Postgraduate Certificate in Shipping Decarbonization Strategies

Maritime Energy Systems and Emissions

Alternative Fuels – fuels that differ from conventional heavy fuel oil (HFO) and marine diesel oil (MDO) and offer lower greenhouse gas (GHG) emissions. Related terms: bio-fuels, liquefied natural gas (LNG), methanol, ammonia, hydrogen. Alternative fuels can be derived from renewable sources (e.g., bio-ethanol, bio-diesel) or from low-carbon feedstocks (e.g., LNG, green hydrogen). Their adoption reduces carbon intensity of ship propulsion and aligns with IMO's carbon reduction targets. Example: a container vessel converted to run on LNG experiences a 20-25 % reduction in CO_2 per tonne-nautical-mile. Practical application includes retrofitting existing engines with dual-fuel capability and designing new vessels with dedicated fuel tanks. Challenges encompass fuel availability at ports, higher upfront capital costs, storage safety considerations (especially for cryogenic hydrogen), and the need for robust certification standards.

Ballast Water Management – the process of treating, storing, or exchanging ballast water to prevent the transfer of invasive species and to comply with the International Maritime Organization's Ballast Water Management Convention. Related terms: ballast water treatment system (BWTS), discharge standards, invasive species, IMO D-2 Standard. Effective management protects marine ecosystems and avoids penalties. Example: a bulk carrier equipped with a UV-based BWTS can meet the $\leq 10^{-3}$ organisms per litre discharge limit without chemical additives. Practical applications include integrating BWTS into existing hull designs and automating discharge monitoring. Challenges involve high energy consumption of treatment technologies, space constraints on older vessels, and the need for regular maintenance to ensure system reliability.

Carbon Intensity – the amount of CO_2 emitted per unit of transport work, typically expressed in grams CO_2 per tonne-nautical-mile (gCO_2/t-nm). Related terms: Energy Efficiency Design Index (EEDI), carbon rating, IMO 2023 carbon intensity reduction framework. Carbon intensity is a key metric for assessing a vessel's environmental performance and for compliance with upcoming IMO regulations that will impose annual reduction targets. Example: a modern Ro-Ro ferry with an optimized hull form and hybrid propulsion achieves a carbon intensity of 45 gCO_2/t-nm, well below the 2025 baseline. Practical applications involve using real-time monitoring systems to track emissions and adjusting operational parameters (speed, trim) to stay within limits. Challenges include the variability of fuel quality, the difficulty of measuring auxiliary power consumption accurately, and the need for fleet-wide data harmonization.

Decarbonisation Pathways – strategic routes that maritime operators can follow to achieve net-zero emissions by mid-century. Related terms: scenario analysis, transition fuels, technology roadmaps, policy incentives. Pathways typically combine short-term efficiency measures, medium-term adoption of low-carbon fuels, and long-term integration of zero-emission technologies. Example: a shipping company may plan a three-phase approach: (1) install energy-saving devices and adopt slow steaming; (2) transition to LNG and bio-LNG by 2030; (3) deploy hydrogen fuel cells for new builds after 2035. Practical applications require detailed carbon accounting, investment appraisal, and stakeholder alignment. Challenges include uncertainty in fuel price trajectories, regulatory evolution, and the risk of stranded assets if technologies mature slower than anticipated.

Energy Efficiency Design Index (EEDI) – a mandatory performance indicator that quantifies the CO_2 efficiency of newly built ships, expressed as grams CO_2 per tonne-nautical-mile. Related terms: Energy Efficiency Existing Ship Index (EEISI), IMO MEPC, baseline curve. The EEDI sets progressively stricter limits for different ship types, incentivizing designers to adopt hull form optimization, lightweight materials, and advanced propulsion. Example: a newly constructed chemical tanker with an EEDI rating 15 % below the 2025 baseline incorporates a bulbous bow, propeller boss cap fin, and a waste heat recovery system. Practical application involves using simulation software during the design phase to predict EEDI compliance. Challenges include balancing cost versus performance, ensuring that measured gains translate into real-world operational savings, and updating the index to reflect emerging low-carbon fuels.

