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# Enhancing Thermodynamic Efficiency through Hybrid Energy Storage Integration in Cogeneration Plants

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***Abstract:***-This study explains why it's important to build larger energy storage facilities in order to accommodate growth in renewable electricity generation. Compressed air energy storage at massive sizes may be feasible for low-cost grid-scale energy storage due to excellent heat control. If cost-effective underground storage options are unavailable, compressed air could be stored in pressurised steel tanks above ground. Liquid air energy storage, on the other hand, is portable and flexible since it does not require a pressurised storage vessel, is light, and has a high volumetric exergy density at ambient pressure. Compressed air energy storage devices have a higher round-trip efficiency than this one. We examine a hybrid power supply that includes two types of air storage that can both function at ambient temperature and pressure. Both the forward (compressed air to liquid air) and reverse (liquid air to compressed air) thermodynamic processes are investigated using hypothetical heat engine and heat pump systems. It has been hypothesised that very efficient heat pump/heat engine systems can achieve a roundtrip efficiency of 53%. Following this, we will investigate the economic viability of hybrid energy storage and conduct a thorough research of heat pump and heat engine systems.

***Keywords***: *Renewable, Hybrid energy storage, Liquid air, cogeneration.*

## 1. Introduction

Increasing energy efficiency and reducing reliance on fossil fuels are of critical importance as the world's energy demands rise. Between 2003 and 2030 [1], natural gas consumption is expected to rise by 91.6% and oil consumption will rise by 47.5%. Because greenhouse gas concentrations in the atmosphere are already at unsustainable levels [2], this trend is very worrisome. The production of energy, for example, is just one industrial process that produces a lot of waste heat. Compared to centralised electricity production and independent heat generation, cogeneration that makes use of this waste heat can significantly boost a system's efficiency[3, 4]. Using waste heat alone can boost the efficiency of a power generation system by 35-55% [5, 6]. Using the hot effluent exhaust from a combustion gas turbine (CGT), cogeneration plants simultaneously produce both electrical and thermal energy, such as steam or hot water. Using a district energy (DE) system, the cogeneration facility's produced heat can be piped to surrounding structures. District heating systems that rely on cogeneration are extremely popular in Europe. Cogeneration provides 75% of Denmark's district heating energy [7] and 30% of Sweden's [6]. The operational limitations of cogeneration systems and the seasonal variation in the availability of fossil fuels create economic and environmental drawbacks, despite the fact that the coupling of cogeneration and DE increases the overall system efficiency in comparison to centralised power production. Because of this, peak energy demand periods rarely coincide with supply, and electricity generation is limited by the thermal load. During times of high demand, these constraints lead to price spikes and supply interruptions. Thermal energy storage (TES) is a method that could help close the gap between energy supply and demand and increase the cogeneration system's ability to generate electricity.

An overview of the topic is presented in the first section, followed by a literature review in the second, a discussion of thermal energy storage and cogeneration in the third, a description of thermal energy storage in the fourth, a description of sensible heat storage in the fifth, a description of tank thermal energy in the sixth, a description of borehole thermal energy storage in the seventh, and a description of TRNSYS Simulation in the eighth,result and discussion presented in ninth and conclusion described in tenth section.

## 2. Literature Review

**Kevin Attonaty, 2020**, as intermittent renewable sources grow increasingly commonplace in the global energy mix, the issue of energy storage becomes more pressing. We examine a power-to-power electrical storage system that operates at very high temperatures (900 °C) and makes use of sensible storage. It is crucial to find a balance between optimising the power-to-power conversion process and increasing the value of energy reserves. The energy storage system uses either a gas cycle or a mixed cycle to generate electricity, with an electrical heater and fans making up the charging loop. It is crucial to evaluate the interdependent effects of the storage and discharge cycles in order to establish a workable basis for the system. Thermodynamic modelling and first law (or exergy) experiments followed. The findings demonstrate that selecting a certain discharge cycle results in different pressure and temperature levels, and hence has a significant impact on the total storage capacity. Discharge phase combustion increases fuel consumption but reduces storage space and improves power-to-power efficiency. Finally, the power-to-heat conversion results in significant exergy degradation in the charging loop relative to typical heat input from combustion systems. Exergy is lost during storage, however it is little because of the high temperature.

