Economic Analysis of Liquid CO_2 Energy Storage System Integrated to a Conventional PWR

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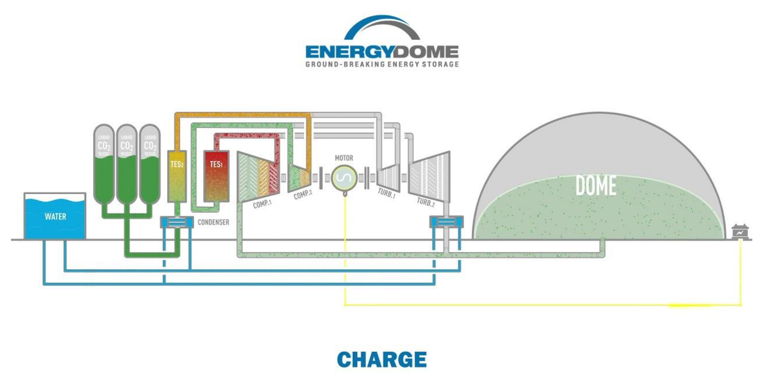
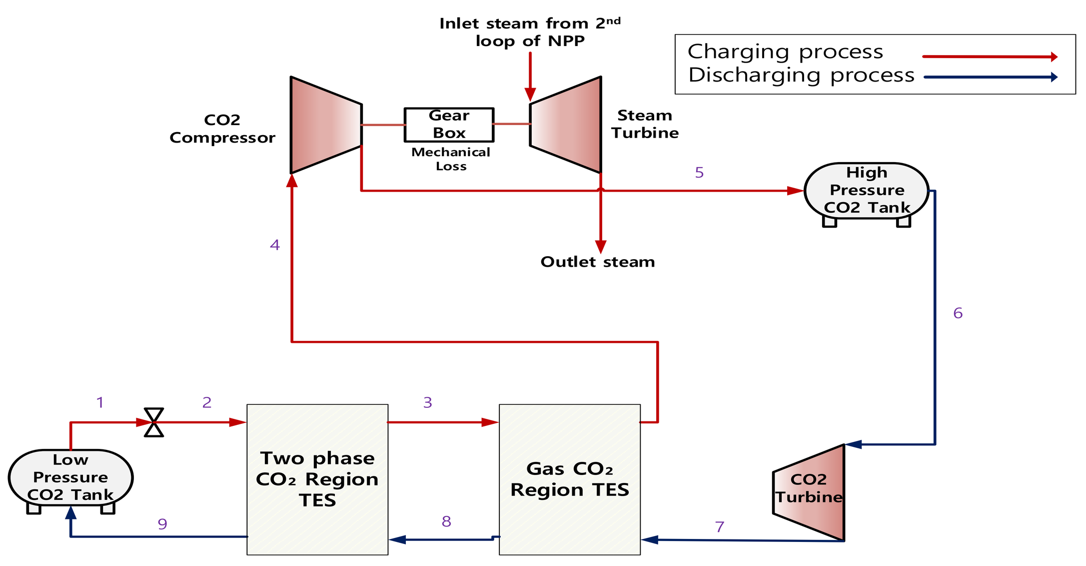
Introduction

- ✓ Recently, the energy production from renewable energy (RE) sources is increasing globally to reduce greenhouse gas emission, but RE has unexpectable intermittency during power generation. This issue can be alleviated by load-following operation of a nuclear power plant (NPP).
- ✓ Energy Storage System (ESS) attached to the power cycle can solve this issue. Among the various ESSs, compressed CO_2 energy storage (CCES) is promising ESS due to high round-trip efficiency (RTE) and simple layout.
- ✓ Startup 'Energy Dome' has scored its first commercial licensing agreement for its carbon dioxide-based energy storage solution, with Italian power engineering firm 'Ansaldo Energia'.



- Layout and flow CCES of 'Energy Dome'

- ✓ CCES had quite low energy density. For higher energy density, liquid CO_2 energy storage (LCES) with PWR was studied thermodynamically as shown below Figure.
- ✓ In order to evaluate the feasibility further, the economy of the proposed system should be evaluated and understand the associated cost.



