Dedicated to transformative energy storage systems capable of unprecedented high electrical power delivery using cost effective, earth friendly, recyclable materials.

GLOBAL ENERGY SCIENCE (GES)

GES Battery Architecture Presentation
Ultra Low Electrode Resistance for Electrochemical Applications

Prepared by Global Energy Sciences
August 4, 2016

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The purpose of this presentation is to facilitate independent development of licensed GES battery technology:

We propose an independent laboratory undertake at least Step 1 of a 4-step Proof Of Concept (POC) test plan to confirm;
Ultralow resistance electrodes for electrochemical cells.

GES has proven the following with experimental data:

1) Cohesive graphene structures (pellicles) containing nanoscale surfaces are attached, without being penetrated, to metal surfaces with **unprecedented low ohmic resistance** using our electrode architecture concept. Graphene surfaces can be coated with faradaic materials as described in many published articles.

2) We have further discovered that such pellicles can be formed containing lodged and immobilized insoluble sub–micron size particles that will not wash out under permeation velocity of 1 cm/sec if and only if the pellicle is attached as described. Otherwise they do wash out.

Global Energy Science, LLC, is a small business that has spent ~$1.6M over a 6-year period researching, developing and patenting unique electrodes for electrochemical cells having unprecedented ultralow electrical resistance.

GES has created **new ARCHITECTURE** for batteries, fuel cells and supercapacitors, which **can improve energy storage density, deliver unprecedented concentrated power for fast charging and cool operation** not available in today's market to **reduce the:**

- size of power delivery systems
- cost to manufacture compact energy storage and power delivery systems
- heat and hazard connected with delivering electrical power
- vulnerability of the grid to excess load & tampering
- carbon footprint and
- time to recharge a battery

GES' objective is to work with respected research institutions and qualified manufacturers engaged in battery and related electrochemical technology to confirm GES' proffer and technology via proof of concept (POC). We look forward to publication of their findings in peer reviewed scientific journals.

The gold standard for scientific and technical achievement is repeatability.

Present Battery Architecture and Technology <u>Discussion</u>

- The issue we wish to address is electrode resistance. In batteries it essentially comprises ohmic resistance to electrical charge transfer which adds in series with resistance to ion exchange between polar electrodes and intercalation kinetics.

- In capacitors resistance is essentially ohmic.

- Ion and, in particular, cation permeability in ion selective semipermeable membranes will be seen to be irrelevant to our discussion. The reason is addressed.

- We reserve discussion of fuel cells and convection as a separate issue.

- Our proffer is applicable to virtually any electrochemistry. Some examples are addressed but the principles apply generally.

- It is understood by those skilled in the art that lower electrode resistance means higher electrode current density enabling faster charging of the stored energy and less heat generation.

Battery Architecture and Technology
From Daniel to Present Day

John Frederick Daniell, 1790-1845

- Thin electrode sheets are separated by expensive ion selective semipermeable membranes
- Pastes applied to metal in thin layers over large area contain resistive interfacial barriers
- GES' graphene electrode is also a short ion flow path but has no obstructing membrane
- GES' unprecedented low resistance is due to compressed or embedded interfaces
- GES' 3-D high voltage stacks hold energy storing material for energy capacity optimization.

Cell construction NOW

Negative terminal with O-ring seal

Separators

Positive terminal with O-ring seal

Negative electrode

Stainless steel case

Positive electrode
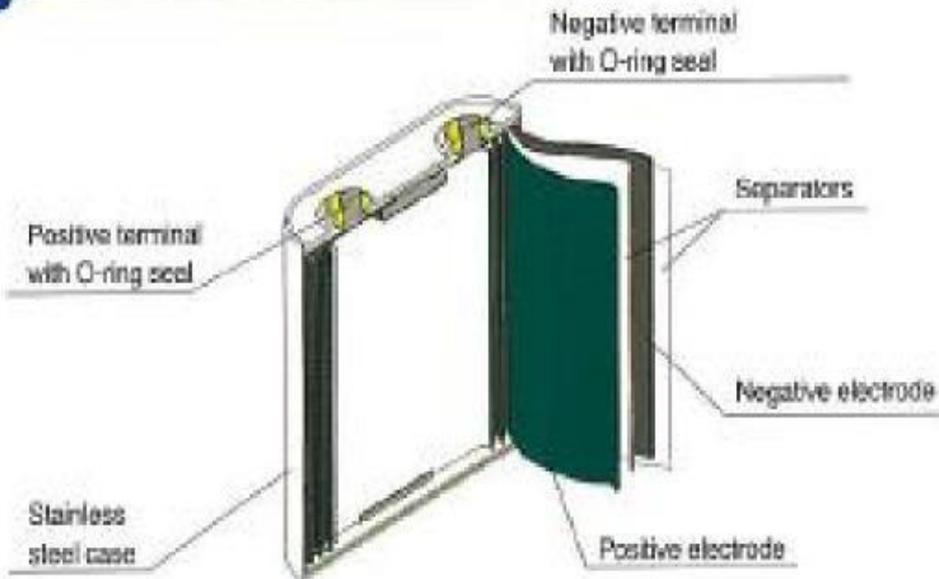
GS Yuasa Lithium Power, Inc. typical folded electrode battery

Positive Terminal

Exhaust Gas Hole

PTC Element

Pressure Release Valve

Gasket

Positive Terminal Lead

Insulation Plate

Separators

Case

Negative Electrode

Negative Terminal Lead

Insulation Plate

Positive Electrode
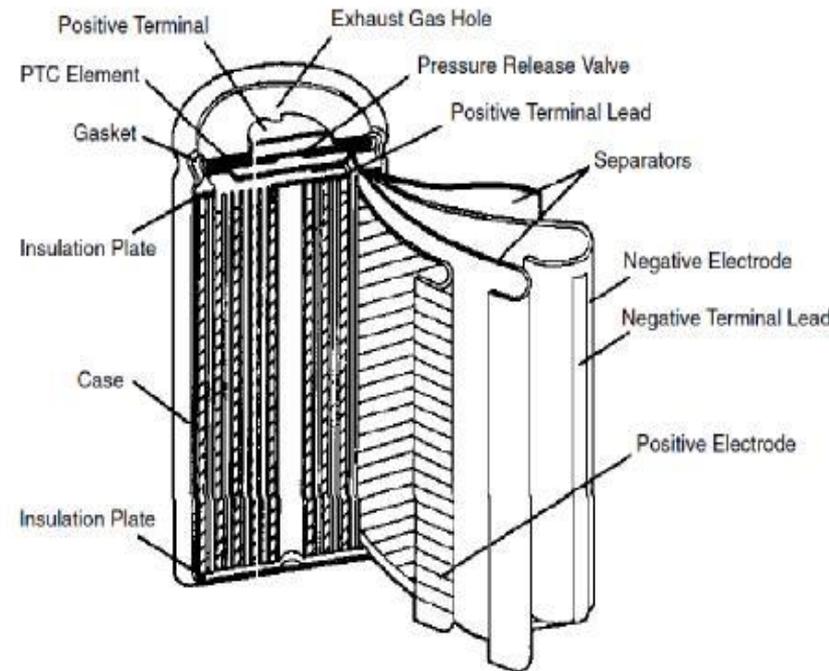
Panasonic NCR18650B typical spiral wound electrode battery

*Li-ion State of The Art "*Chemists are contributing to incremental improvements of the conventional strategy while retaining a Li⁺ conductivity ρLi > 10⁻³ S cm⁻¹,.."*

(It's like trying to improve a mechanical typewriter with better ribbon ink. GES statement.**)**
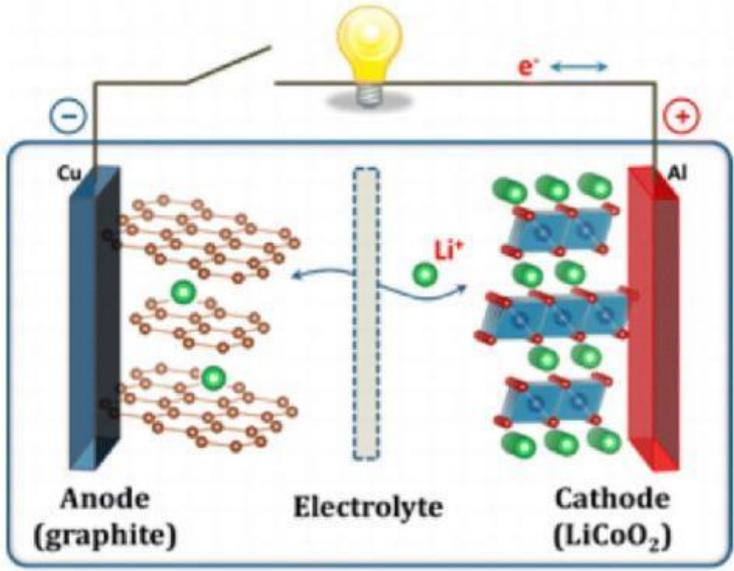
Each cell of a battery stores electrical energy as chemical energy in two electrodes, a reductant (anode) and an oxidant (cathode), separated by an electrolyte that transfers the ionic component of the chemical reaction inside the cell and forces the electronic component outside the battery.

Opened sample of cells tested from top: Panasonic NCR18650A, Panasonic NCR18650B

- Ion selective membranes are expensive cost drivers and add resistance to the exchange of ions
- Typical 100 μm coatings cause cell resistance of 10 ohms for 1 cm^2 of electrode surface area
- High ohmic resistance is inherently embedded within SOA Li-ion battery paste architecture
- It is not widely appreciated that battery electrode resistance is so high or current limiting , e.g. <10 mAmp/cm^2
- Muencel* measured complex impedance for *Commercial 18650-Format* cells – 0.055 ohm D.C.
- Confirming ≈10 ohm-cm^2 for 220 cm^2 electrodes.
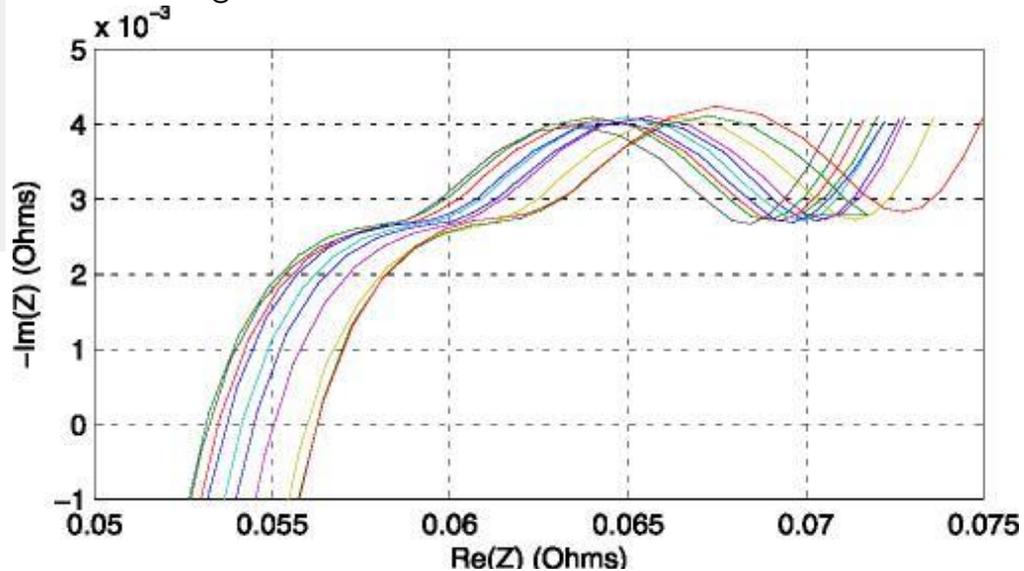
Measurement variations during EIS testing of a Panasonic 3.4 Ah battery - Nyquist plot –Electrochemical Impedance Spectroscopy

