Enhancing liquid air energy storage efficiency through integration with LNG: comparative analysis of cold energy recovery methods

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Abstract

This study proposes the integration of an external cold source with the LAES system to recover cold energy and enhance the system's energy efficiency. Liquefied Natural Gas (LNG) serves as an effective external cold source when coupled with LAES. The coupling of LNG and the LAES is achieved by providing cold energy to the system in two ways: reducing the system's compression work and supplementing cold energy to assist in liquefaction. This study conducts a comparative analysis of these two approaches to system improvement, offering valuable insights for the advancement of combined LNG and LAES systems.

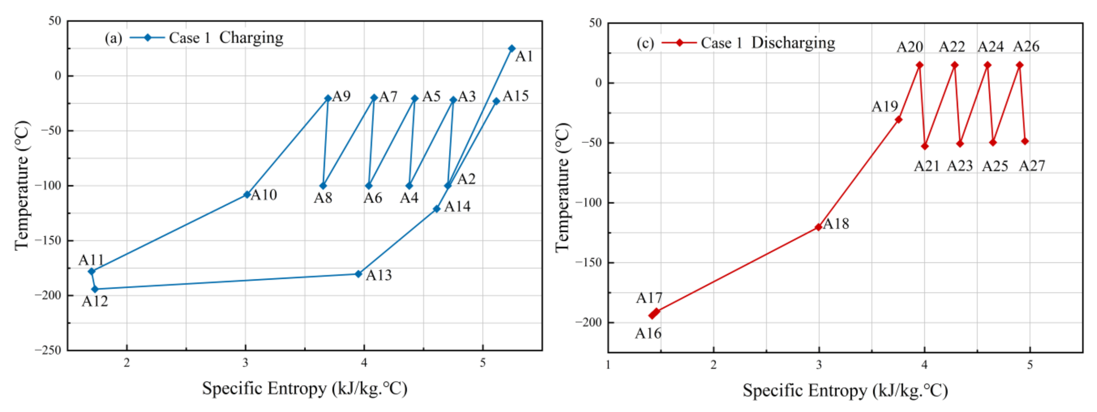

Fig 3. T–s diagram for energy release and energy storage process.

- The air undergoes compression at low temperatures (A1-A9), leveraging the LNG's cold energy for the compression in Case 1.
- The compressed high-pressure air is then liquefied using methanol and propane tanks to storage the cold energy (A9-A11).
- The liquid air is pressurized and gasified, and the recovered cold energy is converted back into high-pressure air (A16-A19)
- The expansion power generation process for Case 1, where air is rewarmed using seawater (A19-A27), resulting in a modest power output due to the air's low pre-expansion temperature.

