Major challenges in research and development of advanced power sources:

1. **Electro-mobility is not a dream. We reach highways with promising technologies.**
2. **The challenge of large energy storage.**

Doron Aurbach

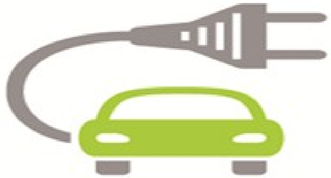
Department of Chemistry

Bar Ilan University

Ramat Gan

ISRAEL

In the framework of INREP
Israel National Research center
for Electrochemical Propulsion
23 research groups, 6 Israeli prominent institutions



Many thanks to the faithful Innovative and diligent research groups at Bar-Ilan university

In collaboration with:

Prof. Yang-Kook Sun
Hanyang university
South Korea

Israel National Research center for Electrochemical propulsion

23 research groups from top 6 Israeli universities

Annual meeting, April 30th & May 1st 2018

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INREP Research Topics

INREP intends to fulfil a major goal of the Israeli Government in the field of energy:
Israeli science & technology should raise a significant contribution to release the world from dependence in petroleu.

Consequently, INREP develops power sources for electro-mobility.

- **Developing most advanced research methodologies: computational, analytical electrochemical tools.**

- **Advanced cathode materials for high energy density Li ion batteries.**
- **New high capacity Li-Si-C anodes**

- **Li-oxygen, Li-sulfur, Na ion, metal (Na,Zn,Al) - air battery systems.**

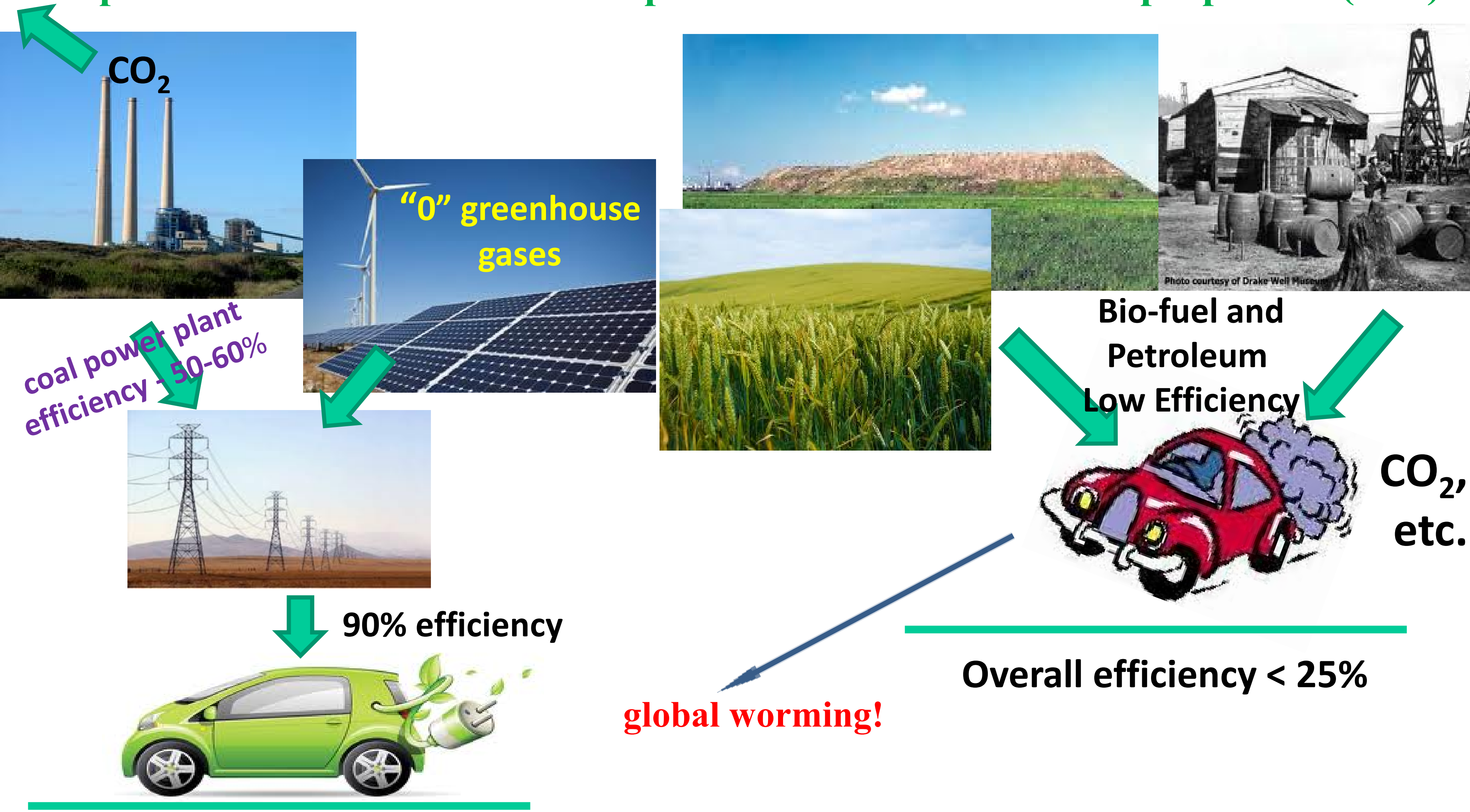
- **Wide potentials liquid and solid electrolytes for advanced batteries.**

- **Advanced super-capacitors.**

- **Hydrogen/oxygen fuel cells designed for electric vehicles.**

Why Electro-mobility?

The petroleum alternative for transportation is electrochemical propulsion (EVs).



Overall efficiency > 40%

We should switch propulsion energy sources from petroleum to electricity.
In parallel, power stations operated by combustion of coal, will be gradually replaced by sustainable energy sources: wind turbines & solar panels

The (full) Electric Vehicle challenge

we want to drive normal cars, the cars makers are very conservative.

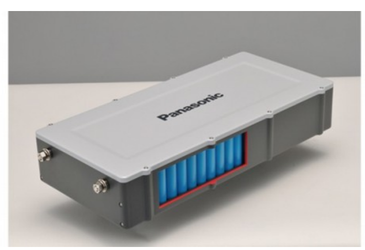
So, we can install batteries that weigh no more than 300-500 Kg (150-250 L)

An EV battery comprises many single cells connected in series and in parallel to form modules. The modules form high voltage/high capacity via the BMS (battery management system)

Single cells

+

Module



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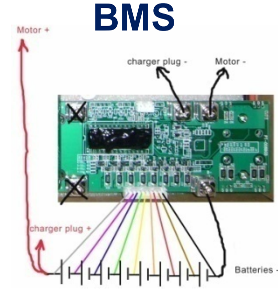
BMS



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Full battery
220V, 30-50 kWh

Relevant Li ion battery technology: graphite- Li[NiCoMn]O_2 Ni > 80%
because of safety, cycle life….
150Wh/Kg per a single cell!

