential for new job creation

Tidal Energy – Regulatory Considerations



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- IMO Standards in reducing GHG
- Safety Protocols
- IEC TC 114, Marine energy – Wave, tidal and other water current converters
    - Published 10+ technical specifications for marine renewable energy such as design, resource characterization, acoustic characterization, moorings, and power performance assessment
    - 62600-3:2020 mechanical load measurements of marine energy converters
- Federal Energy Regulatory Commission (FERC)
- Non-Federal hydroelectric power projects interconnected with the interstate electric transmission grid. They have also created a stream-lined pilot project licensing process to allow the licensing of demonstration hydrokinetic projects for testing purposes
- Permitting by U.S. Army Corps of Engineers (COE) under Section 404 of Clean Water Act (this regulates the discharge of dredged or fill materials into waters of the United States)
- Section 10 of Rivers and Harbors Act (regulating construction and other work in navigable waters
- Permitting by the Department of Environmental Protection (DEP)

Tidal Energy - Commercialization

Availability and Market Areas

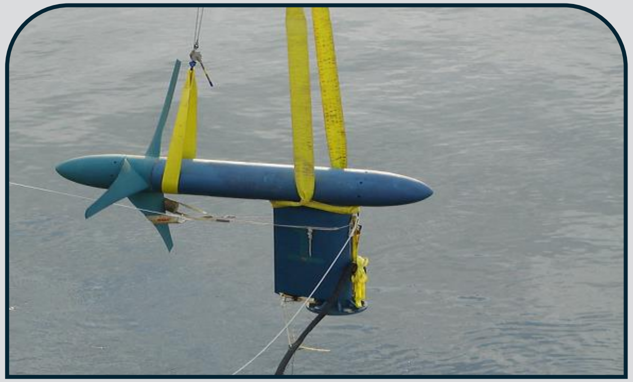
- Investment in tidal energy from tidal high regions such as France, UK, and Canada
- Development of smaller tidal energy farms and tidal turbines in specific locations
- Availability depends on suitable locations
- Able to sell excess electricity back to the grid

Fuel Cost

- Investment into infrastructure to withstand marine conditions
- High initial capital costs
- Long-term cost savings from decreased operation and maintenance costs

Infrastructure Needs

- Onshore facilities and sub shore cabling upon installation
- Any maintenance systems installed need to be able to withstand harsh marine conditions
- Grid management systems need to be advanced to integrate this energy to the power grid
- Microgrids are needed for isolated ports or communities for optimal energy usage



Credit: Department of Energy

Tidal Energy – Limitations & Concerns

Technical and Safety Issues

- High initial capital costs
- Impacts on marine habitats and species
- Need for further technological development which is currently slow
- Concerns for environmental effects

Regulation Hurdles

- Compliance with IMO guidelines

Potential concerns for scalability

- Limited locations that are suitable for tidal energy
- Fully dependent on technological advancement and cost reductions

Credit: Department of Energy

Tidal Energy – Short- & Long-Term Implications

Short-term

- Adoption of initial pilot projects and small-scale deployments for feasibility testing
- Hybrid systems combining tidal energy with other renewable energy sources
- Research and development investment
- Necessary development in infrastructure
- Potential for government incentives
- Development of standards and protocols

Long-Term

- Widespread adoption with major shipping companies and ports
- Improvements in turbine technology and efficiency
- Enhancement in materials to withstand marine conditions
- Reductions in GHG
- Creation and adoption of international standards

Credit: Department of Energy

Electrification - Introduction

Production & Storage Technologies

- Diesel-electric propulsion
  - Combines diesel engines with electric generator and motors working to drive a ship’s propeller
  - Takes mechanical energy from the diesel engine and converts it to electrical for the ship's propellers
- Battery electric propulsion
  - Powered mainly/entirely by batteries storing electrical energy
  - Common batteries include lithium-ion, nickel-metal hydride, and advanced lead-acid batteries
  - For energy needs onboard generation such as solar can provide energy
- Shore Power (cold ironing)
  - Auxiliary engines turned off when docked and connect to local grid for powering on board systems
  - Either the ships will have connection points, or the ports will be equipped with these electrical connections
- Fuel Cells
  - Converting chemical energy from fuels (ie hydrogen) into electrical energy through electrochemical reaction
  - Types include: PEM, SOFC, MCFC
- Electric motors
  - Provides propulsion and power for ship operations
  - Convert electrical energy to mechanical driving equipment
  - Types: Induction, permanent magnet, and synchronous

Electrification – Current Uses & Characteristics

Benefits, Properties & Characteristics

- Zero emissions
- Higher energy efficiency because there is direct use from electrical energy to mechanical
- Operational cost savings
- Flexible energy source allowing for potential integration with various renewable energy sources

Current Uses

- Used in smaller vessels like tugboats, ferries, and yachts
- Adoption increase in commercial shipping and cruise lines short sea routes
- Transportation, buildings, industry, and agriculture
- Transportation include light-duty electric vehicles (EVs)
- Buildings: heat pumps, water heaters, and electric or induction cooktops
- There are advance technologies for electric propulsion systems