*Valentin Muenzel et al, *A Comparative Testing Study of Commercial 18650-Format Lithium-Ion Battery Cells*, Journal. ECS, **162** (8) A1592-A1600 (2015)

*John B. Goodenough and Kyu–Sung Park, *The Li–Ion Rechargeable Battery: A Perspective*, *J. Am. Chem. Soc.*, 2013, *135* (4), pp 1167–1176
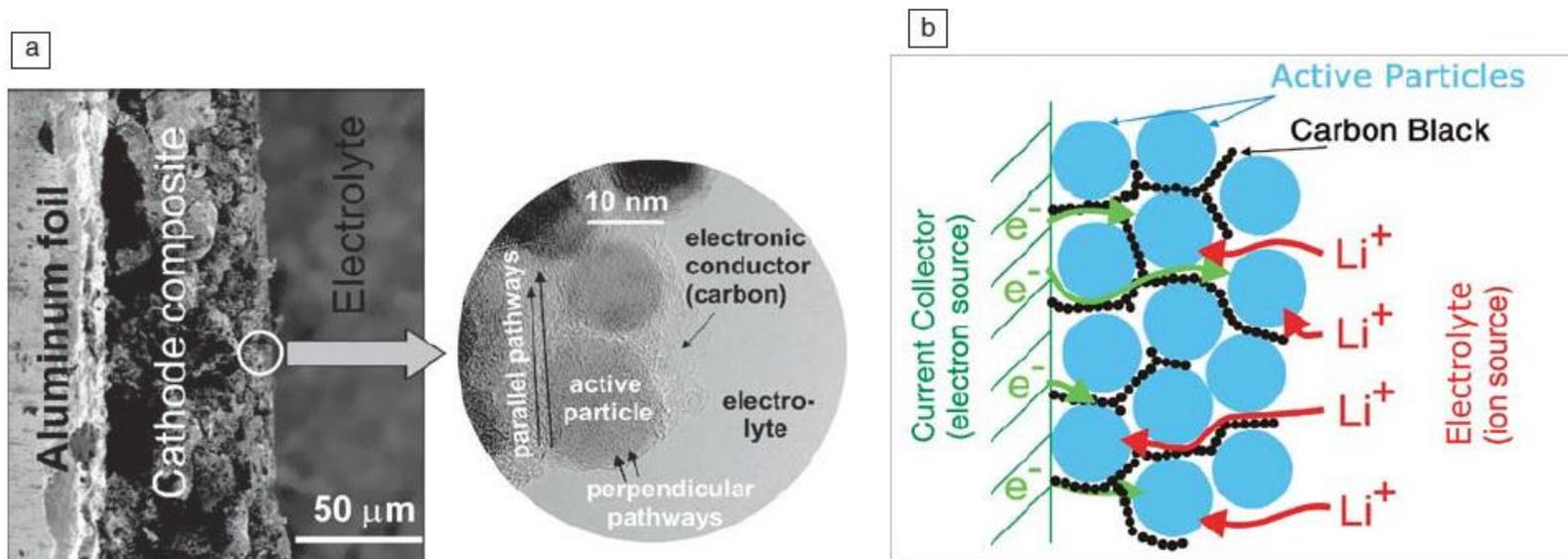
Figure 1. Typical Li ion battery electrode. (a) Low magnification (on left) and high magnification (insert on the right). (b) Schematics showing the main phases constituting a modern insertion cathode and their role in transport. The polymeric binder is not shown (its effect on the transport is thought to be marginal).

*Abstract

"During the past decade, the electrochemical properties (energy density, power capability, and cycling stability) of practical lithium (Li) batteries have been enormously improved. Surprisingly, although the knowledge exists of how to prepare excellent batteries, a detailed understanding of how they actually work is still lacking."

"In particular, the impact of interfaces in electrode composites is poorly understood."

"Most surprisingly, we find that the high-frequency impedance arc is due to the contact impedance between the metal and the electrode material. This is in fundamental contradiction with previous interpretations."

"As shown in the Results and Discussion section, the **present measurements reveal, very surprisingly but consistently, that the origin of the high-frequency impedance arc, the most remarkable electrode impedance feature, is due to the contact impedance between the metallic substrate and the electrode material**. This is in fundamental contradiction with most, if not all, existing interpretations which presume that this arc is due to an interfacial phenomenon between the electrolyte and the active particles (e.g., due to charge-transfer resistance, SEI resistance, etc.)."

"Assuming that there is an **SEI (or similar) layer around the active particles** does not help much. Namely, a similar calculation in which we additionally assume that the relative dielectric constant of SEI film is 5 shows that the film thickness should be about 90–450 nm to give the measured range of capacity due to arc A. Thus, a 100 nm large particle should be surrounded by **an enormously thick film, which certainly has not been observed."**

"The effects shown in Fig. 2, again, **point against the conventional explanation** for arc A. It is unclear how the resistance between a particle and the surrounding electrolyte (or, alternatively, the resistance of SEI covering the active particles) could be affected reversibly and instantaneously by relatively small changes in external pressure on the cell (this pressure represents only a fraction of pressure inside mesopores, etc). Such **effects are much easier to explain** if, for example, we assume that arc A is **due to some contact impedance inside the testing cell."**

"Figure 3, (a) Total resistance (R_{tot}) of dry $LiFePO_4$/C (+carbon black + Teflon) composites as a function of the external load and the type of substrate. (b) Resistance and capacitance due to arc A as functions of the external load."
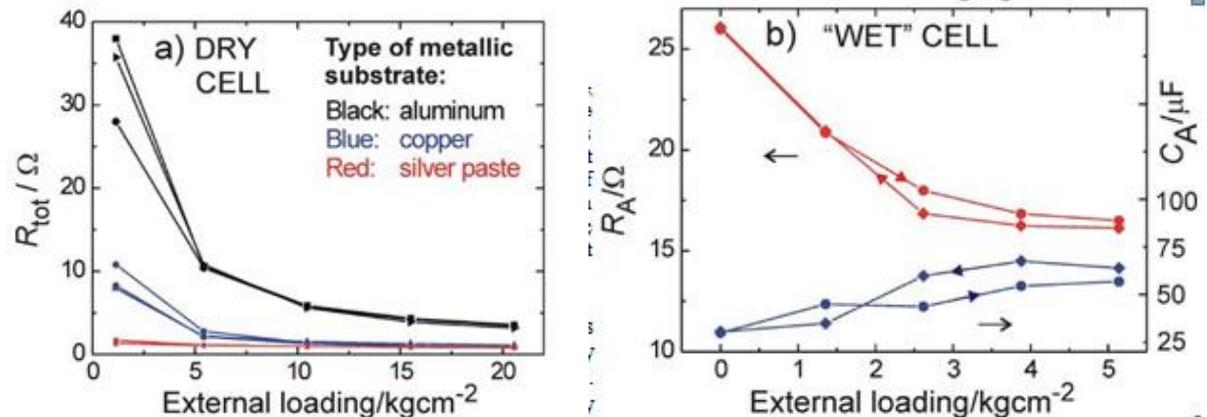
"The present experiments show unambiguously that contacts represent a significant contribution to the overall kinetics in a typical Li battery electrode. In particular, the magnitude of the high-frequency impedance arc that appears in basically all electrode studies represents mainly the contact resistance between the electrode composite material and the metallic substrate …"

Actual Data:

- 0.5C for 2 hours uses 1.625A constant current and ½ Volt above cell potential

- Gross cell impedance is 0.5/1.625 or 0.31 ohm which relates to lost energy

- Charging energy is (1.625A times 3.85V)(110/60) = 11.5Wh to input 3 Ah

- Average 3.3 discharge volts is 10 Wh useful energy so i^2R yields R = 0.31 ohm.

- That is 6 times Muenzel's real axis Nyquist intercept value of 0. 055 ohm.

- Electrode area is ≈220 cm^2 so 0.055 ohm measured impedance is ≈12 ohm-cm^2.

- The fast charging disparity can be largely explained by slow membrane permeation of selective cations.

- Tefel slope dV/di in the Butler-Volmer equation is equivalent to resistance seen as a loss of current for applied overvoltage.

- It relates to completion of ion exchange between electrodes. Electrical current balances and cannot exceed charged ion current in a battery.

- SEI and intercalation resistance is mitigated in GES' advanced strongly coupled faradaic surfaces.

- GES separators are, at most, fluid permeable filters.

- Remaining is ohmic resistance.

- What is needed is an effective way to distinguish these phenomena. That is what is proposed here.

Lithium Ion
Panasonic **NCR18650B**

Features & Benefits
- High energy density
- Long stable power and long run time
- Ideal for notebook PCs, boosters, portable devices, etc.

*At temperatures below 10°C, charge at a 0.25C rate.

Specifications

Rated capacity[1]	Min. 3200mAh
Capacity[2]	Min. 3250mAh Typ. 3350mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1625mA, 4.20V, 4.0 hrs
Weight (max.)	48.5 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density[3]	Volumetric: 676 Wh/l Gravimetric: 243 Wh/kg

[1] At 20°C [2] At 25°C [3] Energy density based on bare cell dimensions

Dimensions
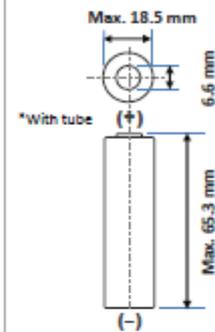
Max. 18.5 mm
6.6 mm
*With tube (+)
Max. 65.3 mm
(−)
For Reference Only

Charge Characteristics

Charge: CC-CV 0.5C (max) 4.20V, 65mA cut-off at 25°C
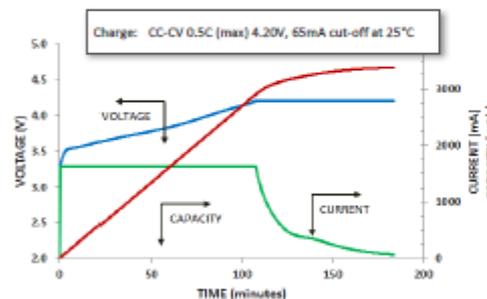
Cycle Life Characteristics

Charge: CC-CV 0.5C (max) 4.20V, 65mA cut-off at 25°C
Discharge: CC 1C, 2.50V cut-off at 25°C
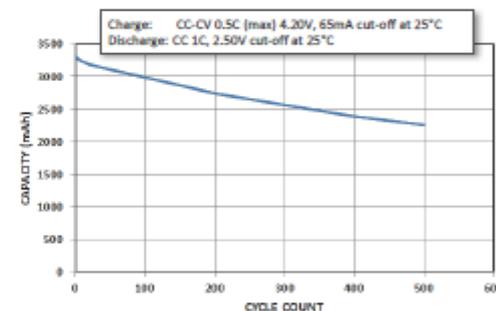
Discharge Characteristics (by temperature)

Charge: CC-CV 0.5C (max) 4.20V, 65mA cut-off at 25°C
Discharge: CC 1C, 2.50V cut-off at each temperature

— -20° C — -10° C — 0° C — 25° C — 40° C
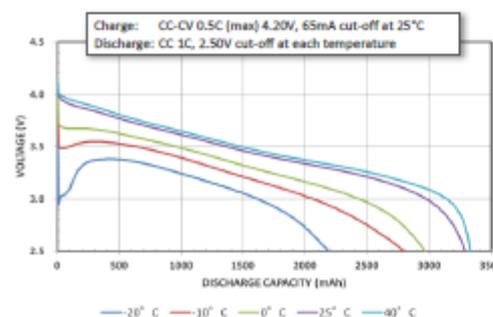
Discharge Characteristics (by rate of discharge)

Charge: CC-CV 0.5C (max) 4.20V, 65mA cut-off at 25°C
Discharge: CC, 2.50V cut-off at 25°C

— 0.2C — 0.5C — 1C — 2C
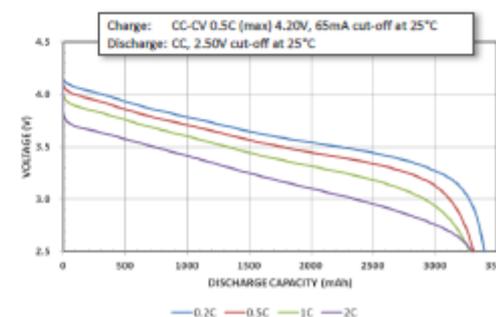
The data in this document is for descriptive purposes only and is not intended to make or imply any guarantee or warranty.

