1st Lighten The Load Inc
'World Changing Technologies'

Cost Comparison Between
LTL's
Energy Storage Technology
&
That Of Its Closest Competitors

Date: January 04, 2011 ver. 1.4
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1.0 Introduction

There are many different energy storage technologies from ultracapacitors through to batteries. The purpose of this document is to compare a number of the most promising technologies to that developed by LTL. The document uses the cost of materials to manufacture each technology to determine their degree of competitive advantage. Further, it predicts whether or not one technology will dominate the market place by meeting the most important requirement of low cost while simultaneously meeting the minimum utility requirements of various applications.

1.1 Forward-looking Statements

This document may include forward-looking statements within the meaning of Section 27A of the US Securities Act of 1933 and Section 21E of the US Securities Exchange Act of 1934. These statements are based on LTL's current expectations as to future events. However, the forward-looking events and circumstances discussed in this document might not occur, and actual results could differ.

The information within this document comes only from public sources including but not limited to the internet and do not necessarily represent a company's or technology's state of the art. 1st Lighten The Load Inc. has made all efforts to ensure the accuracy of the information within this document. However, LTL assumes no responsibility for any errors or omissions in the document.

2.0 Competing Technologies

The capacitor technologies being compared are either electrostatic, similar to that developed by LTL, or electrochemical which is often referred to as "double layer". The battery technologies are either currently in production or under development.

The capacitor companies with competing electrostatic capacitor technology are General Electric, Strategic Polymer Sciences Inc. and Faradox Energy Storage Inc. The competing electrochemical ultracapacitor technologies are Carbon Aerogel made by Cooper Bussmann and an exotic double layer type under development by EAMEX. The remaining technologies mentioned are represented by the best results achieved in a lab with commercial production of the technology either absent or at a significantly lower energy density.

2.1 Technology's Cost Of Manufacture

There are few methods that can be used to precisely determine the manufacturing cost of a specific energy storage technology. The method used in this analysis simply takes into account the material cost and the cost to process per unit of energy storage. Direct environmental costs or end-of-life product disposal costs are not included in the analysis.

Solid materials purchased to manufacture a product are historically sold by unit of weight. This makes it necessary to calculate the weight of each material used in the manufacture of a unit of energy storage. This is accomplished in TABLE 1 by first determining the specific density of the materials used in a competing technology compared to that of LTL's, the reference used for the purpose of comparison. Next it is necessary to determine the energy density of a technology then compare it to the reference. Finally the purchase price in large volume per unit of weight of material is calculated relative to that of the reference. Using relative values, the component density multiplied by the amount of material per unit of stored energy, multiplied by the material cost, yields the material cost for an energy storage technology relative to that of LTL's.

The final cost of manufacturing is related to the direct manufacturing equipment costs and waste materials that are involved in the manufacture of a specific energy storage technology. These figures are difficult to find and have been estimated in most cases. There is a direct relationship to the total volume of materials required to manufacture a unit of storage energy. For example, a technology with an energy density one tenth that of LTL's will require the manufacture of 10 times more volume of product. The costs of equipment are not necessarily 10 times as much but are dependent on the process used. For example, many processes are less expensive per unit of volume to manufacture than LTL's, but the volume of material is often considerably greater.

The most expensive technology is the manufacture of aerogel ultracapacitors. The manufacturing process requires a long time to dehydrate the aero gels and a long time to infuse them with conductive electrolytes. Both dehydrating and infusing steps make it necessary to invest in many vacuum drying ovens per unit of daily production.

2.2 Why Is The LTL Technology Less Expensive?

LTL's technology in TABLE 1 is the lowest cost due to both material cost and the manufacturing technology. Hydrocarbon based polymers were selected because they have the lowest density, typically the same as water, and the lowest materials cost. Secondly, and most importantly, the LTL electrical orientation process increases the energy density of a dielectric by 5 to 10 times, greatly decreasing the total amount of material needed per unit of stored energy. For example GE's technology is highly competitive until its energy density is compared to that of LTL's. The GE technology is uncompetitive because it does not use LTL's patent pending process to increase its energy density. The disadvantage becomes even greater because LTL has developed a further set of processing steps, unique to its technology which, for many materials, is capable of increasing the energy density by an additional factor of three. The key to LTL's low cost per unit of stored energy is the efficient use of material and the use of optimization technologies to squeeze the highest amount of energy possible in each unit of material.

Materials with high potential energy density, such as ceramics, glass and PVDF, suffer from high material densities i.e. they weight much more than LTL's. For example, most ceramic materials are 6 times the density of those used by LTL and 3 times more expensive per kg, making ceramic materials about 18 times more expensive than LTL's. This applies for PVDF and glass materials which are on average 1.7 and 2.4 times greater density respectively than LTL's. The problem is further compounded, because these materials are significantly more expensive per unit of weight over those used by LTL. The PVDF material disadvantages are so great that they are only used to manufacture energy storage or capacitors for applications that specifically require their unique properties.

2.3 LTL's Manufacturing Compatibility

The heart of LTL's technology is its patent pending roll-to-roll three dimensional fabrication machine. The machine is capable of manufacturing a number of different multilayered structures using a high speed industrial ink jet printing process. Specifically, it fabricates a multilayered capacitor structure using a roll to roll process on a substrate using high dielectric constant polymer materials. The capacitors use a self-healing metal electrode structure that is a few nanometers thick to form the inner electrodes and conductive polymers to make the external electrical connections.

2.4 Technology Figure of Merit

In order for a company to make money, its product manufacturing cost must be lower than the competition. A "*Technology Figure of Merit*" is a measure of the relative cost of manufacturing, in this case a unit of stored energy, using differing technologies. Table 1 comprises the closest competing ultracapacitor technologies, and all are electrostatic except for iv. which is a double layer or electrochemical type. The Carbon Aerogel ultracapacitor (iv.) is included because it has demonstrated the highest energy density in the laboratory to that of any electrochemical or double layer type.

