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Summary of Projected Power and Energy Density Parameters for the "New Generation" LLNL Electromechanical Batteries

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The "New Generation" LLNL electromechanical battery (flywheel-based energy storage modules) are specifically aimed at "bulk storage" electric power applications, e.g., those that arise in connection with solar or wind-power systems, or for utility network uses. As such, they are aimed at applications where the discharge times are measured in tens of minutes or longer, and where the storage times, during which the energy losses must be minimal, may be a day or more. An equally important requirement for bulk storage systems is that they should require minimal maintenance and have a service life measured in decades. These needs are in sharp contrast with those of most presently available flywheel storage systems, where the discharge times may be measured in seconds in order to satisfy such needs as phase control or those of dealing with power outages where diesel generators provide emergency power, but require 15 to 30 seconds for startup.

To meet the above bulk storage needs the new LLNL flywheel system has adopted some major departures from present-day practice. These include the substitution of LLNL-designed "passive" magnetic bearing systems for the "active" magnetic bearings used in present-day systems. Our passive bearings have very low losses, are maintenance-free, and do not require the complicated sensors and controlled electromagnets needed for "active" magnetic bearings.

Most importantly, in the new system the electromagnetic generator/motor used in all other flywheel storage systems has been replaced by a new type of generator/motor based on electrostatic principles, with several positive consequences. First, the E-S generator/motor itself is virtually loss-free. It has no internal stator windings with their losses and their need for a cooling system. Second, the electrode structure of the E-S generator is much lighter than the permanent-magnets used in most present-day systems, simplifying the problem of handling the localized centrifugal loads caused by the magnets. Although the demand-response time between zero power and full power of the new system can be milliseconds, what is sacrificed in the exchange of generator/motor type is the possibility of achieving few-second-long full-discharge times.

With the above remarks in mind an example list will be given below of some code-calculated power and energy densities for the LLNL flywheel system. Because of the scaling laws involved the power density (kW/kg) will be a function of the size of the unit, whereas the energy density (kwh/kg) will depend mainly on the choice of the fiber used in the composite flywheel rotor of the EMB.

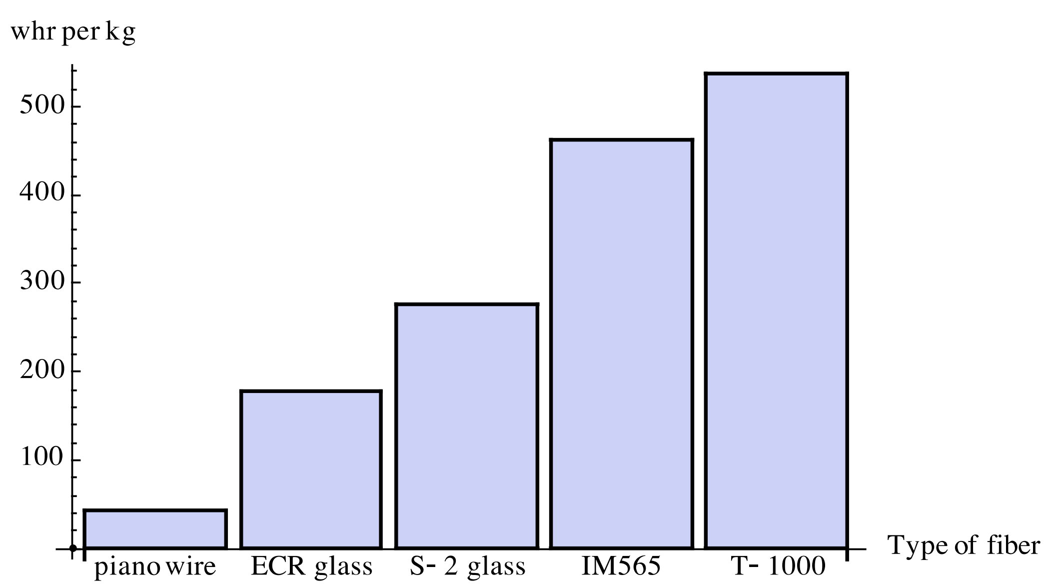
Power Density Examples

Composite	Rotor diam.	Rotor length	RPM	kW	kWh	T50*	kW/kg
T1000 c. f.	0.32 m.	0.45 m.	90000	100.0	5.0	1.5	4.0
IMS65 c. f.	1.1 m.	1.1 m.	21000	1400.	100.0	4.0	1.8
E-CR glass	1.0 m.	1.0 m.	15000	130	40.0	18.0	0.2