9

GES Battery Architecture and Technology

GES electrochemical architecture depends upon ultralow resistance electrodes as now described.

- We use highly conductive graphene structures to provide a low resistance charge transfer pathway between most redox (i.e. charge producing) chemistries and a metal current collector.

- The key novelty is elimination of interfacial charge transfer resistance.

- It is done with less carbon mass which minimizes displacement of active faradaic material to optimize and improve energy storage density over prior art.

- The same technique may, for the first time, improve intercalation activity (rate) at the ion/electrolyte interface with electrically connected faradaics. (needs proof for particles; proven for CNT coatings).

- GES electrochemical cell architecture and technology is indifferent to known galvanic chemistry.

# Low Resistance Electrode Concept - U.S. Patent 9,337,474 + Pending cases
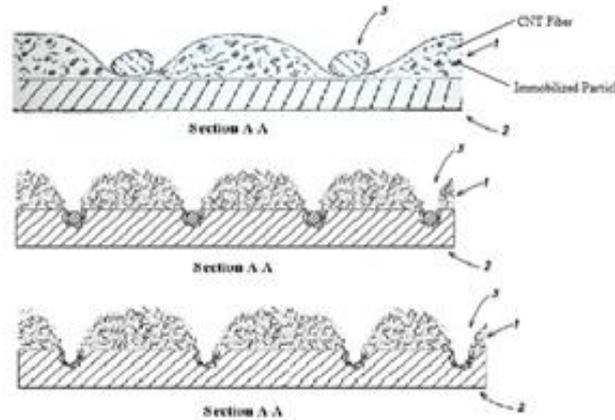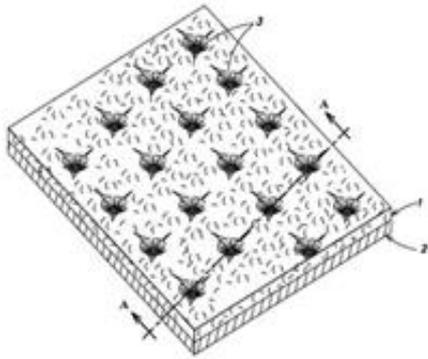
High Compression Low Resistance Attachment of Non-Woven CNT Cohesive Galvanic Pellicle to Metal Current Collector at a Plurality of Closely Spaced Locations.

Maximum compressed area is 10%. No point within an uncompressed area can be further from a nearest compressed area than three times pellicle thickness. Net pellicle resistance is $<10^{-3}$ ohm-cm^2
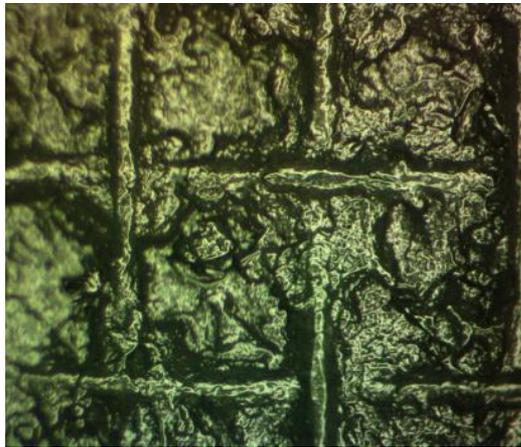
Center to Center Distance 250 μm
Wire screen impression
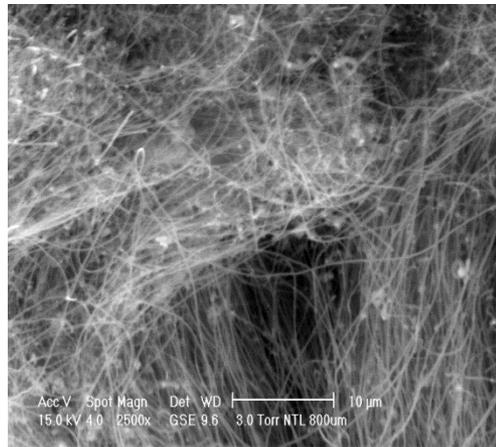
SEM Image of MWCNT Mat
Made by GES

1) **It is based upon a fundamental departure from electrode design and battery architecture.**

2) **We do not lower contact resistance. We bypass it altogether and render it irrelevant.**

3) **We provide an entirely different charge transfer path having unprecedented low resistance to a metal current collector.**

4) **Ion kinetic resistance (ion diffusion mobility) is reduced by compressing interfaces and short path length 3-D architecture.**

5) **Recharge time is greatly reduced by high current density having negligible heat load. 1Amp/cm^2 vs. 10mA/cm^2.**

Bulk CNT ≈$10/kg

- Particles Lodged and Immobilized

Cohesive nonwoven CNT mat made in GES laboratory at LP*. Particles are typical ≈1μm size anode or cathode faradaic. When particles are mixed with CNT they can form a cohesive membrane by coprecipitation, but they can only be securely lodged and immobilized when the pellicle is attached to the metal current collector by means described here.

Acc.V   Spot Magn   Det WD ├──────┤ 1 μm
15.0 kV 3.0   20000x   GSE 7.5   3.5 Torr
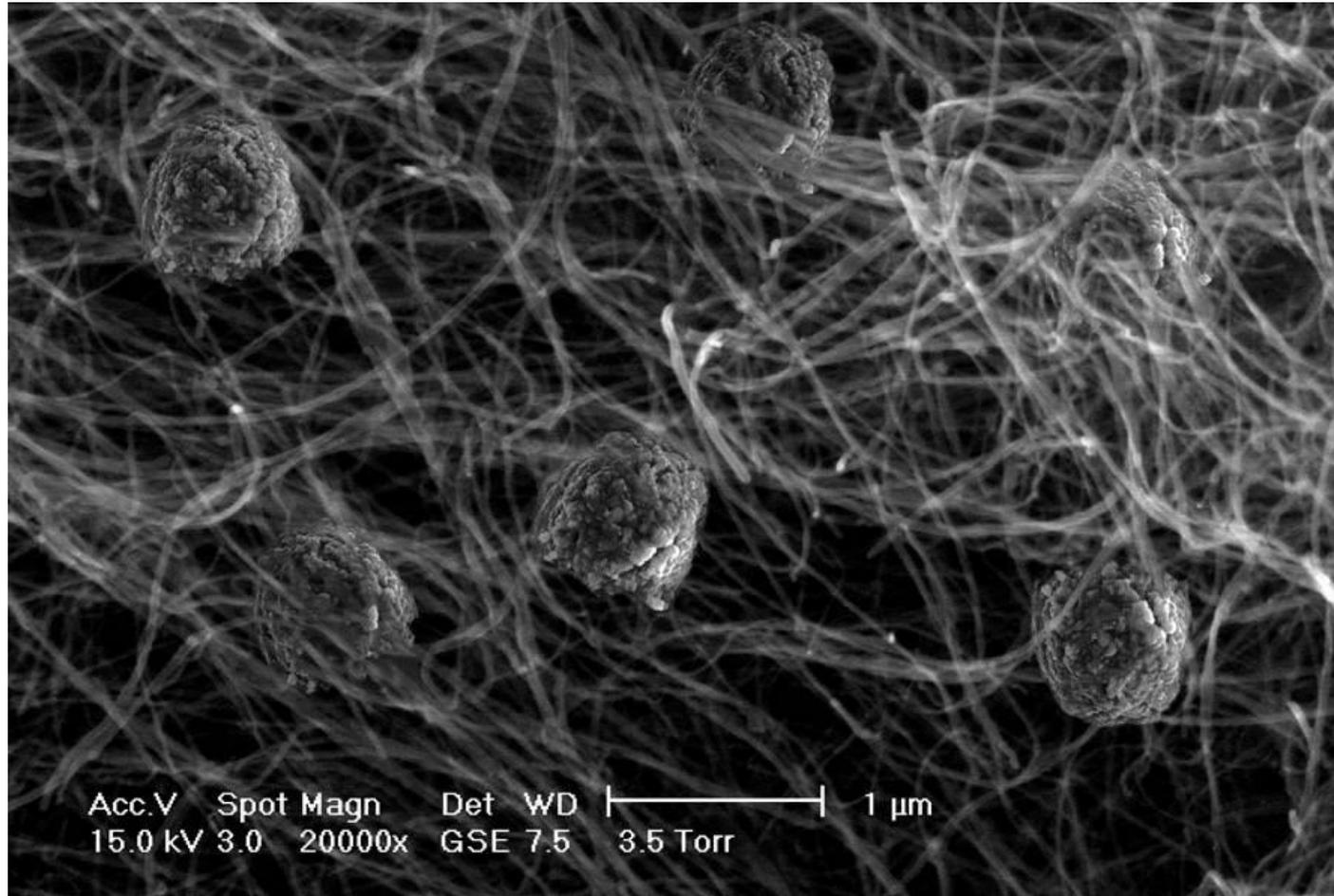
Pellicle Permeability Data

