DQE Battery Container – Operation

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Battery Container Assembly

As a platform enabling technology, the DQE battery container is chemistry agnostic and battery system interoperable. Chemistry agnostic means the container can accept and improve any electro-chemical components and improve their energy, power, and life-cycle performance. System interoperability means the container can be configured for many types of battery systems; we have conceptualized: typical electrode film, metal-air, redox-flow, etc. For the initial protype and commercialization we've selected film NMC and LFP electrodes with a pressurized, high-performance, electrolyte.

The container assembly (main cylinder, end caps, flanges) will have an expected life of 50 years, 5-10x longer than the current small-format long-duration batteries. The interchangeable and interoperable features of the retainers will allow the container to be updated with existing and future chemistries or battery systems.

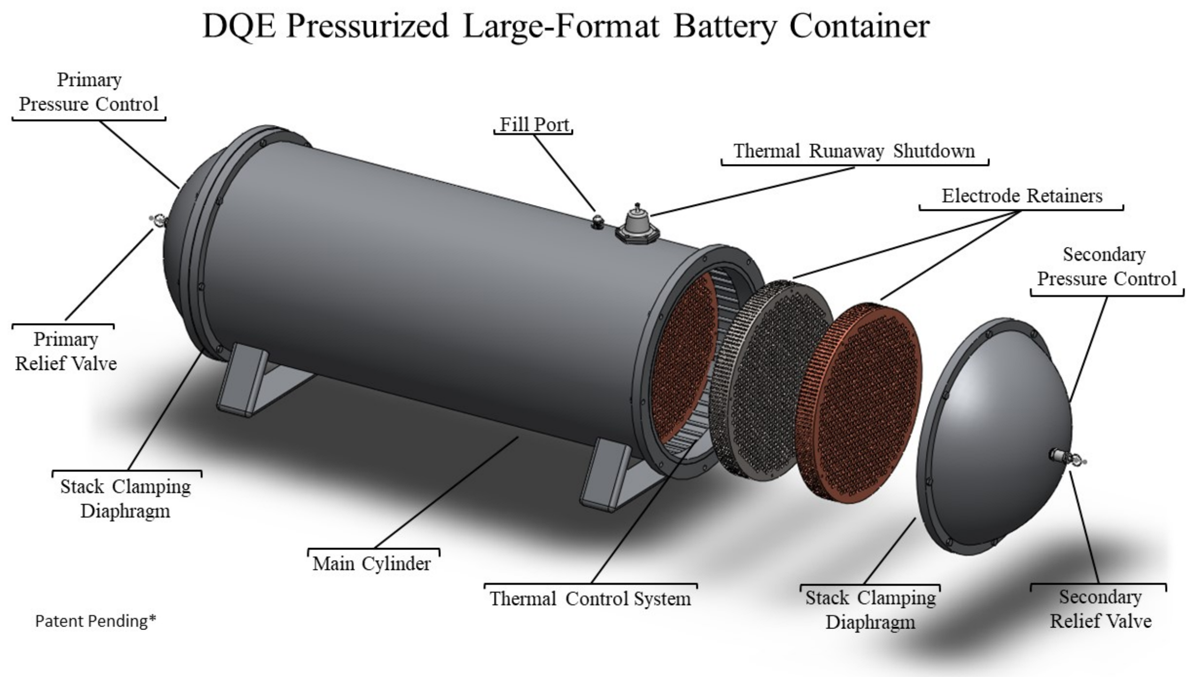


Figure 1

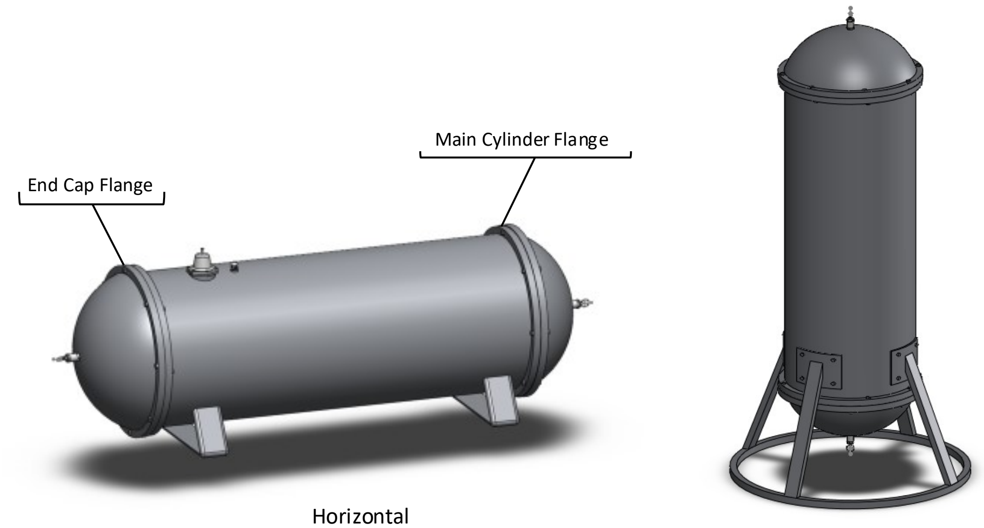
Main Cylinder: The main cylinder is a structure to create a container assembly so that battery chemistries can be installed, and air/gas pressure can be applied. When the end caps are installed at each end of the main cylinder, a pressure vessel is created for desirable battery chemistry reactions, thermodynamic control, electrolyte, and chemical retention. The main cylinder and end caps can made of metal, composites or plastics based on customer needs, internal chemistry requirements, external environmental requirements, electrical insulation, dimensions, weight etc. Because of the large-format, the container is designed to handle significant static loads and would be considered a structural member. As such the container can handle loads from being buried underground, even acting as frame members in electric vehicles.

End Caps: The end cap provides a structure to close off each end of the main cylinder to create a battery container that is a pressure vessel. The main method to attach the endcap to the main cylinder it by a bolted flange. It can also be welded, bonded, brazed, integrated composite, and is serviceable, inspected, repaired. There are also several other functions the end caps do. The split line between the end cap flange and the main cylinder flange can be sandwiched with a diaphragm/membrane of suitable material to apply, and translate, associated pressure to the main cylinder creating the primary and secondary expansion