

Green Hydrogen Production Container Produced By Electrolysis Cell By Means of Solar Panel

Team 71

CHE: Abdulaziz Moalwi / Turki Alharbi

ISE: Ibrahim Alhunief / Abdullah AlSayed

EE: Abdulaziz Alshahrani / Abdullah Almohammedali



Introduction

The objective of this project is to provide a hydrogen package unit to help Saudi Arabia address its hydrogen vehicle infrastructure challenges as it strives to meet its 2030 vision goals for CO₂ emissions reduction. A key obstacle is the scarcity of hydrogen filling stations. To navigate this, the country is focusing on a sustainable approach to hydrogen production. The project will work in line with the following specifications and constraints.

Specifications:

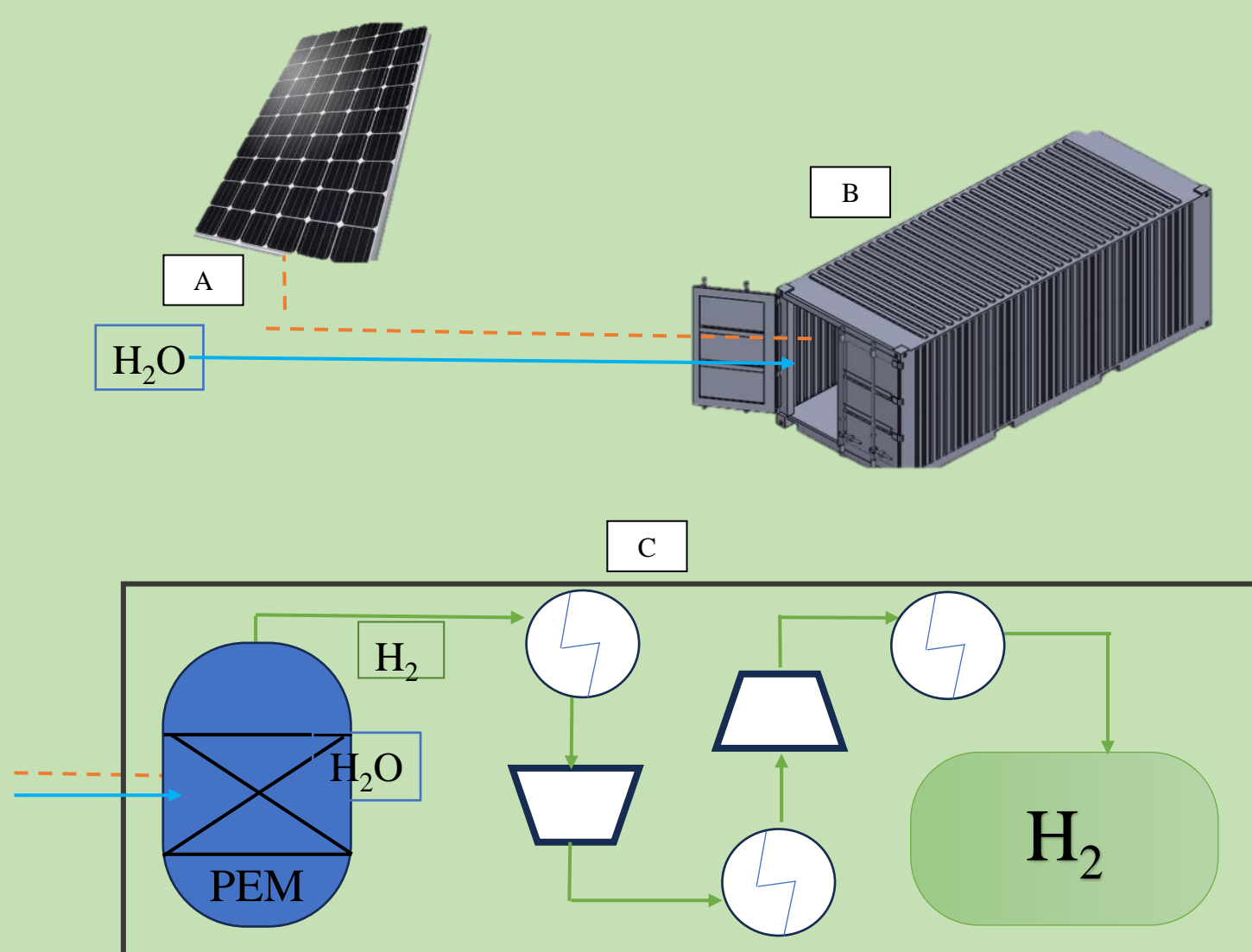
- $33\text{ m}^3 \leq \text{Volume of Container} \leq 76\text{ m}^3$
- $12\text{ kg/hr} \leq \text{H}_2 \text{ electrolysis production} \leq 18\text{ kg/hr}$
- $6\text{ kg} \leq \text{H}_2 \text{ Storage tank} \leq 12\text{ kg}$
- $3\text{ mins} \leq \text{Time to fill the vehicle} \leq 20\text{ mins}$
- $90\text{ g/hr} \leq \text{prototype production} \leq 100\text{ g/hr}$