Figure 5
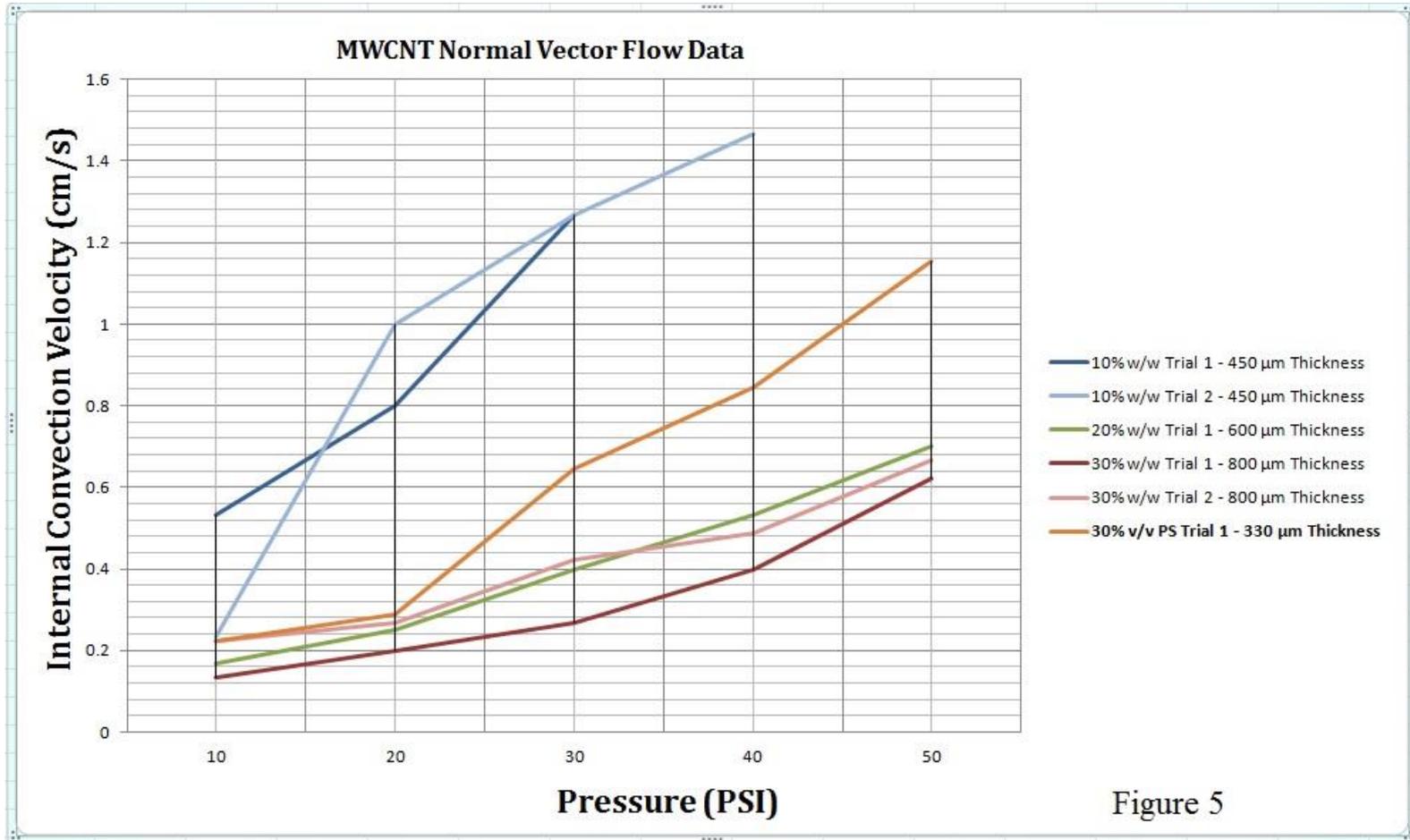
Data at 1 cm/s convection velocity proves GES's particle immobilization discovery.
When the pellicle is attached by closely spaced multipoint compression or embedment as
described in the invention, particles do not wash out under 1 cm/s permeation velocity.
Electrolyte runs clear. Absent such attachment particles wash out.

13

- Carbon powder is normally used to increase electrical conductivity

- Carbon powder (e.g. Ketjen black) in PTFE binder displaces active material

- The density of a CNT Chiral fiber is 1.4 g/cm^3

- The density of a cohesive nonwoven CNT pellicle varies from 0.2 to 0.5 g/cm^3

- Thus, the volume fraction of CNT in electrodes is about 14% to 35%

- Assuming 25% for electrolyte wetting of CNT surfaces, about 40% to 60% of electrode volume remains for active battery material

- Cathode material density is 4.1 g/cm^3 with energy density of *0.658 Wh/g

- Two electrode unit cell coatings 100 μm thick on 100 μm metal sheet plus an electrolyte gap is 0.547 to 0.82 g of spinel or 0.36 to 0.54 Wh/ml ≈ ½ kWh/Liter

- A 300 μm cathode yields ≥ 1 kWh/L.

*Xiaohua Ma, et al, High Rate Micrometer Ordered LiNi$_{0.5}$Mn$_{1.5}$O$_4$, *Journal, Electrochemical Society,* **157** 8 A925-A931 (2010)
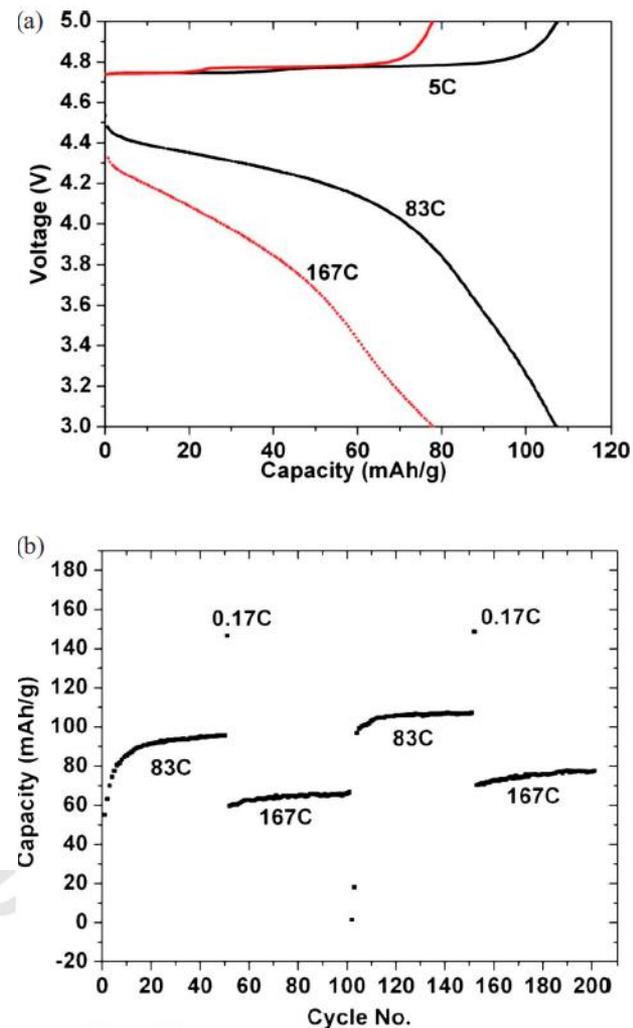
**Figure 9.** Color online a Rate and b cyclability performance of LiNi0.5Mn1.5O4 with 65 wt % carbon. Charge rate is 5C. Voltage window is 3–5 V.

a) **CNT Fabric** — 500 nm

b) **Si-coated CNT Fabric** — 500 nm

a) Current Collector — 1, 2, 3 — Separator Membrane — Current Collector

b) 4, 5 — Active Material — Current Collector — Active Material — Current Collector
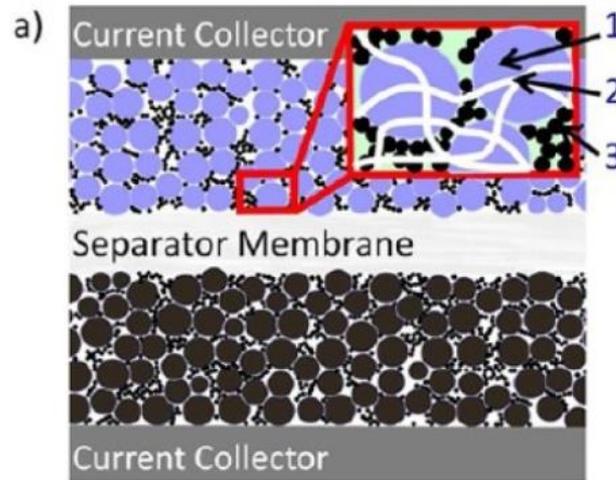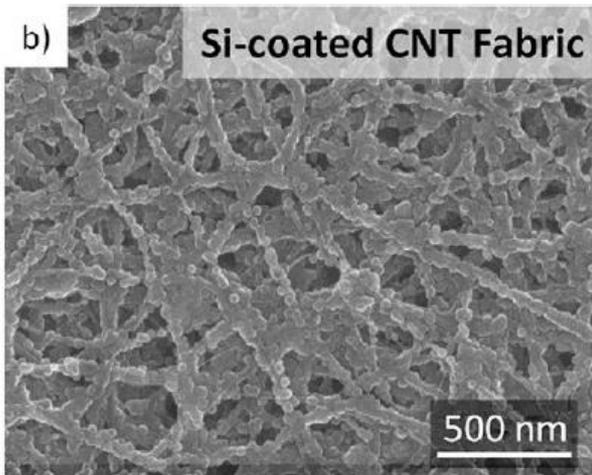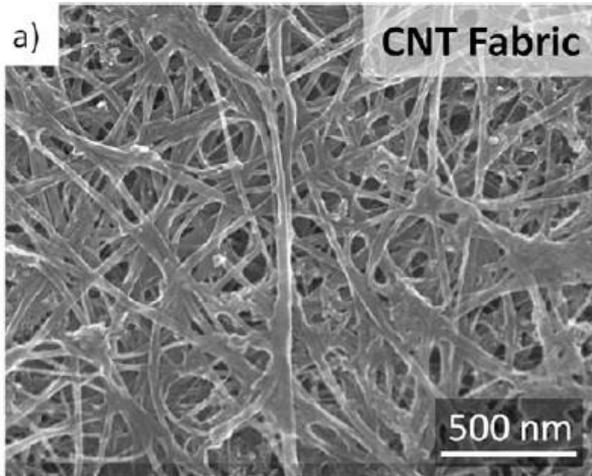
State of the Art Battery Architecture Using Conductive Pastes With Membrane Separation
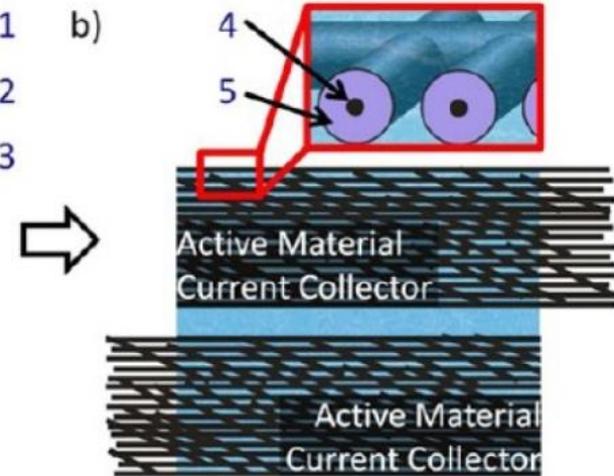
High Resistance Current Collector Attachment With Electrolyte Separation

Si holds more Li metal than carbon alone (6 C/Li minimum atomic ratio). Intercalation of Li in Si is enhanced by GES's stronger interfacial contact.

▸ *Kara Evanoff, et al. "Ultra Strong Silicon-Coated Carbon Nanotube Nonwoven Fabric as a Multifunctional Lithium-Ion Battery Anode." ACS Nano, 2012, 6 (11).