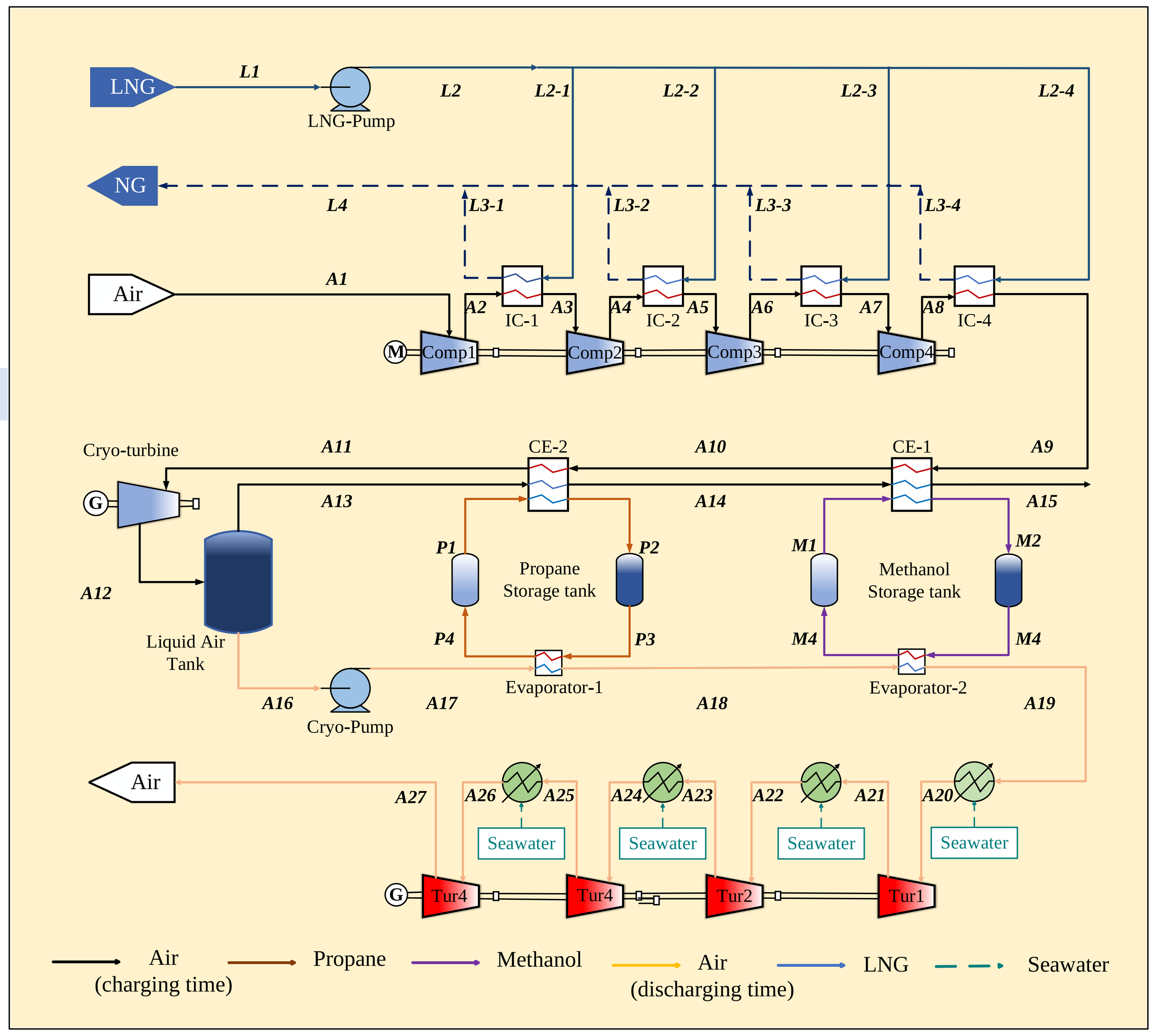

Fig 1. Conceptual design of LNG-LAES system Case1.