In the full battery level The energy density is Up to 120 Wh/Kg

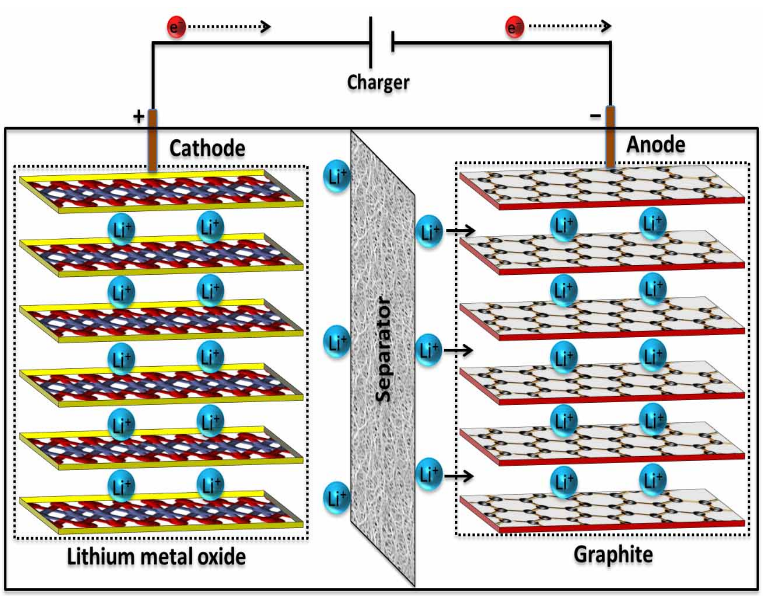
We can expect 40K – 80K Wh Up to 500 km between charges.

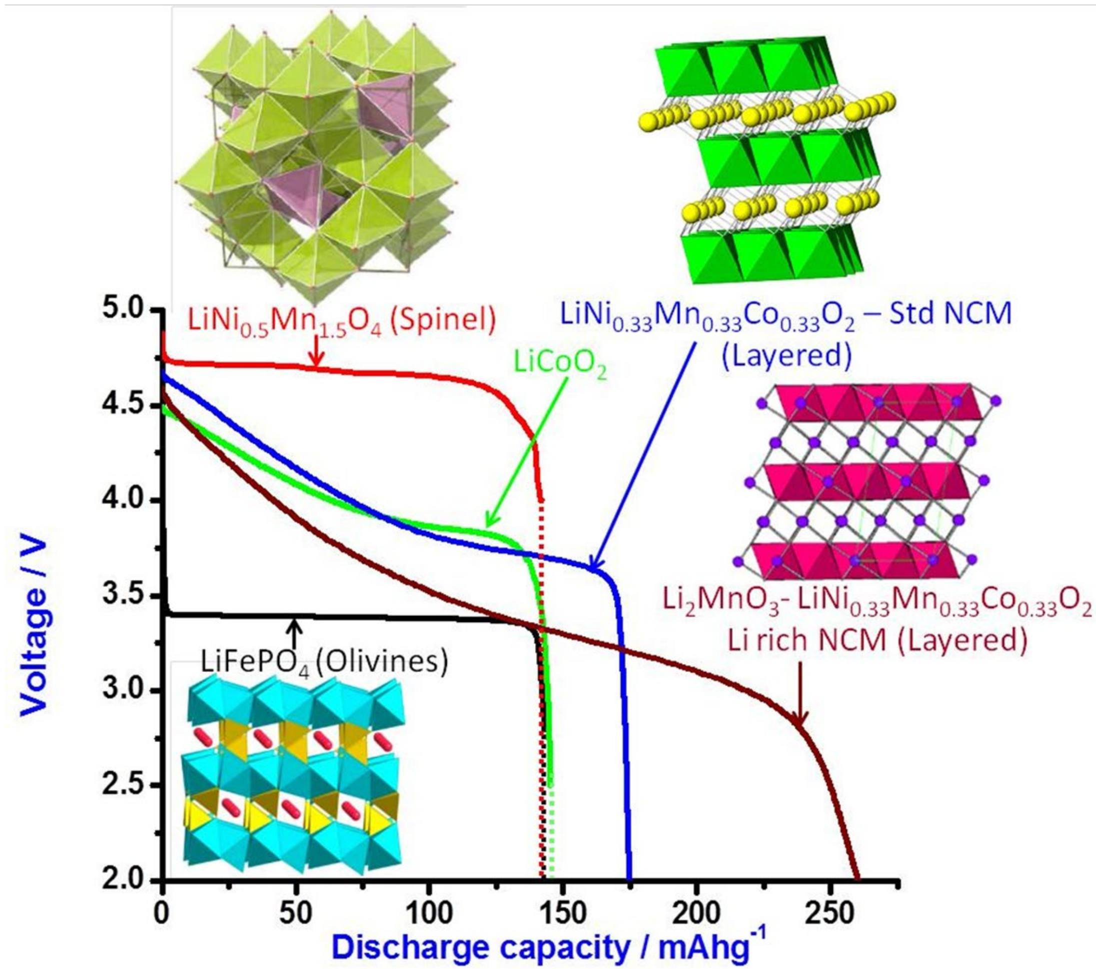
We can use range extenders: small ICE, turbines, primary (recyclable Al-air batteries)

Li ion batteries are the right technology for electro-mobility. We can stay with modified graphite anodes. Cathodes are the key factor, determining the energy density.

Main types of positive electrodes (cathodes)

A Scheme of Li ion batteries





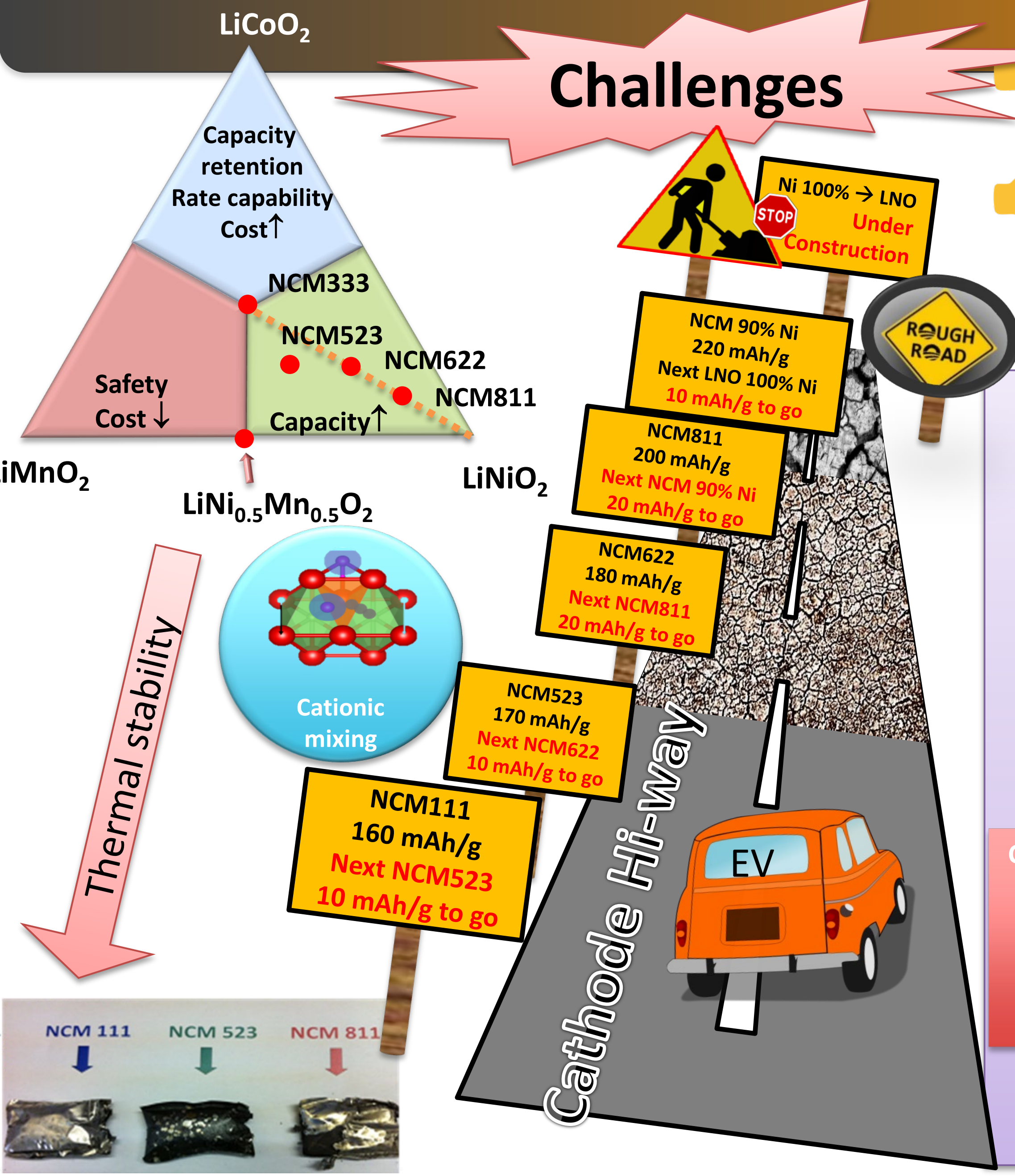
The positive electrodes (cathodes) are the limiting factor for energy

