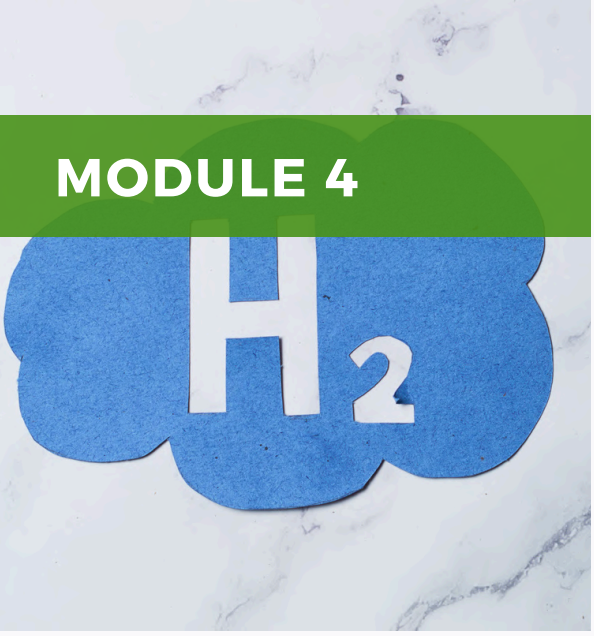
MODULE 4



Introduction:
Germany, a leader in energy transformation within Europe, is making substantial investments in the establishment of a hydrogen economy. The nation is prioritizing the decarbonization of industry and transportation, viewing green hydrogen as essential for attaining climate neutrality. The German government has unveiled a National Hydrogen Strategy, which seeks to create a global hydrogen market and enhance domestic infrastructure.

CASE STUDY: DEVELOPING AN INTEGRATED GREEN HYDROGEN SUPPLY CHAIN FOR A LOGISTICS CENTER IN GERMANY

Facts and statistics regarding hydrogen infrastructure in Germany (as of June 2025):

- **Production:** Germany is vigorously promoting the advancement of electrolyzers. A multitude of Power-to-X projects is underway, aiming to reach an installed electrolyzer capacity of 10 GW by 2030. Pilot plants are currently operational, while several larger facilities are either under construction or in the planning phases.
- **Fueling stations:** Germany boasts one of the most comprehensive networks of hydrogen fueling stations globally. According to the Hydrogen Council and H2 Mobility Germany, the number of public hydrogen fueling stations in the country surpasses 100 and continues to expand. The majority provide compressed hydrogen at 700 bar for passenger vehicles and 350 bar for buses and trucks.
- **Transport and Pipelines:** Current natural gas pipelines are undergoing assessment for their potential modification to facilitate hydrogen transport. A specialized "Hydrogen Backbone"—a network of hydrogen pipelines extending several thousand kilometers—is slated for construction by 2030. Additionally, hydrogen is transported via pressurized and cryogenic tankers.

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- **Demand:** The increasing demand for hydrogen is driven by the industrial sector (refineries, chemicals, steel) and the transportation sector, where an expanding number of companies are testing and deploying hydrogen vehicles (buses, trucks, trains, and even ships).

Situation Description - Case Analysis

International logistics firm GreenFlow Logistics intends to inaugurate a new, fully automated Logistics Center (CL) in proximity to Hamburg, Germany. The CL will manage the warehousing and distribution of goods for clients in the e-commerce and light industrial sectors. In alignment with its sustainability strategy, GreenFlow Logistics has made the bold decision to operate the entire center and a portion of its transport fleet using green hydrogen.

Operational specifics:

- **Fleet size:** Initially comprising 20 hydrogen trucks designated for regional distribution (each capable of covering up to 500 km per day) and 50 hydrogen forklifts intended for warehouse operations. The fleet is projected to expand to 100 trucks within five years.
- **Hydrogen Demand:**
  - Forklifts: Approximately 100 kg of hydrogen produced daily.
  - Trucks: Approximately 25 kilograms of hydrogen per truck daily (assuming refueling occurs once a day), totaling 500 kilograms of hydrogen per day for 20 trucks.
  - Total initial demand: approximately 600 kg of hydrogen daily. Ultimately, with 100 trucks, demand will rise to approximately 2,600 kg of hydrogen per day (2.6 tons).
- **Objective:** Establish a self-sustaining and optimized green hydrogen supply chain by leveraging cutting-edge technologies, including Warehouse Management Systems (WMS), Transportation Management Systems (TMS), Internet of Things (IoT), and Artificial Intelligence (AI) systems.

Available opportunities in the Hamburg area:

- **Hydrogen Suppliers:** Numerous initiatives in the Hamburg region are generating green hydrogen through electrolysis, utilizing both offshore and onshore wind energy. It is feasible to collaborate with a local producer or establish your own electrolysis facility.
- **Transport infrastructure:** The proximity of the Port of Hamburg presents future opportunities for hydrogen imports. Germany's extensive highway network enhances road transport. Plans are underway to construct hydrogen pipelines in the region.