Table 1. Energy Storage Technology Comparison Matrix

	1	2	3	4	5	6	7	8	9
Ref	Company or Technology	Density kg/L	Material Density Relative LTL	$/kg	$/kg Relative LTL	Energy Density in J/cc	Energy Density Competitor/LTL	Capital Cost Wh Relative to LTL (est.)	Figure of Merit Relative To LTL Columns = 7/(3*5*8)
i.	LTL	1.0	1	5.5	1	300 (500)	1	1	1.0000
ii.	SPS	1.7	1.7X	27.5	5X	30	0.1 X	2X	0.0059
iii.	Ceramic	5.8	5.8X	17.6	3.2X	85	0.29X	2X	0.0078
iv.	Aerogel	1?	1X?	11?	2X?	325	1.09X	4X?	0.1400
v.	Faradox	2.6	2.6X	12?	2.2X?	5	0.005X	2X	0.0015
vi.	GE	1.0	1.0X	7.7	1.2X	50	0.17X	2X	0.0710
vii.	Glass	2.4	2.4X	8.8	1.6X?	35	0.12X	2X	0.1500
viii.	PVDF+	1.7	1.7X	27.5	5X	400	1.33X	1.5X?	0.1000
ix.	EAMEX	1.6	1.6X	16.5?	3X? (4X?)	47 (900)	0.16X (3)	2X? (1X?)	0.0170 (0.5X)

Notes:

1. The information represented in TABLE 1 comes from public sources such as the internet and does not necessarily represent a company's state of the art technology.
2. Values with a "?" are estimated, because data was not available.
3. Column 8 estimates the manufacturing cost using the fact that lower energy density requires a larger capital investment to produce a greater volume of product per unit of stored energy.
4. Column 9 is the Figure of Merit of a technology relative to LTL where a number less than 1 means it is more expensive.

5. In column 6, (500)J/cc is the LTL energy density for portable electronic equipment which typically requires product life < 10 years.
6. TABLE 1 is a tool that identifies the relative competitiveness of a technology and the areas where development work needs to be focused to become more competitive.

2.5 Guide to Company or Technology in TABLE 1

i. LTL is the reference technology that the other capacitor company's' costs of manufacture are compared to. www.1-LTL.com

ii. SPS refers to Strategic Polymer Sciences Inc. (SPS) www.strategicpolymers.com which is a biaxial orientated fluorocarbon film capacitor technology. Their technology uses the conventional metalized film capacitor manufacturing process with a different dielectric material. Their material has an average density of 1.7g/cc, polymer cost of $27.5/kg (see (x.) for link to current polymer pricing). Eventually they expect to achieve an energy density of 30J/cc. The high material cost in combination with higher material density makes the technology uncompetitive except for applications that require its unique properties. Their website is www.strategicpolymers.com

iii. Ceramic refers to a ceramic based multilayer capacitor technology with a published record energy density of 85J/cc, recently achieved by Argonne National Laboratory. Ceramic materials have a density of 5.0 to 6.0 g/cc with material cost of over $17.6/kg. Ceramic capacitor technology is widely used for the manufacture of general purpose capacitors. The LTL self-healing technology, if applied to the manufacture of multilayer ceramic capacitors, would reduce by up to 50% the size and cost of manufacture of these components. Ceramic capacitors are not expected to be competitive in commercial energy storage applications due to their high material costs and greater material density. Both these factors make the material about 12 times more expensive per cc of volume over LTL's. In order to be competitive against LTL, ceramic capacitors would require energy densities exceeding 3,000 J/cc. Article Link: http://www.anl.gov/Media_Center/Highlights/2010/100607.html

iv. Carbon Aerogel capacitors are a double layer or electrochemical capacitor in operation. The current laboratory record energy density is 325 J/g (90 W·h/kg). Aerogel capacitors are available from Cooper Electronic Technologies (Cooper Bussmann) in energy densities <36J/cc. The problem of this technology is the high cost of materials and a very lengthy manufacturing cycle.
Article Link: http://www.aip.org/tip/INPHFA/vol-10/iss-5/p26.pdf)

v. Faradox Energy Storage Inc. uses a sputtered material on a continuous substrate that contains the capacitor electrode structures. Their highest energy density was achieved using silicon dioxide dielectric films with a material density of 2.6g/cc and energy density of 5J/cc. Their rate of capacitor manufacture is slow and volume production could be capital intensive. This technology is expected to find applications only where its unique properties give it a competitive advantage. The web link is www.faradox.com

vi. GE refers to General Electric. They have a patent for a ceramic polymer capacitor technology US7542265. The maximum energy claimed in the patent was 80J/cc with a practical energy density target of 50J/cc. The capacitor uses a cyanoresin as the dielectric material and is similar to the research done in this field by a number of universities. Cyanoresins have been experimented with for use in the manufacture of capacitors for many years prior to the filing of GE's patent. The LTL manufacturing technology is expected to reliably make self-healing capacitors with two to ten times the energy density that the GE patent is capable of achieving. The GE manufacturing process is very similar to that covered in a pending LTL patent application that predates GE's. LTL views the GE technology as having been made obsolete by LTL's current technology.

vii. Glass refers to a capacitor with a thin glass layer as the dielectric. A number of university labs around the world have been researching glass capacitors. For example, Penn State has achieved 37 J/cc, and, with time, expects to reach far greater energy levels. Glass capacitors, when manufacturing issues are resolved, should be well suited to high temperature operation. Their costs of manufacture are not well known at this time, with existing glass capacitors used only in specialty high stability applications. A link to there most recent work can be found at
http://www.mri.psu.edu/articles/09s/lightning/index.asp

viii. PVDF+ Refers to a film capacitor made using a fluorocarbon based polymer. Mr. Stephen Ducharme at the University of Nebraska was able to demonstrate, under a unique situation, an energy density of 400J/cc in a film a few nanometers thick. The technology used is not commercially viable as demonstrated and represents a lab maximum. The much higher material costs and high density material makes energy storage ultracapacitors made using the materials about 10 times more expensive than LTL's. To be competitive against LTL's technology the energy density of PVDF+ would have to be increased to over 3,000J/cc. Its inclusion is only as a representation of the limits achieved thus far in electrostatic capacitors.