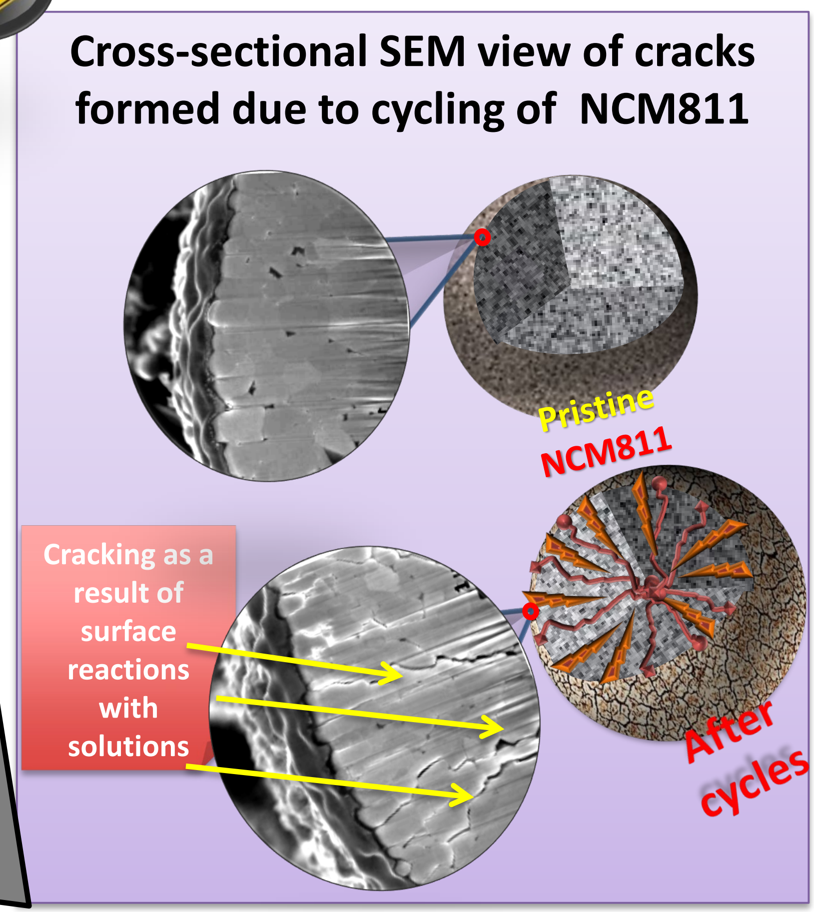
Aurbach et Al. ,Energy Environ. Sci., 4, 3243(2011)

Ni rich $Li[NiCoMn]O_2$; Ni → 100% is the winning cathode materials

High Ni content >50% leads to unstable performance of NCM cathodes.

Interactions with EC-EMC/LiPF6 solutions result in side reactions with highly reactive Ni-O surface.



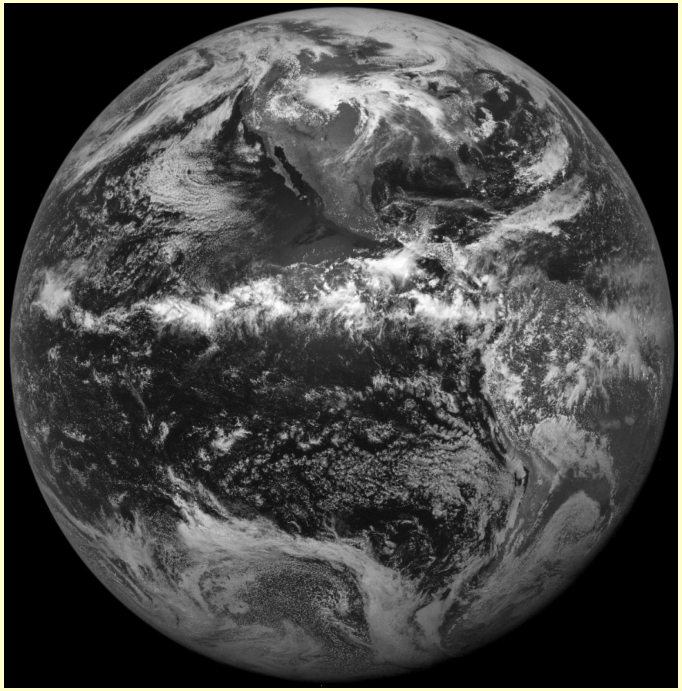


Next challenge: to use renewable energies instead of fossil fuels: oil, coal, in order to reduce global warming.

The world energy consumption is around 17-18 TW

Biomass

50% of all cultivatable land: 7 TW **(H_2O)**



Wind

Gross: 50 TW
Economic: 3 TW
Installed: 0.08 TW

Hydroelectric

Gross: 4.6 TW
Economic: 0.9 TW
Installed: 0.6 TW

Solar

potential 1.2×10^5 TW
practical 600 TW

Geothermal

Gross: 12 (+30 ocean)
Economic: 2 TW
Installed: 0.01 TW

On the global energy challenges:

We do not have a real energy crisis. We have enough coal for electricity production for the next millennium. We suffer from energy related crises: environmental problems due to the use of fossil energy sources, the green house effect, global warming due to evolution of gases such as CO_2. Hence, there is a strong incentive to move faster to sustainable energy sources.

The world's current power supply needs several TW

Main sustainable energy sources: Wind & Sun

Wind: Up to 4-5 TW theoretical

20% from it practical.

Storage !!

We lack Suitable Energy storage Technologies.