areas (Fig 5). The main cylinder, end caps, and diaphragms creates three distinct and separate compartments for chemistries and pressures. The flange fasteners may be a desirable place to attached mounting brackets for horizontal and vertical applications, or integration with a pack, structure, vehicle, or building. Typical shapes for the end caps would elliptical, standard dish, hemispherical, or a shape consistent with current Pressure Vessel Design.

Flanges: The main cylinder and end caps has flanges on each end of the cylinder to allow for installation of the end caps (Fig 1 and 5). Removable end caps improve accessibility to internal parts and provides a route to simple and effective maintenance, recycling old chemistry, updating container with future chemistry systems, and replacement of internal parts.

Mounting Points: Based on the mounting requirements for a stationary setup, vehicle, trailer, structure, building etc., mounting points to accommodate vertical or horizontal mounting of the battery cylinder assembly (Fig 2) can be integrated into the flange fasteners or a band clamp can be installed around the circumference of the main cylinder. Metal main cylinder can have mounting points welded on, and plastic or composite tanks the mounting points can be integrated into the molding or layup process.

Mounting Configurations



Horizontal

Vertical

Figure 2

Pressure Ports: A port in the main cylinder and end caps (Fig 1) will allow for pressure of the of the main cylinder and pressure control areas to be filled and/or adjusted with the desired liquids and gases for any battery chemistry. The port may be finished with a shutoff valve and pressure-relief valve. Based on the specific battery chemistry utilized and installation requirements, the BMS may change pressure through the port during storage, charge, and discharge or under/over temp conditions. Thermal runways mitigation may not be required or desirable for certain battery chemistries and battery systems.

Pressure Relief Valves: The end caps creating the primary and secondary expansion areas will each have a pressure relief valve to release any over-pressure from thermal runaway events while maintain the integrity of the container and chemicals to the main cylinder. In the event the primary and secondary pressure relief valves do not mitigate a thermal event, a third pressure relief valve, and ultimate fail-safe will depower the main cylinder of chemicals and shutdown any thermal runaway events. This prevents catastrophic failures of the container, fires, and explosions.

