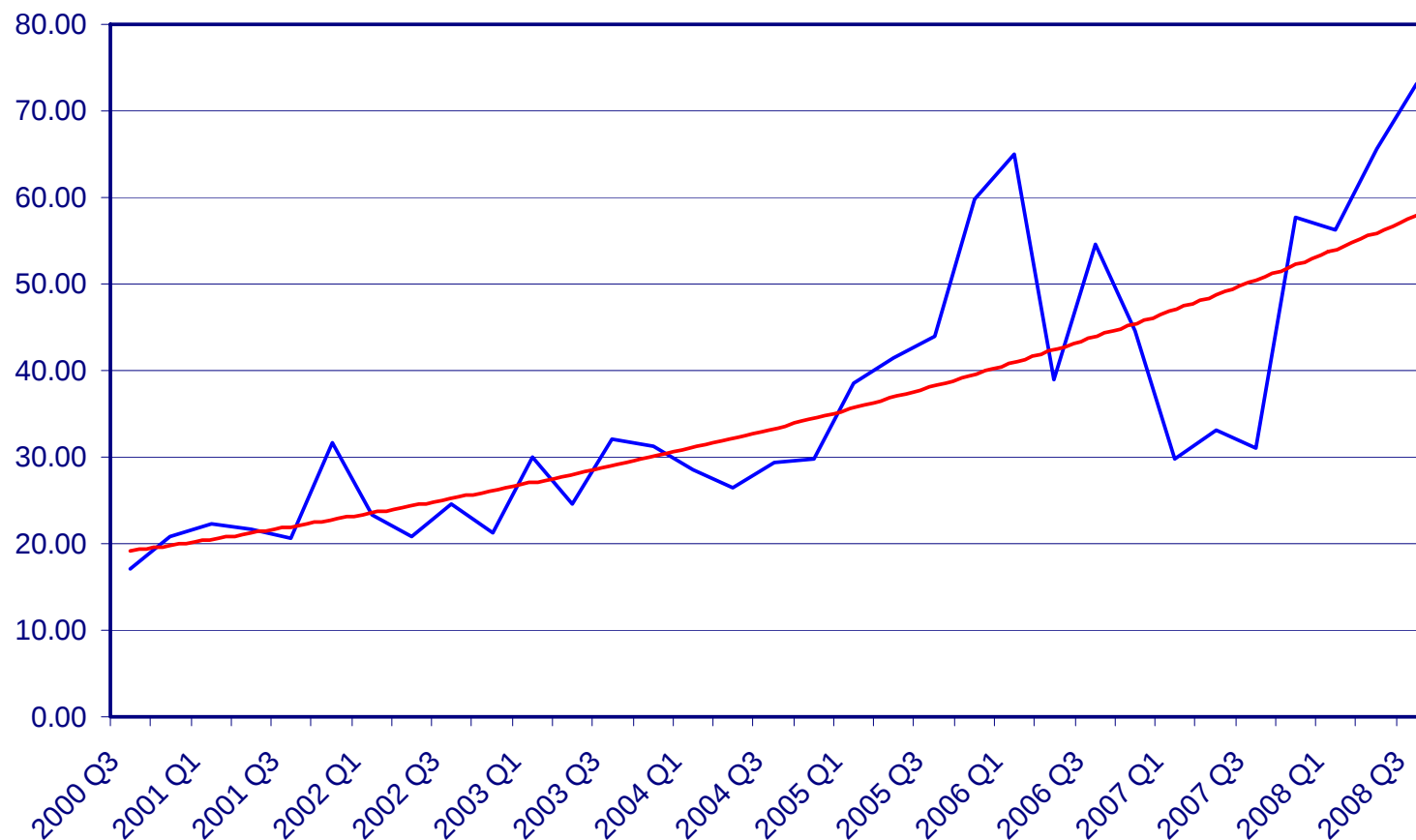


TROLLEYMOTION
18-19 November 2008
Zürich

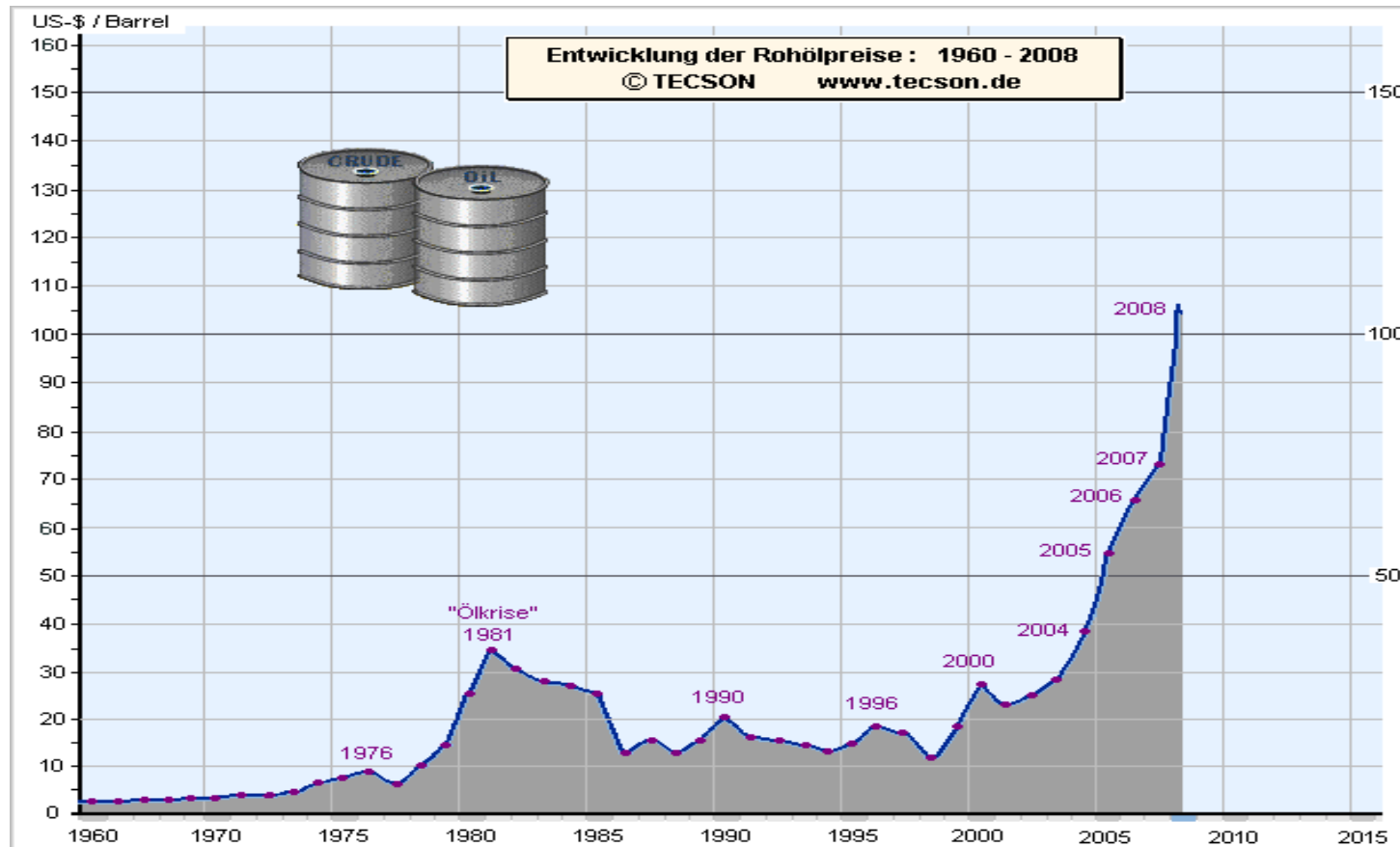
Maxwell
TECHNOLOGIES

What about electricity prices?

EEX Electricity Price Average in €/MWh



Source: European Energy exchange



Source: Tecson

Prices increase over the period 1965–2008:

9% per year

Prices increase over the period 2001–2008:

25% per year



- Founded in 1965
- 370 Employees
- Revenue \$58mil (2007)
- Listed on Nasdaq – Symbol: MXWL
- Locations in San Diego, CA and Rossens, Switzerland



- 1992 Maxwell starts development of Ultracapacitors
- 1995 Maxwell introduces first large Ultracapacitors
- 1997 Montena starts development of Ultracapacitors
- 2000 Montena introduces first Ultracapacitors to market
- 2002 Fusion of Maxwell and Montena
- 2004 Maxwell produces own, proprietary Electrode
- 2005 Maxwell becomes supplier of proprietary Electrode
- 2007 Production starts in China