**Wey H. Leong, 2019**, this study demonstrates the thermodynamic feasibility of integrating a simple ORC into the DLSC to improve the performance of a BTES operating in the 60–80 °C range. "As long as the BTES loop's heat source is above 67 degrees Celsius, the ORC can produce enough net power to operate the pumps in the BTES and district heating loops. Despite its poor thermal efficiency (between 1.34 and 5.05%), the ORC is still a good investment because of its high efficiency as a cogeneration system (about 94.1%), and the overall efficiency of the BTES-ORC-district system is still respectable (around 87.1%). Although there is an increase in efficiency and environmental benefit, it is still necessary to do an economic assessment to confirm its viability. More research is required to learn how different ORC configurations (such as those with an internal heat exchanger, supercritical, etc.) and working fluids can provide better, more practical, and optimal systems.

**Silvia Trevisan, 2020**for cutting-edge concentrated solar power applications, this research provides a rigorous literature evaluation of the most important high temperature sensitive and latent materials suitable for a multilayered thermal energy storage system. Three high-temperature metallic phase transition materials (Al-12.2Si, Al-20Si, and Cu-Si27 Mg17) are included in the thermodynamic evaluation of six alternative stacked packed-bed thermal energy storage configurations. The efficiency of each layered storage system was compared based on the layer thickness of the phase change materials used. The addition of a high temperature phase transition material at the top of the multilayered thermal energy storage, as predicted, brings about the most significant advantages. There is a potential for a two-hour increase in the discharge phase time and a 5% increase in energy output. The top high-temperature layer can have its energy output somewhat increased by adding a layer of low-melting-point phase transition material. The additional complexity and expense introduced by such a storage unit design, however, makes this look to be of little utility. The results show that as the number of phase change materials is increased, the discharge efficiency decreases because the temperature difference between the heat transfer fluid and the storage media grows larger. Conclusions more investigation into multilayered Cu-17Mg-27Si/rock thermal energy storage is warranted based on the results of the current study, particularly in the form of experimental tests to assess the influence of potential corrosion issues and various encapsulating and coating options on the system's lifetime. Integration of advanced TES systems with state-of-the-art concentrated solar power plant designs requires techno economic studies to be performed as well.

According to BharathKantharaj (2015), the importance of energy storage will rise as renewable electricity generation capacity expands. Using efficient heat management, compressed air energy storage has the potential to offer cheap grid-scale energy storage. Compressed air could be stored in pressurised steel tanks above ground if suitable geologies are unavailable, but this would be prohibitively expensive. Liquid air energy storage, on the other hand, has a high volumetric exergy density at ambient pressure, does not require a pressurised storage vessel, and may be positioned virtually anyplace. In contrast to compressed air energy storage technologies, its round-trip efficiency is lower. An innovative energy storage system is the topic of this study; it combines the advantages of liquid air storage at ambient pressure with those of compressed air storage at room temperature. Both the forward (compressed air to liquid air) and reverse (liquid air to compressed air) thermodynamic calculations are then performed on fictitious hea pump and heat engine systems. The preliminary findings suggest that a round-trip efficiency of 53% is possible with highly efficient heat pump and heat engine systems. Heat pump and heat engine system economics, as well as hybrid energy storage economics, will be the focus of future research.

**Ugo PELAY, 2021,** says that solar thermal energy, especially concentrated solar power (CSP), is becoming more and more widely adopted as a viable renewable energy option. However, one of the major components affecting the growth of CSP to overcome its intermittent nature and become more economically competitive is the introduction of efficient and low-cost thermal energy storage (TES) devices. This research summarises the many methods used by CSP reactors to store thermal energy. Storage concepts for their integration into CSP plants and a variety of TES system technologies for high temperature applications (200 °C - 1000 °C) are discussed. At least 70% of all new CSP facilities must have TES systems installed. Because of its dependability, low cost, ease of deployment, and extensive experimental feedback, sensible heat storage method is the most widely employed technology in existing CSP facilities. Because of their significantly higher energy densities, thermochemical and latent storage methods may take central stage. Cascading TES of modularized storage units with intelligent temperature control is another idea for TES integration, as is coupled technology for higher operating temperatures.

The primary contributions of this review paper are the in-depth analyses of CSP plants, TES systems, and methods for boosting heat and/or mass transfers, and novel strategies for integrating TES systems.

