Volume 9, Issue 10, October – 2024 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT743

An Evaluation of the Levelised Cost of Storage of Buoyancy Energy Storage Technology at Smaller Scales

Saahas Ajmera

Abstract:- Buoyancy Energy Storage Technology (BEST) offers a promising solution to the intermittency of renewable energy sources like wind and solar. This paper aims to evaluate the feasibility of using BEST for small-scale energy storage applications. The methodology involves calculating the levelized cost of storage (LCOS) and energy capacity of two BEST variants: Fabric BEST and Reeling BEST. Results indicate that Fabric BEST can store 96 kWh per cycle with an LCOS of $356.73/MWh, while Reeling BEST stores less energy at a significantly higher cost of $683/MWh.

I. INTRODUCTION

The energy transition is an imperative goal that countries all around the world are working towards. The energy crisis, being such a temporal problem, requires collaboration between firms, countries and global citizens at a rapid pace. China, being the world's largest carbon emitter, accounted for nearly 40% of all global renewable capacity additions, to realize its goal to peak carbon emissions by 2030. Simultaneously, countries all around the world are investing in green energy technology to promote carbon neutrality. Germany's Energiewende strategy aims to phase out nuclear energy and transition entirely to renewables like wind and solar by 2050.

There remain, however, several unanswered questions about the transition. One of them being about the capacity to store energy from these renewable sources. Most renewable energy sources, particularly wind and solar power are intermittent. Solar energy generation is dependent on sunlight, which is only available during the day and fluctuates due to weather conditions. Similarly, wind energy relies on wind patterns that are often unpredictable and vary across seasons. Hydroelectricity could also fluctuate depending on the weather conditions and could vary based on the flow of the water that is a common ancillary impact of anthropogenic activity. This variability creates a mismatch between energy production and consumption, particularly during peak demand periods, such as in the evening when solar power is unavailable. This means that even if countries are moving towards technology like solar or wind energy, if they do not have the infrastructure to be able to sufficiently store this energy, the system efficiency would drastically decrease. Not only would this create even more environmental problems when other sources are used, but it would also lead to greater price surges for electricity and could also disincentive countries from participating in the transition in the first place. This creates the demand for a technology that can fulfill these requirements.

Obviously, there already exist storage technologies that are potential candidates to become mainstream, yet, they all have issues of their own. The first major candidate for a viable Electrical Energy Source (ESS) are batteries. While there is significant research done that proves that batteries might be a good short term storage technology (however, batteries can suffer from high rates of energy loss and self-discharge over time, particularly during longer storage duration), the large-scale use of batteries, both in energy systems and mobility, raises concerns about the availability of key materials like lithium, cobalt, and nickel. Mining and processing these materials have significant environmental impacts, such as habitat destruction, water pollution, and high carbon emissions. This means that while batteries might be able to suffice for shorter term targets, they are not a viable long term solution because of the scarcity of the resources that go into producing them. Along with this, the usage of batteries in things like electric vehicles is also going to dramatically increase, making these resources even scarcer and more expensive. The next contender for large scale storage is Pumped Hydro. Although Pumped Hydro has shown acceptable practical results in terms of efficiency and its levelized cost of energy, it is limited by geography. Pumped Hydro and other EES that store energy in the form of gravitational potential energy, reach maximum efficiency in mountainous regions. This leaves out a vast majority of places that may not have land of high altitude in proximity. Obviously, there exists research on other technologies, however, none of them have become as mainstream as these two yet.

This paper is going to involve an evaluation of the feasibility of using Buoyancy Energy Storage Technology (BEST) as a solution for the intermittent energy problem. BEST functions on the fundamental principle of storing energy as potential energy by lowering a float underwater using a motor in times where there is excess energy, and bringing the float back up when there is a demand for electricity. This technology is extremely new to the market and only has substantial theoretical research done on it, there are almost no large scale applications of this technology in the world yet. There exist different variations of this technology that use slightly modified systems, yet function on the same core principle.

One variant, Reeling BEST, uses a float attached to a reel system. Energy is stored by reeling the buoyant float to great depths underwater, creating potential energy that can later be harnessed when the float is allowed to rise. As the float ascends due to buoyancy, the mechanical energy generated is converted into electricity. While this method is straightforward, it is not without challenges. Reeling BEST suffers from mechanical losses, as confirmed by experimental validation. Recent studies have focused on improving efficiency by experimenting with different materials, coatings, and gasses for the float. For instance, a silicon-coated air-filled PVC float demonstrated a 15.44% improvement in energy output compared to an uncoated plastic float (Alami 2023). This enhancement was largely attributed to the reduction in drag force, highlighting the importance of material optimization in reducing energy loss during the system's operation.