CNT Coating Methodology for Anodes and Cathodes*

Schematic drawing of an ultrafast Ni – Fe battery made from inorganic/carbon hybrid materials. A Ni(OH)$_2$/ MWNT hybrid was used as the cathode and a FeO$_x$ / graphene hybrid was used as the anode.

1 M aqueous KOH solution was used as the electrolyte.

On charging, Ni(OH)$_2$/MWNT and FeO$_x$/ graphene were converted to NiOOH/MWNT and Fe/ graphene, respectively.

On discharging, NiOOH/MWNT and Fe/graphene were converted back to Ni(OH)$_2$/MWNT and FeO$_x$/graphene, respectively.

Anode: FeO$_x$/graphene — Cathode: Ni(OH)$_2$/MWNT
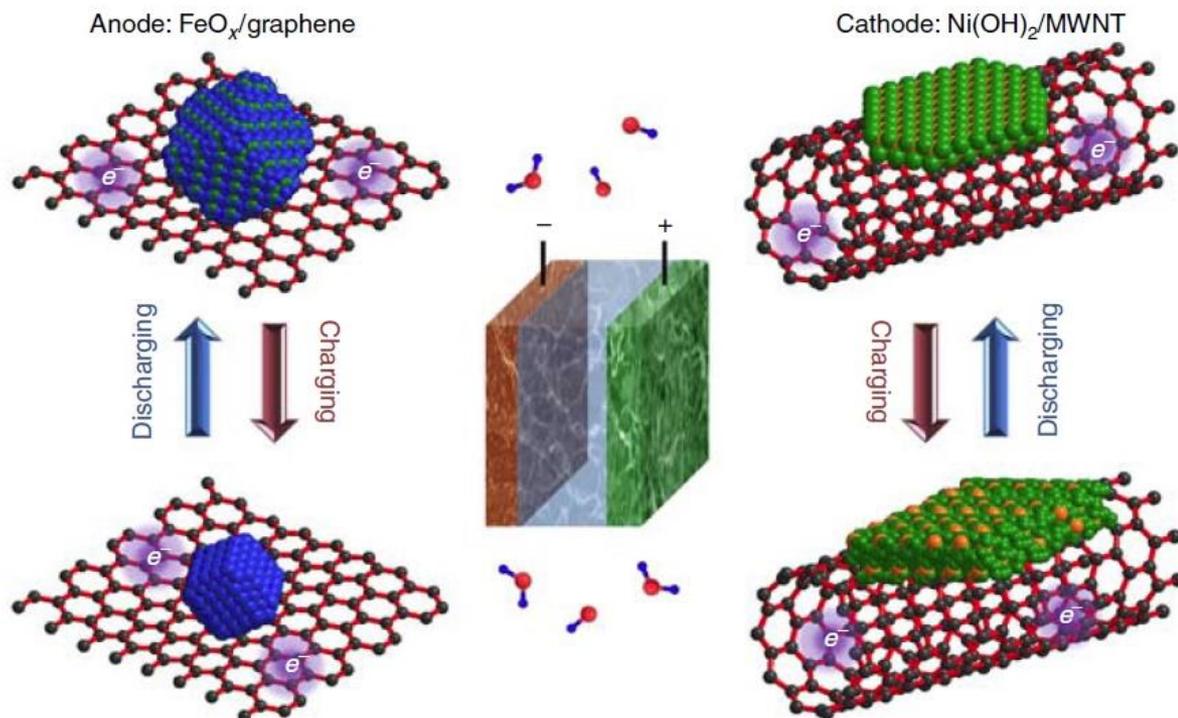
FeO$_x$/graphene may be in the form of submicron flakes or particles lodged and immobilized within cohesive nonwoven CNT pellicles.

*Hailiang Wang, et al, "An ultrafast nickel–iron battery from strongly coupled inorganic nanoparticle/nanocarbon hybrid materials." Nature Comm. 2012. 3 (917)

Cohesive MWCNT Resistance Data
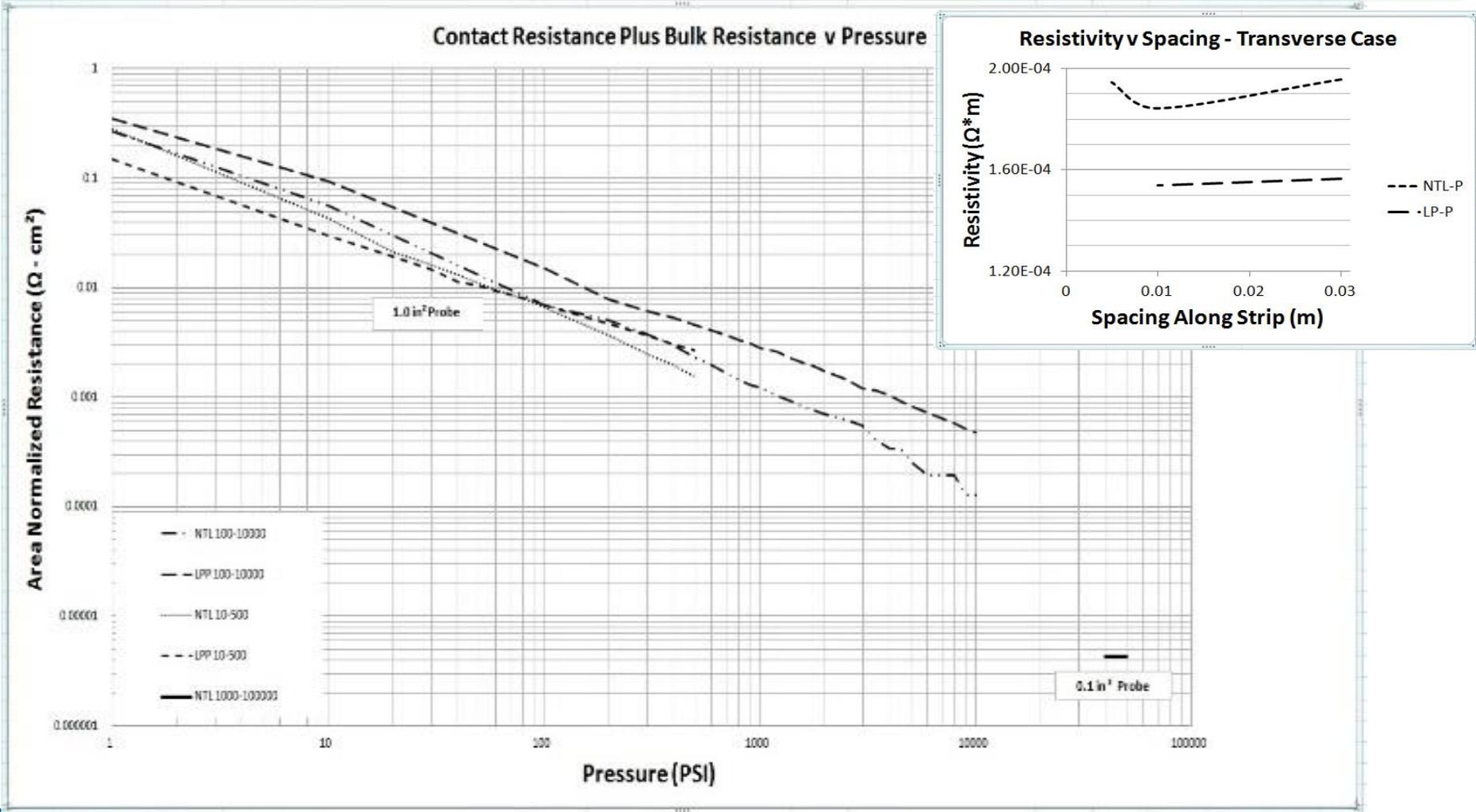
GES data showing ultra low contact resistance vs pressure. Used as a closely spaced plurality of electrical conduction sinks.

GES 4-Step Proof of Concept Roadmap

# Proof of Concept Roadmap: Four Step Progressive Plan

An outline appears below. Computer modeling studies can be performed prior to actual laboratory work but Comsol does not include provision for our novel electrode architecture. GES proposes four progressive categories with each successive milestone building upon the previous result. GES would provide further details as required at each phase.

- **Step 1.** Construct two ultralow resistance electrodes, each using commercially available cohesive nonwoven CNT, some other catalog items and a custom laser-cut thin hard plastic separator to comprise a unit cell of a supercapacitor to serve as a test bed as further described in our information. This will prove low resistance, high current density and insignificant reduction of active electrode area.

- **Step 2**. Assemble a stack of identical such unit cells in series electrical connection yielding high voltage and current density as well as improved energy storage capacity for a supercapacitor. The objective is to prove this radical electrochemical architecture for batteries as described below.

- **Step 3.** Repeat unit cell architecture but this time incorporating faradaic (battery) materials. There are several chemistry options and ways to do this depending upon lab preference. Those that involve coating the CNT are widely published in the scientific literature by many developers. Direct durable coating of anodic or cathodic material onto CNT lodges and immobilizes these materials within the electrode structure. There is also considerable advantage and value to using micron size particles that have only been used in paste form in prior art but cannot be used that way in low resistance electrodes. A very important proof will be that such particles can indeed be lodged and immobilized in GES CNT ultralow resistance electrodes. Either way (CNT coatings or entrained particles) the result is a unit cell battery. It should be tested as such. Note that this becomes a unique test bed for new and emerging materials.

- **Step 4**. Repeat Phase 3 with a stack of identical unit cells. The essential properties will have been proven but this would serve as a prototype battery with remarkable energy storage capacity and discharge/recharge power. The high voltage simplifies testing and use in many applications.

Battery impedance with respect to **a)** charge transfer ohmic resistance, **b)** ion kinetics with regard to diffusion and mobility in an electric field, **c)** passivation and **d)** intercalation pathways are collectively subsumed within cited references to Li^+ conductivity. GES' reduction of charge transfer ohmic resistance to negligible levels makes it possible to distinguish ion kinetics in impedance measurements. Once that is accomplished other resistances can be largely mitigated by 3-D architecture profiles offered by GES.

Electrode Layer Components - 1st low cost POC steps

1) We propose assembly of electrodes using catalog or in-house CNT cohesive 'buckypaper' comprising a mixture of SW and MW CNT.

2) 100 or 30 mesh SS square weave wire screen is used to compress the CNT pellicle against a metal platen. (mesh size is chosen for large clear window fraction)

3) Cover with a thin sheet of hard plastic with laser cut windows to match wire screen. This may have to be made in-house or by a vendor.

4) Cover that with another layer of wire screen in window matching registry. (Care is needed here)

5) Cover that with another layer of buckypaper.

6) Add electrolyte and compress the stack with a metal piston (not sealed within the cylinder).

7) Compression is varied from about 1 to 5,000 psi.

