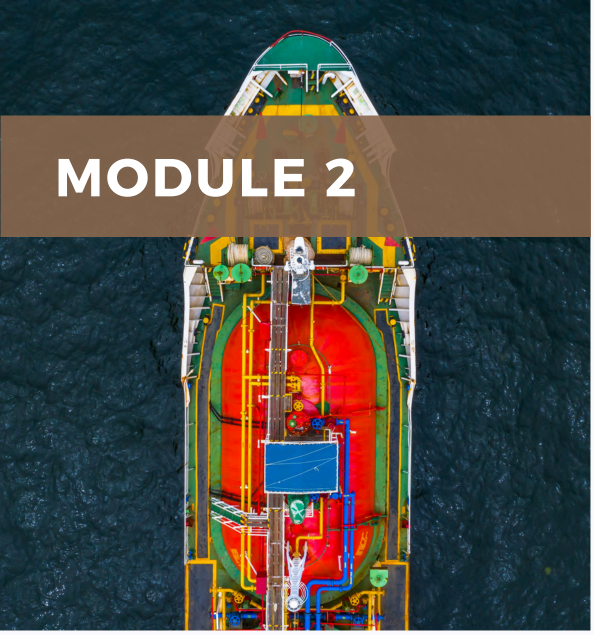

MODULE 2

CASE STUDY: INTERNATIONAL HYDROGEN SUPPLY FOR AN OFFSHORE WIND FARM

Description:
As a consulting firm specializing in hydrogen logistics, "AquaH2 Solutions" has been engaged by the Baltic Hydrogen Alliance (BHA), an energy consortium comprising prominent European energy and technology enterprises.

BHA is undertaking a revolutionary initiative, "Wind-to-H2 Offshore," to establish a cutting-edge, fully automated offshore wind farm in the Baltic Sea, situated roughly 150 km northwest of the Port of Gdynia. The project seeks to showcase an innovative model for the production and export of green hydrogen directly at sea.

The wind farm, featuring turbines with a total capacity of 1 GW, will incorporate advanced marine electrolyzers directly powered by wind energy. During the testing phase, the farm is projected to generate up to 25 tons of green hydrogen daily. This hydrogen will subsequently be liquefied on a specialized marine-industrial platform, known as the Floating Liquid Hydrogen Production Unit (FLHPU), into liquid hydrogen (LH2), which possesses a volumetric energy density of approximately 70.8 kg/m^3. The liquefaction process, executed using cryogenic technologies based on the Brayton or Claude cycle, necessitates substantial energy consumption (approximately 10-12 kWh/kg LH2), which is mitigated by access to cost-effective renewable energy.

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A segment of the LH2 production, estimated at 5 tons per day, will be retained on the FLHPU platform as an operational buffer and for local maintenance activities. Excess production, approximately 20 tons of LH2 per week, is scheduled for transport to shore.

The ultimate receiving point is the recently expanded Hamburg Energy Terminal in Germany, situated approximately 600 km by sea from the wind farm. From Hamburg, the hydrogen will subsequently be distributed to key industrial clients in Germany that are undergoing a decarbonization transition (e.g., steelworks, chemical plants).

Challenges and Context

- **Extreme LH2 storage and transport conditions:** The transportation of LH2 necessitates the maintenance of a temperature of -253°C (20 K). This requirement mandates the utilization of advanced cryogenic vessels featuring optimal thermal insulation, such as vacuum tanks equipped with multi-layer superinsulation. A significant concern is the "boil-off" phenomenon, which refers to the continuous evaporation of hydrogen resulting from inevitable heat transfer from the surrounding environment. Typical boil-off rates for large cryogenic vessels range from 0.05% to 0.2% of their volume per day. In maritime transport, the motion of the ship and varying weather conditions can influence this rate. Strategies for managing boil-off may involve reliquidating the gas onboard the vessel or employing it as a propellant for the transport vessel.
- **Marine Environment:** Cargo handling and transportation operations occur on the open sea, subjecting them to fluctuating weather conditions, waves, and salinity. This necessitates particular vessel designs, corrosion-resistant materials, and specialized anchoring and docking systems.
- **Safety Considerations:** Hydrogen, an explosive and flammable gas, presents considerable hazards. Its flame is colorless and imperceptible in daylight. The transportation and handling of hydrogen carry the risk of frostbite upon skin contact and the potential for creating flammable atmospheres in the event of a leak. Safety protocols must incorporate advanced hydrogen detection systems, fire suppression systems specifically designed for hydrogen fires, and stringent operational and emergency procedures.

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- **Regulatory Complexity:** International maritime transport is subject to extensive regulation. Prominent regulations include the IMDG Code (International Maritime Dangerous Goods Code) governing the transport of packaged hazardous materials, and the IGC Code (International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk) applicable to gas carriers transporting liquefied gases in bulk. These regulations are further supported by classifications and guidelines from the IMO (International Maritime Organization).
- **Cost versus Efficiency:** The substantial expenses associated with constructing specialized vessels and port infrastructure (cryogenic terminals) necessitate operational optimization. Key considerations encompass vessel size (economies of scale), sailing frequency, route optimization, and technologies aimed at minimizing losses.

Group Assignment

As the AquaH2 Solutions team, you are tasked with formulating a comprehensive logistics plan for the marine transportation of liquid hydrogen (LH2) from an offshore wind farm in the Baltic Sea to a terminal in Hamburg. This plan will be presented to the board of the Baltic Hydrogen Alliance.

1. **Analysis of challenges and selection of methods for maritime transport of LH2:**

- What are the primary technical and operational challenges associated with transporting 20 tonnes of LH2 weekly from an offshore platform to a destination port within a marine environment?
- Propose and delineate the optimal vessel types (e.g., dedicated hydrogen gas carriers, modified LNG tankers, IMDG cryogenic container barges) that would be most appropriate for transporting LH2 over this scale and distance. Justify your selection based on capacity, safety, cost, and efficiency.

2. **Approaches to mitigate losses and enhance safety:**

- Propose targeted technological and operational solutions to reduce hydrogen losses due to boil-off during maritime transport. Explore systems for the reliquefaction of gas on board vessels or its utilization as fuel.
- Propose essential safety measures (technical: e.g., gas detection systems, shut-off systems, ventilation; and operational: e.g., cargo handling procedures, crew training, emergency plans) to be implemented aboard the ship and at the Hamburg port terminal.

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3. **Adherence to international standards and regulations:**

- Identify the international standards and regulations (e.g., IMDG Code, IGC Code, IMO guidelines on hydrogen bunkering and transport) that will be essential for this LH2 maritime transport project. Discuss the importance of compliance with these standards for ensuring safe and legal operations.
- Briefly examine the certification and training prerequisites for ship crew and port personnel engaged in LH2 operations.

4. **Analysis of cost and operational efficiency:**

- Identify the primary cost categories related to the proposed LH2 maritime transport system (e.g., capital expenditures for vessels and infrastructure, operational expenditures – fuel, boil-off management, port fees, crew expenses, insurance).
- Propose strategies to enhance operational efficiency and reduce costs while upholding stringent safety standards.

5. **Presentation of recommendations and the implementation plan:**

- Prepare a professional presentation (5-7 slides) in which the team articulates its recommendations to the Baltic Hydrogen Alliance board. The presentation should encompass key decisions, their justifications (grounded in technical, safety, cost, and regulatory analyses), and a preliminary implementation strategy.

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