Electrification – Perspectives

Environmental Impacts

- Reduction in GHG emissions and air pollution
- Reduction of noise pollution
- Has potential when combined with renewable energy sources to have zero emissions
- Environmental impacts due to battery production and disposal
  - Sources for battery material such as lithium and nickel have both societal and environmental impacts

Business Implications

- Long-term cost savings from reduced fuel and maintenance costs
- Reduced fuel expenses
- Business opportunities in battery production, infrastructure, and electric vessel manufacturing
- Provides great benefit for meeting environmental regulations

Electrification – Regulatory Considerations

- IMO Standards in reducing GHG
- Safety Protocols
  - Battery Storage
- Standard charging connectors and protocols
- EMSA guidance for battery energy storage systems(BESS)
- MARPOL Annex VI for mandatory technical and operational energy efficiency measures to reduce GHS emissions from ships
- IEC 60092 electrical installation in ships
- IEC 60364 electrical installations of buildings
- IEC 60529 Degrees of protection provided by enclosures
- NFPA guidelines for electrical installations on vessels operating in U.S waters
- IMO SOLAS, MARPOL, ISM code

Electrification - Commercialization

Availability and Market Areas

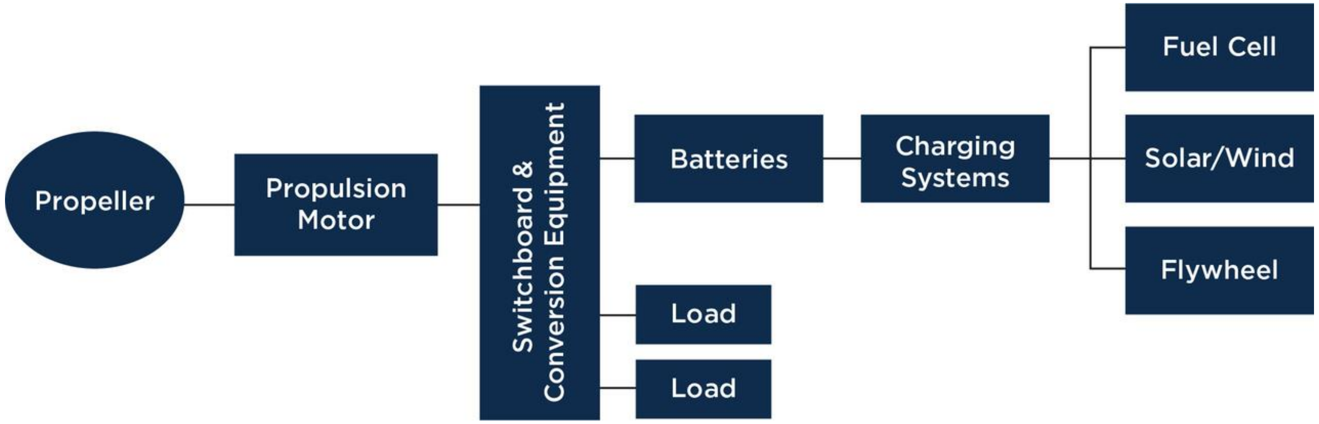
- Demand for electric and hybrid vessels for short-shipping is growing
- Shore power facilities growth
- Battery manufacturing facilities are said to expand
- Investment in charging infrastructure

Fuel Cost

- High initial costs from retrofitting existing vessels or developing new ships
- Reduced fuel and maintenance expenses

Infrastructure Needs

- Charging Infrastructure
  - Charging stations will need to be developed at major ports or shipping routes
  - Need for a standard charging connector
- Grid integration
  - Need for a way to integrate with local and regional electric grids
  - Shore power connections for docking
- Recycling programs



Electrification – Limitations & Concerns

Technical and Safety Issues

- Limited energy density from batteries
- Concerns of battery overheating and
- Fuel cells need improvements in efficiency, durability, reduction of size, and cost. Additional need for uninterrupted hydrogen supply for electricity generation. Only can really replace one power generation unit
- Capacity relative to size

Regulation Hurdles

- Compliance with IMO guidelines
- International standard requirements
- Safety and environmental regulations

Potential concerns for scalability

- High investment costs for infrastructure and retrofits
- Fully dependent on battery technologies advancements in range and efficiency

Credit: Argonne National Laboratory

Electrification – Short- & Long-Term Implications

Short-term

- Adoption of small-scale deployments for smaller vessels and short sea shipping routes
- Pilot projects including hybrid systems with batteries and fuels
- Necessary development in infrastructure
  - Grid integrations and shore power connections
- Potential for government incentives
- Compliance with IMO and MARPOL standards
- Development of standards and protocols for electric and hybrid vessels

Long-Term

- Widespread adoption with major shipping companies and ports
- Improvements in battery technology specifically energy density and charging times
  - New energy storage including advanced fuel cells
- Reductions in GHG
- Cost competitive
  - Increased production and supply chain
- Creation and adoption of international standards