Constraints:

- Power sources efficiency $\geq 20\%$
- Hydrogen temperature $\leq 500^\circ\text{C}$
- Hydrogen storage pressures $\geq 700\text{ bar}$

This package unit establishes a robust and secure hydrogen infrastructure, facilitating the widespread adoption of hydrogen vehicles and aligning with Saudi Arabia's ambitious sustainability objectives.

How it Works



Form of the final product consists of three parts (A) the inlet of water feedstock and source of power from solar panels, (B) the container that is equipped by the system, and (C) the process that includes the electrolyzer that produces hydrogen, the heat exchangers that cool down the hydrogen the compressors that compress the hydrogen and the cylinder tank to store hydrogen.

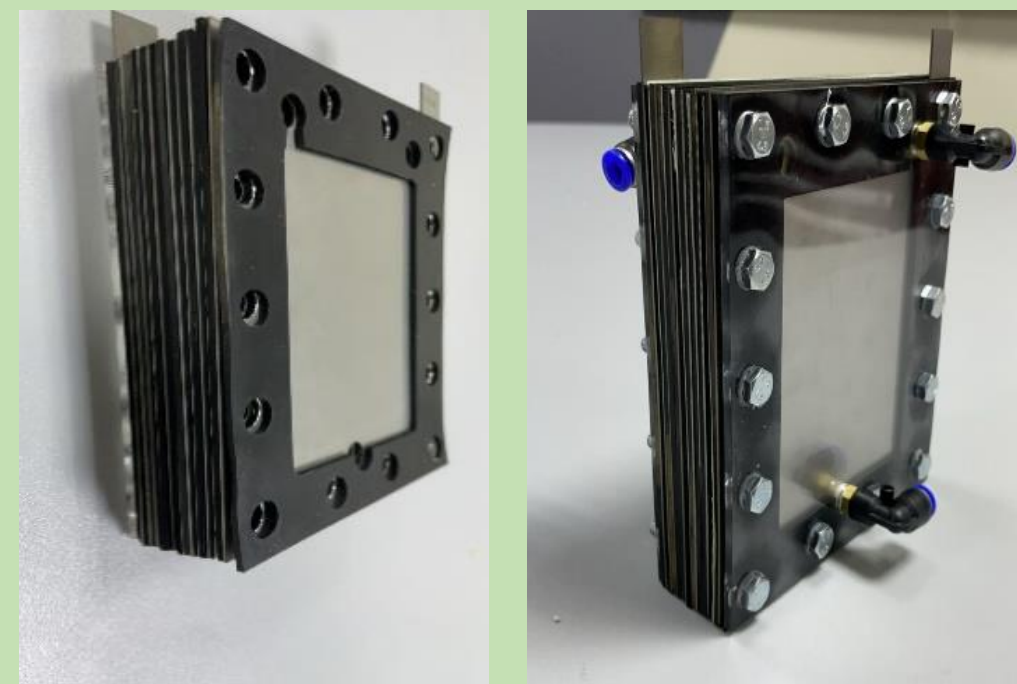
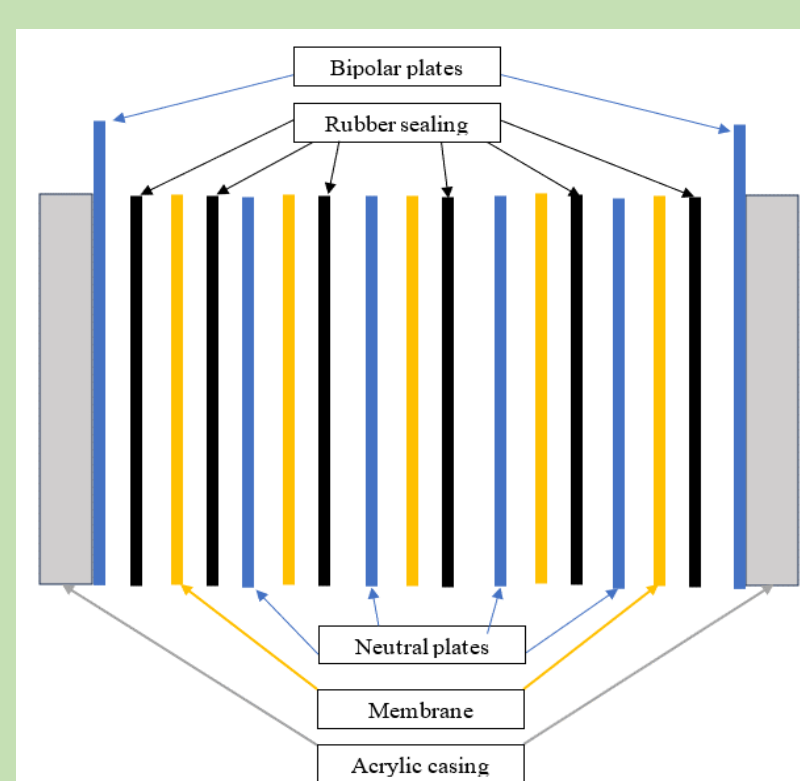
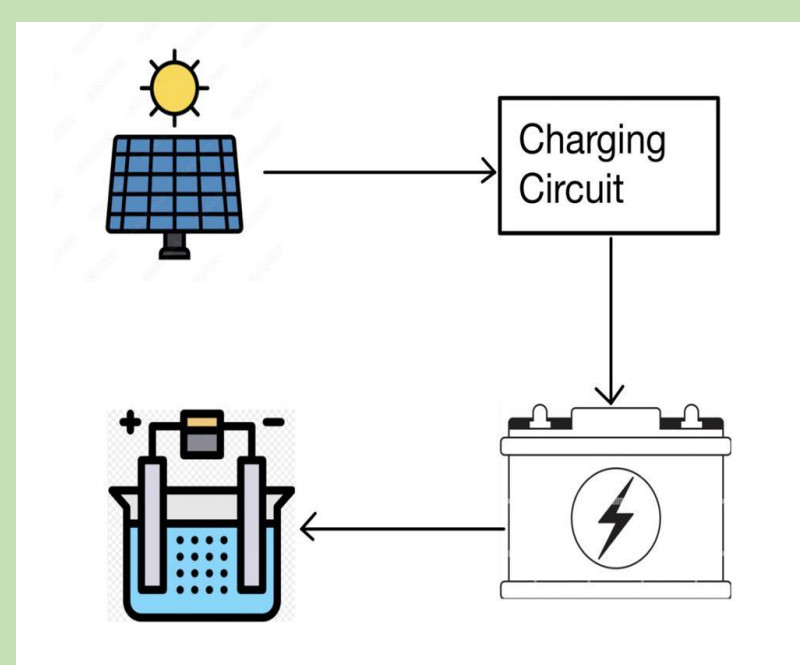
Prototype

The figure on the right shows the main components of the prototype which consisted of:

1. Solar Panel (110 W)
2. Circuit Charger
3. Battery (12 V, 75 Ah)
4. Electrolyzer

Electrolyzer Design:

The sizing is based on the current that the battery will provide which is 75 A and the current density should be 2 A/cm². Therefore, the active area is 37.5 cm². After calculating the required active area, initiate the design of the plates starting from the inside towards the outside to account for rubber seal clearance and the tightened holes. The figure on the right shows a side view of the electrolyzer orientation each plate is 2 mm thick and it should be compacted together without any space in between. This orientation is known as a dry cell PEM electrolyzer. This provides a very compact device as water flows through the plates it splits into oxygen and hydrogen. The bipolar polar plates will be connected to a 12 V battery to provide the needed voltage and current to the electrolyzer neutral plates are needed to divide the 12 V to the 2 V between each two plates so that the device works at optimum voltage. The rubber seals and the acrylic plates are needed to protect the water from leakage.



