

MODULE 2

PODCAST: HYDROGEN IN TRANSIT: FUTURE STORAGE AND TRANSPORTATION SOLUTIONS

Welcome to "Hydrogen on the Move: Storage and Transport of the Future" – a podcast dedicated to exploring the innovative technologies that are pivotal to the energy revolution.

Hydrogen, frequently referred to as the fuel of the future, possesses significant potential; however, its journey from production to end-user constitutes a genuine engineering challenge. How can it be stored both safely and efficiently? How can it be transported over varying distances? Today, we will address these inquiries by exploring storage technologies and the intricate logistics of hydrogen transport.

Part 1: Hydrogen Storage – Challenges and Technologies

Let us begin with the fundamentals: hydrogen, despite its lightness, occupies a significant amount of space. Its low volumetric energy density presents considerable challenges for storage. Today, we will concentrate on two primary methods: compressed hydrogen and liquid (cryogenic) hydrogen.

Imagine compressed hydrogen; it resembles the act of packing air into a balloon, albeit at significantly higher pressures. We are discussing typical pressures of 350 bar, or even 700 bar, in vehicles. This solution is relatively straightforward and cost-effective to implement. Compressed hydrogen tanks have undergone considerable evolution. There are four primary types, ranging from the oldest, all-metal Type I tanks—heavy yet robust—to the ultralight, composite Type IV tanks. The latter, constructed from a non-metallic liner encased in carbon fiber, represent true engineering achievements. They are lightweight, durable, and perfectly suited for hydrogen-powered vehicles. The compression process necessitates energy; this is where specialized compressors, such as piston compressors, come into play, pushing

the hydrogen into the tanks while consuming a specific amount of energy in the process.

But what if we must store substantial quantities of hydrogen in a compact space? This is where liquid hydrogen (LH2) technology becomes essential. It represents a fundamentally different approach—we must cool the hydrogen to an extraordinarily low temperature of minus 253 degrees Celsius.

It may sound extreme, and indeed it is! The primary benefit lies in its markedly higher volumetric energy density, enabling the transportation and storage of substantial amounts of hydrogen within a reduced volume. This solution is particularly well-suited for aviation, the aerospace sector, and maritime transport, where every centimeter of space is crucial.

The liquefaction of hydrogen is an exceptionally energy-intensive process, consuming as much as 30% of the energy inherent in the hydrogen itself. Additionally, the phenomenon known as 'boil-off' occurs; hydrogen, even when stored in specialized, insulated cryogenic tanks, gradually evaporates. This situation is akin to storing ice in sunlight—it melts, albeit at a slow rate. Effective management of this process is essential, as each lost molecule represents wasted energy and financial resources. Regarding safety, both compressed and liquid hydrogen present distinct risks: high pressure associated with compressed H₂ and extremely low temperatures that can render materials brittle in the case of LH₂. Proper design, vigilant monitoring, and strict adherence to established procedures are vital to mitigate the risks of leaks and fires.

Part 2: From Warehouse to Recipient – Hydrogen Transportation Logistics

Now that we comprehend the methods of hydrogen storage, let us proceed to another critical aspect: transportation. This is where the true logistical challenge arises, necessitating precision and an understanding of specific standards.

Let us begin with road transport, the most prevalent and often the most adaptable method. Compressed hydrogen is conveyed in specialized pressurized tanks, commonly referred to as 'tube trailers.' These consist of a series of interconnected, high-capacity cylinders. Liquid hydrogen, on the other hand, is transported in cryogenic tanks, which feature a distinct design with double walls and advanced insulation. However, road transport has its constraints, particularly regarding the volume of hydrogen transported and the distances covered. This is where international standards, such as ADR – the European Agreement concerning the International Carriage of Dangerous Goods by Road – prove invaluable. This set of

regulations delineates the safe transportation of hazardous materials, specifying vehicle labeling, required documentation, necessary driver training, and emergency procedures. A lack of familiarity with ADR can be detrimental!

What of larger volumes and extended routes? This is where rail transport becomes essential. Trains can transport considerably more hydrogen—both in compressed and liquid forms—than individual trucks. This presents an optimal solution for transportation between regions or to major industrial hubs. Hydrogen tank wagons are, naturally, specifically designed to guarantee maximum safety.

What if hydrogen were to traverse oceans, for instance, from low-cost countries to Europe? In that scenario, maritime transport would become paramount. Here, liquid hydrogen (LH2) holds a dominant position. Specialized, large gas carriers are being constructed to transport it in massive, highly insulated tanks. Why LH2? As we know, it facilitates the transportation of the largest quantities of hydrogen within the smallest volume. However, maritime transport encompasses more than just pure hydrogen. An increasing amount of hydrogen is being transported in the form of chemical carriers such as ammonia or MCH (methylcyclohexane). These substances are more manageable to transport, allowing for the "release" of hydrogen upon arrival. Additionally, maritime transport is governed by stringent regulations, primarily the IMDG Code – International Maritime Dangerous Goods Code, which ensures the safe transport of hazardous materials by sea.

Regardless of the selected transportation method, operational procedures are essential—from loading to transportation and ultimately unloading. Each phase must be meticulously regulated and compliant with established guidelines to guarantee the safety and efficiency of the entire supply chain.

Part 3: Logistics System Design – Expenses, Risks, and Efficiency

We are addressing the core issue: how can we incorporate all of this into an efficient and cost-effective system? Designing a logistics system resembles assembling a puzzle, where each component—from the selection of tanks to the mode of transport and the final mile—must align seamlessly.

When choosing a transportation method, several factors must be taken into account: distance, the volume of hydrogen to be transported, delivery frequency, existing infrastructure, and, of course, budget. We will approach the design of city bus refueling stations differently, as a road system will likely be the most suitable option in this case

transport of compressed H₂ – and conversely for deliveries from another continent, where maritime transport of liquid hydrogen prevails.

A fundamental aspect of any project is cost. We must evaluate both capital expenditures (CAPEX), which encompass initial costs such as the acquisition of tanks and vehicles and the construction of transshipment infrastructure, and operating expenses (OPEX), which include ongoing costs such as energy for compression or liquefaction, transportation fuel, maintenance, insurance, and, importantly, personnel salaries. Additionally, we must account for costs related to risk management and, specifically for liquid hydrogen, boil-off losses.

Let us not overlook the aspects of risk and efficiency. Each mode of transportation presents distinct risks, ranging from road accidents to leaks and delays. It is imperative that we evaluate these risks and establish suitable mitigation strategies. Efficiency encompasses not only cost reduction but also the minimization of CO₂ emissions linked to transportation. The overall equilibrium—from production to consumption—is what truly matters. The objective is to optimize each route, reduce empty runs, and meticulously plan for demand.

End

Hydrogen storage and transport technologies represent a rapidly evolving domain, characterized by challenges as well as significant opportunities. The hydrogen economy extends beyond the mere production of green hydrogen; it also involves a sophisticated logistics network that must operate seamlessly. With the aid of innovation, heightened awareness, and increasingly stringent regulations, hydrogen possesses the potential to serve as a genuine catalyst for decarbonization within the global economy. We trust this episode has illuminated these intriguing subjects. Thank you for your attention, and we look forward to your presence in the next episode of "Hydrogen in Motion"!

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