Fuel Cell Technology – electrochemical devices that convert hydrogen or other fuels directly into electricity, producing only water and heat as by-products. Related terms: proton exchange membrane (PEM), solid oxide fuel cell (SOFC), green hydrogen, zero-emission vessels. Fuel cells offer high efficiency (up to 60 % electrical) and can power both propulsion and auxiliary loads. Example: a coastal ferry equipped with a PEM fuel-cell system of 2 MW can operate entirely on green hydrogen, achieving zero tailpipe emissions on a 150-km route. Practical applications include integrating fuel cells with battery storage for load-leveling and using them as range extenders on hybrid vessels. Challenges involve hydrogen storage density, the need for refuelling infrastructure, high capital costs, and durability of fuel-cell stacks under marine conditions.

Greenhouse Gas Emissions – gases such as CO_2, CH_4, N_2O, and fluorinated gases that trap heat in the atmosphere, with shipping contributing roughly 3 % of global CO_2 emissions. Related terms: carbon accounting, emission inventories, IMO GHG strategy, carbon markets. Reducing GHG emissions is central to climate mitigation efforts and is regulated through IMO targets (40 % reduction by 2030, 70 % by 2050 compared to 2008). Example: a fleet of container ships implements a fleet-wide speed optimization program, cutting CO_2 emissions by 12 % annually. Practical applications include adopting digital emission reporting platforms, investing in low-carbon fuels, and participating in voluntary carbon offset schemes. Challenges consist of data collection accuracy, aligning corporate targets with international regulations, and financing the transition without compromising commercial competitiveness.

Hybrid Propulsion – a system that combines two or more power sources, typically diesel engines with electric motors and batteries, to improve fuel efficiency and reduce emissions. Related terms: diesel-electric, battery-assisted propulsion, plug-in hybrid, energy management system. Hybrid systems enable optimal engine loading, enable zero-emission operation in emission-controlled zones, and support smoother maneuvering. Example: a Ro-Pax vessel uses a diesel-electric configuration with a 5 MWh battery, allowing it to operate on battery alone while docked, eliminating auxiliary emissions. Practical applications involve designing propulsion layouts that accommodate battery packs, integrating control algorithms for seamless power transitions, and leveraging shore power connections. Challenges include battery weight and volume constraints, life-cycle management of battery packs, and the need for sophisticated control software to prevent performance degradation.

International Maritime Organization (IMO) – United Nations specialized agency responsible for regulating shipping, including safety, legal matters, and environmental protection. Related terms: Marine Environment

Protection Committee (MEPC), Convention on the Prevention of Marine Pollution, IMO 2023 strategy. IMO sets global standards such as the MARPOL Annex VI regulations on NOx, SOx, and CO_2, and develops market-based measures like the Carbon Offsetting and Reduction Scheme for International Shipping (CORS). Example: the IMO's adoption of the 2023 carbon intensity reduction framework obliges ship owners to report annual emissions and achieve yearly reduction percentages. Practical applications involve aligning corporate sustainability strategies with IMO mandates, participating in working groups, and ensuring compliance through audits. Challenges include reconciling divergent regional policies, addressing the cost of compliance for small operators, and navigating the lag between policy adoption and implementation.

Methanol – a liquid fuel (CH_3OH) that can be produced from natural gas, coal, or renewable feedstocks (green methanol) and used as a drop-in replacement for marine diesel. Related terms: methanol-compatible engines, low-sulphur fuel, carbon-neutral methanol, fuel handling regulations. Methanol offers lower NOx emissions and, when sourced from renewable electricity, can achieve near-zero carbon intensity. Example: a 10,000-dwt product tanker retrofitted with a dual-fuel methanol engine demonstrates a 30 % reduction in CO_2 emissions compared with baseline HFO operation. Practical applications include establishing methanol bunkering facilities at major ports, modifying fuel pipelines to prevent corrosion, and training crew on safe handling procedures. Challenges involve the lower energy density of methanol (requiring larger storage volumes), limited global supply infrastructure, and the need for robust safety standards due to methanol's toxicity and flammability.