ix. EAMEX The values are shown for the double layer capacitor technology, not their hybrid lithium battery double layer capacitor technology. The value in brackets is their target energy density and remains to be proven. The material costs are estimated and are expected to be more expensive than LTL's as it is a lithium ion containing polymer. EAMEX has developed a hybrid battery ultracapacitor with energy density similar to that of a lithium battery, with a 2 hour charge time with its costs remaining unknown. Link: http://www.eamex.co.jp/capa2_e.html

x. This link provides pricing information for large quantity purchases of polymers. http://www.ptonline.com/articles/200903rprice.html . If the link does not work then for a more recent price list I recommend that you try either
http://www.ptonline.com/articles or http://www.ptonline.com .

2.6 Conclusion: Capacitor Figure Of Merit

Table 1 clearly indicates the significant effect that the cost of materials has on the competitiveness of a product. PVDF+ had by far the highest energy density of any dielectric material, but is not competitive because the material is far more expensive than that selected for use in the LTL ultracapacitor. A second problem with the PVDF+ material is that the energy density represented the maximum that could be achieved by a very small laboratory sample and is in no way representative of results that would be expected in commercial production.

The next competing technology is the carbon aerogel ultracapacitor. The carbon aerogel ultracapacitor needs considerable improvement in materials cost and a much simpler manufacturing process before it can be a serious competitor to LTL. Secondly the energy density of the carbon aerogel reported in Table 1 is the highest achieved under ideal lab conditions. However, current commercial devices achieve only about 37J/cc or about 1/10th the energy density reported in Table 1.

2.7 Dominance Over Competing Technologies

The LTL 3-D roll to roll fabrication process is unique to the ultracapacitor industry and represents the lowest cost method to fully utilize the energy storage properties of most dielectrics. TABLE 1 clearly demonstrates that final product cost is directly related to the amount of material that is required to store a unit of energy. LTL expects to maintain its market lead through its hard work and careful attention to product manufacturing costs. LTL believes that "*the dominant energy storage technology will be the one that is the lowest cost that meets customers' requirements*."

3.0 Energy Storage Comparison to Batteries

The following table is a comparison of various battery technologies to LTL's.

Table 2. Comparison of battery technologies to LTL's

Type	Voltage[a]	Energy density[b]			Power[c]	Effi.[d]	E/$[e]	Disch.[f]	Cycles[g]	Life[h]
	(V)	(MJ/kg)	(Wh/kg)	(Wh/L)	(W/kg)	(%)	(Wh/$)	(%/month)	(#)	(years)
1-LTL	10-500,000	0.3	83	83	>50,000	>95%	8-15	1% - 10%	>500,000	>50
Double CAP	2.0-3.5		10-60		6,000	95%	0.5		>500,000	>10
Lead-acid	2.1	0.11-0.14	30-40	60-75	180	70%-92%	5-8	3% - 4%	500-800	5-8 (car battery), 20 (stationary)
NiMH	1.2	0.11-0.29	30-80	140-300	250-1000	66%	2.75	20%	<1000	
Ni-zinc	1.7	0.22	100	280	900		2-3.3		<1000	
Li ion	3.6	0.58	250-340	250-360	1800	80-90%	2.8-5	5% - 10%	<1200	2-3
Li polymer	3.7	0.47-0.72	130-200	300	3000+	90?%	2.8-5.0		500~5000	2-3
LiFePO$_4$	3.25		80-120	220	>1400		2.0-1.0		2000+	10
Li sulfur	2.0	0.94-1.44	400	350						
Nano Titanate	2.3		120		4000+	87-95%[r]	0.5-1.0		9000+	20+
Thin film Li	?			350	959	?	?[p]		40000	
ZnBr			75-85							
V redox	1.15-1.55		25-35			80%		20%	14,000	10(stationary)
NaS	2.0		150			89%-92%	3.3-4.0		4,500	

Revised: 26 September 2010

Notes:

1. The Battery Efficiency was modified from the original Wikipedia website to correct errors on Lithium Battery Technology. The Efficiency substitutes came from the individual Wikipedia battery pages. See http://en.wikipedia.org/wiki/Rechargable

2. For brevity, entries in the table had to be abbreviated. For a full description, please refer to the individual article about each type.

[a] Nominal cell voltage in V.
[b] Energy density = energy/weight or energy/size, given in three different units
[c] Specific power = power/weight in W/kg
[d] Charge/discharge efficiency in %
[e] Consumer price/Energy in US$/Wh (approximately)
[j] Safe Depth of Discharge to maintain lifecycles
[f] Self-discharge rate in %/month
[g] Cycle durability in number of cycles
[h] Time durability in years
[i] VRLA or recombinant includes gel batteries and absorbed glass mats
[p] Pilot production
[r] Depending upon charge rate

In Table 2, the second line represents the double layer ultra-capacitor technology current and projected capabilities. It is shown to demonstrate that other capacitor technologies can achieve battery level energy density. The primary advantage of the LTL ultracapacitor technology is that its cost is significantly less than most electrical storage energy technologies, see the ***E/$*** column for comparison. In addition the LTL technology can be designed for any working voltage rather than stacking 100s of batteries in series as currently done in automobiles.