The figure on the left shows the electrolyzer After we acquired all the components, assembled the electrolyzer, and added the piping connections. There are four connections the first one is for the water inlet the second is for the water outlet, the third is for the oxygen outlet and the fourth is for the hydrogen outlet. This design is the optimum to match the required specification for the prototype which is H₂ 100 g/h

Demand Forecasting & Optimal Locations

Demand Forecasting:

We collected the historical demand data from Al-Edrees fuel station company. Moreover, we were able to conclude from the literature that approximately 1.26% of cars will be hydrogen-fueled cars in 2030 in SA. Furthermore, we used XGBoost predictor to forecast and the implementation of the model was done via python.

City	Avg. Monthly Demand in Al-Edrees Stations	Avg. Monthly Hydrogen Cars Demand
Dammam	866,288	910
Khobar	385,963	405
Qatif	77,096	81
Jubail	110,946	117

Optimal Location:

The clustering process was executed across 78 stations using the K-means algorithm and using silhouette scores, and the elbow method. After applying the algorithm, it concluded that 17 clusters were to be chosen. To initiate the disaggregation, we employed a weighted approach, recognizing the inherent differences among clusters in terms of population size, educational institutions, and other key indicators that reflect the potential demand for hydrogen cars. The result was that 4 stations should be implemented, one station in each city.

Decision Variable :

$$X_{z,s} = \begin{cases} 1, & \text{if Station } (s) \text{ in Zone } (z) \text{ is Selected} \\ 0, & \text{o/w} \end{cases}$$

Objective Function :

$$\text{Min} \sum_{z=1}^{17} \sum_{s=1}^{78} SC_s X_{z,s}$$

Parameter :

WD_z : Weighted Demand in Zone (z)

C_s : Capacity of Station (s)

SC_s : Set up Cost of Building and

Operating a Hydrogen Fuel Container

$d_{i,j}$: The Distance Between Zone (i) to Zone (j)

$$a_{i,j} = \begin{cases} 0, & \text{if } d_{i,j} \geq 0.5892641 \\ 1, & \text{o/w} \end{cases}$$

$$i = 1 \dots 17 \quad j = 1 \dots 17$$

$$s = 1 \dots 78 \quad z = 1 \dots 17$$

s_i : Set of Stations in Zone (i)

Constraints:

1. Each City has at least one Station

$$\sum_{s=31}^{34} X_{17,s} + \sum_{s=38}^{45} X_{12,s} + \sum_{s=46}^{59} X_{6,s} + \sum_{s=60}^{69} X_{16,s} + \sum_{s=70}^{78} X_{3,s} + X_{10,35} + X_{16,36} + X_{11,37} \geq 1$$

$$\sum_{s=25}^{26} X_{2,s} + \sum_{s=27}^{28} X_{8,s} + \sum_{s=29}^{30} X_{4,s} \geq 1$$

$$\sum_{s=16}^{21} X_{7,s} + \sum_{s=22}^{23} X_{9,s} + X_{14,24} \geq 1$$

$$\sum_{s=1}^5 X_{5,s} + \sum_{s=6}^{11} X_{1,s} + \sum_{s=12}^{15} X_{13,s} \geq 1$$

2. Each Zone Must Satisfy its Weighted Demand

$$\sum_{s=1}^{78} X_{z,s} C_s \geq WD_z \quad \forall z$$

3. A Station (l in set s_i) in Zone (i) can not be used for Zone (j) if the distance exceeds the threshold

$$X_{i,l} \leq a_{i,j} \quad \forall i, j \quad \forall l \in s_i$$

4. Range of the Decision Variable:

$$X_{z,s} \in \{0,1\}$$



Based on our OR model output, the suggested locations for placing an H₂ fuel container at the suggested stations are shown on the map. Four containers to these locations to meet the demand.

Conclusion

Conclusively, our project introduces an innovative solution. A portable green hydrogen container package unit, where hydrogen is produced by a PEM electrolyzer and powered by solar panels. This groundbreaking initiative not only aligns with Saudi Arabia's renewable energy objectives but also addresses the pressing need to curb CO₂ emissions, marking a significant stride toward a sustainable future.