Hydrogen Storage Within Cellular Pressure Vessel

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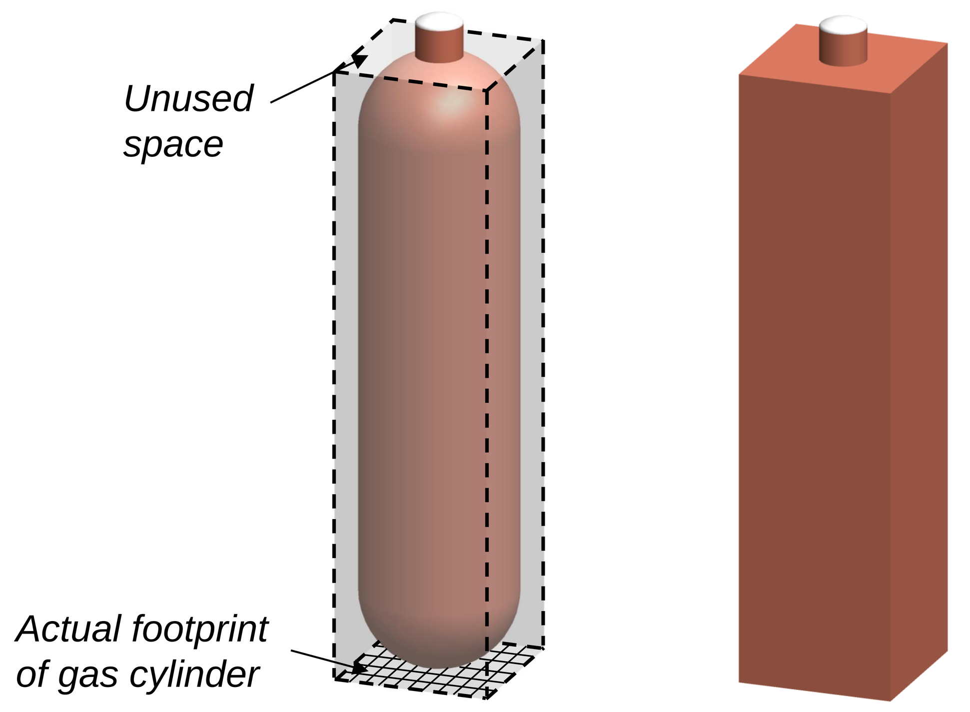
ABSTRACT

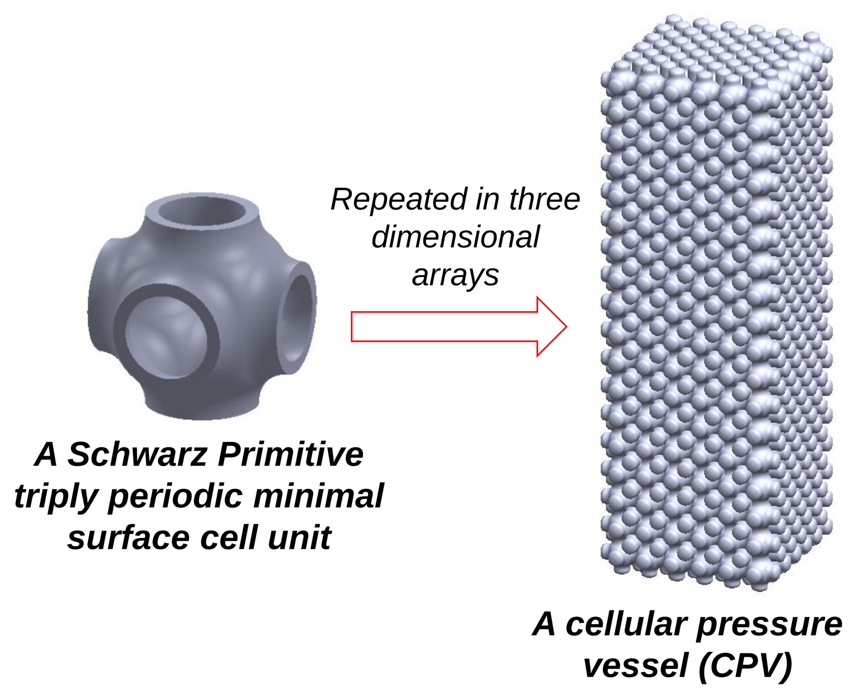
The demand for hydrogen has grown more than threefold since 1975 and is projected to continue rising in the future. Besides its important role as a feedstock in industrial applications, it is also a promising energy carrier in future energy systems. However, due to its extremely low density, there remains a big challenge of its storage and transportation. Currently, the most ubiquitous storage solution is by compression or liquefaction which requires the use of pressure vessels. These pressure vessels often take the shapes of sphere or cylinder able to distribute stress uniformly. Although these shapes have high structural stability, their volumetric efficiency is low, about 25-50% lower than that of prismatic shape. To close this gap, we propose the concept of a cellular pressure vessel (CPV) and prove it via three-dimensional printed prototypes. We demonstrate that the CPV has a high volume efficiency and comparable structural strength with conventional cylinders, besides the ability to be made into different shapes.