3.1 Links To Battery Technologies

LTL	www.1-LTL.com
Double CAP	http://en.wikipedia.org/wiki/Electric_double-layer_capacitor
Lead-acid	http://en.wikipedia.org/wiki/Lead-acid_battery
NiMH	http://en.wikipedia.org/wiki/Nickel_metal_hydride_battery
Ni-zinc	http://en.wikipedia.org/wiki/Nickel-zinc_battery
Li ion	http://en.wikipedia.org/wiki/Lithium_ion_battery
Li polymer	http://en.wikipedia.org/wiki/Lithium_ion_polymer_battery
LiFePO$_4$	http://en.wikipedia.org/wiki/Lithium_iron_phosphate_battery
Li sulfur	http://en.wikipedia.org/wiki/Lithium_sulfur_battery
Nano Titanate	http://en.wikipedia.org/wiki/Lithium-titanate_battery
Thin film Li	http://en.wikipedia.org/wiki/Thin_film_rechargeable_lithium_battery
ZnBr	http://en.wikipedia.org/wiki/Zinc_bromide_battery
V redox	http://en.wikipedia.org/wiki/Vanadium_redox_battery
NaS	http://en.wikipedia.org/wiki/Sodium-sulfur_battery

3.2 Other Competing Technologies

The Paper Battery Co. manufactures an electrochemical capacitor in large sheets using a roll-to-roll printing process. The products energy density is about 1/4th of LTL's and about 10 times more expensive to manufacture: website www.paperbatteryco.com.

3.3 Comparison of Competing Energy Storage Technology To LTL's

FIGURE 1 represents a cost comparison of the more commonly used energy storage technologies. The relative Value scale is logarithmic and represents a 10,000 to 1 range of relative comparison.

The first section of comparison is the relative cost $ per kWh of energy storage. The most expensive technology to use for storing electrical energy is the conventional double-layer ultracapacitor. The LTL storage technology is the lowest cost just slightly less than lead acid batteries.

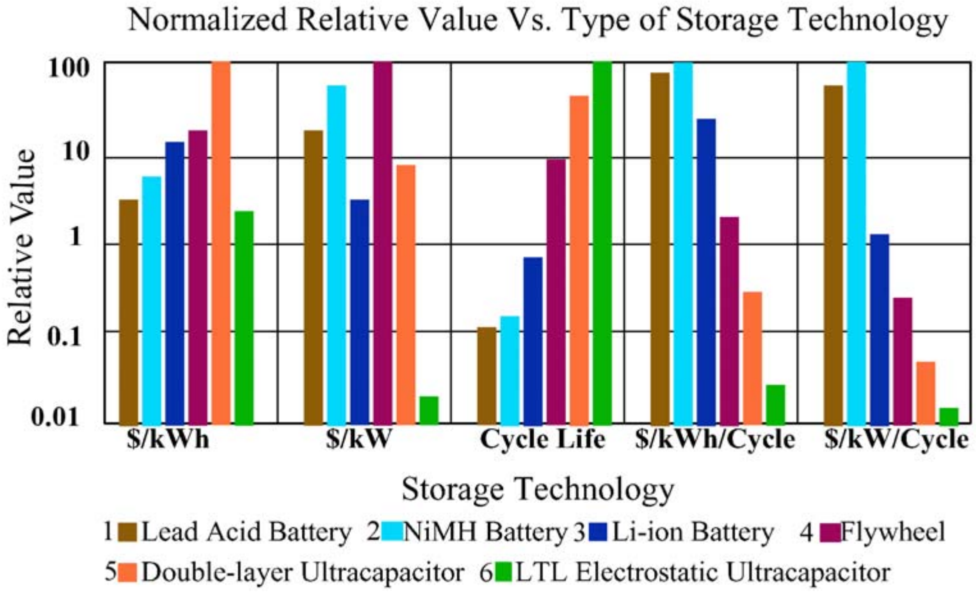


FIGURE 1. Normalized Relative Value

The second section compares the relative cost per kW of power, or, in other words, how fast the storage technology is able to deliver the storage energy to the load. The LTL technology <u>is more than two orders of magnitude better than every other technology</u> with regard to cost per kW. Electrostatic capacitors are the technology of choice when very high peak power is required. The LTL technology greatly increases the amount of stored energy while preserving the high peak power capability of the classic electrostatic capacitor.

The third section, Cycle Life, represents how many times a storage technology can be charged and discharged before it needs to be replaced. The LTL technology has the highest number of charge/discharge cycles. The LTL technology does not involve the physical movement of ions to store energy. The specification for the lifetime number of charge/discharge cycles is expected to exceed 1 million cycles for nearly all applications of the LTL technology.

The fourth section, cost $ per kWh Per Cycle is representative of the relative operating cost when the charging and discharging of a storage device is taking place frequently in an application. This would represent applications such as grid storage where electric power is stored from a solar cell array, windmill, or electric vehicle.

The fifth section is very similar to the previous one except that it is the relative cost $ per kW of Peak Power required during each charge discharge cycle. The LTL technology is shown exaggerated in the graph and in fact would be expected to be less than 0.01 or 1/10,000 the cost of a NiMH battery.

3.4 Other Advantages Of The LTL Technology

TABLE 3 has been created as a side-by-side comparison of the advantages and disadvantages of the LTL technology when compared to double layer or electrochemical ultracapacitors and batteries.

TABLE 3. Advantages of LTL Technology

Description	LTL	Double Cap	Batteries
Cost per kWh	Lowest	Highest	Higher
Time to recharge	0.2 to 5 min.	0.05 to 2 min.	> 8 min. to 2 hours
Easily recycled	Yes	Medium	No
Contains Toxic Materials	No	Occasionally	Yes
Global Limited supply of materials	No	Medium	Yes (Lithium)
Number of series cells for 600Vdc	1	182	182
Special protection circuit required for each cell	No	Yes	Yes
Risk of cascade failure for series cell circuits	No	Yes	Yes
Weakest cell limits energy pack performance	No	Yes	Yes
Maximum operating temperature Celsius	85-105	70	60
Lowest operating temperature (without heating)	-20 (expect -30)	-20	-5
Cycle life	1 Million	>0.5 Million	<10,000
Loses charge capacity over time (wear out)	No	Very Slow	Yes

4.0 LTL's Ultracapacitor Technology

The LTL manufacturing process, in its simplest form, constructs three dimensional multi-layered structures on a continuous substrate using a roll-to-roll process. The resulting structures can be composed of many layers of different materials deposited by one or more methods. The preferred processes are industrial ink jet in combination with LTL's roll to roll transfer printing.