We need rechargeable batteries for load leveling applications.

Can Li ion battery technology contribute to the storage of sustainable energy?

Main solar power sources: Solar - photo thermal

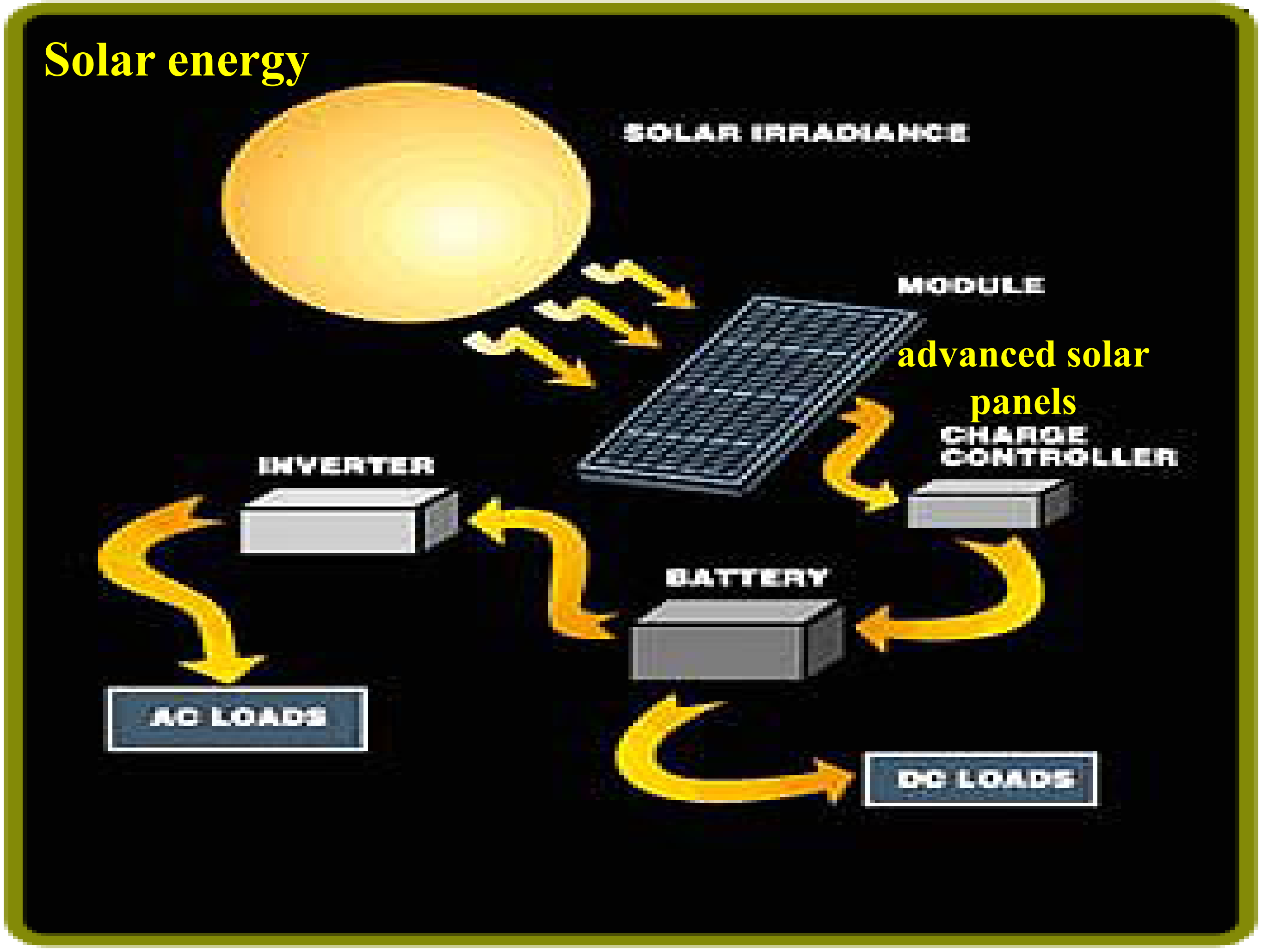
Solar – photovoltaic

Figure 13.12. Part of a large multi-megawatt array.

Solar energy: unlimited! Hundreds of TW theoretical

Our dream:

Develop effective autonomous electricity supply for hundred millions of people that have no connection to the grid. We intend to promote Israeli industry that will produce completed energy solutions.



We develop at BIU rechargeable battery systems for large energy storage based on abundant and cheap elements:

Sodium
Manganese
Carbon
Oxygen
Nitrogen
Aqueous electrolytes

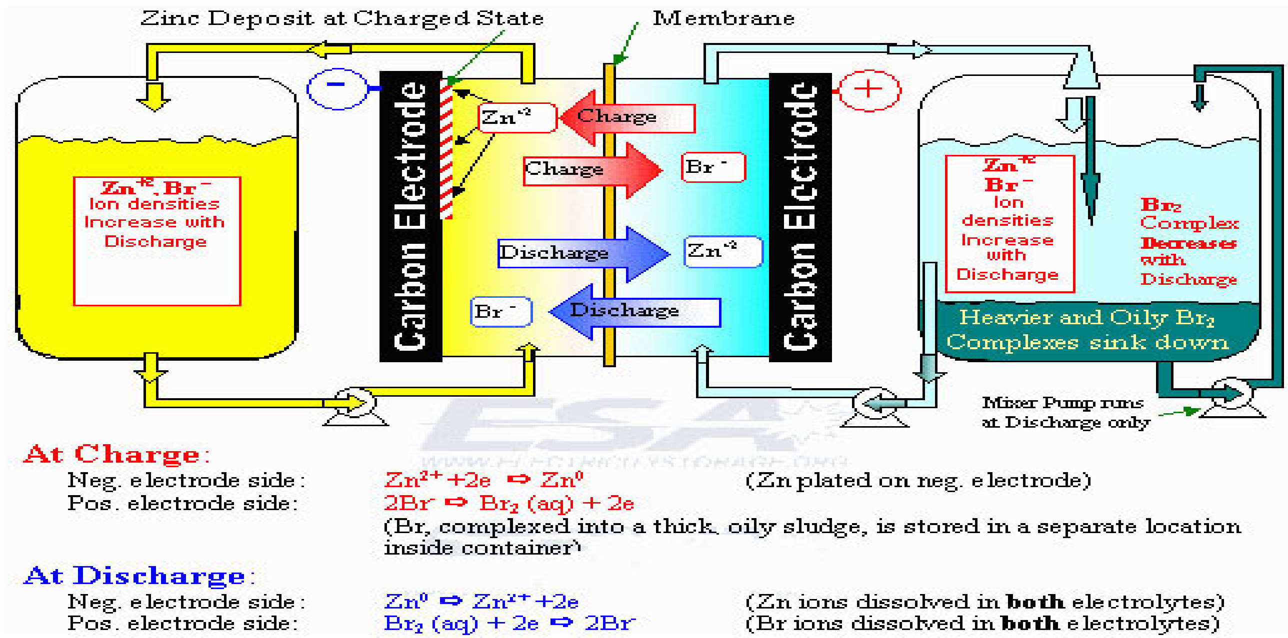
Many millions of potential customers wait anxiously to our energy solutions: solar panels with appropriate long term energy storage technologies

Electrochemical devices for load leveling applications.