Square weave metal wire screen

Metal plate

CNT pellicle with lodged immobilized galvanic particles

CNT pellicle with lodged immobilized galvanic particles

Metal plate
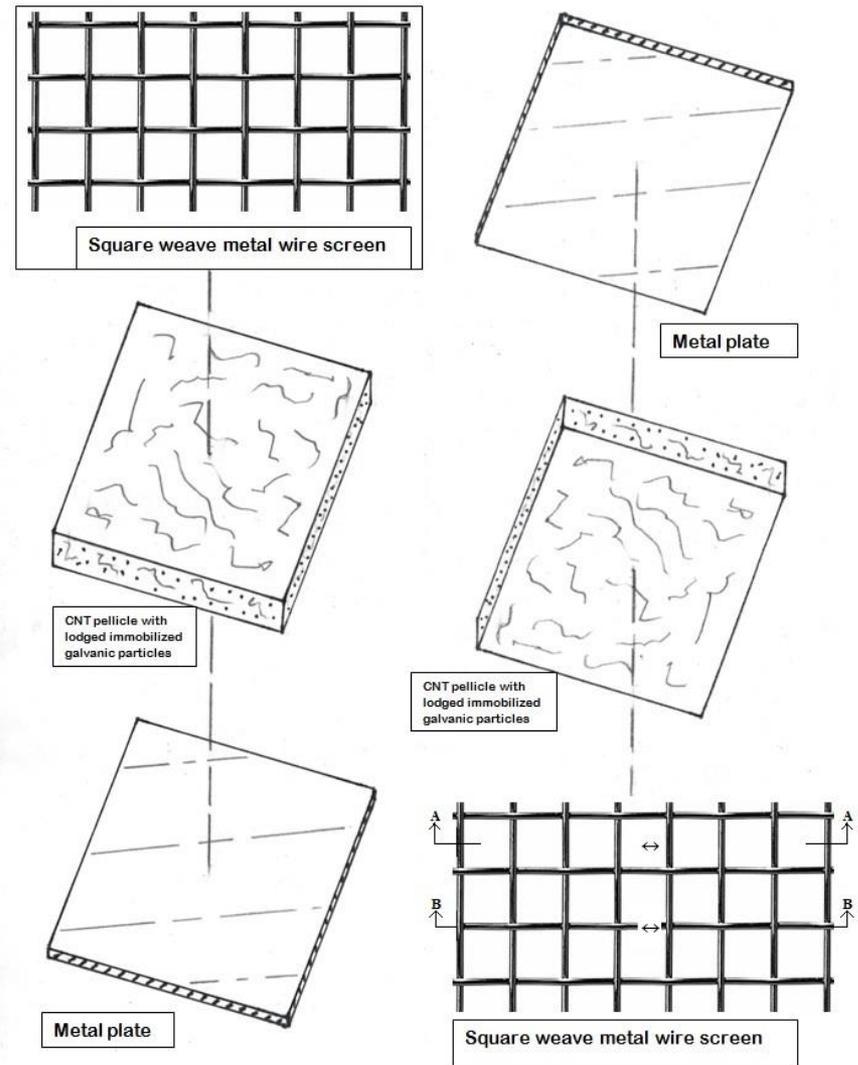
Square weave metal wire screen
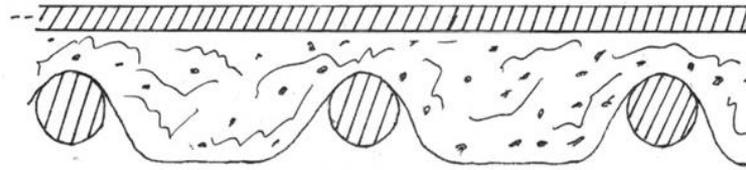
Section, A-A (3 layers compressed; metal sheet, pellicle and square weave wire cloth)
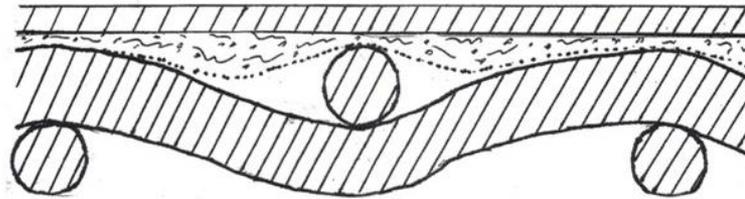

Section, B-B (3 layers compressed; metal sheet, pellicle and square weave wire cloth)
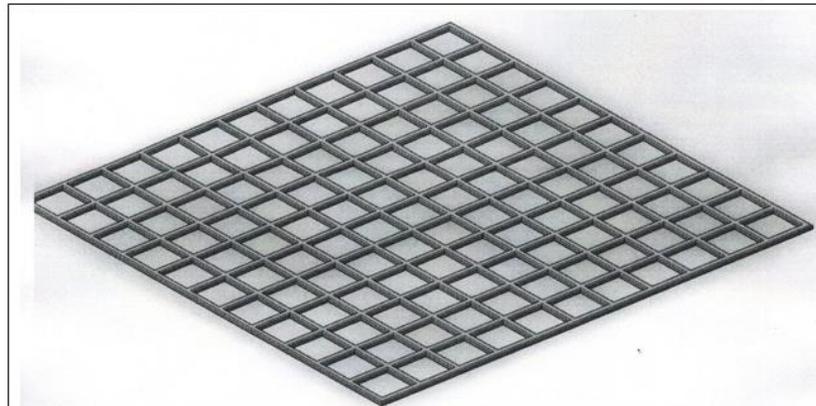
Dielectric Screen with windows separating two 3-layer polar electrodes.

21
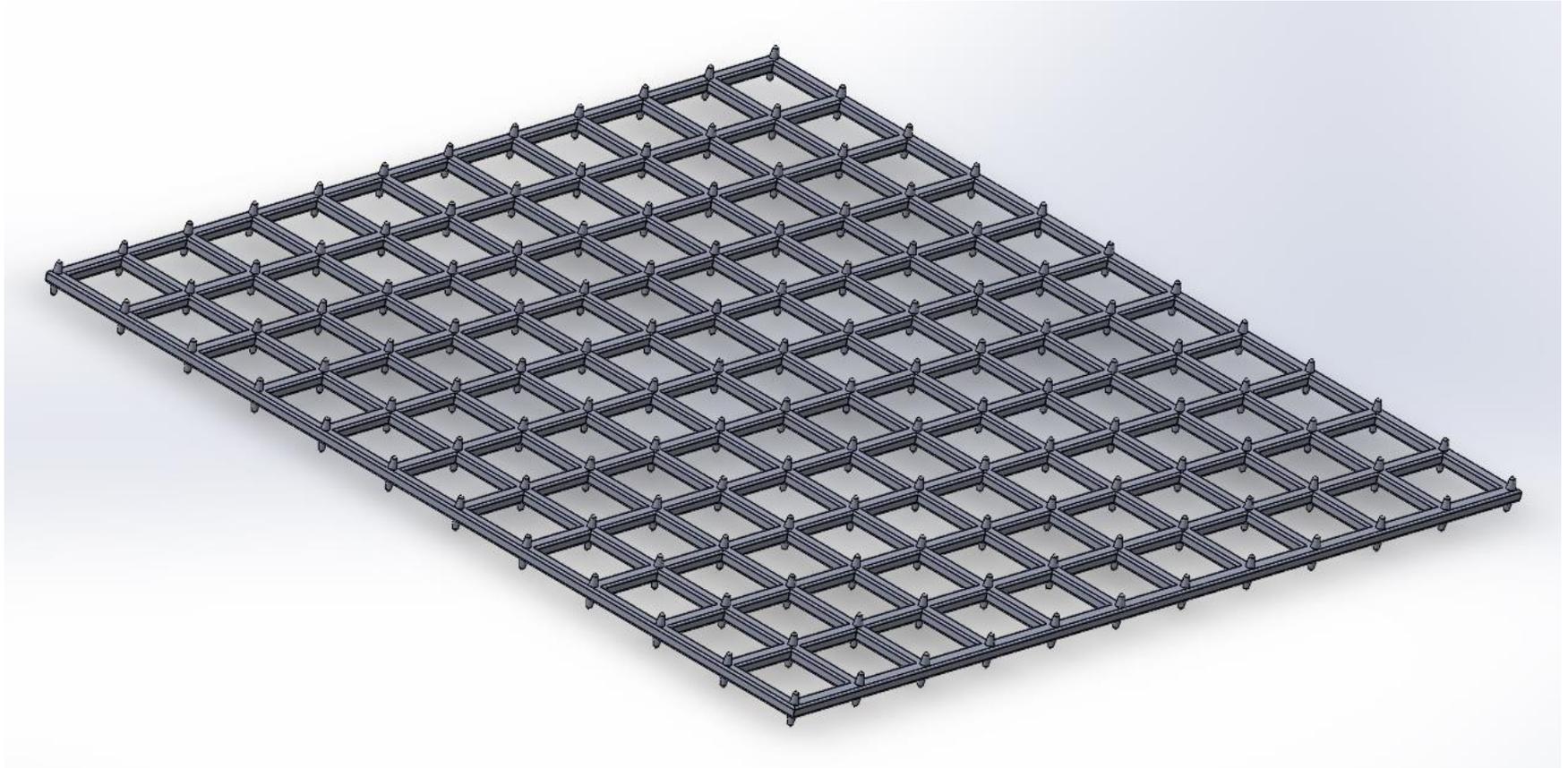
Villi replace square weave metal wire screen

This is a supercapacitor (because of DL adsorption on the large CNT surface area) when platen and piston are connected to electrode terminals. Of interest is ultralow ESR at high pressure and the voltammetry characteristics of the unit-cell. Enclosing the cell with calorimetry will find very low heat production at high pressure. Variation in electrolyte dissociated ion concentration (aqueous @ 1 volt or aprotic @ 3.5 volts) will have an effect on current density due to polarization but unprecedented current density will be proven. A comparison between fine and coarse mesh and associated pellicle thickness will affect those parameters.

This is an experiment using inexpensive materials. It is a simple idea with profound implications.

Addition of faradaic material as coatings on CNT or as entrained and immobilized particles converts capacitor architecture either to pseudosupercapacitor or battery.

The essential novel architecture for significantly lowering electrode resistance is clearly indifferent to galvanic particle or CNT coating chemistry or in relation to fluid or gel electrolyte. Galvanic materials can be faradaic for batteries or catalytic for fuel cells.
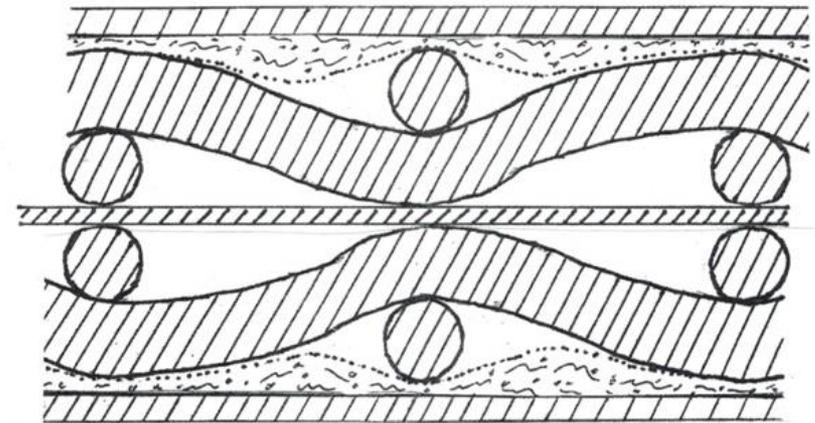

Final Assembly of Anode and Cathode 3-layer subassemblies separated by dielectric screen. Section B-B.
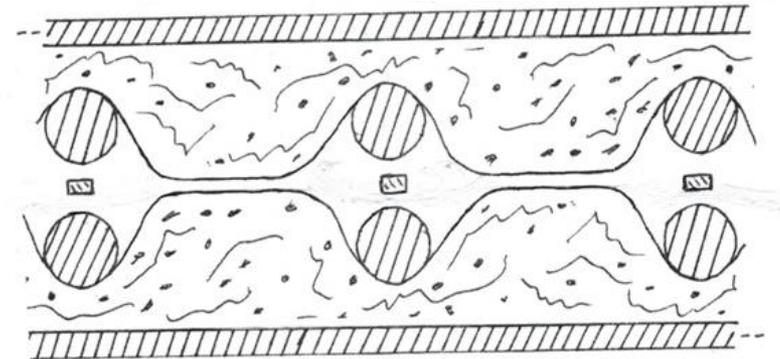
Final Assembly of Anode and Cathode 3-layer subassemblies separated by dielectric screen. Section A-A.