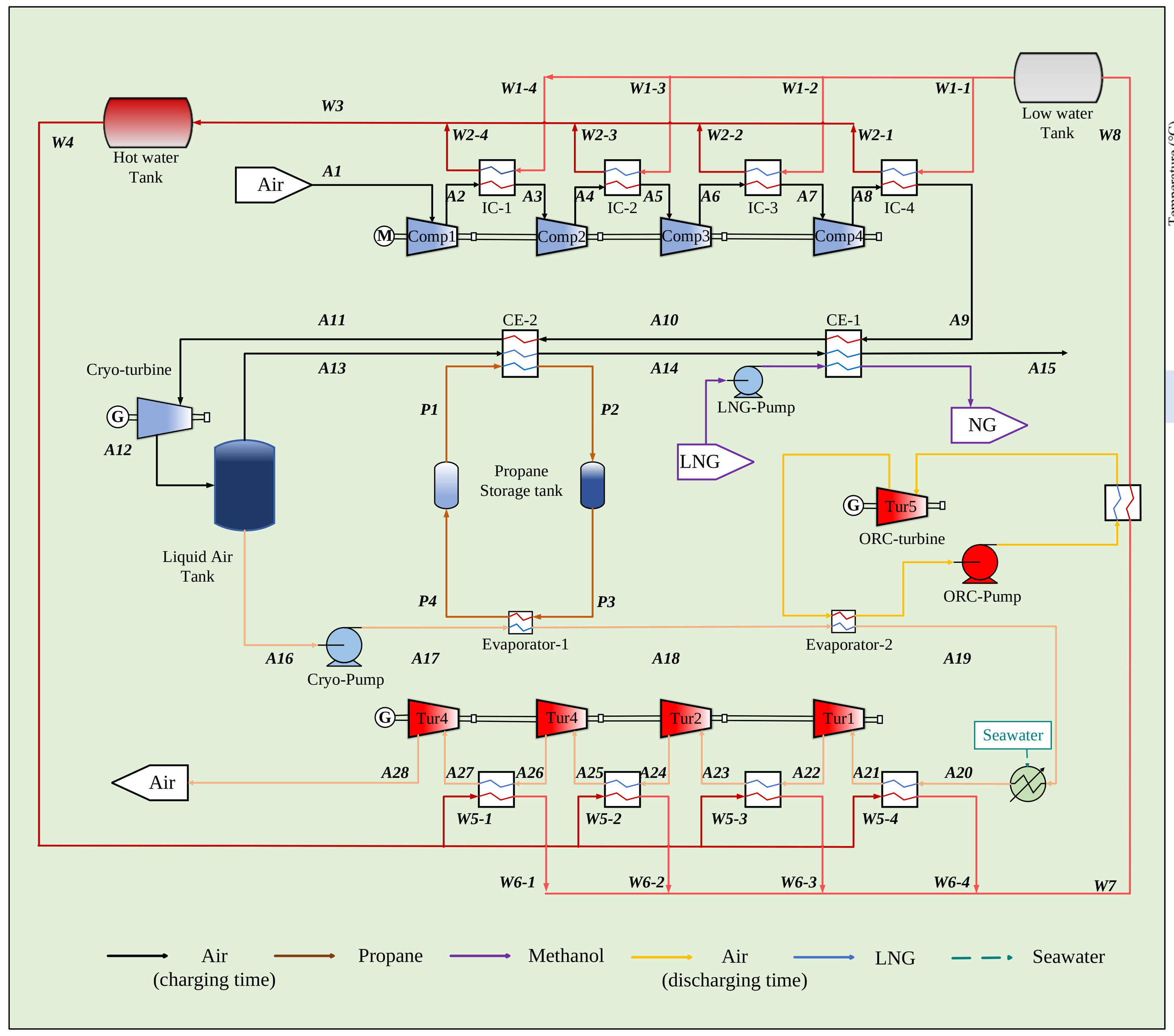

Fig 2. Conceptual design of LNG-LAES system Case2.

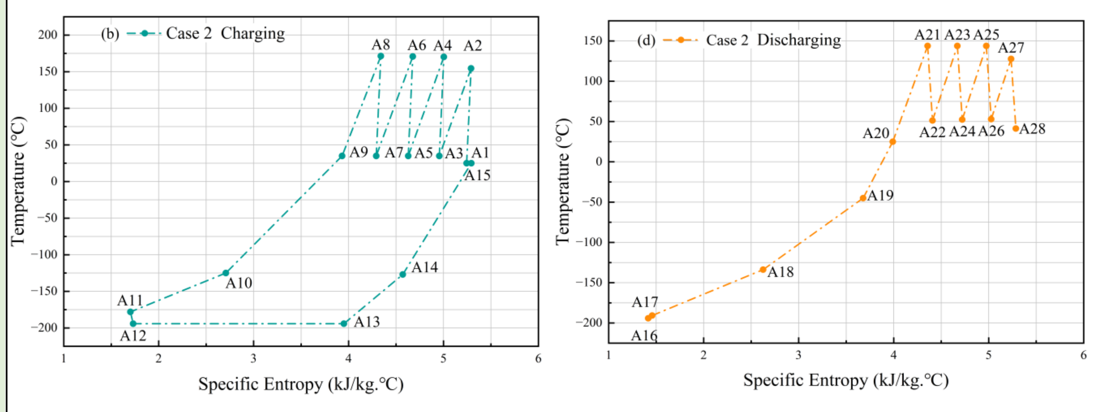

Fig 3. T–s diagram for energy release and energy storage process.

- The air is compressed at ambient temperature .
- The air undergoes multi-stage compression, with pressurized water employed between compressor stages to cool the air and store the resulting heat in hot water storage tanks(A1-A9).
- The cold energy derived from LNG is harnessed to liquefy the air for charge cooling (A9-A10).
- The air is further cooled using propane storage, and the remaining cold energy drives the Organic Rankine Cycle (ORC).
- The air is preheated with hot water from a storage tank (A20-A28).