Primary and Secondary Expansion Areas

Pressure Control: The primary and secondary pressure control and relief areas are formed by clamping a diaphragm/membrane between the main cylinder flange and the flange of the end cap (Fig 4). The area in the end cap created is isolated from the main cylinder yet allows pressures to be transferred between the separated chambers. The main purpose of the expansion areas as part of the battery container, end caps, and diaphragm/membrane is to function as a damper or pressure accumulator that will allow a consistent operating environment inside the battery container main cylinder during charge/discharge cycles, adjustments for diurnal and seasonal temperature changes and solar heating factors (Fig 6), and to automatically adjust to thermal and charge-state expansion/contraction of the electrodes regulating the cell stack clamping pressure (Fig 5).

Primary/Secondary Pressure Control and Thermal Runaway Mitigation

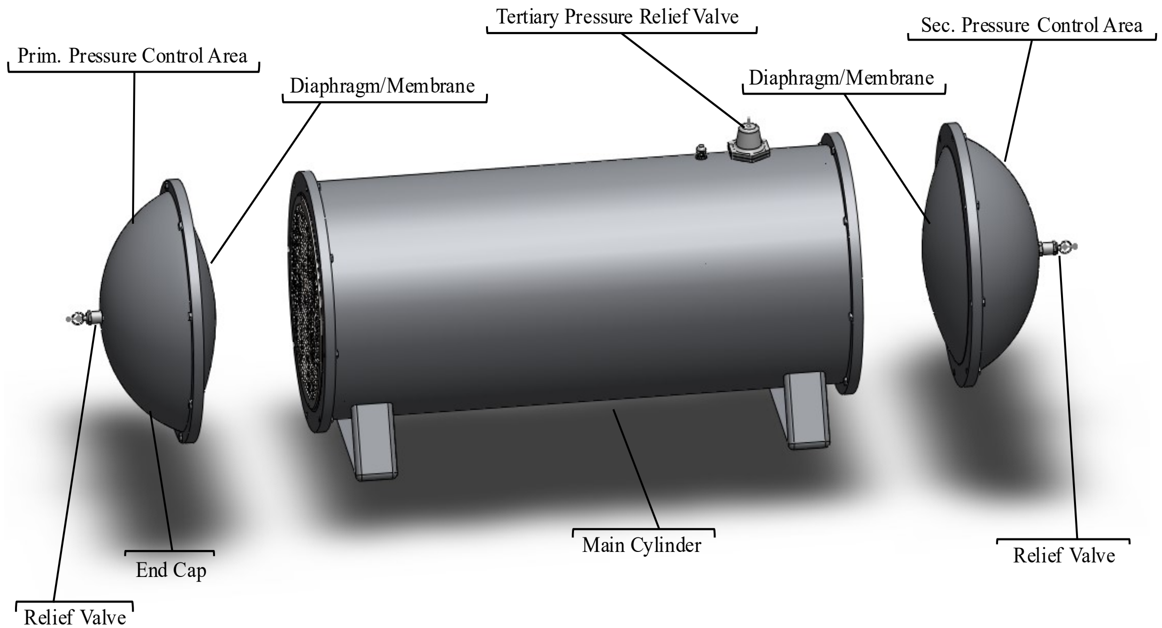
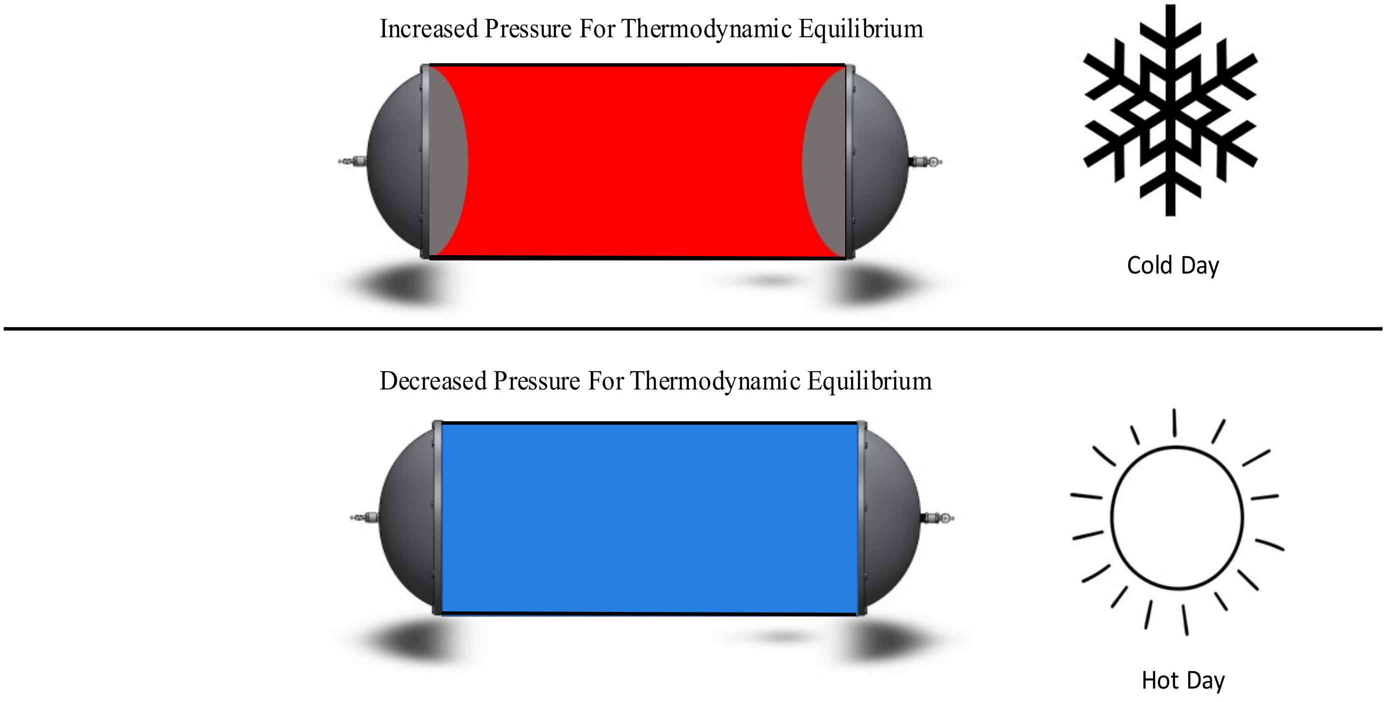