Optional Electrolyte Filter Barrier
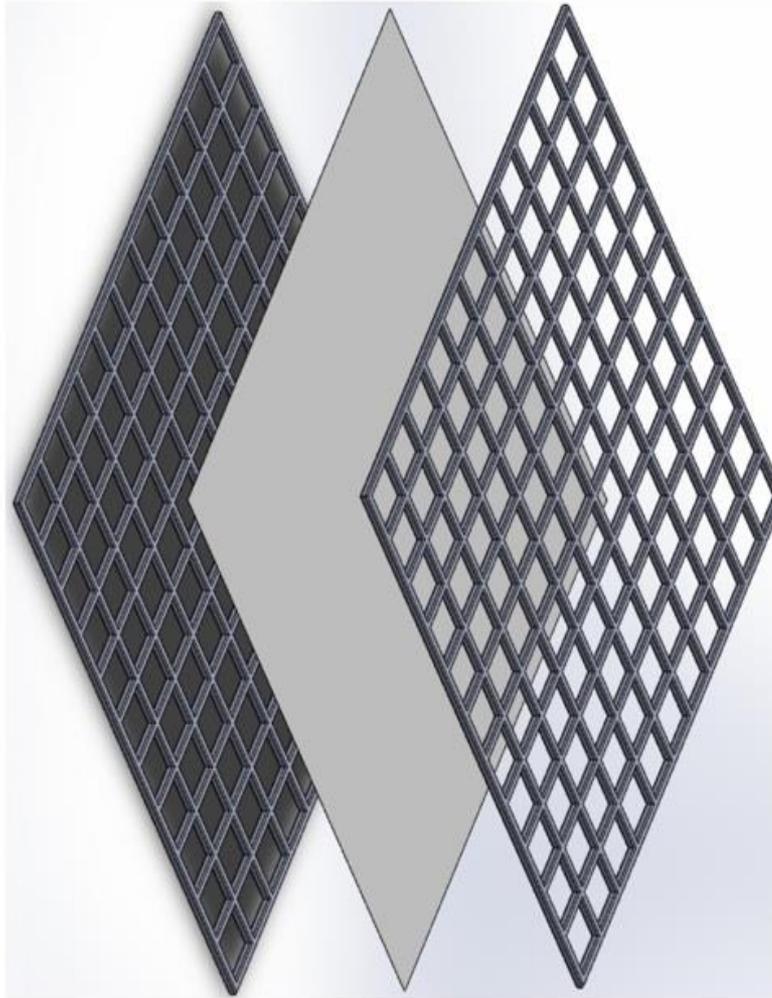
Optional 3-layer dielectric separator comprising two open window screens separated by electrolyte permeable filter, e.g., Millipore 1 to 5 μm.

Electrical Stacking Options
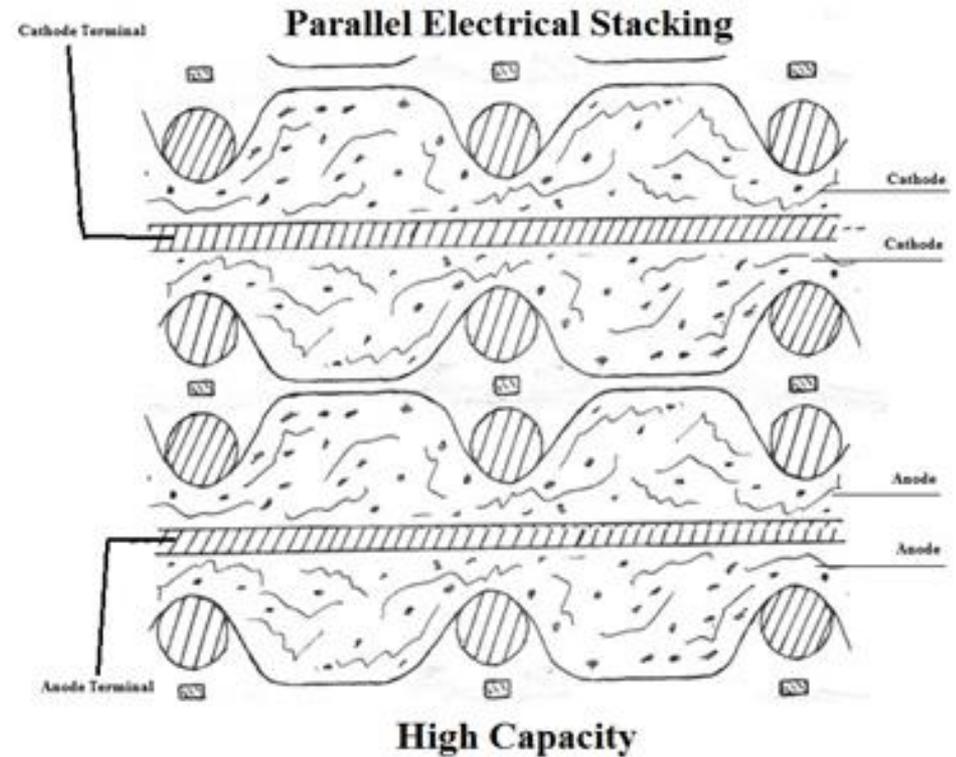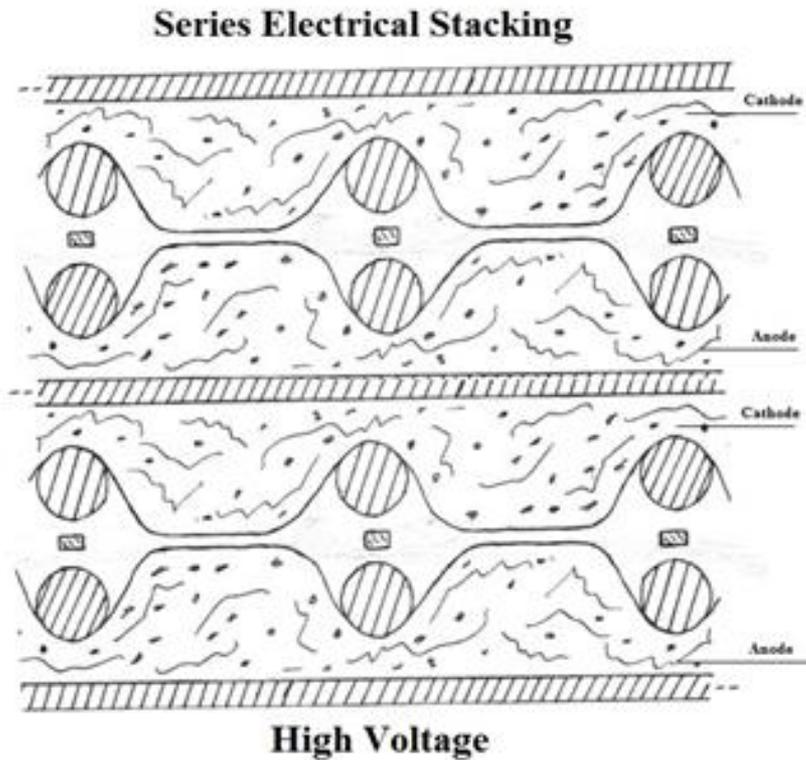
As shown above, the cohesive nonwoven CNT pellicles illustrated here may contain uncoated CNT to comprise an advanced supercapacitor or have CNT coated with faradaic material or the pellicles may lodge and immobilize faradaic particles to comprise a secondary battery structured for high unit cell capacity or for high voltage. Either is capable of very fast charging because of ultralow impedance and concomitant high current density.

3-D High Voltage Electrode Assembly Without Compression

Batteries can be produced as freestanding sheets of metal bearing attached ultralow resistance electrodes on each side for subsequent assembly in a variety of configurations. A dielectric filter separator is optional and must be highly fluid permeable.

- A 18650[*] Li-ion form factor battery has 55 mΩ or 12 Ωcm^2 resistance on 220 cm^2 area[**].

- The discharge profile can yield 10 Wh but a comparison to stored energy shows that 10%, ≈¾ watt for 2 hours goes to heat.

- 7,100 batteries in a single pack is 5.3 kW. Obligatory cooling volume cuts energy density in half from 0.67 to 0.33 kWh/L.

- Our version contains 100 stacked unit cells with 2.2 cm^2 area each and thickness of 0.6 mm to fit the same 18650 form factor with 50% more faradaic material volume as the referenced cell.

- Using the same 1.625A charge current but 385 average volts the GES version loads the required energy in about 1 minute with negligible loss at 0.264 watt.

- It is due to 100 layer resistance of 0.1 ohm.

- High current density, 0.825A/cm^2 instead of 1/100th that value permits fast charging.
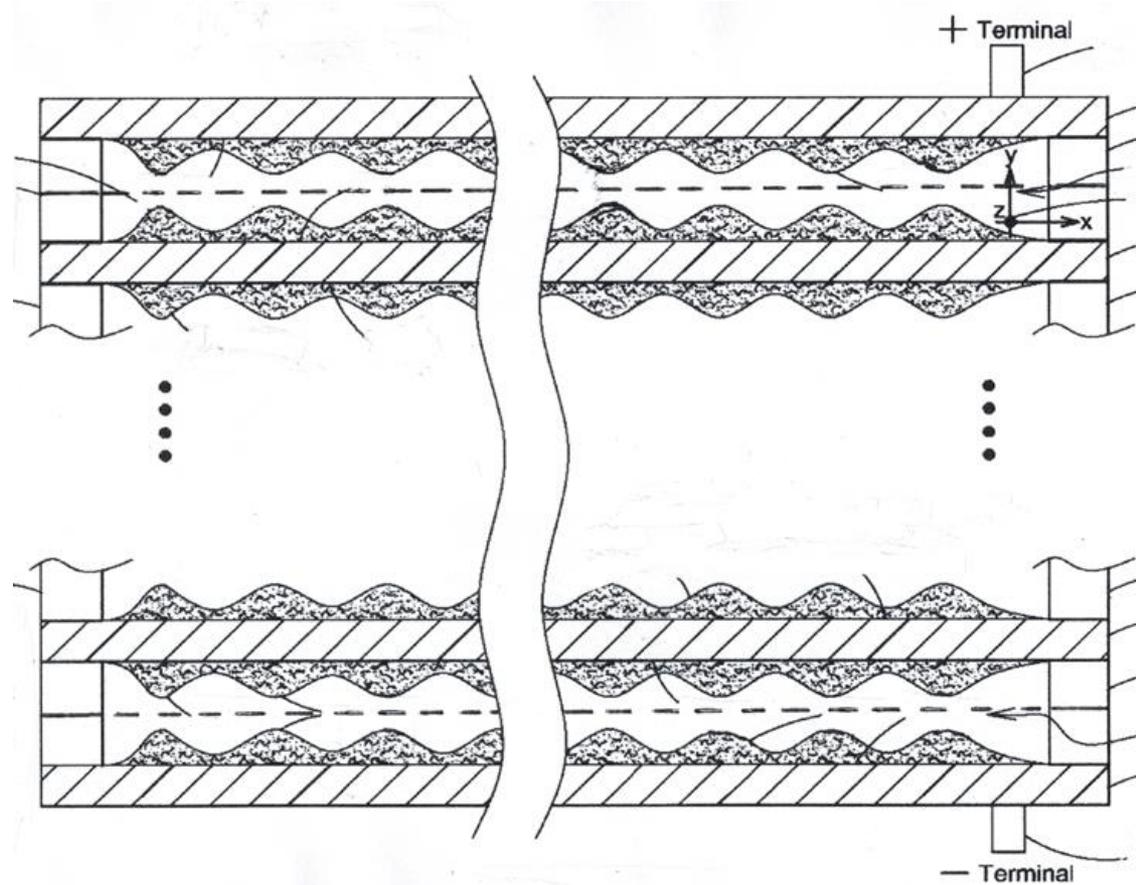
Opposite polarity pellicle membranes are embedded at a plurality of closely spaced areas of attachment into metal sheet layers separated by a dielectric filter membrane. Each spaced apart electrode pair is a unit cell stacked in series for high voltage and low current density.