Nitrogen Oxide (NOx) Regulations – limits on nitrogen oxide emissions from ship exhaust, aimed at reducing air pollution and acid rain formation. Related terms: Tier III, ECA (Emission Control Areas), selective catalytic reduction (SCR), exhaust gas cleaning system. IMO's Annex VI sets tiered NOx limits based on engine speed and installation date, with stricter standards in designated ECAs. Example: a cruise ship operating in the North Sea ECA installs an SCR system, achieving a 90 % NOx reduction and complying with Tier III requirements. Practical applications involve selecting appropriate after-treatment technologies, integrating them into existing exhaust layouts, and monitoring compliance through continuous emission measurement systems. Challenges include the high capital and operating costs of SCR, the need for urea storage and dosing infrastructure, and the impact on engine performance and maintenance schedules.

On-board Energy Management System (OEMS) – a digital platform that monitors, analyses, and optimises a vessel's energy consumption in real time. Related terms: condition-based monitoring, predictive analytics, digital twin, energy performance indicator (EnPI). OEMS integrates data from propulsion, auxiliary generators, HVAC, and cargo handling equipment to identify inefficiencies and suggest corrective actions. Example: a container ship equipped with OEMS reduces fuel consumption by 4 % over a six-month period by adjusting generator load distribution and optimizing hull cleaning schedules. Practical applications include automated reporting for regulatory compliance, integration with shore-side energy management for coordinated port-call operations, and support for crew training on best-practice energy behaviours. Challenges involve data interoperability across equipment vendors, cybersecurity risks, and ensuring crew acceptance of automated decision-support tools.

Port Emission Control Areas (ECAs) – designated sea regions where stricter emission limits are enforced to protect coastal air quality. Related terms: sulphur cap, NOx Tier III, IMO Annex VI, regional regulations. In

ECAs, ships must use fuel with sulphur content ≤0.10 % m/m and meet tighter NOx standards. Example: a tanker transiting the Baltic Sea ECA installs a scrubber to comply with the sulphur cap while retaining the use of high-sulphur fuel in open-sea voyages. Practical applications involve planning voyages to minimise ECA exposure, installing compliant exhaust treatment systems, and coordinating with ports for fuel switching. Challenges include the cost of compliance equipment, potential incompatibility of scrubbers with certain fuels, and the need for accurate geofencing to avoid inadvertent violations.

Renewable Energy Integration – the incorporation of renewable sources such as wind, solar, and wave energy into ship power systems. Related terms: rotor sails, solar panels, kite-assisted propulsion, hybrid renewable-diesel systems. Renewable technologies can offset a portion of a vessel's propulsion or auxiliary power demand, reducing fuel consumption and emissions. Example: a bulk carrier fitted with a 1 MW rotor sail system achieves a 6 % fuel saving on a typical North Atlantic route. Practical applications include designing modular renewable modules that can be retrofitted, developing control algorithms to optimise renewable contribution based on weather forecasts, and integrating energy storage to smooth intermittent generation. Challenges involve the added weight and deck space requirements, variability of renewable resource availability, and the need for rigorous structural analysis to ensure vessel stability.