**H.J. Xu, 2015,** Cascaded heat storage (CHS) is a powerful tool for maximising thermal efficiency and making use of multi-graded thermal energies. In this research, we offer thermodynamic modelling of the CHS for direct thermal utilisation using the lumped parameter technique for PCMs. The entransy hypothesis is used to find the optimal temperatures for both the heat transfer fluid (HTF) and the multistage phase change material (PCM). The optimal temperatures of HTFs and PCMs can be found analytically by doing heat optimisation for fixed entransy dissipation and entransy optimisation for fixed heat. Critical stage numbers are proposed in addition to existence criteria for the two optimisations. The results demonstrate that CHS can extend the temperature window in which various thermal energy grades can be utilised. Improved heat transfer is necessary for multi-stage heat storage. Parameter C is distributed uniformly throughout all stages, which improves thermal efficiency. Current thermodynamic optimisation and solutions can be utilised as a starting point for further research on CHS and as a criteria for selecting PCMs.

### 3. Thermal energy storage & cogeneration

Thermodynamic and financial efficiency of thermal systems may be enhanced by employing thermal energy storage (TES). When energy use and generation occur at different times throughout the day, these strategies are used to minimise costs. Dincer [8] explains why combining TES with cogeneration plants can be beneficial. The thermal load on a system is typically taken into account while managing a cogeneration plant. Cogeneration plants may be able to run more profitably with the help of TES if they deviate from the required demand (thermal load). This varies on a daily basis, seasonal basis, or both to shift energy use to cheaper times. Cogeneration systems are more efficient when they are operating at full load with steady demand [9]. The inconsistent nature of thermal demands makes this impractical in most cogeneration systems. But if you use a properly sized TES system, you can keep your thermal load constant and complete. More power can be generated during peak hours, and peak heating needs can be mitigated, saving a significant amount of money by separating the two processes. In conclusion, an efficient TES system could extend the life of the cogeneration plant, leading to greater energy savings and reduced emissions.[10].

## 4. Thermal energy storage

All methods of storing heat energy are essentially the same at their core. The apparatus collects and stores the energy until it is required. The storage duration, the operating temperature, and the medium utilised to store data are the main distinguishing factors amongst systems. These features of the storage system's design are influenced by the system's thermal requirements. TES systems used in solar thermal power plants must be able to function reliably under extreme conditions. Solar power installations need diurnal TES systems to assure continuous power generation due to the sun's inconsistent output. However, large-scale TES storage systems are needed, such as those found in district heating networks. The storage, charging, and discharging stages make up the storage system life cycle.

## 5. Sensible heat storage

TES systems are often categorised as either chemical thermal energy storage, sensible thermal energy storage, or latent thermal energy storage [11]. When the temperature of a substance rises or falls without causing a change in the substance's phase experience, the resulting energy is referred to as sensible heat [12]. The temperature of the storage medium rises as energy is added to a system.

The amount of energy stored can be calculated using the following calculation, which takes into account the specific heat, the mass of the storage medium, and the change in temperature [13].

$$Q_s = \int_{Ti}^{Tf} mc_p \, dT = mc_p(T_f - T_i)$$

where,

| | | |
|---|---|---|
| $Q_s$ | = | Sensibleheatstored, J |
| $T_f$ | = | Finaltemperature, °C |
| $T_i$ | = | Initial temperature, °C |
| $m$ | = | Massofstorage medium, kg |
| $C_p$ | = | Specificheatofthe storage medium, J/kg°C |

Solids (rocks, concrete, and metal) and liquids (oil, water) are typical sensible storage materials. Tank pit, borehole and aquifer thermal energy storage are the most widely used sensible energy storage systems.