Figure 4

A certain and specific volume/pressure (based on end cap shape) can be relieved at each primary and secondary-stage relief activation allowing a commensurate temperature adjustment simultaneously (Gay-Lussac’s Law). A design feature of the diaphragm/membrane contains battery chemistry and hot gases to the main cylinder while pressures in the main cylinder area is reduced, first mitigating, and possibly shutting down the thermal runaway event. In the rare event that the first two tiers of pressure control do not mitigate a thermal runaway event, the tertiary failsafe will chemically shut down the battery, while retaining chemicals and hot gases to and envelope (Fig. 3).

Seasonal/Daily Adjustments To Initial Pressure or Vacuum


Increased Pressure For Thermodynamic Equilibrium

Decreased Pressure For Thermodynamic Equilibrium

Figure 6

Tertiary Pressure Failsafe: The tertiary failsafe is the ultimate pressure relief mechanism (valve or rupture disk) and safety feature of the main cylinder. This third line to mitigate and shut down catastrophic thermal runaway events of the battery container, assembly and only actuates after the primary and secondary expansion area release valves have exceeded their pre-set activation limits. After the primary and secondary pressure relief mechanism have been activated by a sequential increase in pressure, the third and final mechanism is the tertiary pressure failsafe. The tertiary failsafe (Fig 3) has two functions that operate automatically in a tiered manner. The first-tier activation releases the main cylinder pressure and hot gases, and contents, into an envelope sized appropriately (Fig 3) to depower the battery chemically, shutting down thermal runaway event, yet retaining the chemicals in an envelope preventing a release to the atmosphere. In the unlikely event that the battery remains powered up after this significant dump of chemicals, the second-tier activation of the tertiary failsafe is a metered release of pressure from the envelope venting pressure to the atmosphere. This is a reminder that all the pressure relief mechanism prevents release of chemicals and gas into the atmosphere (retaining them to the container or envelope) until tier two of the tertiary failsafe is activated.