The LTL ultracapacitor structure is composed of different materials built up on top of each other in a predetermined pattern all done under computer control. In many ways it is like a printed document that has 50 different layers of ink on it rather than 4. FIGURE 2 represents a cross section of a LTL ultracapacitor that is manufactured using the fabrication technology.

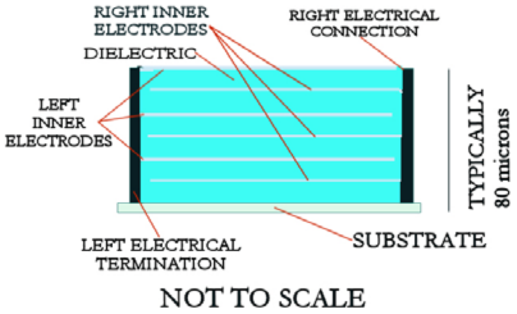


FIGURE 2. Cross section of LTL Ultracapacitor

The structure is made using 4 different materials. The first is the substrate upon which the structure is built. The substrate provides the mechanical strength for the structure. Next are the dielectric layers where the energy is stored and interweaved by right and left inner electrodes through which the electrical energy is conducted into and out of the ultracapacitor. Last there are the left and right electrical connections through which the ultracapacitor is connected to an external electrical circuit. The dielectric material is made of polymers typically in layers 0.2 to 10 microns thick. The inner electrodes are often an aluminum alloy a few nanometers thick, with their thickness shown greatly exaggerated in FIGURE 2. The substrate is a polymer film or Kraft paper less than 10 microns thick. Finally the external electrical connections are a material that is electrically conductive which may be a conductive polymer or a polymer filled with metal powder. The finished structure is typically 80 to 300 microns thick before it proceeds to the next manufacturing stage.

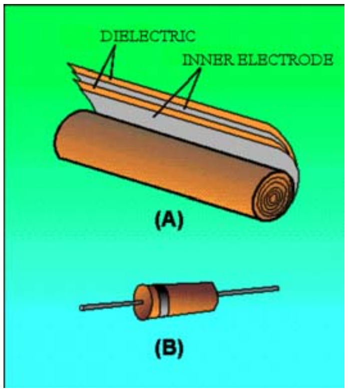


FIGURE 3. LTL Axial Ultracapacitor

FIGURE 3 represents a view of the LTL ultracapacitor showing the main layers during the process of being wound into an axial capacitor.

4.1 Self-healing Ceramic Capacitors

Ceramic capacitors are used in large quantities in electronic equipment because of their low cost and small size. However, ceramic capacitors have a serious problem. When a ceramic capacitor fails it appears to an external circuit as an electrical short. The shorted component then overloads the power supply in the electronics. The electronics then fails to function properly resulting in a warranty return and a dissatisfied customer.

The LTL 3-D roll-to-roll manufacturing technology is the first that is capable of fabricating a self-healing multilayer ceramic capacitor. The self-healing process used in ceramic capacitor is similar to that used by metalized film capacitors. A single layer of metal a few nanometers thick is transfer printed on top of a green ceramic layer instead of screen printing a metal paste. During an electric short circuit, caused by a small dielectric failure, the very thin electrode layer oxidizes or reacts with the ceramic turning it into an electrical insulator. The portion of the dielectric that has failed is then disconnected from the rest of the capacitor before it is permanently damaged. It acts like a fuse in an appliance disconnecting it from the input power if it should fail before it starts a fire.

The incorporation of self-healing capability into multilayer ceramic capacitors will double their operating voltage, decreasing product size and greatly improving product reliability. The removal of the risk of an electronic product failing because of a shorted ceramic capacitor and the manufacturing cost savings is expected to make the technology quickly adopted by the industry.

4.2 Manufacturing Machine Example

A simplified representation of an LTL manufacturing machine is shown in FIGURE 4. The machine image is a composite assembled from several different industrial ink jet machine elements. The machine in its basic form transfers the substrate from the SUBSTRATE ROLL under a number of industrial ink jet heads which deposit the various materials onto the SUBSTRATE. Some of the heads deposit dielectric structures and other heads deposit the electrical terminations. After the material is deposited, the structure is wound onto an OUTPUT ROLL. The structure is wound onto this roll until a predetermined size is reached at which point the roll is changed and a new one started. This picture is a composite representation of an older version of the LTL technology (not a real photograph), and it does not include a transfer printing section.

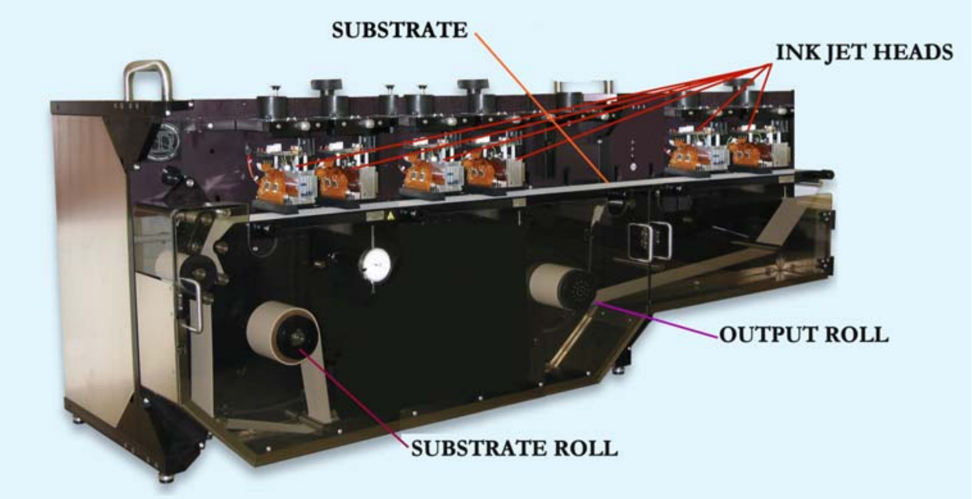


FIGURE 4. LTL Manufacturing Machine

FIGURE 5 shows a representation of the types of axial capacitors that can be made using a machine such as the one represented in FIGURE 4. The ultracapacitors are put into different cases depending upon the environment of their end application.