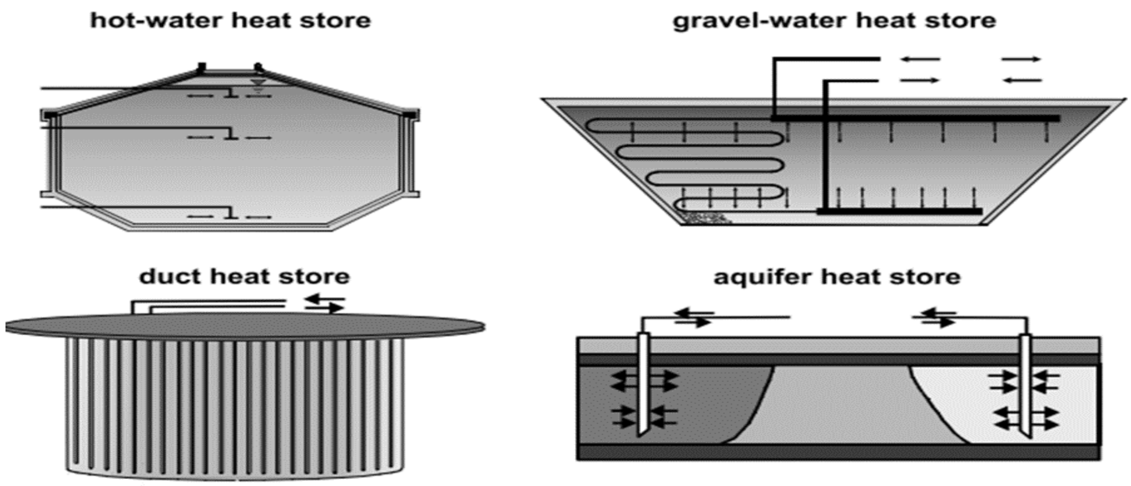


**Figure.1- Typesofsensibleseasonalthermalenergysystems**

## 6. Tankthermalenergystorage

Reinforced concrete is used for the exterior of a tank thermal energy storage (TTES) system, and stainless steel is used for the interior to prevent corrosion from moisture. Water is frequently used as the storage medium due to its high specific heat capacity. It is possible to keep temperatures in these subsurface storage tanks between 30 and 90 degrees Celsius [15]. Bauer evaluated the efficiency of seasonal energy storage in German central heating systems [16]. A tank thermal energy storage (TTES) plant at Friedrichshafen, Germany, was one of the technologies investigated. The tank's dimensions were 32 metres in diameter, 20 metres in height, and 12,000 cubic metres in capacity. This TTES system was found to be 60% effective. The TTES system is powered by two condensing gas boilers and solar collectors (providing a solar percentage of around 33%).

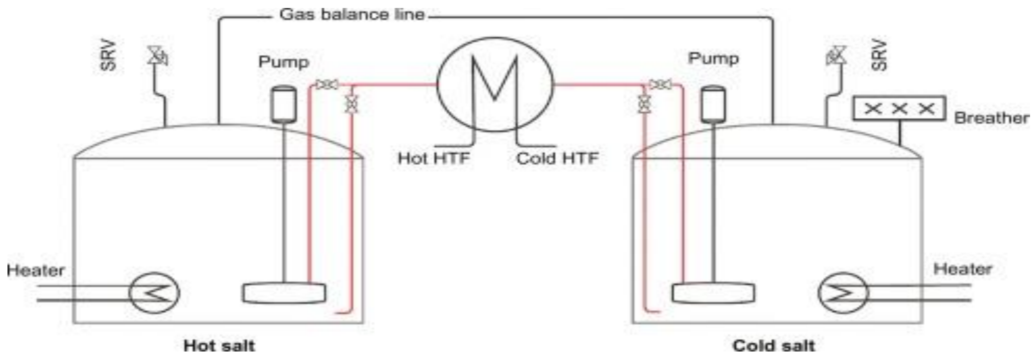


**Figure.2- Tank thermal energy storage system**

## 7. Borehole thermal energy storage

Each well in a down hole thermal energy storage system (BTES) is typically filled with a heat exchange pipe (often a PEX pipe) and a thermally conductive bentonite slurry. To use the earth as a heat sink, water or propylene glycol is poured through underground pipelines. The maximum efficiency is 90%, the minimum well depth is 20 metres, and the maximum well temperature is 90 degrees Celsius. Soil's limited specific heat capacity necessitates vast quantities of storage. Since heat loss is related to surface area, it makes sense to minimise exposed surfaces wherever possible. Since the system's volume is inversely proportional to its energy storage capacity, it is also vital to find the ideal volume-to-area ratio within the constraints of the site's