Tertiary Failsafe (Thermal Runaway Shut-Down) With Retention Envelope.

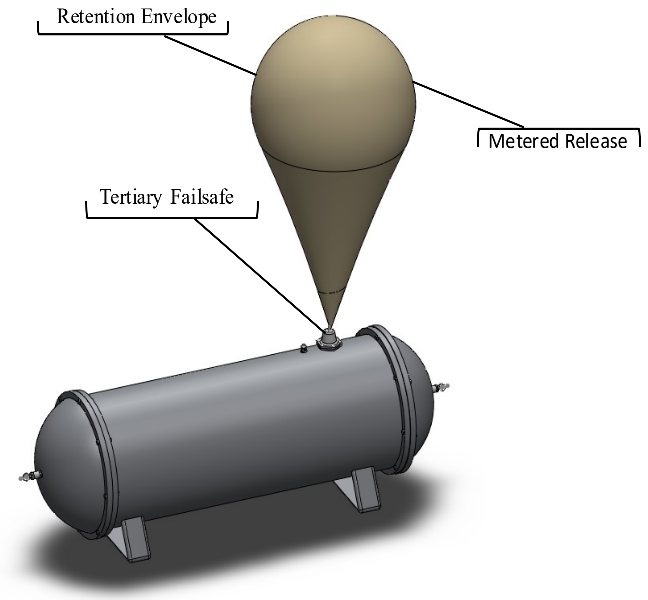


Figure 3

Electrode Retainers

Electrode retainers provide a modular, systematic way to install NMC and LFP electrodes, separators, electrolyte, and current collectors in the battery container assembly. The retainers support a platform approach for repair, maintenance, updating, and recycling of old electrodes at their end of life. The retainers and electrode material inside the retainer can be arranged in series and/or parallel for different voltages and currents desired. The electrode material may be installed in a jellyroll, stacked wafers, or bulk media (Fig 7) format.

The battery main cylinder can be configured to operate with or without the use of electrode retainers installed inside. The retainers simply represent a few configurations that battery engineers and chemists can use to insert proprietary battery chemistries of cathodes, anodes, electrolytes, etc. while using existing industry electrode manufacturing processes, tooling, and films manufactured at gigafactories, etc.

Perpendicular Electrode Retainer: Stacked disk-shaped or wafer electrodes retainer perpendicular to the longitudinal axis of the battery container main cylinder (Fig 7). Another positive design aspect of the electrode retainers is it prevents the electrode from coming into contact (electrical insulation) with the main cylinder material in the case of metallic main cylinders. The external and internal parts of the electrode retainer have a “slip-fit” feature to account for electrode expansion and contraction while allowing the end caps fastening method to provide clamping force to the retainer stack (Fig 7). The diaphragm/membrane installed between the flanges of each end cap and main cylinder, with an appropriately controlled primary/secondary expansion area, can also provide the clamping force required for the slip-fit feature of the retainers to adjust with the expansion/contraction of each perpendicular retainer.