1. Flow batteries.

Examples: Zn (negative) / Br_2(positive);V^{3+}/V^{2+} (negative) – V^{5+}/V^{4+} (positive)

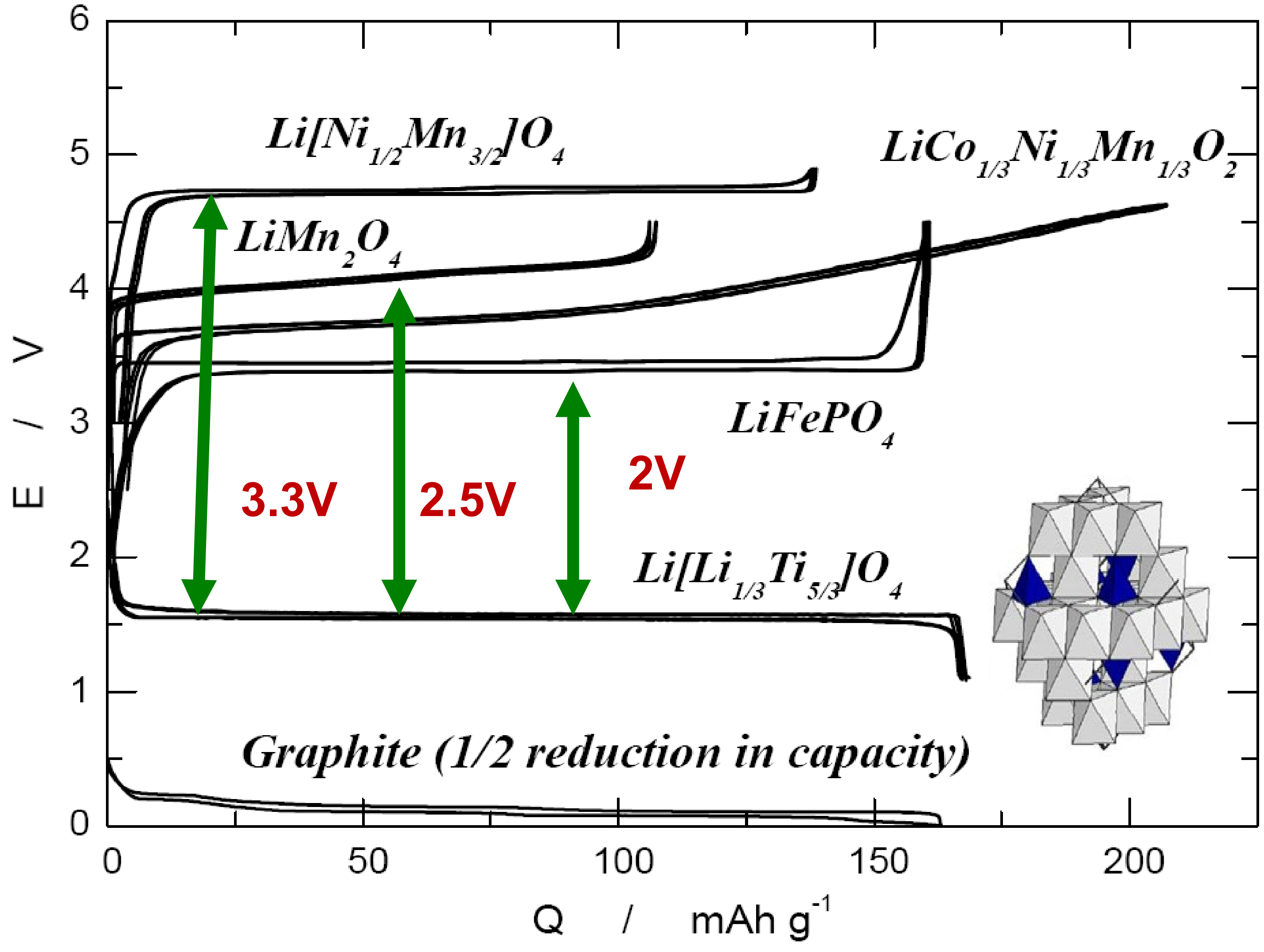
More: iron couples, non-aqueous Li electrochemistry……



2. Lead – Acid batteries (cycle life should be extended!) discussed later.
3. Sodium ion batteries– following Li ion batteries, parallel elements.
4. Sodium-Sulfur batteries (Na/ ceramics/ S , high temperatures).
5. Li ion batteries (cost, safety & stability issues) discussed later.
6. Rechargeable Mg batteries (R&D stage).
6. Super –capacitors (low energy density) discussed later.

Low voltage, long life Li ion batteries, based on LTO anodes.

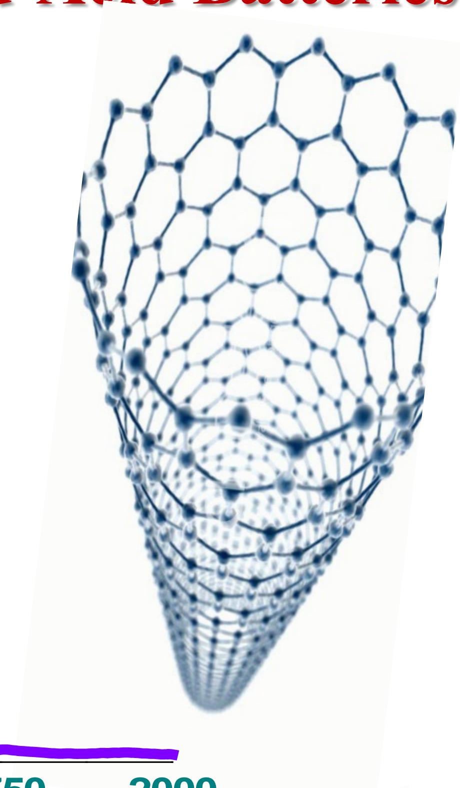
A contribution of Li ion technology for load leveling applications?