Scrubber – an exhaust gas cleaning system that removes sulphur oxides (SOx) from ship emissions, allowing the use of high-sulphur fuel while meeting IMO sulphur regulations. Related terms: open-loop, closed-loop, hybrid scrubber, wash water discharge. Scrubbers work by spraying seawater (or a recirculating solution) through the exhaust stream, capturing SOx which is then treated or discharged. Example: a Panamax container ship installs a hybrid scrubber that operates in open-loop mode in international waters and switches to closed-loop when entering ECAs with strict wash water discharge limits. Practical applications include selecting the appropriate scrubber type based on operating regions, ensuring compliance with local discharge standards, and integrating monitoring sensors for real-time performance tracking. Challenges encompass the high initial investment, potential for increased fuel consumption due to added drag, and regulatory scrutiny over wash water impacts on marine ecosystems.

Zero-Emission Vessels (ZEVs) – ships that operate without emitting CO_2 or other regulated pollutants during normal service, typically powered by electricity from renewable sources, hydrogen fuel cells, or ammonia. Related terms: battery-only ships, hydrogen-fuel-cell vessels, ammonia-powered ferries, decarbonisation target. ZEVs represent the ultimate goal of maritime decarbonisation and are increasingly supported by national and regional incentives. Example: a 50-meter electric ferry operating on a 30-km route uses shore-side renewable electricity to charge its 10 MWh battery, achieving a fully zero-emission profile. Practical applications involve designing vessels with optimized hull forms to minimise energy demand, establishing robust charging or refuelling infrastructure, and developing safety protocols for high-energy storage systems. Challenges include limited energy density of batteries for long-haul routes, the nascent state of ammonia handling infrastructure, and the need for standardised certification regimes for new propulsion technologies.

Carbon Capture and Storage (CCS) on Ships – technologies that capture CO_2 from ship exhaust and store it for later transport and sequestration, aiming to mitigate emissions from vessels that cannot immediately switch to zero-carbon fuels. Related terms: post-combustion capture, CO_2 liquefaction, ship-borne storage tanks, offshore sequestration. CCS can be integrated with existing propulsion systems to reduce net emissions. Example: a research-grade tanker equipped with a pilot CCS unit captures up to 2 % of its CO_2 emissions, compresses the gas, and stores it in high-pressure tanks for off-load at a designated port. Practical applications include using captured CO_2 for enhanced oil recovery (EOR) or for on-board utilization in synthetic fuel production. Challenges are the high energy penalty of capture processes, limited storage capacity onboard, added weight affecting vessel stability, and the lack of a commercial market for ship-borne CO_2 transport.

Digital Twin for Vessel Performance – a virtual replica of a ship that simulates its physical behavior under varying operational conditions, enabling predictive optimisation and proactive maintenance. Related terms: simulation modelling, data analytics, IoT sensors, performance verification. By linking real-time sensor data to the digital model, operators can evaluate fuel consumption, emissions, and hull fouling impacts before they occur. Example: a shipping line uses digital twins of its fleet to test speed-reduction scenarios, identifying an optimal 0.7 knots reduction that saves 5 % fuel without compromising schedule reliability. Practical applications include scenario testing for regulatory compliance, crew training using virtual environments, and integrating with OEMS for automated decision-making. Challenges involve ensuring model fidelity, handling large data volumes, protecting sensitive operational data, and aligning cross-departmental responsibilities for model upkeep.

Energy-Saving Devices (ESDs) – equipment installed on ships to improve propulsive efficiency by reducing resistance or enhancing thrust. Related terms: pre-swirl stator, ducted propeller, propeller boss cap fin, hull-mounted fins. ESDs can provide fuel savings of 5-15 % depending on vessel type and operating profile. Example: a bulk carrier fitted with a ducted propeller experiences a 7 % reduction in fuel consumption on its standard trade route. Practical applications involve conducting a cost-benefit analysis before installation, performing CFD assessments to predict performance gains, and scheduling installation during regular dry-dock periods. Challenges include ensuring compatibility with existing propulsion geometry, avoiding cavitation or increased vibration, and verifying long-term durability in harsh marine environments.