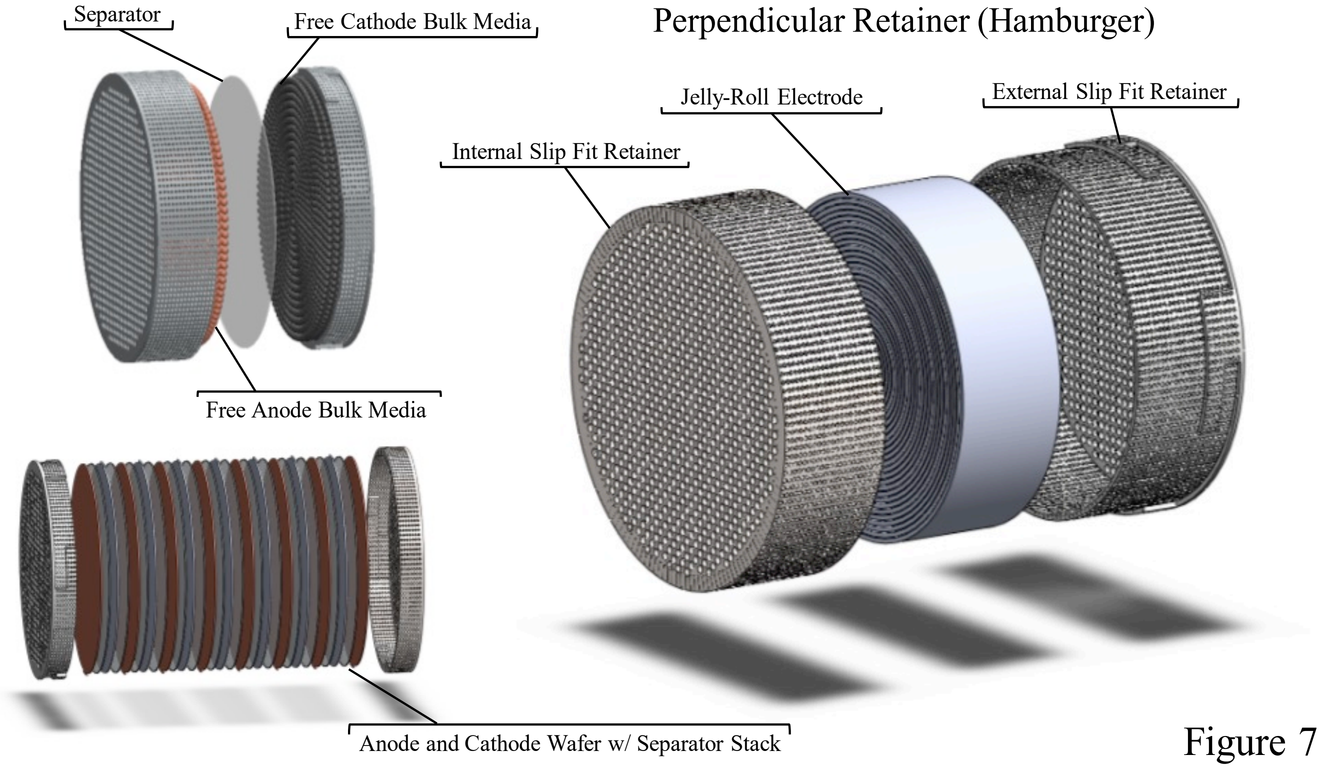


Figure 7

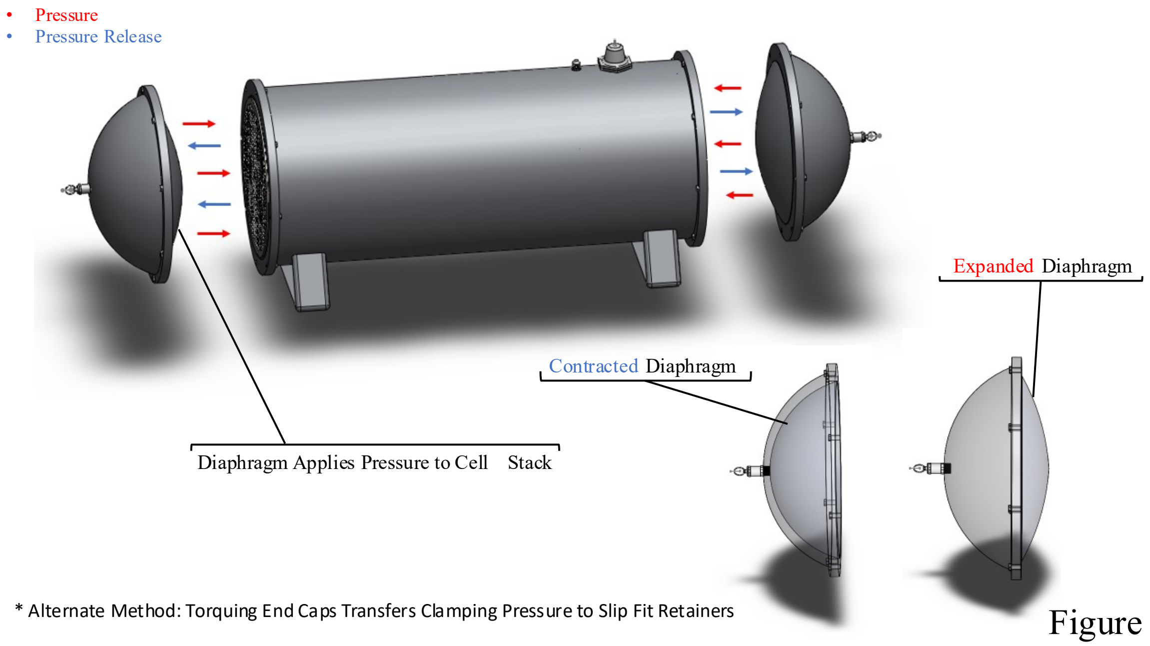
Cell Stack Clamping: It is well understood by battery engineers and scientist that providing a clamping force to a cell will instantly increase cell capacity and reduces degradation of cell components due to expansion and contraction. The DQE container is purpose-built to provide significant clamping force (pressure) to the retainer and electrodes. The container design achieves this in several aways:

- By applying a greater air pressure to the primary and secondary expansion areas, the resulting force on the diaphragm or membrane translates that force to the main cylinder and cell stake from both sides. This clamping force acts in a longitudinal direction to the main cylinder body.

- With electrode retainers, the slip-fit feature and an "over-fill" process can be utilized to translate a clamping force through any size stack of retainers. This method to generate the force can be created as the retainer and end caps are fastened and torque is applied, thereby, squeeze the slip-fit retainers together.

- The main cylinder walls are designed to resist the radial expansive forces of jelly-roll applications also. On initial installation the jelly-roll can be super-cooled and interference fit in the main cylinder. As the jelly roll warms to ambient temperatures, it will already be experiencing significant clamping forces. As the battery operates at various SoC generating heat, the expansion of the jelly-roll will provide further clamping pressures.

Cell Stack Clamping Pressure Mechanisms *



* Alternate Method: Torquing End Caps Transfers Clamping Pressure to Slip Fit Retainers

Figure 5

Thermal Management

Geological Thermal Management: This a first-of- a-kind buried long-duration energy storage battery. The large-format, vessel style, and long cycle-life is conducive to burying the battery container underground. This sub-terrain installation smooths out the battery thermal management requirements for diurnal, seasonal, solar heating, and radiative heat loses, etc. Although thermal management related to internal electrical resistance and charging still needs to be addressed, the consistent temperature experienced just under the surface of the earth provides a more desirable, stable, environment for consistently regulated electrochemical reactions of any long-duration, large-format, energy storage device. In addition, the form-factor of buried underground battery containers are subject to enhanced security, reduced war or terrorism risk and exposure to natural disasters such as fires or extreme heat waves and cold-snaps events.

Passive Thermal Management: For stationary aboveground installations, the battery container will be made of a thermal conductive material to allow heat to leave the battery container assembly via radiative cooling and attached to the battery when specific cooling properties are desired.

Active Thermal Management: For vehicle installations there may be open-loop active thermal management such that an electrolyte is pumped to an external cooling unit or heat exchanger to transfer heat away from the internal battery container assembly. Using the electrolyte utilizes an existing fluid and is circulated offering ion transfer similar to flow batteries.

With a closed-loop active thermal management, internal channels, pipes, and plumbing are installed to allow a separate cooling fluid to be circulated to the internal portion of the battery. Heat is transferred from the battery to the cooling fluid, and then routed to external cooling units and heat exchangers to transfer the heat to the atmosphere.

With existing and future pressurized battery chemistry technologies developments, there will be an ever-increasing demand for thermal management of the battery container and its contents for continued and consistent battery performance. The ability to thermal regulate a pressurized battery will become a limiting factor for such things as electrolyte stability, oxidation and lithium-plating of the anode as ultra-fast charging and discharging cycles are pushed to the extremes for optimum output and efficiency.

Interoperable Battery Systems

Beyond the scope of this fundamental white paper on the operation of the DQE battery container it should be emphasized the patent protected container is infinitely configurable as a current and future test-bed for battery system innovations such super-capacitor, pressurized metal-air, pressurized redox-flow, fuel-cell applications… even a pressurized Metal-Air Flow Battery. This keeps us excited every day.