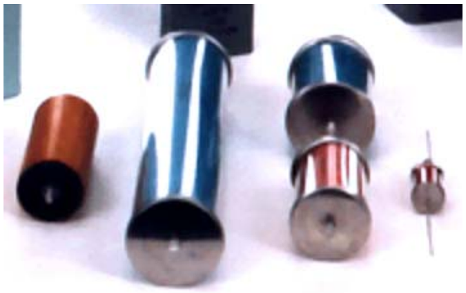


FIGURE 5. Typical Axial Capacitors

Larger versions of the manufacturing machine are represented by the block diagram in FIGURE 6. In this figure, labels are absent, however, the sections of the machine are easily identified. At the top left a substrate roll is fed into the machine, which then passes though a number of repeated identical sections represented by the series of boxes. Each box represents a machine segment that builds a complete layer of the ultracapacitor. After a predetermined number of layers of the structure have been constructed, it passes to the output section where it is wound into rolls as in FIGURE 5 or it is cut into sheets and stacked. The largest manufacturing machines are 100 feet long, operate 24 hours a day, with a capacity to build 1.1 tons of ultracapacitors each day. A single machine will manufacture sufficient ultracapacitors to build about 1,000 electric cars per year representing annual revenue of $5 to $10 million.

The lower part of FIGURE 6 represents the contents of each box of the machine. In each box there are a number of industrial ink jet heads printing dielectric and output electrodes. The inner electrode layers are placed using the LTL transfer printing process represented by the 3 rollers in the right potion of the lower part of FIGURE 6.

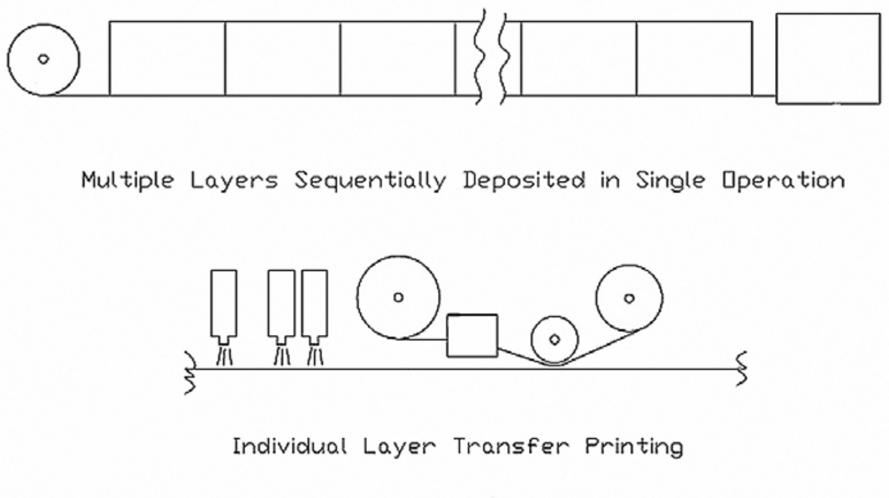
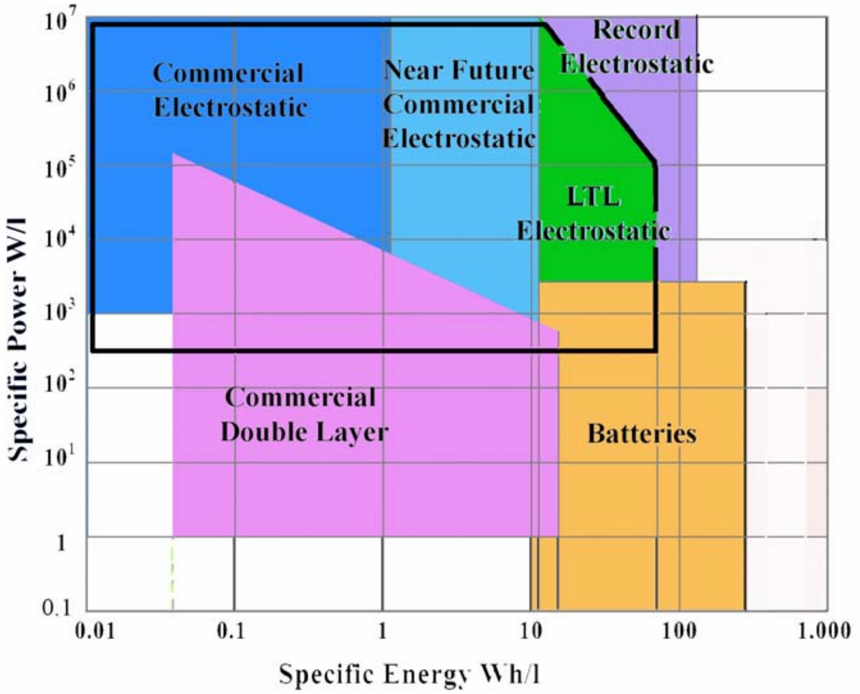


FIGURE 6. Block Diagram of LTL Machine

4.3 Process Capability

FIGURE 7 represents the electrical energy density of various different types of capacitor and battery technologies. The numbers have been taken from many different published sources, and the data used for electrostatic capacitors is current as of September 2010. What FIGURE 7 displays is that commercially available electrostatic capacitors are now available with energy density well into the area that once was the exclusively domain of Double-Layer or electrochemical ultracapacitors. These ultracapacitors have energy densities of 15 Wh/liter. The Near Future Electrostatic (light blue) represents technology that is under commercial development at a number of Universities.