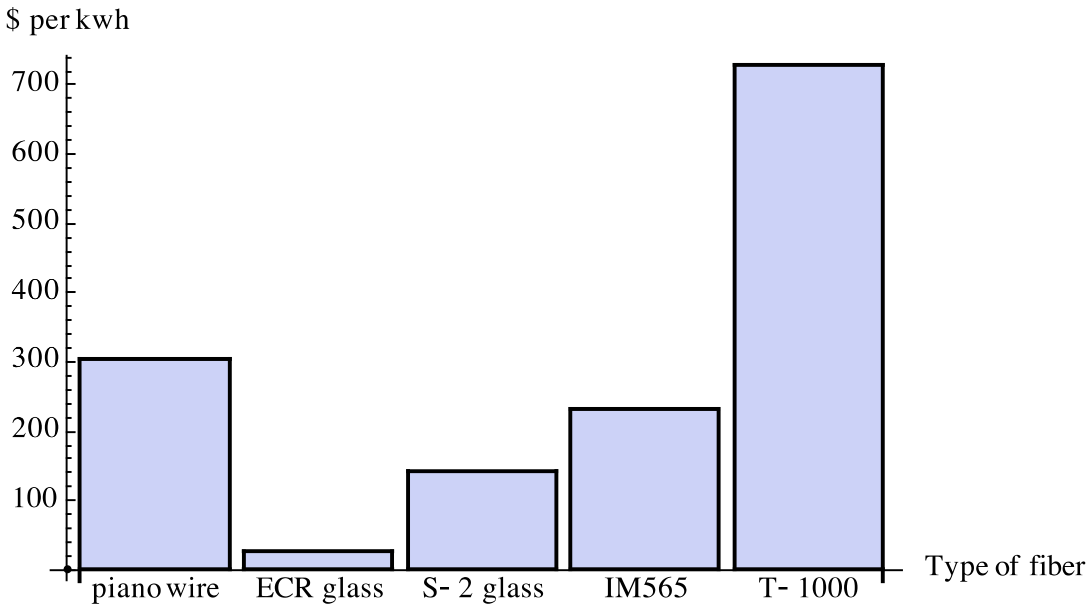
*T50 = Time in minutes to discharge to 50% of full charge.

As can be seen from the table above, when high power densities and short discharge times are required, the use of T1000 carbon fiber in fairly small units is indicated. The less-expensive IMS65 carbon fiber could be suitable for large units that require few-minute discharge times. However, for bulk storage units where typical discharge times are fractions of an hour to hours, the low cost of E-CR fiber and the employment of large units is indicated. As seen from the Table, the example given above of an E-CR rotor would have a T50 discharge time of order 20 minutes if required. Smaller E-CR units would have even shorter discharge times. For a bulk storage system that might require both short time (minutes) discharges and long-time (1 hour or longer) discharge times the storage facility might consist of a mix of large and small units feeding into the grid.

Finally, to summarize the mechanical properties of candidate fibers and their approximate cost per kwH stored, the two figures below are presented.



Energy storage per kilogram of selected fibers



Approximate cost per kWh stored for selected fibers.

In the two figures above two carbon-fiber examples are shown (IM565 and T-1000). T-1000 is the carbon fiber with the highest tensile strength, and is the highest cost one. As can be seen, however, IM565, with about 80 percent of the strength, has a much lower cost per stored kWh. Of all the fibers, however, E-CR glass fiber, manufactured by both Owens-Corning and the Canadian firm Fiberex, has by far the lowest cost per stored kWh.

In the calculations described above the results listed for power output were obtained from an in-house simulation code based on the computer program Mathematica®. A description of the circuits analyzed in this code and an example result is given in the LLNL report LLNL-TR-635770.