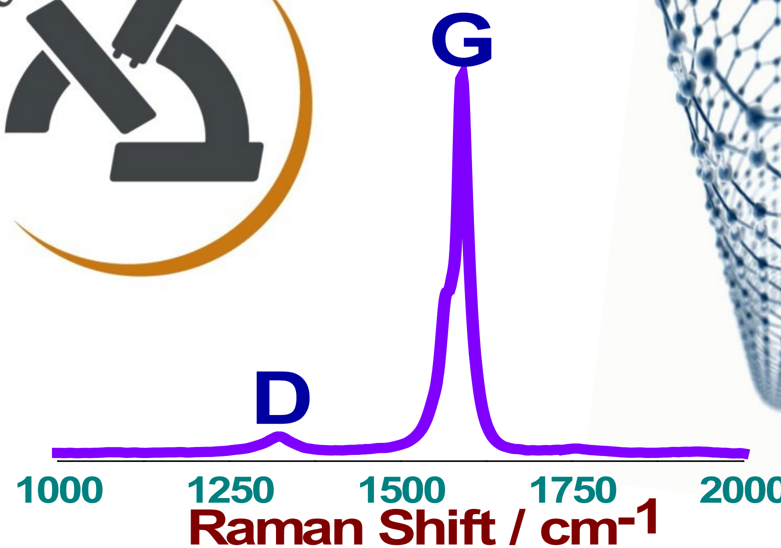


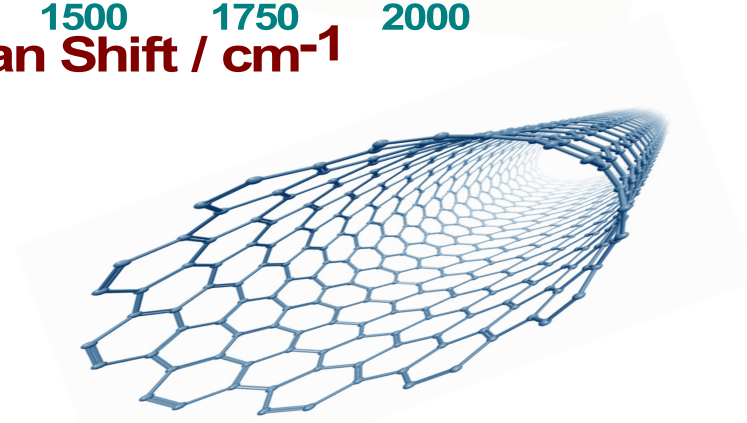
Single-Wall Carbon Nanotubes Doping in Lead-Acid Batteries:

A New Horizon

Tradition of Excellence

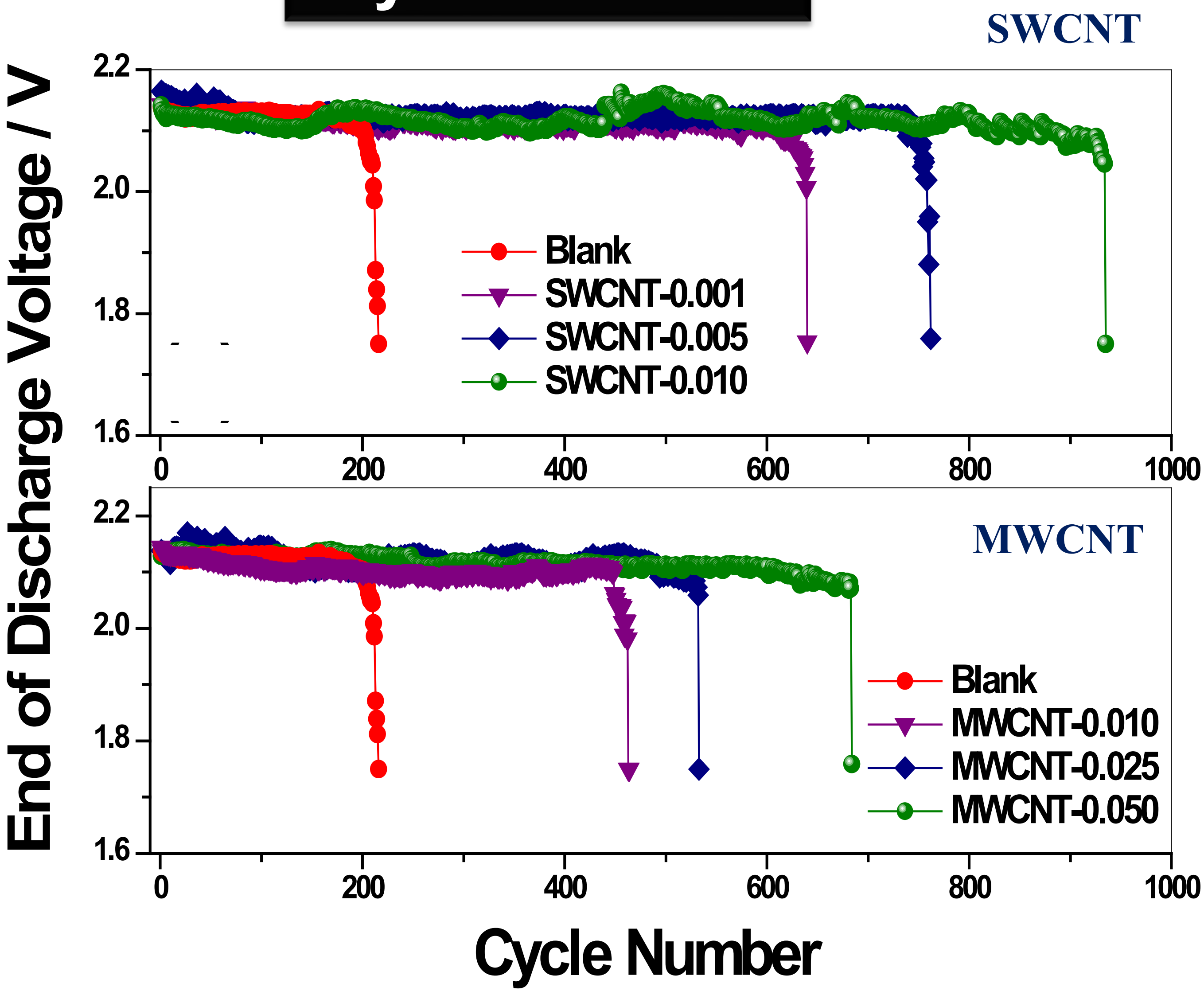






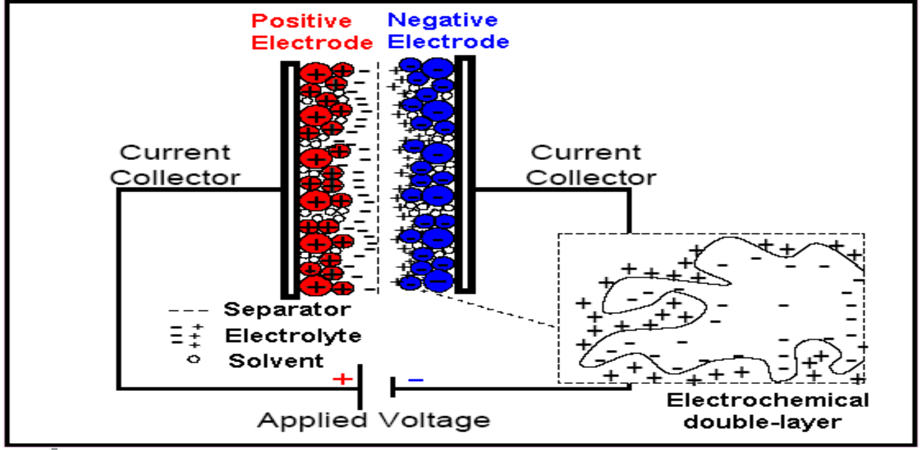
D. Aurbach et. Al, ACS Applied Materials & Interfaces, 2016

Cycle-life tests



Life-cycle data for two-volt flooded lead-acid cells with and without CNT additives.

