MODULE 2

WORKSHEET 1: SELECTING THE IDEAL HYDROGEN STORAGE SYSTEM

The Objective

The objective of this worksheet is to enhance your comprehension of the critical factors that affect the choice of suitable hydrogen storage technology and tank type, as well as to cultivate your abilities in analyzing and designing a preliminary storage system for particular applications.

Introduction

Hydrogen storage represents a significant challenge in the advancement of a hydrogen economy. The selection of appropriate technology is contingent upon various factors, including the necessary hydrogen volume, process pressure and temperature, available space, duration of storage, safety requirements, and both economic and operational considerations.

Let us revisit the primary forms of storage we examined:

- **Compressed hydrogen (CGH2)** is stored at high pressures, typically ranging from 350 bar to 700 bar. This method is noted for its rapid refueling capabilities and relatively straightforward infrastructure, although it exhibits a lower bulk density. The tanks utilized are predominantly Types III and IV, with Types I and II being employed less frequently for lower pressures.
- **Liquefied hydrogen (LH2)** necessitates extremely low temperatures (-253°C). It provides a significantly higher bulk density, which is beneficial for substantial volumes; however, it is linked to elevated liquefaction costs and evaporative losses ("boil-off").

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- **Alternative approaches:**
  - Metal hydrides: secure chemical bonding, yet characterized by low weight density and sluggish processes.
  - Liquid organic hydrogen carriers (LOHC) facilitate transport under standard conditions; however, they necessitate energy-intensive hydrogenation and dehydrogenation processes.
  - Ammonia (NH_3) as a hydrogen carrier: more readily liquefiable and transportable than H_2, with extensive existing infrastructure; however, it presents challenges related to toxicity and cracking.

Each of these methods possesses distinct advantages and disadvantages that must be evaluated within the context of a particular application. It is important to remember that there is no universal solution; the most effective system is invariably a compromise.

Guidelines for Training Participants

For each of the subsequent scenarios:

- Thoroughly examine the context and essential requirements.
- Recommend the most appropriate form of hydrogen for storage (CGH2, LH2, metal hydrides, LOHC, ammonia).
- If it is CGH2, specify the optimal tank types (I-IV).
- Justify your selection by referencing the particulars of the provided scenario and the characteristics of the suggested technology. Concentrate on: hydrogen volume, necessary pressure and temperature, available space, safety standards, operational and capital expenditures, and efficiency.
- Identify possible challenges or risks related to the selected solution.
- Please record your responses in the designated area.

Scenario 1: Hydrogen Storage for Fuel Cell Electric Vehicle Refueling Stations

Context: Envision your role in designing a new hydrogen refueling station in the heart of a major city. This station will cater to an expanding fleet of fuel cell vehicles (FCEVs), comprising around 50 city buses and 200 passenger cars daily. Essential requirements encompass swift refueling (reducing vehicle idle time), safety in densely populated regions, and congested urban environment and restricted space available for installations.

Task:

- What type of hydrogen (compressed or liquefied) and which category of pressure vessels (I-IV) or alternative storage method would you recommend for this station?
- Justify your selection, considering:
  - Hydrogen Quantity: What is the estimated daily requirement of H2 for the station?
  - Pressure/Temperature Requirement: What pressure is required to refuel a Fuel Cell Electric Vehicle (FCEV)?
  - Available space: In what ways does constrained space influence technology selection?
  - Safety Requirements: What are the primary concerns, and how does the proposed technology mitigate them in an urban setting?
  - Operating Costs: In what ways do expenses influence station profitability?
  - Refueling Speed: In what ways does the selected method guarantee efficient refueling?
- Identify two primary potential challenges or risks related to the implementation and operation of this station.

Scenario 2: Hydrogen Storage for Steel Manufacturing Facility (Decompression)

Context: You are consultants tasked with overseeing the energy transition of a large steel manufacturing facility. The plant is shifting to hydrogen as a reducing agent in its steel production process, focusing on decarbonization. A substantial, reliable, and continuous supply of hydrogen in significant volumes is essential. The facility has ample space, yet prioritizing cost-effectiveness (minimizing hydrogen expenses) and ensuring the highest safety standards on an industrial scale are paramount.

Task:

- What type of hydrogen storage and which tanks or methods would you recommend for this facility?
- Justify your selection, considering:
  - Substantial quantities of hydrogen: How does the selected method address the storage of industrial volumes?
  - Supply continuity: In what ways does a buffer warehouse within the chosen technology guarantee the stability of the production process?

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    - Industrial-Scale Safety: What are the specific safety requirements for such a substantial installation, and how does the proposed solution address them?
    - Investment and operational expenses: In what manner does the selected technology influence the overall cost of steel production?
- Identify the two primary potential risks associated with such an installation in an industrial facility.

Scenario 3: Seasonal Hydrogen Storage Utilizing Surplus Renewable Energy

Context: You are engineers tasked with designing an innovative energy storage facility adjacent to a substantial wind farm. The objective is to store surplus electricity generated by wind in the form of hydrogen, subsequently utilizing it to produce electricity during peak energy demand periods, such as winter, when wind activity is diminished. This necessitates the storage of significant quantities of hydrogen for prolonged durations (e.g., several months).

Task:

- What optimal type of hydrogen storage method would you recommend for this seasonal energy storage?
- Justify your selection, considering:
    - Long-term storage: In what ways does the selected solution reduce hydrogen losses over time (e.g., "boil-off" for LH_2)?
    - Large Volumes: What are the feasible options for storing substantial quantities of H_2?
    - Integration with energy infrastructure: What are the considerations for connecting to the wind farm and the power grid?
    - Costs: What are the primary long-term costs (both capital and operational) associated with this method?
- Identify the two primary obstacles to the large-scale implementation of this type of solution.

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Practical advice for participants

- Ensure consistency: Verify that your selection of storage technology is rational and defensible in relation to your refueling pressure and spatial requirements.
- Cost versus Efficiency: It is essential to recognize that the least expensive solution is not invariably the most advantageous. Occasionally, a higher upfront investment may lead to reduced operational expenses or enhanced security.
- Safety is paramount: Always assess potential risks and evaluate how they can be mitigated.
- Space and infrastructure: Consider the available space and how the storage technology will influence the necessary infrastructure at the station (e.g., compressors, cooling systems, ventilation).
- Scalability: Does the selected system permit future expansion of the station?

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