[*]https://na.industrial.panasonic.com/sites/default/pidsa/files/ncr18650b.pdf
[**]Valentin Muenzel et al, *A Comparative Testing Study of Commercial 18650-Format Lithium-Ion Battery Cells, Journal. ECS,* **162** (8) A1592-A1600 (2015)

GES Proof of Concept Plan – Supercapacitors

- In aqueous electrolyte @ 1 volt $\frac{1}{2} CV^2 = 0.05 = 1.4 \times 10^{-5}$ Wh/cm^2 per electrode

- In an actual capacitor with opposed polar electrodes the value is 1/4th of that per electrode or $\approx 7 \times 10^{-6}$ Wh/cm^2

- On a volumetric basis assuming a 0.09 cm thick unit cell it is only 8×10^{-2} Wh/L

- 33 µF/cm^2 is based upon 10^{15} atoms/cm$^2 \rightarrow 0.2$ e/atom @ 1V,

- MnO$_x$-Fe opposed coatings yield 2 volts and capacitance that can be 60 times carbon double-layer systems

- Faradaic pseudocapacitance yields ≈ 500µF/cm^2 or 2.5 e/atom of accessible surface

- 2×10^3µF/cm^2 for either redox or adsorption surface reaction is theoretically possible

- In aprotic electrolyte pseudocapacitance energy storage may reach $\frac{1}{2}$ kWh/L

- Batteries involve 1 to 3 e/molecule per redox valence

If θ represents surface DL coverage fraction:

$$\theta/(1 - \theta) = K \cdot exp(VF/RT)$$

$d\theta/dV = (F/RT)[K \cdot exp(VF/RT)/(1 - K \cdot exp(VF/RT)^2]$ and **F** is Pseudocapacitance
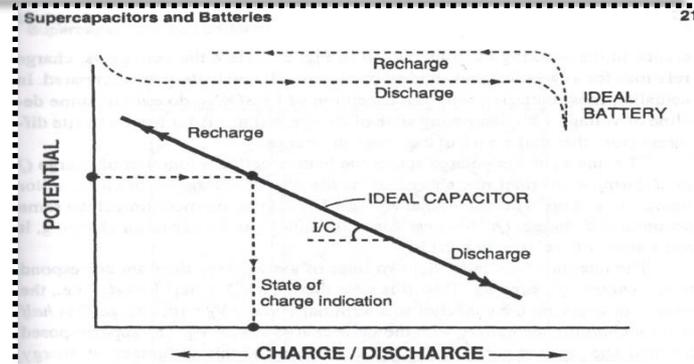
FIGURE 2.1. Difference of discharge and recharge relationships for a capacitor and a battery: potential as a function of state of charge, Q.
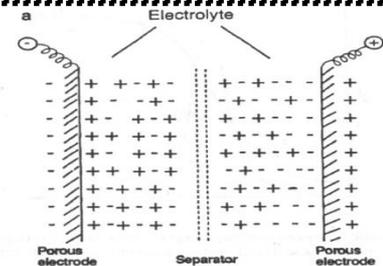
Configuration of an electrochemical capacitor requiring two electrodes and thus two double-layers
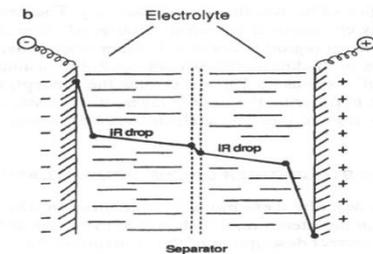
Potential profile across an electrochemical capacitor on discharge

FIGURE 6.1. Diagrams of electric potential profiles in an electrochemical capacitor comprising a double layer at each of two electrodes: (a) charged capacitor at open circuit, (b) capacitor passing current on discharge with IR drops.

Electrochemical Supercapacitors, B.E. Conway – (1999) Plenum

Summary – Present State of the Art (SOA)

The following statements should be considered by scientists working in the field of battery development.

1) Present commercial battery electrode resistance is 10 ohms for 1 cm^2 of electrode area.
2) These electrodes are limited to charging current of <10 milliamp/cm^2 and not much more at discharge.
3) Present art electrode resistance is comprised of;
   a) ohmic electron charge transfer resistance plus;
   b) ion kinetic resistance.
4) Experimental studies with graphene structures (e.g. CNT) notwithstanding, present battery art uses anode and cathode materials mixed with carbon powder and PTFE binder pastes separated by resistive ion selective semipermeable membranes.
5) Miran Gaberscek,"… the principal source of resistance is interface contact. "Most surprisingly, … due to the contact impedance between the metal and the electrode material. This is in fundamental contradiction with previous interpretations."
6) Wang, Evanoff, et al; when active faradaic materials coat the CNT or graphene surfaces the ion kinetic barrier is negligible. That aspect of resistance is reduced by three orders of magnitude as claimed by Wang. His version tested at low current density remains limited by charge transfer resistance, i.e. ohmic.
7) Xiaohua Ma tested particles as advanced Li-ion cathode material in conventional paste form using 15 wt.-% to as much as 65 wt.-% carbon black to remove "*rate limitations*" at high C-rate, proving the latter is due to ohmic resistance – not ion kinetics in thin compressed electrodes while sacrificing <u>volumetric</u> energy storage density.

Present SOA batteries use ≈5 wt.-% carbon black to allow for volumetric energy storage capacity which is why they have such high electrical resistance. The concept least understood by many workers in the field is that the dominance of electrical resistance in favor of energy storage limits electrode current density which controls charge/discharge power and leads to lengthy recharge interval.

We have found a way to dramatically reduce electrical resistance without having to overwhelm electrode volume with conductive material (carbon black). It is based upon patented closely spaced multipoint compressive attachment of nonwoven cohesive CNT graphene structures to a metal substrate. We do not sacrifice energy storage density in order to achieve high C rate performance; 1 amp/cm^2 instead of the present art limitation of $1/100^{th}$ amp/cm^2. It also allows stacking thin electrodes in series for accumulating energy storage at high voltage. As supercapacitors that means a significant increase in energy storage capacity (i.e. ½ CV^2) where C can be increased by virtue of CNT coatings ("Electrochemical Supercapacitors", B.E. Conway, Chapter 10). For batteries it means virtually insignificant heat generation and safety at high power.

Why would anyone make and use slow charging hot batteries when they could just as easily make fast charging cool ones?

In summary we can state the two main principles of our electrochemical cell.

A. The electrode comprises cohesive graphene structures, e.g. nonwoven CNT, attached to metal with less than 10^{-3} ohms of resistance for 1 cm^2 of electrode area. That is four orders of magnitude improvement over the present state of the art. It is a fact proven by data.

B. Ion kinetic resistance follows the examples of Gaberscek, Wang and others for the following reasons:

   1) We use CNT or other graphene as used by many workers in the field of nanoscale technology to attach active faradaic material and derive a concomitant benefit as to reduction of ion kinetic resistance when the electrode is attached to metal as in A above. The separating membrane that dominates cell resistance because of its limited ion kinetic mobility (10 times higher in the plane of the membrane where it is useless as opposed to directly through it where it must actually function) is no longer required.

   2) Some of the best faradaic materials cannot be applied as coatings on graphene or CNT. They are particles which we can lodge and immobilize in nonwoven CNT – but only when that is attached as in A above. This is also a fact proven by testing. The method of attachment immobilizes the particles by tightening CNT fibers around the particles. It is *likely* that the resulting intimate interface will behave approximately like a faradaic coating. That needs to be tested but the *potential* benefit is clearly worth the effort; and it is easy to implement.

Like the wheel this is a simple idea with profound consequences. Unlike the wheel it is patented.

GLOBAL *ENERGY SCIENCE*

Halbert Fischel, Founder, GES Managing Member, and Lead Inventor
Beginning 55 years ago, Halbert Fischel led a consulting group as innovator for industry, NASA and the military in electro-optics, space simulation and cryogenics for space systems relating to 'Star Wars'. As a prominent inventor he founded and sold startup companies and disrupted and created new markets with revolutionary entrepreneurial inventions that impacted many disciplines and sectors including:

* **Dialysis (membrane) ~$75.0B market [1]:** is a process for removing waste and excess water from the blood, and is used primarily as an artificial replacement for lost kidney function in people with kidney failure.

* **Plasmapheresis ~$1.1B [2]:** is a process in which the liquid in blood, i.e. plasma, is separated from the cells and used as a donation for medical purposes. In some people, plasma can contain antibodies that attack the immune system. A machine removes the affected plasma which is replaced with good plasma or a substitute.

* **Rebreather:** is a covert underwater breathing apparatus that absorbs the carbon dioxide of a user's exhaled breath to permit the rebreathing (recycling) of unused gas with controlled oxygen content added for each breath.

Source: 1) http://geschaeftsbericht2013.fresenius.de/reports/fresenius/annual/2013/gb/English/30201010/the-dialysis-market.html
2) http://www.transparencymarketresearch.com/pressrelease/apheresis-equipment.htm

Philip Lubin, Ph.D. Chief Scientist, GES

Philip Lubin is a distinguished Physics professor at the University of California in Santa Barbara focusing on creating space probes for measuring deep space microwave background signatures of the early universe. Notable accomplishments, case studies, and published papers from his years of academic experience are the following:

- Experimental cosmology
- Cosmic Background Radiation – spectrum, anisotropy and polarization
- Satellite, balloon-born and ground-based studies of the early universe
- Fundamental Limits of Detection
- Directed Energy Systems

Brad Paden, CEO, LaunchPoint Technologies, Inc.

R&D for GES was carried out at LaunchPoint Technologies, Led by Brad Paden, Ph.D., professor of mechanical engineering at UC Santa Barbara. LaunchPoint is an incubator for GES technology development. **http://www.launchpnt.com/**

GES Investor Group

From its inception, GES has incorporated strategic investors to help facilitate the start-up requirements from conception to proof of concept along with its continuous involvement as lead advisors on the long-term strategic plan for GES.