The LTL Electrostatic region (green) is the energy density that is expected by applying the electrical enhancement process developed by LTL to increase both the working voltage and dielectric constant of a number of different - some which are proprietary - ceramic-polymer and polymer-polymer dielectric materials. The area defined by the Black Outline is the process capability of the LTL manufacturing process and the respective energy density of ultracapacitors that can be made. The operating characteristics of LTL ultracapacitors are determined primarily by the properties of the dielectric material used in the manufacturing process. It is relatively easy to customize a capacitor's electrical and mechanical properties to meet customers' requirements.



Notes: These technologies are yet to be proven with a working lab sample.

☐ --- Represents the energy density range of the LTL manufacturing process.
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FIGURE 7. Specific Energies of Storage Technologies

The light purple represents the record set for the energy density of an electrostatic capacitor, which was 400J/cc. The light purple-pink (mauve) area represents the energy density of commercially available and soon to be released double-layer ultracapacitors. The orange represents the capabilities of the more common battery families.

The type of dielectric used during the manufacture of an LTL ultracapacitor determines its self-discharge, peak power, energy density, operating temperature, and cost. There is no other manufacturing technology that is as easy to customize to meet customers' special needs. The polymers used in LTL's ultracapacitors construction have a density of typically 1 Kg/liter and cost from $5 to $10 per Kg.

In summary, electrostatic ultracapacitors represent a proven method that can be used to store electrical energy with very high working energy densities. Many of the above energy densities are not an invention of LTL but the result of progressive and tireless development by a large number of researchers. LTL's technological leap was the development of a proprietary fabrication process that quickly commercializes the research done on the alternative dielectric materials. In addition, LTL has developed a proprietary electrical enhancement process that increases both the dielectric constant and operating voltage of a number of these materials.

4.4 LTL's Energy Density Enhancement Process

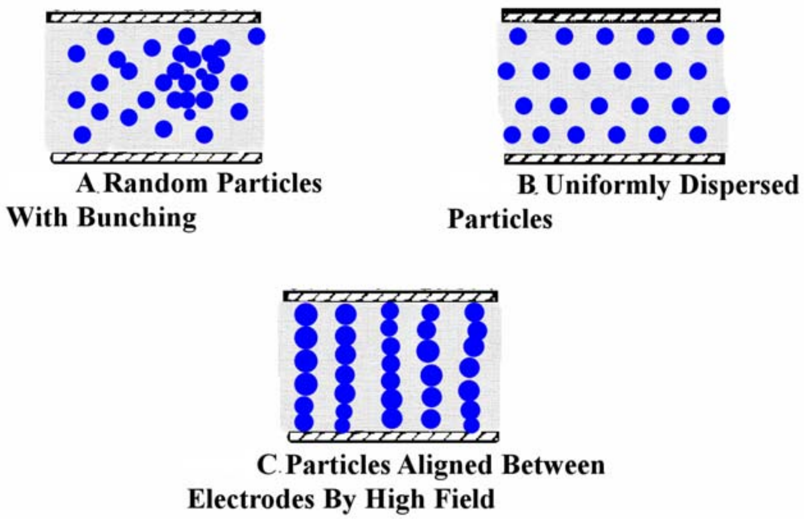
Capacitors made with ceramic-polymer or polymer-polymer blends as dielectric often use dispersing agents combined with the materials to make them uniformly spread throughout the bulk polymer matrix. Experiments using dispersing agents have demonstrated some increase to both the breakdown voltage and dielectric constant, but they remain far less than desired.

At LTL, it was recognized that the ceramic-polymer and polymer-polymer mixtures, before curing, were electrorheological fluids. It was discovered that, by exploiting the unique properties of the fluid, it was possible to greatly increase both the dielectric constant and working voltage of the resulting capacitors. Research resulted in the development of a proprietary manufacturing process that increased the energy density of some ceramic-polymer or polymer-polymer dielectrics by over 10 times.

LTL is the first company to exploit the behavior properties of electrorheological fluids in its ultracapacitor fabrication process. The new process applies a voltage between the electrodes of the ultracapacitor prior to curing the polymer. Applying a voltage across a ceramic-polymer or polymer-polymer mixture makes the high dielectric portion of the mixture pull together into pillars of alternating high and low dielectric constant material between the electrodes. The problem of uniform dielectric dispersion is resolved because the materials of high dielectric constant are connected together in chains between the electrodes. The result was dielectric constants up to 13 times normally expected and working voltages up to 4 times higher than achieved by prior methods.

FIGURE 8 represents three different methods that can be used to mix two differing materials. In these examples one is a solid (blue spheres) the other a liquid polymer. There are many technical papers about the behavior of mixtures of differing materials with the following brief explanation purposely simplified. The explanation should not be interpreted that research into the problem is in any way a trivial matter.

The blue spheres in FIGURE 8 represent a material with a much higher dielectric constant (solid) than the bulk polymer (liquid), light gray. High voltage research has proven that mixing materials with different electrical properties often result in poor electrical insulators. The mixture should have a homogeneous dielectric constant throughout, even if made from differing materials, such as a polymer and ceramic powder. When an insulator has regions of higher and lower dielectric constant, the areas with the lowest dielectric constant will have the greatest electric field stress. The high electric fields are where corona discharge will initiate chemical reactions that slowly breakdown the insulator, eventually resulting in failure.


A Random Particles With Bunching

B Uniformly Dispersed Particles

C Particles Aligned Between Electrodes By High Field

FIGURE 8. Electric Fielded Assembled Nano-structured Dielectric

<u>FIGURE 8 (A)</u> shows a dispersion of blue spheres, 5 to 50% by volume of high dielectric material, randomly mixed with a few agglomerates of particles. A material constructed in this manner would have breakdown voltage only a fraction of the polymer that surrounds the spheres. The operating voltage of mixtures represented by FIGURE 8 (A) may be as low as 1/6th that of the unfilled polymer. The reduction in the working voltage of the mixture often negates the increase in energy density that occurs by adding a high dielectric material. Experimental research concluded that this method is not likely to provide a dielectric with a high energy density.