In addition to Reeling BEST, the technology has evolved to incorporate other energy storage mechanisms, leading to several variations. One of the prominent advancements is the integration of Pumped Hydro Storage (PHS) into the BEST system. This variation uses a tank that pumps water into a reservoir to store energy as gravitational potential energy. The energy is discharged when the water is released back into the reservoir, driving a turbine to generate electricity. There are multiple designs within this category. In one version, the system incorporates an air-tight tank with a flexible air cushion that deforms under pressure as water is pumped in. The deformation energy stored in the air cushion is later released during discharge, adding an extra layer of energy capture beyond traditional PHS (Jian Yew 2024).

Another variation of BEST with PHS involves charging the system by pumping water out of the reservoir rather than into it. This method increases the energy storage capacity by leveraging the weight of the additional water when it refills the reservoir. The floats attached to mooring lines in this design primarily serve to stabilize the system and prevent lateral movement, ensuring efficient operation. In all variations of BEST with PHS, a pump-turbine system is utilized, allowing for energy conversion between potential energy during charging and mechanical energy during discharging. Ref

The progression of BEST has led to the development of the Fabric BEST system, which integrates principles from both PHS and Compressed Air Energy Storage (CAES) technologies. The Fabric BEST consists of a crumpled cylindrical fabric tank divided into water and air chambers connected by an umbilical link. Water is pumped into the water chamber, compressing the air chamber and stretching the fabric tank. During discharging, compressed air drives the water through a turbine, generating electricity. Although the Fabric BEST system requires more energy for charging compared to earlier BEST designs, it offers significantly higher energy storage capacity. The energy density of Fabric BEST is approximately ten times greater than that of traditional BEST with PHS, reaching 201.33 Wh/m³. This increase in energy density allows for more efficient and compact energy storage solutions, making it highly promising for large-scale applications such as offshore floating solar or wind farms.

However, though minimal, there exists research on the possibility of using BEST at large scales that includes at offshore energy farms that might use offshore wind energy or floating solar. This is because BEST would be the most effective at large depths of the water, which exists solely at deep ocean farms. This paper will instead explore the possibility for using this technology at smaller scales. This would involve first understanding what it means to be small-scale and define the bounds of this paper in terms of the scope of my research. Second, calculate and estimate the capability of BEST at small-scales in terms of energy storage capacity. This section would involve using calculations that currently exist on the capacity at larger scales and using the same method to arrive at an estimation of how this would work on a smaller scale. Third, calculate the cost feasibility of this technology at small-scales. Fourth, evaluate this cost against different other technologies that could work. And lastly, understand the applicability of this technology and global potential. It might turn out to be true that this technology is not suited for small scale application, but to come to this conclusion there needs to be research done. Even this conclusion is extremely useful, because the goal is to cross out all the technology we have so far until we find the one that is best suited for these kinds of applications. If it turns out that my research shows that there is a scope for some implementation of this technology then this technology could be researched further to push towards the implementation of BEST at small scales.

Acronym	Full Form
BEST	Buoyancy Energy Storage Technology
LCOS	Levelized Cost of Storage
PHS	Pumped Hydro Storage
CAES	Compressed Air Energy Storage
CapEx	Capital Expenditure
OpEx	Operational Expenditure
ESS	Electrical Energy Source
PVC	Polyvinyl Chloride
HDPE	High-Density Polyethylene

Fig 1: Abbreviations Used in the Paper

Variable	Explanation
H	Water level difference in meters (height difference in the tank during charging and discharging cycles)
V	Submerged volume of the system in cubic meters
g	Gravitational acceleration, typically $9.81\,\mathrm{m/s}^2$
ρ_s	Density of seawater, typically around $1027\,\mathrm{kg/m}^3$
ρ_c	Density of compressed gas (such as hydrogen or air), varies with depth
m	Mass of the buoyancy recipient (including cables, assumed proportional to the scaled volume)
v	Velocity of buoyancy recipient (rate at which the float ascends or descends)
e	Efficiency of the system (usually around 80%)
E	Total energy stored in one cycle (combining gravitational potential energy and compressed air energy)
P	Power generated during a single cycle
$LCOS$	Levelized Cost of Storage, a measure of the cost per unit of energy stored over the system's lifetime
T	Time for one complete charging and discharging cycle
n	Number of cycles per year
C_{CapEx}	Capital expenditure, total investment cost for system installation and setup
C_{OpEx}	Operational expenditure, the ongoing cost for system operation and maintenance
$C_{charging}$	Cost of charging the system over its lifetime
E_{total}	Total energy stored over the system's lifetime (sum of all cycles)
p_e	Price of electricity in dollars per kilowatt-hour