- **Refueling stations:** Numerous public hydrogen refueling stations (700 bar and 350 bar) exist in and around Hamburg; however, their capacity may prove inadequate for a substantial fleet of trucks and forklifts.

Statistics and facts to be incorporated into the analysis:

- **Hydrogen Price:** The prevailing price of green hydrogen in Germany varies but remains higher than that of gray hydrogen. Long-term contracts may provide price stability. The objective is to attain price competitiveness with fossil fuels.
- **Electrolysis efficiency:** Contemporary PEM electrolyzers attain an efficiency of 70-80% in the conversion of electrical energy into chemical hydrogen energy.
- **Refueling station expenses:** Establishing a specialized hydrogen refueling station for trucks and forklifts requires an investment of several million euros, contingent upon the capacity and compression ratio.
- **Hydrogen Vehicle Costs:** Hydrogen trucks and forklifts have a higher initial purchase price compared to their internal combustion engine equivalents; however, they provide reduced fuel expenses over time and produce zero emissions.
- **Hydrogen embrittlement:** The impact of hydrogen on tank and piping materials necessitates careful consideration, mandating the use of specialized alloys and routine inspections.
- **Safety standards:** The German and EU standards (e.g., DIN EN 17124, ISO 19880) for the safety of hydrogen systems must be rigorously adhered to.

Questions and Assignments for Participants

Your team is the **"GreenFlow Logistics"** project group tasked with formulating a detailed strategy for establishing a green hydrogen supply chain for the new logistics center in Hamburg.

1. **Hydrogen Procurement Strategy:**

- Action: Assess hydrogen production alternatives:
  - Acquiring green hydrogen from an external supplier in Hamburg,
  - Construction of a small, proprietary electrolysis installation on the CL (Power-to-Gas) premises.
  - A synthesis of both.

- Questions: What are the primary advantages and disadvantages of each option concerning initial demand (600 kg/day) and anticipated growth (2.6 tons/day)? Which criteria (investment costs, operating costs, delivery reliability, environmental considerations) hold the greatest significance for GreenFlow Logistics? Recommend the optimal solution and provide justification.

2. **Storage and Distribution in CL:**

- Action: Develop a concept for the storage and internal distribution of hydrogen within the logistics center.
- Questions:
  - Which method of hydrogen storage (CGH2 or LH2) would be most suitable for the CL area, considering the characteristics of vehicles (trucks and forklifts) and demand? Please elaborate.
  - What essential components must a hydrogen refueling station in CL include to accommodate both types of vehicles (700 bar for trucks, 350 bar for forklifts)?
  - What are the key safety considerations that must be addressed when designing and operating hydrogen storage and refueling infrastructure at CL?

3. **External Transportation (if hydrogen is procured):**

- Action: If you have resolved to acquire hydrogen, suggest the most efficient method for transporting the hydrogen from the supplier to CL.
- Questions:
  - Will transportation via pressurized or cryogenic tanks be more efficient?
  - What factors, such as distance, volume, and road infrastructure, influence this decision?
  - What criteria must be fulfilled for the transport fleet?

4. **The Function of IT Systems and Auxiliary Technologies:**

- Action: Determine how the integration of WMS, TMS, IoT, and AI technologies can enhance hydrogen supply chain management within "GreenFlow Logistics."
- Questions:
  - Provide two specific examples of how Warehouse Management Systems (WMS) and Transportation Management Systems (TMS) can enhance the management of hydrogen operations, particularly in terms of safety, efficiency, and cost-effectiveness.

- What data from IoT sensors (in electrolyzers, storage tanks, trucks, forklifts, and fueling stations) would be essential for real-time monitoring? In what ways could AI leverage this data for predictive maintenance or supply optimization?

5. **Challenges and Risk Mitigation Strategy:**

- Action: Identify the three most significant challenges that may emerge during the implementation of this project over the next five years.
- Questions: For each challenge, propose a detailed action plan or strategy to mitigate the associated risk. (E.g., Challenge: Fluctuating green energy prices. Plan: Establish long-term Power Purchase Agreements with renewable energy providers.)

Guidelines for Participants

1. **Conduct a thorough analysis:** Keep in mind that decisions made at one stage of the supply chain influence subsequent stages. Consider the system as a whole.
2. **Utilize data and facts:** Ground your decisions in the information available regarding German infrastructure and general statistics. Strive to substantiate your decisions with specific arguments.
3. **Anticipate future needs:** The project encompasses a five-year timeline and fleet expansion. Your solutions must be scalable and resilient to future challenges.
4. **Emphasize safety:** Hydrogen is a combustible material. Safety should be prioritized at every phase of the project.
5. **Creativity within realism:** Pursue innovative solutions while remaining grounded in the realm of actual technological and economic feasibility.
6. **Leverage your knowledge from prior modules:** Recall the functions of WMS, TMS, IoT, and AI. In what ways can these tools assist in managing a complex supply chain?
7. **Teamwork:** Collaborate, exchange ideas, and utilize diverse perspectives from team members.
8. **Prepare a presentation:** Be prepared to articulate your conclusions and substantiate your decisions. Clear and concise communication is essential.

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