Symmetrical super-capacitors
Activated carbon electrodes

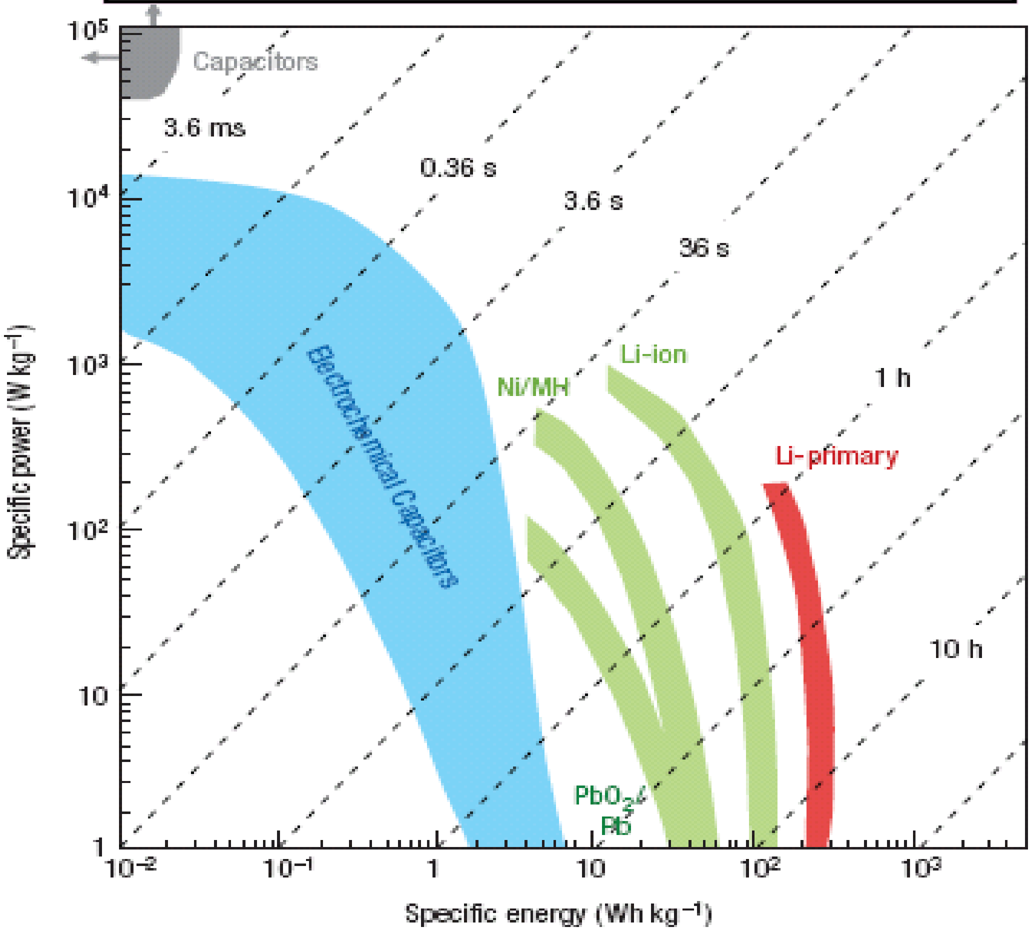


$$C = \frac{A\,\varepsilon_0 \varepsilon_r}{d}$$

A= Surface area, very high in AC

d= Dielectric thickness, single solvent molecule.

ε_r =limited by the solvent properties.



Possible electrolytes:

1. **Aqueous electrolyte, high rates small ions high ionic conductivity, limited voltage.**
2. **Organic electrolyte, moderate conductivity and capacity up to 3V.**
3. **Ionic liquids- Low conductivity, lower capacity, high voltage, safe.**

The preparation of cheap, monolithic carbon electrodes

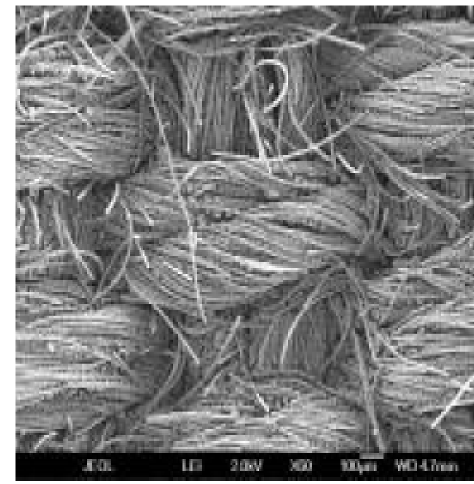
Jeans cloth

carbonation
anaerobic heating
> 500 ^{0}C

Carbon cloth

activation
CO_2 at 900 ^{0}C

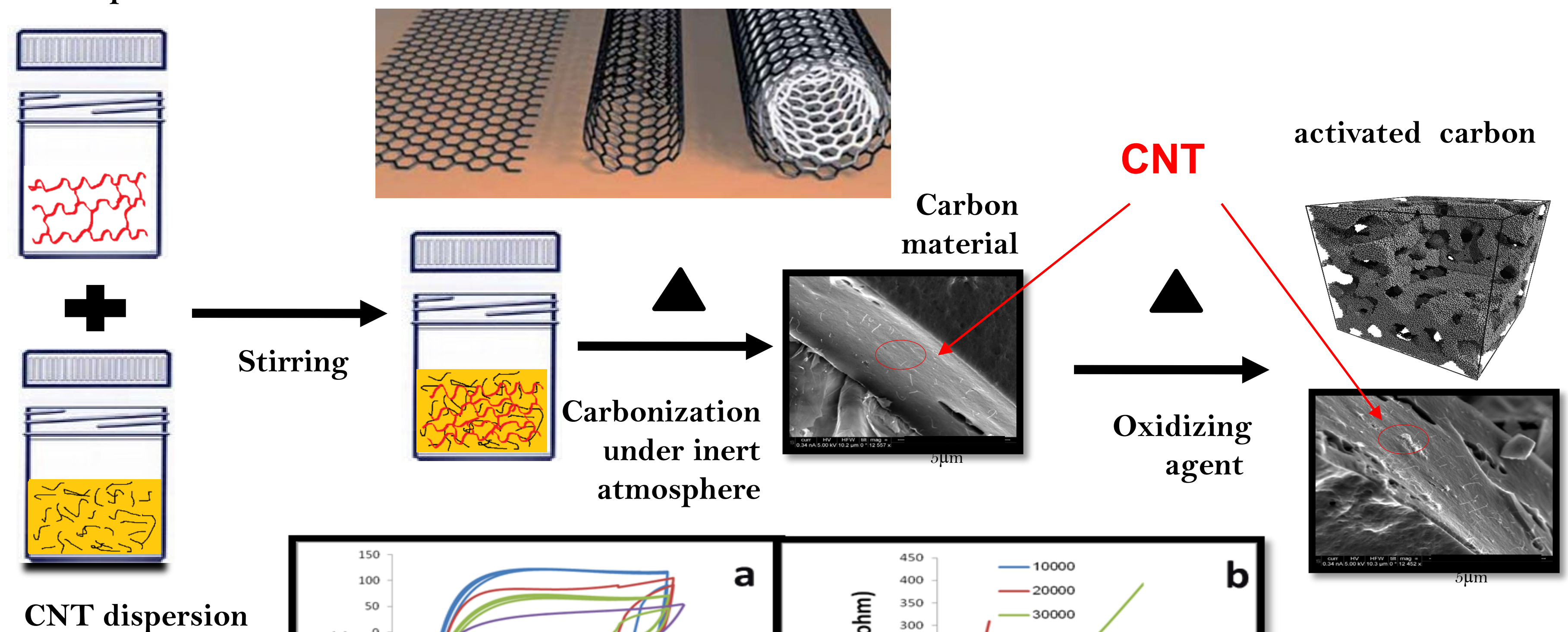
Porous carbon cloth electrode
High surface area (~1500-2000 m^2/g BET)