Fig 2: Variables Used in Equations in this Paper

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT743

II. METHODOLOGY

This paper will calculate and compare the LCOS of both fabric BEST and Reeling BEST. The fundamental difference between the two technologies is that the reeling BEST focuses on mechanical energy storage whereas the fabric BEST is centered around compressed air energy storage.

Firstly, we will show the methodology for calculating the energy potential and the LCOS for fabric BEST. In order to do that, we need to define and assume a few constants for fabric BEST. For small-scale application, the submerged volume is set at 500 m³, which is a practical size for most lakes around the world. Lakes offer a stable, natural environment where buoyancy energy storage systems can be easily implemented without the extensive infrastructure required for offshore installations. Secondly, the water level difference (H) represents the change in height between the water levels inside the tank during the charging and discharging cycles of the system. In this case, the water level difference is set at 10 meters.

To calculate the total energy stored in the Fabric BEST system during one cycle, we use the following equation, which accounts for both gravitational potential energy and the pressure exerted by compressed air in the tank:

$$E = (\rho_{\text{water}} \cdot g \cdot V_{\text{water}} \cdot H) + V_{\text{water}} \cdot (p_{\text{initial}} \cdot 1.38629 - p_0)$$

The first part of the equation calculates the gravitational potential energy, which depends on the volume of water, its height, and gravitational force. The second part of the equation considers the additional energy stored due to the compression of air in the tank. Table 1 below shows the parameters of the equations along with their descriptions.

Now, we will first calculate the total energy stored and LCOS for fabric BEST.

Calculating the first part of the equation:

$$E_{\text{grav}} = (1,000\,\text{kg/m}^3 \cdot 9.81\,\text{m/s}^2 \cdot 500\,\text{m}^3 \cdot 10\,\text{m})$$

$$E_{\text{grav}} = 49,050,000\,\text{Joules} = 49.05\,\text{MJ}$$

This represents the energy stored due to the water being elevated by 10 meters.

Calculating the second part of the equation:

$$E_{\text{air}} = 500\,\text{m}^3 \cdot (500,000 \cdot 1.38629 - 100,000)$$

$$E_{\text{air}} = 500\,\text{m}^3 \cdot (693,145 - 100,000)$$

$$E_{\text{air}} = 500\,\text{m}^3 \cdot 593,145 = 296,572,500\,\text{Joules} = 296.57\,\text{MJ}$$

This represents the energy stored due to the pressure difference created by compressing air inside the tank.

Therefore, by adding the gravitational potential energy and the energy from the compressed air we get:

$$E_{\text{total}} = 49.05\,\text{MJ} + 296.57\,\text{MJ}$$

$$E_{\text{total}} = 345.62\,\text{MJ}$$

Thus, the total energy stored in one cycle is 345.62 megajoules (MJ), or approximately 96 kilowatt-hours (kWh). Therefore, Using a 500 m³ submerged volume and a 10-meter water level difference, the Fabric BEST system can store approximately 96 kWh of energy per cycle.

Now that we have the energy stored in one cycle, we can calculate the total energy stored in the lifetime of one system. We do this by assuming that charging and discharging takes 3,000 seconds each cycle (cite this), which means that one full cycle can last for 2 hours. Since the system would not be constantly charging and discharging, it has been assumed that it would go through around 3 cycles a day which means it is charging and discharging for 6 hours and storing energy for the remaining 18 hours. This means that there can be 3 cycles each day giving us 1095 cycles in a year. This technology has a lifetime of 20 years and an efficiency of 80%. (ref)

To calculate the LCOS, we would also need the total cost for one lifetime. The total cost can be split up into Capital Expenditure (CapEx), Operational Expenditure (OpEx) and the cost of charging the system over its operational lifetime.