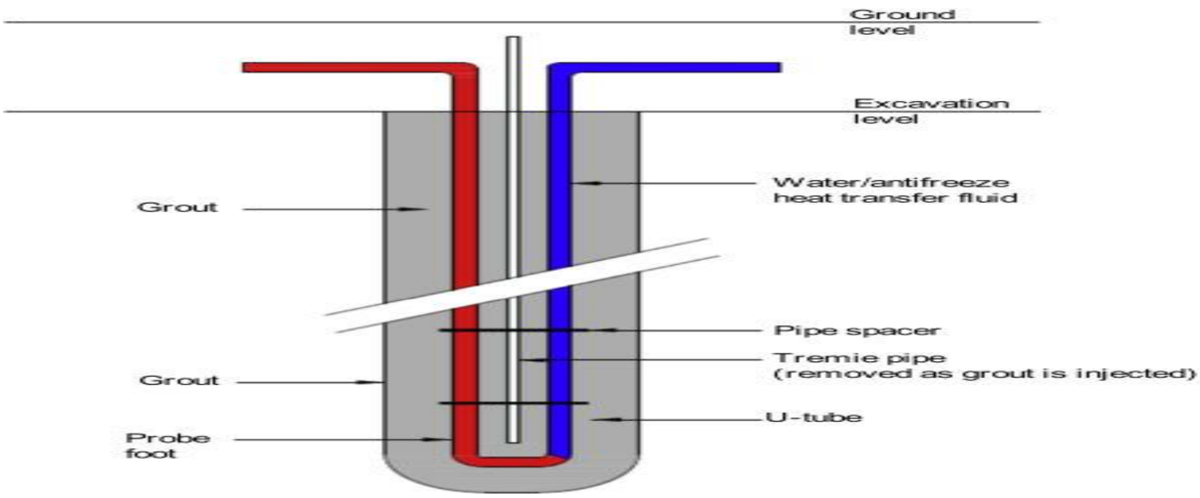


**Figure.3- Thermal energy storage system (BTES)**

geographic and geotechnical features. The Neckarsulm system in Germany has 538 boreholes and a storage volume of 63,360 m3, making it the largest of its kind in the world. In Alberta, Canada, Sibbitt looked studied how well a solar seasonal energy storage system worked. Through a district-heating network, 52 homes were heated using seasonal borehole thermal energy storage. The system is 90% efficient in heating the necessary areas as designed. Sibbitt compared the performance and operation of the system to a TRNSYS model during a five-year period. After five years of operation, the system will be able to heat 90% of the space as intended, according to the study's findings. The results that TRNSYS had anticipated for BTES also came true. After 5 years, the BTES system only had a 36% true efficiency.

## 8. Trnsysmultiplesimulations

Many simulations were run to be the best configuration for the system. Due to the fact that working temperatures over 90 degree Celsius limit can damage the plastic U-tubes, the offered solutions were developed with this temperature as a target. The total number of boreholes ranged from 11,250 to 12,250, give or take 250. The rated charging flow was modified for each system size to keep the loop temperature below 90 degrees Celsius [21]. To provide a balanced system after reaching steady state operation, the rated load was adjusted for each system size so that energy to the load is equal to energy into the BTES after losses. Many simulations were run at increasing system sizes until equilibrium was reached at the desired temperature. In order to achieve steady state performance, each simulation was run for five years at one-hour time steps. Depending on how many boreholes are simulated, a five-year simulation can take anywhere from 10 to thirty minutes.

## 9. Results and discussion

The SCADA system at the UMass cogeneration plant can swiftly store and send data from 675 locations. Thedata set contains a wide range of parameters, such as steam and fuel flows, temperatures, pressures, and the amount of power generated. The existing performance of the campus cogeneration plant was analysed using hourly data from 2011 to aid in estimating its future operation with BTES. The campus' thermal load decreases around the beginning of May, when the spring semester ends, and increases again in September, when the autumn semester begins. Between May and September, the HRSG produces an average of 60,000 pph of steam per hour. In order to employ a BTES system, the HRSG's steam output may be increased to 100,000 pph at this time. An extra 141,086,294 lbs of steam would be produced if the steam flow was raised to 100,000 pph. An additional 232,932 MMBtus (68,318 MWh) of natural gas consumption is needed. Based on the HRSG's exhaust temperature and pressure, the average enthalpy was 1369 Btu/lb. This means that the system has gained a total of 56,647 MWh (193,139 MMBtus) of energy. Using data from the intended cogeneration plant's operations, a BTES system was constructed and simulated in TRNSYS, totalling 11,750 boreholes. This chapter details the assessment's findings.Tables 1 and 2 summarise the proposed and current activities (with TES charge), respectively. Table 1 shows that thermal energy storage is only used as a means of offsetting the effects of ULSD. Table 2 assumes that thermal energy reserves cancel out LNG usage.