monolithic activated carbon cloth

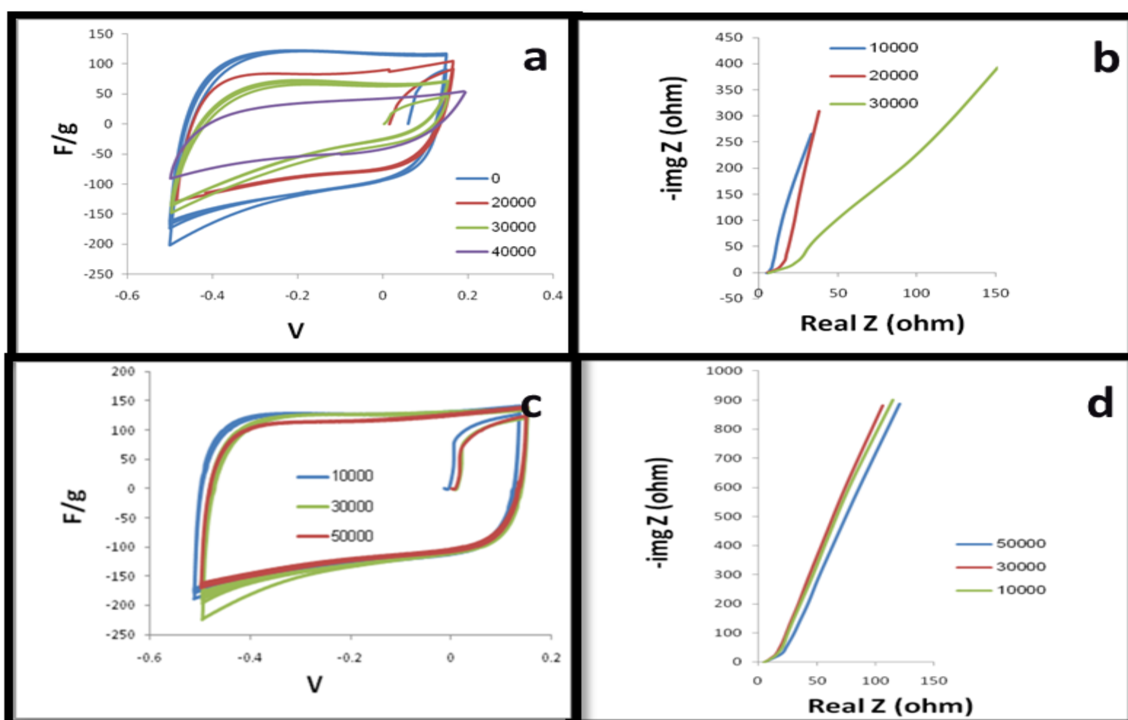
The material keeps its fibrous morphology,
although it lost 85% weight

Very stable electrodes for super-capacitors: activated carbon + CNT



Regular activated carbon electrodes
Glvanostatatic cycling
CV every 10000 cycles

Carbon electrodes containing CNT
Very stable cycling: many ten thousands of cycles, no fading

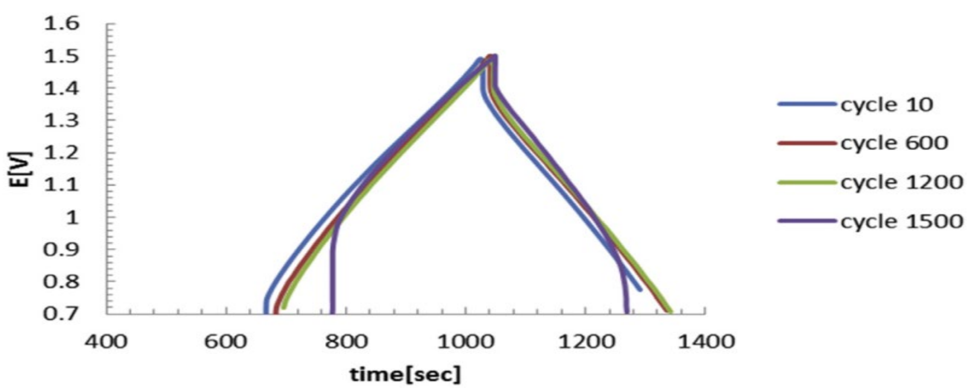


Impedance spectra reflect very stable behavior of CNT containing activated carbon electrodes

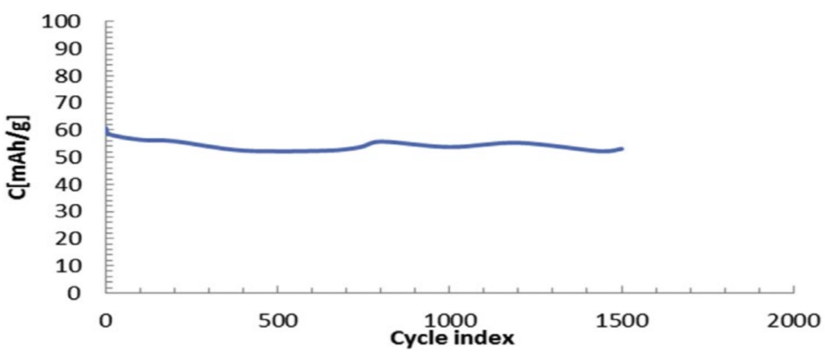
Aqueous energy-storage cells based on activated carbon and $LiMn_2O_4$ electrodes, Ortal Hanna, Shalom Luski, Thierry Brousse , Doron Aurbach, Journal of Power Sources 354 (2017) 148-156

Two electrodes measurements - 1500 cycles, capacity retention of 10%, columbic efficiency of 99.1%, 60mA.cm^{-2} ,mass loading of 7mg.cm^{-2}

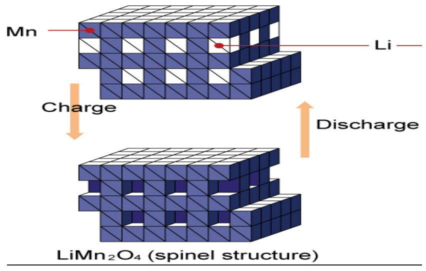
a. Voltage profiles



b. Cycle Stability



- After prolonged cycling the voltage profile exhibits some potential drop and the equivalent series of resistance is higher than measured initially. This means side reactions develop gradually and become significant after prolonged cycling.



Conclusions:

1. Electro-mobility : not a dream! It is real by advanced Li ion batteries. We have now a solid ground: graphite anodes + Ni rich $LiNi_xCo_yMn_yO_2$ ($x \rightarrow 1$) cathodes. We can promise long distance driving.

2. H_2/O_2 fuel cells are becoming highly important power sources for electro-mobility. Major challenges: high durability and cost effective catalysts & membranes.

3. Next great challenge: Large energy storage for grid applications. We can offer very good battery technologies. A key issue – using devices based on most abundant elements.

4. Israeli science and technology can contribute a lot to fields of energy and power sources for both electro-mobility and load-leveling, grid applications.

5. We hope that our developments will promote elaboration of creative Israeli energy industry that will provide global solutions for off-grid populations.

Thank you very much for your kind attention.