The Capital Expenditure (CAPEX) for the Fabric BEST system consists primarily of the cost of materials and the installation process. The system's tank is constructed using carbon fiber fabric, used because of its high tensile strength and lightweight properties, which makes it an ideal choice for this application. The cost of carbon fiber fabric typically ranges between $20 to $40 per kilogram. Given that the tank's total volume consists of 99% cavity space, the amount of material required for a 500 cubic meter tank would be roughly 1% of this volume. This means approximately 5 cubic meters of material is needed, and with a material density of 1,200 kg per cubic meter, the total mass of carbon fiber required is about 6,000 kilograms. At an average price of $30 per kilogram, the total material cost for the tank is around $180,000. Additionally, the system requires industrial-grade pump-turbine systems to manage the flow of water during charging and discharging cycles. Each pump-turbine is estimated to cost between $15,000 and $50,000, depending on its capacity. For the purposes of this estimation, assume two pump-turbine systems, each costing approximately $25,000, which brings the total cost of the pumps to $50,000. The installation of the system, which involves constructing the tank, installing the pumps, and connecting the system to a renewable energy source like a floating solar farm, is another significant expense. Offshore energy systems typically have installation costs ranging from $100,000 to $300,000 depending on the size and complexity of the project. For this small-scale Fabric BEST system, a mid-range installation cost of $150,000 is assumed. Thus, the total CAPEX, which includes the material cost, pump-turbine systems, and installation, amounts to around $380,000.

Operational Expenditure (OPEX) refers to the costs associated with running and maintaining the Fabric BEST system throughout its operational life. Since the system is largely mechanical, relying on the principles of buoyancy and water flow, its maintenance costs are expected to be lower compared to chemical energy storage systems like lithium-ion or lithium-sulfur batteries, which require more frequent maintenance and replacement due to chemical degradation. For the Fabric BEST system, ongoing maintenance primarily involves periodic inspections and minor repairs to the pump-turbine systems, as well as monitoring the integrity of the carbon fiber tank. Industry estimates suggest that maintenance costs for energy storage systems are generally about 1-2% of the system's CAPEX per year. Assuming a maintenance cost of 1.5% annually, the yearly cost for maintaining the $380,000 Fabric BEST system would be approximately $5,700. Over a 20-year operational lifetime, this results in a total maintenance cost of $114,000. Beyond maintenance, the system incurs minimal other operational costs since it operates in a relatively stable environment like a lake and does not require additional energy input beyond the charging cycles.

Charging costs are another important component of the total cost calculation. The Fabric BEST system stores energy by pumping water into a tank, and this energy is then released when the system discharges. Based on the energy storage calculations provided earlier, the system stores approximately 96 kWh of energy per cycle. To determine the total charging cost, the price of electricity must be factored in. Assuming an electricity cost of $0.12 per kilowatt-hour, each charging cycle costs about $11.52. Over its lifetime, the system may go through one complete charging and discharging cycle per day. Therefore, over the course of 20 years, the system would complete 7,300 cycles (365 days multiplied by 20 years). The total charging cost over the system's lifetime would then be 7,300 cycles multiplied by $11.52 per cycle, resulting in a total charging cost of $84,096.

Adding together all these costs gives a comprehensive picture of the total cost of the Fabric BEST system. The initial capital expenditure amounts to $380,000, which covers the material costs, installation, and the pump-turbine systems. The operational expenditure, mostly comprising maintenance over a 20-year period, adds an additional $114,000. Finally, the total cost of charging the system over its operational life comes to $84,096. When these components are combined, the total cost of owning and operating the Fabric BEST system over 20 years is estimated to be $578,096.

With all of this, the LCOS of fabric best can be calculated by dividing the total cost by the total energy. Using this data we arrive at a LCOS of 356.73 $/MWh

Now we will move onto the LCOS for reeling best. To calculate the LCOS for reeling BEST while maintaining the same approach as used in Fabric BEST, we first need to address the specifics for small-scale application and utilize the variables from the previous Fabric BEST calculation. The primary difference lies in the system's operating depth, the energy potential, and how frequently the system can realistically cycle per day, which differs from the assumptions used in the Fabric BEST analysis.