Fuel Sulphur Content Regulations – limits set by IMO Annex VI that restrict the sulphur mass fraction in marine fuels to ≤0.50 % globally and ≤0.10 % within ECAs. Related terms: low-sulphur fuel oil (LSFO), compliant fuel supply chain, fuel testing, fuel oil blending. Reducing sulphur content lowers SOx emissions, improving air quality and health outcomes. Example: a vessel operating in the North American ECA switches to LSFO and installs an on-board fuel sampling system to verify compliance before each bunkering. Practical applications involve establishing reliable fuel procurement processes, conducting regular fuel analyses, and training crew on proper fuel handling to avoid cross-contamination. Challenges include higher cost of low-sulphur fuel, limited availability in some regions, and the need for accurate documentation to defend against potential inspections.

Green Shipping Initiatives – collaborative programmes and industry-led efforts aimed at accelerating the transition to sustainable maritime operations. Related terms: Sustainable Shipping Initiative (SSI), Clean Cargo Working Group, IMO Decarbonisation Strategy, voluntary carbon markets. These initiatives provide frameworks for data transparency, best-practice sharing, and joint investment in low-carbon technologies. Example: a liner company joins the Clean Cargo Working Group, publishing its GHG intensity data annually and committing to a 30 % reduction by 2030. Practical applications include adopting common reporting standards, participating in pilot projects for alternative fuels, and leveraging collective bargaining to secure favorable fuel contracts. Challenges involve aligning diverse stakeholder interests, ensuring data integrity across multinational fleets, and translating voluntary commitments into measurable, enforceable outcomes.

Hybrid Battery Management – the set of strategies and control algorithms used to optimise charging, discharging, and health of batteries on hybrid vessels. Related terms: state-of-charge (SOC), depth-of-discharge (DoD), battery thermal management, life-cycle cost. Effective management extends battery lifespan, maximises energy savings, and ensures safety. Example: a ferry's battery management system maintains SOC between 30 % and 80 % and limits DoD to 50 % during each voyage, achieving a 20 % reduction in degradation rate compared with unrestricted operation. Practical applications include integrating predictive models to anticipate power demand, coordinating with shore-side charging schedules, and implementing real-time monitoring of temperature and voltage. Challenges comprise balancing performance with longevity, handling the impact of marine environmental conditions on battery chemistry, and complying with classification society requirements for battery installations.

IMO Carbon Offsetting and Reduction Scheme for International Shipping (CORS) – a market-based mechanism that allows ship operators to purchase carbon credits to offset emissions that exceed their reduction targets. Related terms: emissions trading, carbon market, offset projects, compliance reporting. CORS aims to provide flexibility while encouraging investment in emission-reduction projects. Example: a shipping line that falls short of its 2030 carbon intensity target purchases verified credits from a wind-farm project, achieving compliance while supporting renewable energy development. Practical applications involve integrating offset purchases into the annual budgeting process, selecting high-quality projects with robust verification, and reporting transactions through the IMO's electronic platform. Challenges include ensuring the environmental integrity of offset projects, avoiding double-counting, and managing price volatility in the carbon market.

Low-Carbon Fuels – fuels that emit fewer greenhouse gases compared with conventional marine diesel, including bio-fuels, synthetic fuels, and renewable gases. Related terms: carbon intensity, life-cycle assessment (LCA), renewable natural gas (RNG), sustainable aviation fuel (SAF) analogues. Low-carbon fuels are essential for meeting IMO's decarbonisation trajectory. Example: a tanker using a blend of 30 % bio-LNG and 70 % conventional LNG reduces its CO_2 emissions by roughly 12 % on a per-tonne basis. Practical applications involve conducting LCA to verify carbon savings, establishing bunkering hubs for renewable fuels, and negotiating long-term supply contracts with producers. Challenges include verifying sustainability criteria of feedstocks, addressing higher fuel costs, and ensuring compatibility with existing engine designs without extensive modifications.