- Layout of liquid CO_2 energy storage system(LCES) integrated to PWR steam cycle

- ✓ Thus, in this paper, **economic analysis of a liquid CO_2 energy storage (LCES) integrated to a conventional PWR are studied.**

Economic analysis

✓ Levelized Cost of Energy

(1) In this paper, levelized cost of energy (LCOE) is used among various indices of economic analysis.

(2) LCOE is a measure of **the average net present cost of electricity generation for a generating plant over its lifetime**.

(3) The ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted sum of the actual energy amounts delivered as seen in the following equation

$$\mathrm{LCOE}\left(\frac{\$}{\mathrm{MWh}}\right) = \frac{I_t + \sum_{t=1}^{n} \frac{M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t : capital investment, M_t : operation and maintenance cost, F_t : electricity cost, E_t : electrical energy generated, r : discount rate, n : lifetime of power plant

Account	Value
Total Cost Investment (TCI) = Direct cost + Indirect cost	
Direct cost (DC)	
Purchased Equipment Cost (PEC)	Sum of all components cost
Purchased equipment installation	20% of PEC
Piping	10% of PEC
Instrumentation & control	7% of PEC
Electrical equipment and materials	10% of PEC
Land cost	10% of PEC
Civil, structural and architectural	30% of PEC
Service facilities	30% of PEC
Indirect Cost (IC)	
Engineering and supervision	9.8% of DC
Construction cost & contractors profit	11.9% of DC
Contingency cost	15.0% of DC
Operation & Management Cost (O&M) = Fixed + Variable O&M	
Fixed O&M (FOM)	1.29% of TCI
Variable O&M (VOM)	9.0% of FOM

- Ratio of LCOE details

(4) I_t and M_t are can be calculated from **the purchased equipment cost (PEC)** and the table about ratio of LCOE details

(5) In this system, the **compressor** is **driven by only steam turbine**. However, PWR power production will be decreased during the charging process of LCES. Thus, F_t is **the opportunity cost of unproduced electricity during the charging process**.

(6) E_t is used from the previous thermodynamic study of LCES

✓ Component cost model

- The cost model is used with scaling parameters(SP) of each components.

(1) Heat exchanger (SP : Overall conductance)

$$C_{HX} = 49.45UA^{0.7544}$$

(2) Compressor & Turbine (SP : Power consumed and produced)

$$C_{Comp} = 1{,}230{,}000W_{Comp}^{0.3992} \qquad C_{Turb} = 182{,}600W_{Turb}^{0.5561}$$

(3) Tank (SP : Volume of tank)

$$C_{Tank} = 40420V_{Tank}^{0.506}$$

(4) Others

- Since steam turbine and motor for this specific configuration do not have cost model, the six-tenth law is applied