For small-scale reeling BEST, we will still use a submerged volume of 500 m³, similar to Fabric BEST. However, the depth and time for charging and discharging will change based on the design of reeling BEST. According to the research, the velocity of the buoyancy recipient is very slow, around 0.01 m/s. The system's total depth varies from 10,000 meters to 3,000 meters, meaning each cycle will take a much longer time compared to Fabric BEST. Given the depth and the system's design, the time taken for one full cycle (charging and discharging) is estimated at 3.5 days, based on the speed of the recipient and the operational constraints. Therefore, the system would realistically go through around 100 cycles per year.

To calculate the LCOS, similar to fabric BEST, first we have to look at the energy stored in one cycle. The total energy stored in one cycle for the small-scale regular BEST system can be calculated using the same principles, but with the adapted variables for depth and gas compression. The formula for power generated during a single cycle is:

$$P = v \times (V \times (\rho_s - \rho_c) - m) \times g \times e \times 10^{-6}$$

v = velocity of buoyancy recipient = 0.01 m/s
V = volume of compressed air in the buoyancy recipient = 500 m³ (from Fabric BEST)
p_s = density of seawater = 1027 kg/m³
p_c = density of compressed gas (hydrogen or air) (varies with depth)
m = mass of the buoyancy recipient (includes cables, assumed proportional to the scaled volume)
g = gravitational acceleration = 9.81 m/s²
e = system efficiency = 80%

Given the operational depth of 10,000 meters, and hydrogen as the compressed gas (due to its buoyancy advantage at high depths), the energy stored in one cycle would be approximately 7.9 MWh for the large-scale system. Scaling this down to a 500 m³ volume, we adjust this

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT743

proportionally, resulting in approximately 0.5 MWh of energy stored in one cycle.

Now we can use this to calculate the total energy stored in the lifetime of the system. With 100 cycles per year (given the time constraints), and a 20-year lifetime, the total number of cycles is 2,000. Therefore, the total energy stored over the lifetime of the small-scale regular BEST system is:

$$0.5 \times 2000 = 1000 MWh$$

Now we can move onto calculating the costs of the system. Similar to fabric BEST, the costs will be broken down into CapEx, OpEx, and charging costs.

The capital expenditure includes the costs for the buoyancy recipient, cables, motor/generator system, and installation, adapted for a smaller scale.

Firstly, we can find the CapEx. For regular BEST, the recipient is typically made of high-density polyethylene (HDPE) pipes. Using a volume of 500 m³, the total material cost is estimated based on similar costs as Fabric BEST but adjusted for HDPE. HDPE costs around $120 per meter, and the total cost for the recipient is approximately $180,000. The length of the cables for the small-scale system would be proportionally reduced, but the cost remains significant. Assuming the same strength and properties, the total cost of cables is estimated at $50,000, based on reduced length but still requiring durable materials. The motor/generator system for a smaller-scale BEST system would be reduced in size but still involve significant expense due to underwater operation and the power capacity. Estimating around $30,000 for this component. Installation costs for smaller systems are generally lower, but since regular BEST operates in deep sea environments, these costs remain substantial. For a small-scale system, installation is estimated at $150,000. Thus, the total CapEx for the small-scale regular BEST system is approximately $410,000.

Operational costs include maintenance of the buoyancy recipient, cables, and generator system. Similar to Fabric BEST, we assume 1.5% of CapEx annually for maintenance. Over 20 years, this totals $123,000.

Charging costs represent the energy required to pull the buoyancy recipient to the bottom of the ocean. For each cycle, the energy required is proportional to the energy stored, adjusted for efficiency. Assuming 0.5 MWh is stored per cycle, and the charging efficiency is 80%, the electricity required per cycle is:

$$\frac{0.5}{0.8} = 0.625 \ MWh$$

At $0.12 per kWh, the cost of electricity per cycle is:

$$0.625 \times 0.12 \times 1000 = 75 \ USD/cycle$$

Over 2,000 cycles, the total charging cost is $150,000.

Therefore, The total cost of the small-scale regular BEST system, combining CapEx, OpEx, and charging costs, is $683,000. We can use this to find the LCOS. The LCOS is calculated by dividing the total cost by the total energy stored over the system's lifetime. Thus, the levelized cost of storage for the small-scale regular BEST system is approximately $683/MWh, significantly higher than large-scale BEST. The higher cost is due to the reduced economies of scale and the substantial time required per cycle in deep sea environments.