Process Calculation

- The round-trip efficiency of Case1 :

$$\eta_{RT1} = \frac{t_{rls}\times(\sum_{i=1}^{4} W_{Tur,i} - W_{Cryo-Pump})}{t_{str}\times(\sum_{j=1}^{4} W_{Comp,j} + W_{LNG-Pump} - W_{Cryo-Tur})}$$

- The round-trip efficiency of Case2 :

$$\eta_{RT2} = \frac{t_{rls}\times(\sum_{i=1}^{4} W_{Tur,i} + W_{ORC-Tur} - W_{Cryo-Pump} - W_{ORC-Pump})}{t_{str}\times(\sum_{j=1}^{4} W_{Comp,j} + W_{LNG-Pump} - W_{Cryo-Tur})}$$

- The exergy efficiency of the two systems:

$$\eta_{Ex} = \frac{Ex_{out}^{Net}}{Ex_{in}^{Net}} = \frac{Ex_{out}^{NG} + \sum W_{Tur}}{Ex_{in}^{LNG} + \sum W_{Comp} + \sum W_{Pump}}$$

- The energy storage capacity:

$$\omega = \frac{W_{rls}}{m_{LNG}}$$

Basic parameter

- Air mass flow: 1 kg/s
- LNG inlet pressure: 1.3 bar
- Natural gas outlet pressure: 70 bar
- Compression pressure: 90 bar
- Expansion pressure: 66 bar
- Storage pressure of liquid air tank: 1.013 bar
- Charging time: 8 h
- Discharging time: 8 h

Thermodynamic Performance

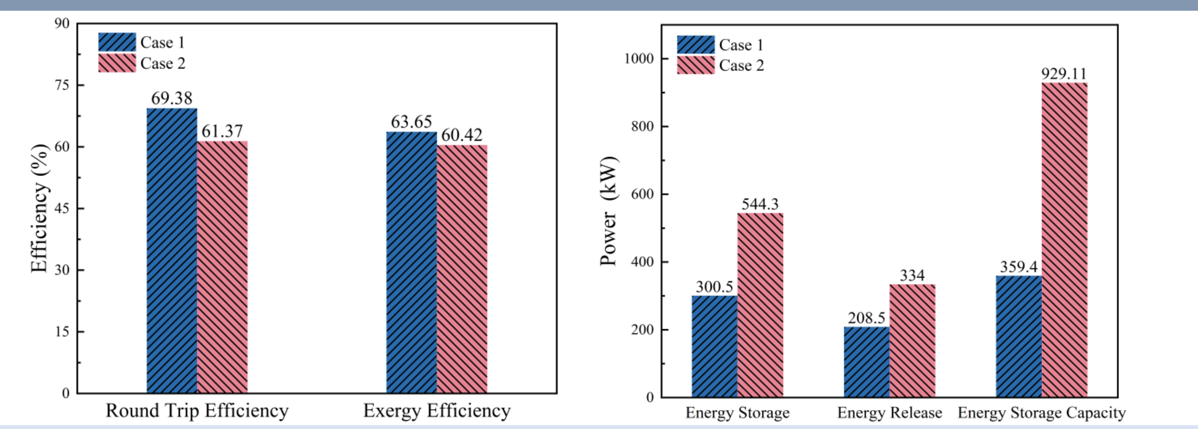

Fig 5. Thermodynamic efficiency and power comparison of the systems.

- Case 1 achieves a round-trip efficiency of 69.38%, surpassing Case 2's efficiency of 61.37%.
- Case 1 exhibits a superior exergy efficiency of 63.65%.
- In comparison to Case 2, Case 1 requires 243.8 kW less electrical energy during the storage phase but also generates 125.5 kW less during the release phase.
- The energy storage capacity of Case 2 is nearly triple that of Case 1. This substantial capacity suggests reduced LNG consumption.

Conclusion

- This study utilizes LNG's cold energy for the air compression and liquefaction processes, achieving a system round-trip efficiency exceeding 60%.
- With identical air volumes, Case 1 exhibits a superior round-trip efficiency of 69.38% and greater energy utilization efficiency, whereas Case 2 delivers a higher power output of 544.3 kW.
- Utilizing LNG's cold energy for air compression diminishes the system's electrical energy demand, albeit at the cost of reduced power generation.
- Future research may explore integrating an external heat source to augment both the power output and the system's efficiency.