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Green Energy Storage: The Potential Use of Compressed Liquid CO_2 and Large Sub-Terrain Cavities to Help Maintain a Constant Electricity Supply

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Abstract

One of the problems using most green energy sources is that there is not a constant supply. Therefore, there is a need for the development of energy storage and release systems. Many different technologies have been developed and employed for storage that among others includes:

1. Pumped hydro-power (potential energy),
2. Railway lines and carriages loaded with stones in hilly terrain (potential energy),
3. Thermal storage (thermo-dynamic energy),
4. Flywheels (kinetic energy),
5. Batteries (chemical energy),
6. Phase transition of salts (thermo-dynamics energy) and
7. Compressed air (thermo-dynamic energy)

Here I propose the potential use of CO_2 and its phase-transition from gas to liquid in large sub-terrain cavities, such as disused mines, for electric energy storage and ground-heat extraction.

Keywords: Carbon dioxide; Compressed air energy storage (CAES); Disused mines; Green energy; Electricity supply

Green Energy Storage: The Potential Use of Compressed Liquid CO_2

Compressed air has been used for energy storage since the 1970s in Huntorf, Niedersachsen, Germany and since the 1990s in McIntosh, Alabama, USA. In these two facilities, of respectively ~1 GWh and ~2.6 GWh, atmospheric air is compressed to 50-70 bar during times of surplus electricity and released while being heated with natural gas when electricity is needed [1]. The technology being used is called diabatic as it does not store the energy released when the air is compressed. The efficiencies of the two facilities are 42% to 52% for a storage cycle, respectively [1]. However, a new type of compressed air energy storage plants, called adiabatic, is under development where the heat released by compression is stored and used to heat of the compressed air during expansion, thus increasing the efficiency of the process to about 70% [2]. Here, I propose that it might be possible to increase this efficiency of the adiabatic approach further, as well as in the process extract ground heat for other purposes, by invoking CO_2 condensation and evaporation.

CO_2 constitute about 0.04% of atmospheric air; it is a colourless gas that condenses to a liquid at about ~56 bar pressure at ~20°C with a density of about ~1101 Kg/m^3, and the specific heat released during this condensation is about 574 KJ/kg [3]. This means that 1 m^3 of liquid CO_2 release 632 MJ of energy when it is formed, at the same time it will store approximately [1101 Kg (weight of 1 m^3 liquid CO2)/ 44.01 g/mol (molecular weight) × 22.4 × 10^{-3} m^3/mol (specific volume of 1 mol perfect gas at 20°C and 1 bar pressure) × 55 × 101325 J/m^3 (energy stored per bar perfect gas)]: 3118.5 MJ of energy when isothermal (the heat released during compression and condensation if fully stored and returned keeping a constant temperature during the process) expanded to 1 bar [3]. Thus, if a volume of condensed CO_2 equivalent to 1000 m^3 was stored 365 times a year, then it would correspond to 1140 × 103 GJ or 316.8 GWh [3].

For this approach to work a larger cavity of ~280 times the 10^3 m^3 volume would be need to store the released CO_2 at approximately 3 bar (such that the pressure of this larger cavity can be kept around 1 bar when the 1000 m^3 liquid CO_2 mentioned above is fully condensed to 56 bar at ambient temperature into the smaller camber). Meanwhile, the thermal energy released during compression and condensation will have to be stored as for other adiabatic systems, and reused during the expansion process [2].

The advantages of this system would be several; since the pressure fall would be from a constant 56 bar to 1-3 bars, the system would generate a more or less constant electricity output during the de-charging of the system as there will a constant CO_2 gas release during the recharge process. While in the current adiabatic system, the pressure fall changes with the release of the compressed atmospheric air, such that the energy output fall with time, or that more compressed gas has to be released with time to compensate [1].

Storing the heat released when the gas is condensed will lead to some energy loss. However, if the temperature of the released CO_2 is kept lower that the temperature of the underground then the expanding gas will absorb heat from the surroundings allowing ground heat to compensate for the loss of energy lost during storage. The amount of heat extracted and the efficiency of a storage cycle and be varied by changing the temperature of the evaporated expanding gas (from about approximately -50°C, extracting the most heat from the underground, to close to the ambient temperature of the surrounding underground (isothermal generation) or above (by additional energy input) for most efficient generation of electricity. Alternatively, the condensed CO_2 could first be allowed to evaporate by increasing the volume approximately five fold, extracting heat from the surrounding in the process, and once the pressure and temperature of the now CO_2 gas again reach close to but below the condensation point at 56 bar and 20°C, then released it for electricity production using a adiabatic process. Indeed, such a system could extract a significant amount of ground heat (~230 × 103 GJ or 64.0 GWh a year).

One additional advantage of such a system would be from the point of view of the socio-economics. Many local areas suffer when mines are closed, including coal mines due to the implementation of green energy. By using otherwise closed mines for energy storage, such local communities will be able to prosper from the change in energy generation, by attracting industries that are requiring a thermal input (cooling or heating) in the production, providing jobs as well as green heating for homes.

There is one danger associated with using compressed CO_2 as an energy storage, and that is that we as humans are sensitive to raised levels of CO_2 as it affects our breathing (7-10% may cause suffocation even in the presence of oxygen [4]). However, by using mines, where the high-pressure compartment is buried deep underground and by keeping the pressure low in the expansion chamber (if there is space enough in the mine/cavity, it could even be kept below 1 bar), and the risk can be minimized.

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