**Table1: Present & Suggested Cogeneration Plant Operation (ULSD Reduction)**

| Summary of Results (ULSD Offset) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Power Produced(MWh) | Steam Produced (lbs) | ral Gas Fuel Input | | LNG Fuel Input | | ULSD Fuel Input | |
| | | | MMBtu | MWh | MMBtu | MWh | MMBtu | MWh |
| Current Operation | 89,367 | 1,026,504,140 | 1,193,600 | 350,079 | 158,197 | 46,399 | 328,651 | 96,392 |
| Proposed Operation | 97,880 | 1,167,590,434 | 1,426,531 | 418,398 | 158,197 | 46,399 | 178,404 | 52,325 |
| Increase(+) Decrease(-) | 8,513 | 141,086,294 | 232,932 | 68,318 | 0 | 0 | -150,247 | -44,067 |

**Table2: Present & Suggested Cogeneration Plant Operation (LNG Reduction)**

| Summary of Results (LNG Offset) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Power Produced (MWh) | Steam Produced (lbs) | ral Gas Fuel Input | | LNG Fuel Input | | ULSD Fuel Input | |
| | | | MMBtu | MWh | MMBtu | MWh | MMBtu | MWh |
| Current Operation | 89,367 | 1,026,504,140 | 1,193,600 | 350,079 | 158,197 | 46,399 | 328,651 | 96,392 |
| Proposed Operation | 97,880 | 1,167,590,434 | 1,426,531 | 418,398 | 6,525 | 1,914 | 328,651 | 96,392 |
| Increase(+) Decrease(-) | 8,513 | 141,086,294 | 232,932 | 68,318 | -151,672 | -44,485 | 0 | 0 |

- **Btes&Systemefficiency**

The overall BTES efficiency is defined as the energy recovered divided by theenergyinput and is given as [8]:

$$BTES = \frac{\text{EnergyRecovered}}{\text{EnergyInput}} = \frac{\text{Energyto load}}{\text{Energyinto BTES}} \quad (1)$$

Additionally, it is vital to determine the effect that the TES system has on the overall efficiency of the cogeneration plant". Past research on the UMass cogeneration plant has concluded that the overall plant efficiency is 73%.

## 10. Conclusion

The purpose of this study was to investigate the efficacy of a seasonal BTES system in a cogeneration facility. To offset the high fuel costs of the winter, the TES system was charged when the price of fossil fuels was relatively low. The BTES system was modelled in TRNSYS using information gathered from the campus cogeneration plant and district heating system. So that we could observe the system in its steady state, we ran this simulation for five years. Results from simulations indicate that the BTES system might replace roughly 36,700 MWh of campus heating energy per year. Furthermore, during the summer months, an additional 8,513 MWh of power may be generated to handle the greater thermal load. The benefits of ULSD and LNG were contrasted in two scenarios. Offsetting ULSD is favoured due to its greater potential for cost savings and emission reductions. The countervailing ULSD determined that the proposed BTES system would result in an annual savings of $2,430,343, or an eight percent reduction on campus utility bills. Not only did this use of TES save money, but it also prevented the release of 836,700 kilogrammes of carbon dioxide and 4,790 kilogrammes of sulphur dioxide into the atmosphere. The annual savings in utility expenses amounts to $2,059,187 thanks to the combination of thermal energy storage and LNG. Because it allows for greater flexibility in the operation of cogeneration, the widespread application of TES to cogeneration has promise for the economy and the environment. In order to hedge against cyclical increases or decreases in the price of fossil fuels, the plant can be strategically operated thanks to its increased adaptability. Tables 1 and 2 summarise the proposed and current activities (with TES charge), respectively. Table 1 shows that thermal energy storage is only used as a means of offsetting the effects of ULSD. Table2assumesthatthermalenergyreservescanceloutLNGusage..

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