BACKGROUND INFORMATION



*Can we make a **prismatic** pressure vessel while **maintaining the structural stability** of a cylinder?*

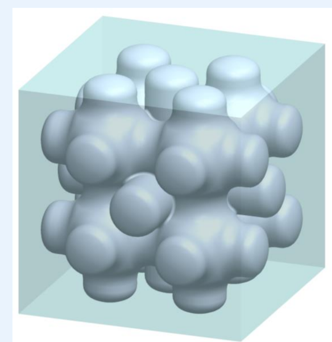
RESEARCH IDEA

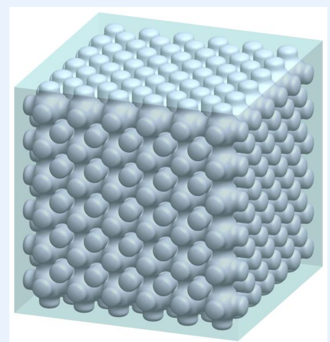


A Schwarz Primitive triply periodic minimal surface cell unit

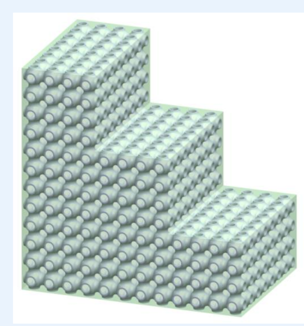
A cellular pressure vessel (CPV)

Advantage 1: **Increased space utilization**





Advantage 2: **Flexibility of shape**



METHODOLOGY

The advantages of a CPV could be proved by comparing its gas storage performance with conventional cylinder. In general, a high performing pressure vessel is able to store more gas with less material usage, low footprint and high energy efficiency. As such the following three main parameters were being used for analysis:

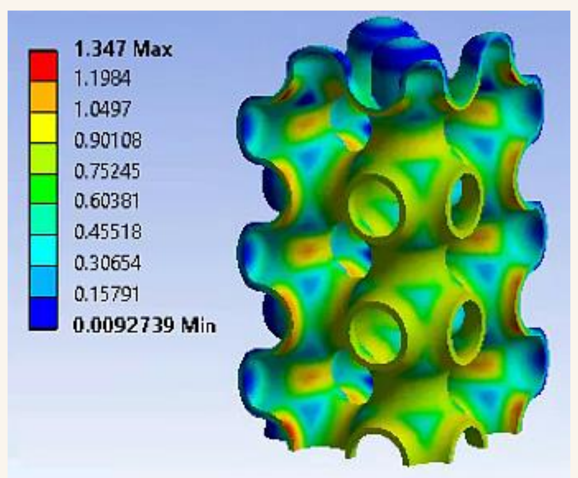
i) $\text{Gravimetric density}\left[\frac{kg}{kg}\right] = \frac{\text{Mass of gas stored}}{\text{Mass of system}}$

ii) $\text{Volumetric density}\left[\frac{kg}{m^3}\right] = \frac{\text{Mass of gas stored}}{\text{Volume of space occupied}}$

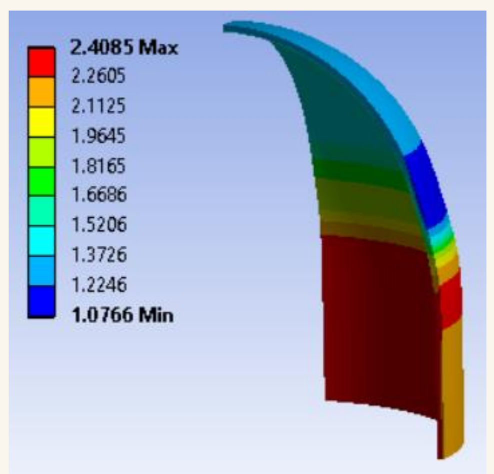
iii) $\text{Gravimetric density per pressure}\left[\frac{kg}{kg.MPa}\right] = \frac{\text{Mass of gas stored}}{\text{Mass of system}} \times \frac{1}{\text{Pressure}}$

Analysis of gas storage performance is based on finite element (FE) modelling technique and experimental verification.