Marine Renewable Energy (MRE) – energy harvested directly from the marine environment, such as wave, tidal, and offshore wind, for ship propulsion or onboard power generation. Related terms: wave energy converters, tidal turbines, offshore wind farms, energy harvesting. MRE can provide clean power, particularly for vessels operating in coastal or offshore support roles. Example: an offshore supply vessel equipped with a wave-energy converter generates up to 500 kW of electricity during moderate sea states, offsetting a portion of its diesel engine load. Practical applications include designing modular MRE units that can be retrofitted, integrating power electronics to manage variable output, and coordinating with shore-based renewable farms for combined energy supply. Challenges involve the added structural loads on hulls, variability of resource availability, and the need for robust marine-grade equipment to withstand harsh sea conditions.

Emission Reporting and Verification – the process by which ship operators collect, validate, and submit data on fuel consumption and emissions to regulatory bodies. Related terms: IMO Data Collection System (DCS), verified emissions reporting (VER), audit trail, data integrity. Accurate reporting is essential for compliance with IMO's carbon intensity reduction framework and for participation in voluntary carbon markets. Example: a fleet adopts an automated emissions monitoring system that uploads fuel flow data to the IMO DCS, reducing manual entry errors by 85 % and facilitating timely submission of annual reports. Practical applications involve establishing standard operating procedures for data capture, training crew on measurement techniques, and engaging third-party auditors for verification. Challenges include ensuring uniformity of measurement equipment across heterogeneous fleets, dealing with legacy vessels lacking modern sensors, and protecting sensitive commercial data from unauthorized access.

Fuel Oil Quality Management – the systematic control of fuel properties (viscosity, density, sulphur content, water content) to ensure safe engine operation and regulatory compliance. Related terms: fuel oil analysis, ASTM standards, fuel polishing, contamination control. Poor fuel quality can lead to engine damage, increased emissions, and non-compliance penalties. Example: a vessel implements a fuel polishing system that removes particulates and water, extending engine life and maintaining emissions within permitted limits. Practical applications include conducting regular fuel sampling, using onboard fuel testing kits, and maintaining a fuel quality log for each bunkering event. Challenges comprise variability in fuel quality across suppliers, the need for rapid on-board testing methods, and managing the logistical complexity of fuel swaps in multi-fuel vessels.

Green Shipping Corridors – designated maritime routes where ships are required or incentivised to use low-carbon fuels and adopt emission-reduction measures. Related terms: alternative fuel corridors, zero-emission shipping lanes, policy incentives, regional cooperation. Corridors aim to create concentrated demand for sustainable fuels, driving market development. Example: the Baltic Sea Green Corridor mandates that all container ships use LNG or certified bio-fuel when traversing the route, and offers reduced port fees for compliant vessels. Practical applications involve coordinating with port authorities to provide bunkering infrastructure, integrating route planning software to optimise fuel usage, and tracking compliance through AIS-based monitoring. Challenges include harmonising standards across multiple jurisdictions, ensuring sufficient fuel supply along the entire corridor, and balancing commercial competitiveness with environmental objectives.

Hydrogen as a Marine Fuel – hydrogen (H_2) can be used directly in fuel cells or combusted in modified engines to provide zero-CO_2 propulsion when produced from renewable electricity (green hydrogen). Related terms: cryogenic storage, hydrogen-fuel-cell propulsion, ammonia as hydrogen carrier, hydrogen safety standards. Hydrogen offers high energy conversion efficiency and eliminates CO_2 emissions at the point of use. Example: a 5 MW hydrogen fuel-cell system powers a coastal research vessel, achieving a fully zero-emission profile on a 200-nm mission. Practical applications include designing insulated tanks for liquid hydrogen, establishing bunkering networks at major ports, and developing dual-fuel engines capable of operating on both hydrogen and conventional fuels during transition periods. Challenges involve the low volumetric energy density of hydrogen, stringent safety requirements for handling and storage, high production costs of green hydrogen, and the current scarcity of refuelling infrastructure.