III. DISCUSSION AND EVALUATION

The Levelized Cost of Storage (LCOS) for Buoyancy Energy Storage Technology (BEST) varies significantly between the two variants: Fabric BEST, with an LCOS of $356.73/MWh, and Reeling BEST, with a higher cost of $683/MWh. When converted to €/kWh, Fabric BEST and Reeling BEST would have LCOS values of approximately €0.34/kWh and €0.65/kWh, respectively. These costs are considerably higher than established energy storage technologies such as pumped hydro storage (PHS) and compressed air energy storage (CAES).

PHS, the most widely deployed large-scale storage solution, has an LCOS of approximately €0.10/kWh, making it nearly four times more cost-effective than Fabric BEST. Compressed air energy storage (CAES) technologies range from €0.11/kWh to €0.15/kWh, positioning them as more economical options for large-scale deployment compared to either BEST variant. Even advanced batteries expected by 2030, like Li-ion (€0.17/kWh) and Pb-batteries (€0.12/kWh), have lower costs than Fabric BEST, indicating that BEST may struggle to compete with these storage solutions, particularly in terms of cost-effectiveness.

Hydrogen storage has an LCOS of around €0.24/kWh, making it more cost-effective than Reeling BEST but still more expensive than Fabric BEST. Hydrogen storage, however, has the advantage of being highly versatile, as it can be used both for electricity generation and as a fuel. Despite this versatility, the higher cost of hydrogen storage compared to established technologies like PHS, combined with efficiency losses during the conversion processes, still places it at a disadvantage in the energy market. When compared to Fabric BEST's €0.34/kWh, hydrogen offers a more favorable cost profile but may still fall short for small-scale applications due to infrastructure requirements.

Vanadium redox flow batteries (VRFB) have one of the highest LCOS values at €0.40/kWh. This makes both Fabric BEST (€0.34/kWh) and even Reeling BEST (€0.65/kWh) somewhat competitive with VRFB in certain contexts, especially when considering their scalability. However, VRFB offers unique advantages like long cycle life and the ability to decouple energy and power capacities, making it a more flexible solution for specific large-scale applications despite its higher cost. In comparison, BEST, while still facing higher upfront costs and operational inefficiencies, could offer benefits in small niche markets where VRFB's size or complexity is impractical.

IV. CONCLUSION

The aim of this paper was to evaluate the feasibility of using Buoyancy Energy Storage Technology (BEST) for small-scale energy storage applications. Through a comparison of two specific BEST variants—Fabric BEST and Reeling BEST—we calculated the energy storage capacities and levelized cost of storage (LCOS) for each, highlighting the potential and limitations of the technology. Fabric BEST demonstrated a reasonable energy storage capacity of 96 kWh per cycle with a calculated LCOS of $356.73/MWh, while Reeling BEST, though capable of storing energy at greater depths, had a higher LCOS of $683/MWh. These results suggest that while BEST offers a technically feasible solution for energy storage, its economic viability, particularly for small-scale applications, remains constrained by high costs.

Despite these challenges, the future prospects for BEST are promising, particularly with ongoing advancements in material efficiency and system design. As R&D continues to push the boundaries of what is possible with buoyancy-based energy storage, we may see significant improvements in both the cost and efficiency of the technology. As such, BEST could play a critical role in supporting the growing need for reliable energy storage in a world increasingly reliant on intermittent renewable energy sources. With further innovation and potential economies of scale, BEST may become a key player in the future energy landscape, particularly in areas where conventional storage methods face geographic or material limitations.

REFERENCES

[1]. Ng, Jian, et al. "Jalan Lagoon Selatan." Renewable Energy, vol. 225, no. 1, 2024, p. 120342, researchmgt.monash.edu/ws/portalfiles/portal/599313203/583735396_oa.pdf, https://doi.org/10.1016/j.renene.2024.120342. Accessed 17 Aug. 2024.

[2]. Hunt, Julian David, et al. "Buoyancy Energy Storage Technology: An Energy Storage Solution for Islands, Coastal Regions, Offshore Wind Power and Hydrogen Compression." Journal of Energy Storage, vol. 40, Aug. 2021, p. 102746, https://doi.org/10.1016/j.est.2021.102746.

[3]. Abdul Hai Alami, et al. "Performance Assessment of Buoyancy Work Energy Storage System with Various Buoy Materials, Coatings, and Gasses." Journal of Energy Storage, vol. 72, 1 Nov. 2023, pp. 108524–108524, https://doi.org/10.1016/j.est.2023.108524. Accessed 13 Nov. 2023.