$$\frac{C_1}{C_2} = \left(\frac{V_1}{V_2}\right)^{0.6}$$

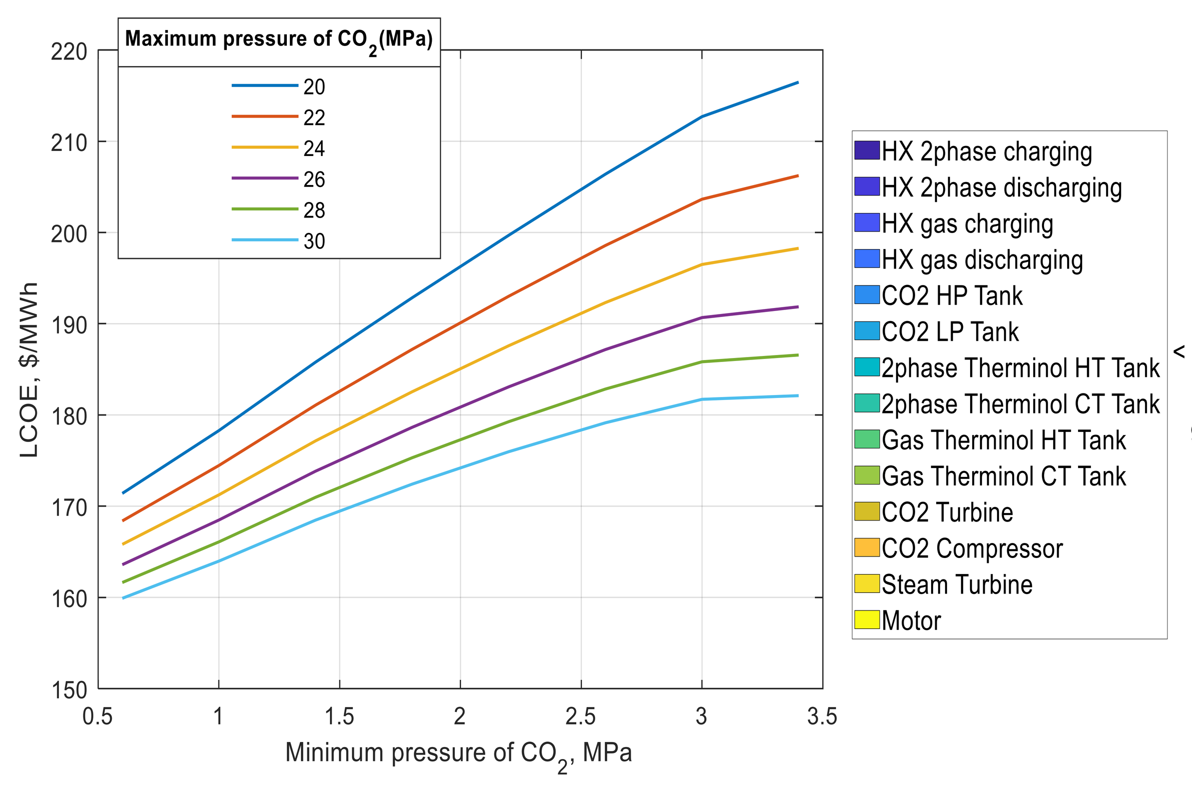
Equipment	Reference cost	Capacity
Steam turbine	10M$	15MW
Motor	0.75M$	15MW

✓ Cycle condition and Parameters

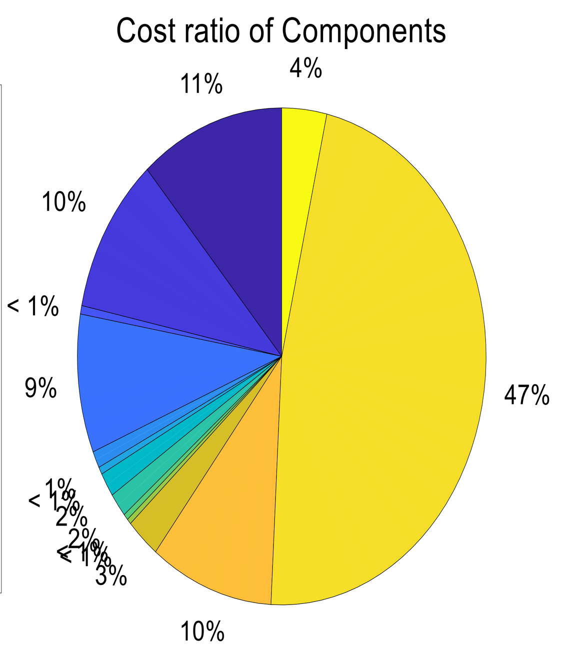
Parameters	Value	Unit
Charging time	8	hr
Discharging time	8	hr
Lifetime	30	yr
Discount rate	5	%
Nuclear price	62	$/MWh

Parameters	Range of Variation	Unit
Pressure of low-pressure reservoir	0.6-3.4	MPa
Pressure of high-pressure reservoir	20-30	MPa

Results



- LCOE vs Minimum and maximum pressure



- Cost ratio of components

Optimization point	Value	Unit
Pressure of low-pressure reservoir	0.6	Mpa
Pressure of high-pressure reservoir	30	Mpa
LCOE	160	$/MWh

Summary and Future works

- ✓ From the result of the liquid CO_2 energy storage economic analysis, it is shown that as the **maximum pressure increases** and the **minimum pressure decreases**, **LCOE decrease**.
- ✓ The **lowest LCOE** is expected to be **$160/MWh**.
- ✓ The **optimized operating conditions** have the **highest RTE** and **energy density**, and the **lowest LCOE**.
- ✓ Further investigation will commence soon regarding **possibility of further decreasing the LCOE of LCES with various layouts** as well.