IMO Energy Efficiency Existing Ship Index (EEISI) – a performance metric for ships already in service, comparing actual CO_2 emissions per tonne-nautical-mile against a reference line based on ship type and size. Related terms: EEDI, operational efficiency, retrofitting, carbon benchmarking. EEISI encourages owners to implement measures that improve fuel efficiency throughout a vessel’s operational life. Example: a container ship improves its EEISI rating by 12 % after installing a hull-cleaning robot and optimizing its voyage planning software. Practical applications involve conducting regular energy audits, applying software-driven speed optimisation, and investing in energy-saving devices. Challenges include obtaining reliable emission data for older vessels, the cost-effectiveness of retrofits versus new-builds, and aligning EEISI improvements with commercial schedule requirements.

Integrated Energy Management (IEM) – a holistic approach that synchronises propulsion, auxiliary, and cargo-related power demands to minimise overall fuel consumption and emissions. Related terms: load-balancing, demand-side management, ship-board optimisation, power electronics. IEM leverages real-time data to shift loads, activate standby generators only when needed, and exploit renewable generation when available. Example: a liquefied natural gas carrier uses IEM to coordinate its main engine, thrusters, and cargo pumps, achieving a 5 % reduction in fuel usage during trans-Atlantic voyages. Practical applications include deploying advanced control systems, integrating battery storage for peak shaving, and training crew on energy-aware operating procedures. Challenges involve the complexity of integrating disparate subsystems, ensuring reliability of the control platform, and meeting classification society requirements for system redundancy.

Lifecycle Assessment (LCA) of Marine Fuels – a comprehensive methodology that evaluates the environmental impacts of a fuel from extraction through production, transport, use, and disposal. Related terms: carbon footprint, cradle-to-grave analysis, sustainability certification, GHG accounting. LCA helps stakeholders compare the true climate benefits of alternative fuels against conventional options. Example: an LCA of synthetic e-methanol shows a 50 % reduction in CO_2 emissions compared with conventional marine diesel when powered by 80 % renewable electricity. Practical applications include using LCA results to inform procurement decisions, supporting claims for carbon-credit eligibility, and guiding policy development. Challenges consist of data availability for upstream processes, variability in regional electricity mixes, and the need for standardized LCA frameworks accepted by regulators and investors.

Marine Diesel Engine Optimisation – the suite of technical and operational measures aimed at improving the efficiency of conventional diesel engines. Related terms: turbocharging, fuel injection timing, cylinder de-activation, engine control unit (ECU) calibration. Optimisation can reduce specific fuel consumption and emissions without major hardware changes. Example: recalibrating the ECU of a 10 000 kW engine to a lean-burn strategy yields a 3 % fuel saving and a proportional decrease in CO_2 output. Practical applications involve periodic engine performance testing, implementing condition-monitoring tools, and training engineering staff on best-practice tuning. Challenges include ensuring that efficiency gains do not compromise engine durability, navigating manufacturer warranty constraints, and integrating optimisation measures across a heterogeneous fleet.

Naval Architecture for Decarbonisation – the design discipline that incorporates energy-efficiency and emissions-reduction considerations into hull form, structural layout, and weight distribution. Related terms: slender hull, bulbous bow, computational fluid dynamics (CFD), weight optimisation. Advances in naval architecture enable vessels to achieve lower resistance, reducing propulsion power requirements. Example: a newly designed liquefied petroleum gas carrier adopts a wave-reducing hull coating and an optimized stern shape, resulting in a 7 % reduction in fuel consumption over its design service life. Practical applications include employing CFD simulations early in the design process, using lightweight composite materials, and performing model-scale testing to validate performance gains. Challenges involve balancing cargo capacity with hull efficiency, managing higher construction costs for advanced materials, and ensuring compliance with classification society rules for novel designs.