Carbon Capture - Introduction

Methods

Post-combustion Capture

- Takes the CO2 from flue gas streams after combustion at low pressure
- Preferred and most common for retrofitting power plants
- Can recover 800 tonnes/day of CO2
- 70% higher electrical energy production cost because of inefficiencies

Pre-combustion Capture

- Removal of CO2 from a gas mixture before combustion takes place
- Usually applied in integrated gasification combined cycle power plants
- Partially oxidizes coal in oxygen/air and steam under high temperature and pressure producing synthetic gas (syngas). Due to its mixture syngas can go through a water-gas shift reaction producing gaseous mixture made up of largely H2 and CO2. This CO2 will be captured, transported and sequestered leaving the H2 fuel for combustion

Oxyfuel Combustion

- Burning of fossil fuels in pure oxygen
- Consist of flue gas that is largely CO2 and water
- When water vapor is condensed almost fully pure CO2 is left and compressed and transported
- Still needs development and not used large scale

Carbon Capture – Current Uses & Characteristics

Benefits, Properties & Characteristics

- Can be integrated with ships exhaust and energy systems for higher efficiency
- Needs to be constantly operated for CO2 capture
- Can be stored and handled on the vessel until offloaded

Current Uses

- Industrial processes and power generation
- Powerplants
- Demonstration projects in various industries

Carbon Capture – Perspectives

Environmental Impacts

- Reduction in CO2 emissions
- Mitigates shipping impacts on global warming and ocean acidification
- Has potential for leakage during storage and transport
- For pre-combustion capture:
  - high efficiency and easier carbon removal from fossil fuels.
  - Enhanced absorption efficiency from high CO2 concentration in syngas. This could mean less environmentally harmful fuel formation
  - Currently being developed for wide-scale adoption/commercialization
  - Easy retrofitting
- For post-combustion capture:
  - Maturity in technology when compared to carbon capture alternatives
  - Existed before WWII and is more developed
  - Potential for a standardized techniques for the adequate incorporation of technology for industrial applications for maintenance
  - Ease of retrofitting

Business Implications

- Long-term cost savings as there are no emissions penalties
- Could be a source of revenue for rising industries who would purchase captured CO2
- Provides great benefit for meeting environmental regulations early

Credit: Department of Energy

Carbon Capture – Regulatory Considerations

- IMO Standards in reducing GHG
- MARPOL Annex VI regulations
- Safety Protocols
  - Handling and storage
  - Offloading and transportation
- IPCC special report on carbon dioxide capture and storage (considerations for design, construction, operation, risk, safety, and costs) CH 4
- European Union’s carbon capture directive on Geological Storage of Carbon dioxide (2009) regulatory requirements for storage
- ISO 27919: Guidelines for design and operation of Carbon Capture systems

Credit: Life of Pix - Leeroy

Carbon Capture - Commercialization

Availability and Market Areas

- Pilot projects and early commercial deployments in power generation
- Carbon capture utilization storage facilities expansion
- Development of CO2 transportation and storage infrastructure

Fuel Cost

- High initial capital costs associated with carbon capture systems and infrastructure

Infrastructure Needs

- Capture systems that can be compatible with marine application
- Onboard storage solutions for safe handling of stored CO2
- Established facilities/ports for offloading and transporting the captured CO2
- Ways to integrate pre-existing industrial CO2 utilization and storage networks

Carbon Capture – Limitations & Concerns

Technical and Safety Issues

- Complexity to integrate capture systems
- Concerns of CO2 storage and leaks

Regulation Hurdles

- Compliance with IMO guidelines
- There are no international standards for carbon capture
- Safety and environmental regulations

Potential concerns for scalability

- High investment costs for infrastructure and systems
- Fully dependent on battery technology advancements for efficiency improvements and cost reductions
- Post-Combustion:
  - Low carbon capture efficiency because of the low CO2 flue gas concentration
  - Large parasitic loads
  - High electrical energy generation costs
- Pre-combustion:
  - the capital cost for base gasification process is above pulverized coal power plants.
  - Cost of absorption for capturing CO2 from IGCC power plant is around $60/tonne
  - Limited IGCC plants
  - Decay issues with hydrogen rich fuels
  - Heat transfer challenges

Carbon Capture – Short- & Long-Term Implications

Short-term

- Adoption of initial pilot projects and small-scale deployments for feasibility testing
- Development of necessary infrastructure at key ports
- Research and development investment
- Necessary development in infrastructure
- Compliance with MARPOL and IMO emissions guides
- Potential for government incentives
- Development of standards and protocols

Long-Term

- Increased usage on marine vessels
- Improvements in carbon capture technology and efficiency
- Enhancement in materials and methods for CO2 storage and transportation
- Reductions in GHG
- Creation and adoption of international standards which includes safety standards
- Cost competitive with emission reducing methods
- Growth in the carbon capture market

Credit: Library of Congress -Highsmith, Carol M., 1946- Carol M. Highsmith Archive.