<u>FIGURE 8 (B)</u> shows a dispersion of blue spheres, 5 to 50% by volume of high dielectric material. This method represents the principal approach that researchers in capacitor dielectrics are experimenting with. The blue spheres in this example are uniformly distributed throughout the polymer. When voltage is applied to FIGURE 8 (B) the area of the polymer near the higher dielectric constant spheres is subjected higher electric fields than the bulk material. Recent research has found that as the size of the particle becomes smaller the breakdown of the mixture improved. However, there are few dielectric materials that have a very high dielectric constant when they are fabricated with diameters less than 50nm. The method does improve to a degree the breakdown voltage of the mixture of differing materials.

FIGURE 8 (C) is a representation of how a dielectric made using the LTL method looks after the polymer is cured. The blue spheres, 5 to 50% by volume of high dielectric material, are aligned between the electrodes in strings of interconnecting spheres. Furthermore, the ceramic spheres will rotate such that the face with the highest dielectric constant will be directed towards the electrodes and the neighboring sphere in the string. It is not only the ceramic particles that move because the polymer molecules also rotate until they have the highest possible dielectric constant. This process alters the dielectric at a nanoscale and molecular level. This process is analogous to crossing a river not by a random set of stepping-stones, but by building a well-constructed bridge.

An "*Electric Fielded Assembled Nano-structured Dielectric"* is what LTL is using in its high energy density capacitors. There is extensive literature and research available on the Internet on the subject of Electrorheological Fluids and the Winslow Effect. The dielectric constant of a dielectric manufactured using the LTL method represented by FIGURE 8 (C) was found to have up to 13 times the value of a similar mixture made following the method of FIGURE 8 (B). The voltage breakdown was not reduced but was representative of the polymer and ceramic used. Further details about the process used by LTL remain a closely guarded trade secret. In early 2008, a Canadian university independently verified that such a process results in an increase in the dielectric constant. A confidentiality agreement prevents us from disclosing details of their work.

The LTL technology will achieve its goal of 300 J/cc because it uses the above manufacturing step that, until now, had *never* been applied to the fabrication of ceramic-polymer or polymer-polymer based capacitors. The process step has been observed to increase the dielectric constant by up to 13 times and to increase the working voltage of the capacitors. The goal will be to make the new ultracapacitor capacitors from newly developed and inexpensive high dielectric constant polymer-polymer blends.

5.0 Applications for LTL's Electrostatic Ultracapacitor Technology

The LTL technology has application in all areas where batteries are used today, including grid storage, electric vehicles, consumer electronics, and renewable energy.

5.1 Electric Grid Applications

Conventional electrochemical/double layer ultracapacitors have been used for energy storage in electric grids where short bursts of energy have to be provided or absorbed for the purpose of stabilization. Typical storage applications are a few minutes or less. However, their high cost, about 10 times that of lithium batteries per kWh, limits their practical use.

Electrostatic ultracapacitors, such as those developed by LTL, are inexpensive and have the long 20 to 30 year life demanded by electric utilities. The LTL ultracapacitors may be manufactured in any desired working voltage from 25 Vdc through 100s of thousands of volts. The application of these parts is intended as primary energy storage, and they are capable of being connected directly to a DC transmission line. Of course, proper fusing and isolating switch gear and an equalizing supply would be required to facilitate interconnection and disconnection if the transmission line were to exhibit a fault condition such as a short circuit. Alternately, the capacitors could be used in large storage banks at a voltage lower than the AC transmission line and use a conventional bi-directional inverter to tie in.

The LTL ultracapacitors for grid storage would be 50kW-hr, weigh about 0.6 ton, and would be supplied with whatever working voltage is required by the utility. The operating temperature of the devices would be -25C to 85C; discharge and charge time <5 minutes, with a cycle efficiency of 97%. Shelter is preferred to keep dirt and moisture from fouling the terminals, although they could be designed to forgo the need for an enclosure. The peak power capability for a 50kwh part would be >6MW, life would be 15 to 30 years and the number of charge discharge cycles >500,000 (10% to 100%).

5.2 Electric Vehicles

The LTL ultracapacitor can be used to replace lithium batteries in electric or hybrid vehicles. The technology has many advantages over batteries, including higher operating temperature (reduced cooling requirements), nontoxic solid, self-healing (no thermal events), and higher output voltage that reduces the cost of the power electronics. Another important advantage is the ability to fully recharge in 5 minutes or less, making fast recharge stations a reality, far superior to plugging in for hours or swapping entire battery packs. The technology is much less expensive than lithium, enabling faster adoption of electric vehicles. Finally, the ultracapacitors do not wear out, so an electric car will have the same operating range when it is old as it was new.

5.3 Consumer Electronics

LTL's ultracapacitor can be used to replace lithium-ion batteries in most portable electronics applications. The most important feature is its ability to be fully recharged in 5 minutes or less, addressing one of the most common consumer complaints of cell phones today. If one's phone needs charging, just pop it into a fast charger. The technology has lower energy density than lithium-ion batteries, but it will last as long as the equipment, eliminating the need to sell replacement batteries or dispose of the old ones. Unlike lithium-ion batteries, the ultracapacitors can be fully discharged so electronics can be safely shipped without risk of fires. The LTL technology can also be integrated into a product's plastic case, providing additional room for extra energy storage and longer operating time or enabling smaller devices. Recycling is easily achieved by simply grinding the phone to dissolve out the metals and either reuse the plastic or send it back for reprocessing.

5.4 Marine/Ocean Vessels

The LTL technology can be incorporated into ocean vessels to provide primary power. Operating an ocean vessel from electric power is less expensive and produces less pollution.

5.5 Industrial

Many applications can use the energy storage to replace diesel powered generator equipment. Diesel generators require regular maintenance and typically have high emissions.

5.6 Renewable Energy

This application is well suited for the LTL energy storage technology. It is an ideal inexpensive technology to use for storing electrical energy when the wind is blowing or sun is shining for delivery later when the power is needed.