Off-shore Wind-Assisted Propulsion (OWAP) – the use of wind-driven devices such as Flettner rotors, rigid sails, or kite systems to supplement engine power. Related terms: rotor sails, rigid wing sails, kite-assisted propulsion, aerodynamic augmentation. OWAP can achieve fuel savings of 5-15 % depending on route wind conditions. Example: a 30,000-dwt bulk carrier fitted with three Flettner rotors records an average 9 % reduction in fuel consumption on a North Atlantic trade lane. Practical applications involve integrating control systems that adjust rotor speed based on wind direction, conducting route-specific wind assessments, and ensuring structural reinforcement of the deck to support the devices. Challenges include added deck weight, potential interference with cargo operations, maintenance of moving aerodynamic components, and the need for crew training on operation and safety procedures.

Port State Control (PSC) Emissions Enforcement – inspections carried out by port authorities to verify that visiting vessels comply with international emission regulations. Related terms: flag state, compliance audit, detention, emission certification. PSC can result in fines, detention, or refusal of entry for non-compliant ships. Example: a tanker is detained in a European port after PSC officers detect sulphur content above the 0.10 % limit in its fuel sample, prompting the shipowner to install a scrubber before departure. Practical applications include maintaining up-to-date documentation on fuel certificates, conducting internal compliance checks before port calls, and establishing rapid response protocols for remedial actions. Challenges include the variability of enforcement rigor across jurisdictions, the potential for operational disruptions, and the cost implications of corrective measures after a PSC finding.

Renewable Diesel (Bio-Diesel) for Marine Use – a fuel derived from biological feedstocks (e.g., vegetable oil, animal fat) that meets the same specifications as conventional diesel but with lower life-cycle CO_2 emissions. Related terms: B100, cetane number, fuel blending, sustainability criteria. Renewable diesel can be used in existing diesel engines with minimal modifications. Example: a coastal ferry operating on a 100 % renewable diesel blend achieves a 20 % reduction in CO_2 emissions compared with conventional diesel, while maintaining identical performance characteristics. Practical applications involve securing certified sustainable feedstock supplies, updating fuel handling procedures to prevent contamination, and verifying compliance through fuel testing. Challenges include feedstock availability constraints, competition with other sectors for bio-feedstocks, and price volatility relative to fossil diesel.

Ship-to-Shore Power (Cold Ironing) – the practice of supplying electricity from the shore to a vessel while at berth, allowing the ship's engines and auxiliary systems to be shut down. Related terms: shore-side connection, high-voltage AC/DC supply, emission reduction at ports, power management. Shore power eliminates the need for diesel generators, reducing local air pollutants and noise. Example: a cruise ship docked for 12 hours in a major European port uses shore power to run hotel services, cutting its on-shore CO_2 emissions by approximately 1,500 tonnes per week. Practical applications include installing compatible on-board power conversion equipment, coordinating with port authorities for power availability, and scheduling berth times to align with shore-power capacity. Challenges encompass the high capital cost of on-board transformers, the need for standardized voltage and frequency across regions, and limited shore-power infrastructure in many ports worldwide.

Smart Shipping Platforms – digital ecosystems that integrate data from vessel sensors, weather services, and market information to optimise routing, fuel consumption, and emissions. Related terms: AI-driven route optimisation, real-time emissions monitoring, cloud analytics, decision support systems. By leveraging predictive analytics, smart platforms can recommend speed adjustments, optimal trim, and fuel-type selection to minimise carbon output. Example: a logistics company adopts a smart shipping platform that suggests a 0.5-knots speed reduction for a trans-Pacific voyage, resulting in a 4 % fuel saving without jeopardising delivery windows. Practical applications include connecting shipboard IoT devices to cloud-based dashboards, integrating emissions data into corporate sustainability reporting, and automating compliance documentation. Challenges involve ensuring data security, achieving interoperability across heterogeneous equipment, and maintaining the reliability of AI recommendations under rapidly changing maritime conditions.