FE simulations to predict burst pressures



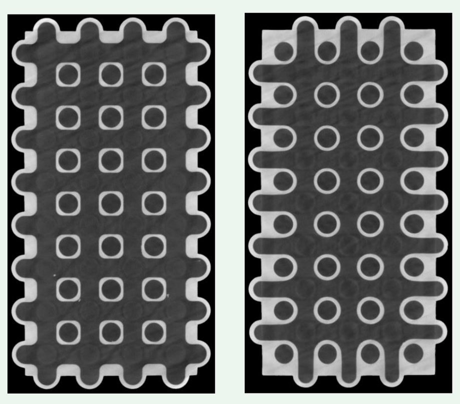
Von Mises stress distribution of a 3x3x6 cell unit CPV



Von Mises stress distribution of a cylinder

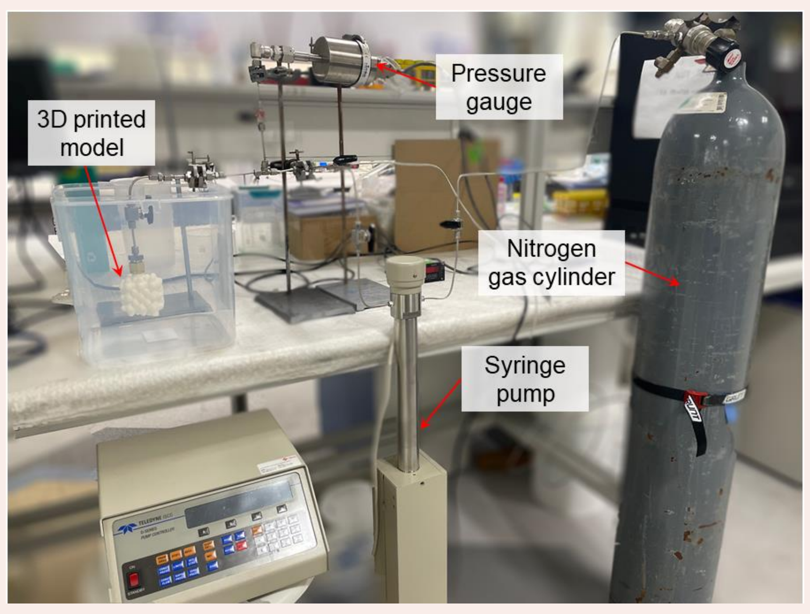
Additive manufacturing of models

3D printed CPV of 3x3x3 cell unit

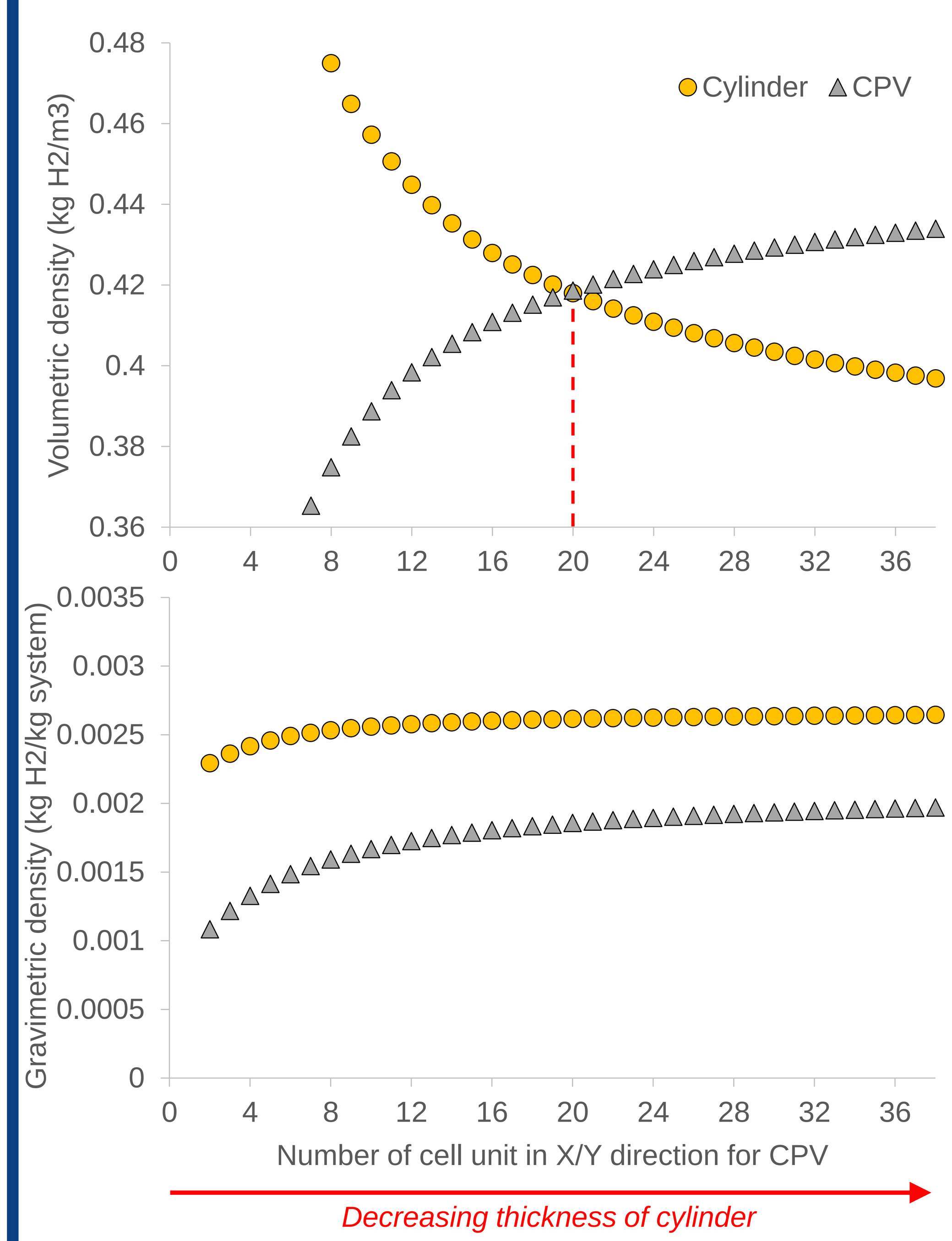


Micro-CT scan of 3D printed 4x4x8 cell unit CPV

Hydrostatic testing to verify burst pressures



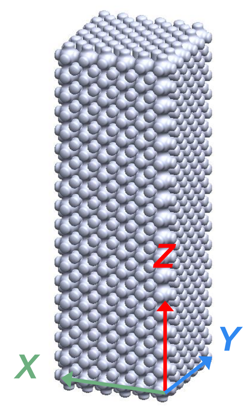
RESULTS & DISCUSSION



Gas storage performance analysis based on simulation results for CPV with various number of cell units and cylinder with various thicknesses

The CPV utilizes space more efficiently than cylinder but only when the number of cell units in X/Y direction exceeds **20**. The maximum volumetric density of the CPV is **1.21** times that of the cylinder at infinite number of cell units. For the relationship follows a power law that rises quickly approaching the limit, the volumetric density of the CPV could be well close to the maximum long before infinity – e.g. the volumetric density of the CPV is **1.17** times that of the cylinder at **100** cell units in X/Y direction.

In all cases, the cylinder is able to store more gas per unit mass of the system than the CPV. However with the increase in number of cell unit, the ratio of gravimetric densities is brought down from **2.12** to **1.26**.



CONCLUSIONS & IMPLICATIONS

It was shown that although the proposed CPV is disadvantaged in terms of gravimetric density, it is able to utilize space more efficiently than conventional cylinders. It also has the flexibility to be made into different shapes. These characteristics are particularly important for transportation of gas in applications with limited space, such as in spacecrafts, submarines, cars and on ships. This way we could fit the vessel to the transportation vehicles, not the other way round. All available space could be fully utilized which leads to minimizing vehicle weight and consequently fuel savings.