Rossens, CH

ISO 9001
ISO 14001
ISO/TS 16949



San Diego, USA



ISO9002, ISO14001

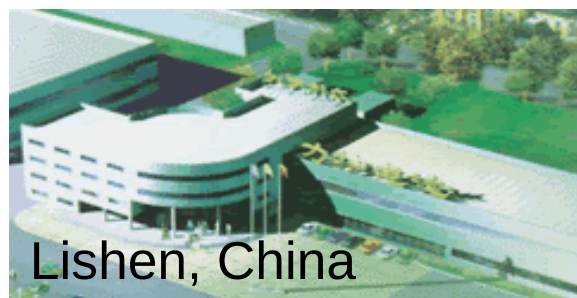
ISO 9001, ISO/TS 16949



Belton Group, China



ISO 9001, ISO 14001, QS9000



Lishen, China

ISO9002



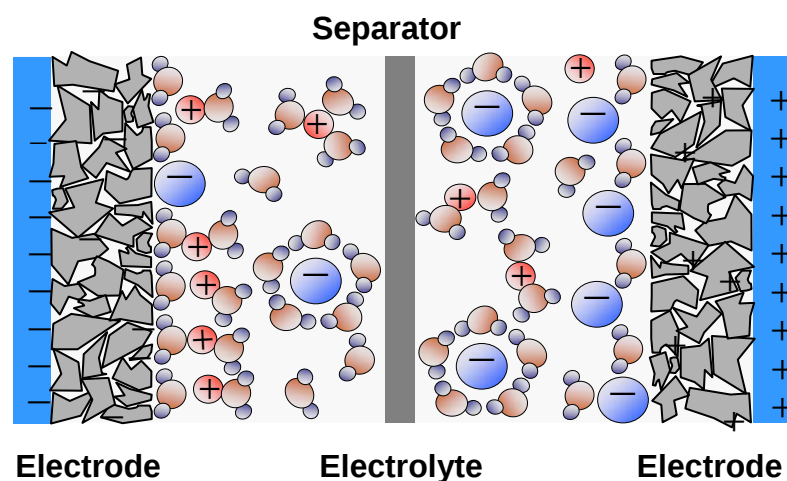
YEC, China

What is a supercapacitor?

Ultracapacitor technology



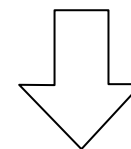
Grind / Activation / Coating / Rolling / kneading / Pasting



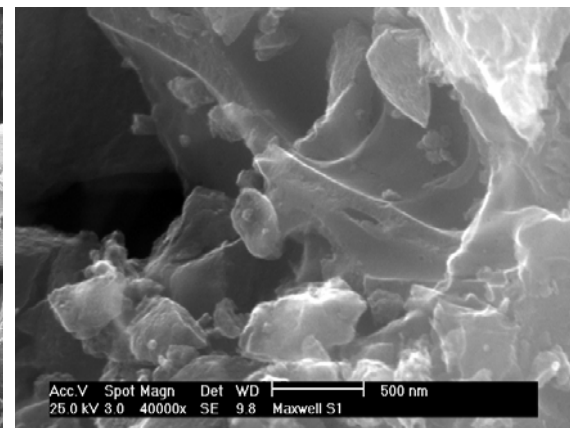
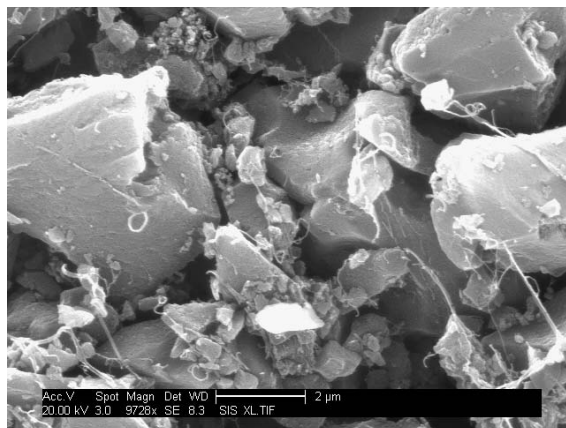
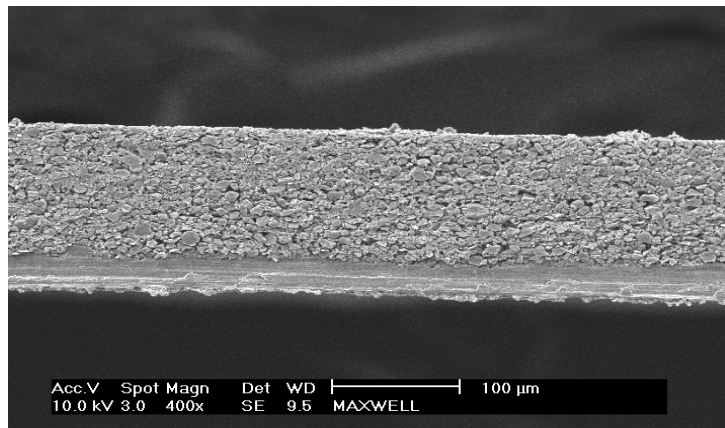
$$\text{Capacitance} \sim \frac{\text{Surface area}}{\text{Thickness}}$$

Thickness of Helmholtz layer ~ 1nm

Carbon powder surface area
up to 3,000m²/g

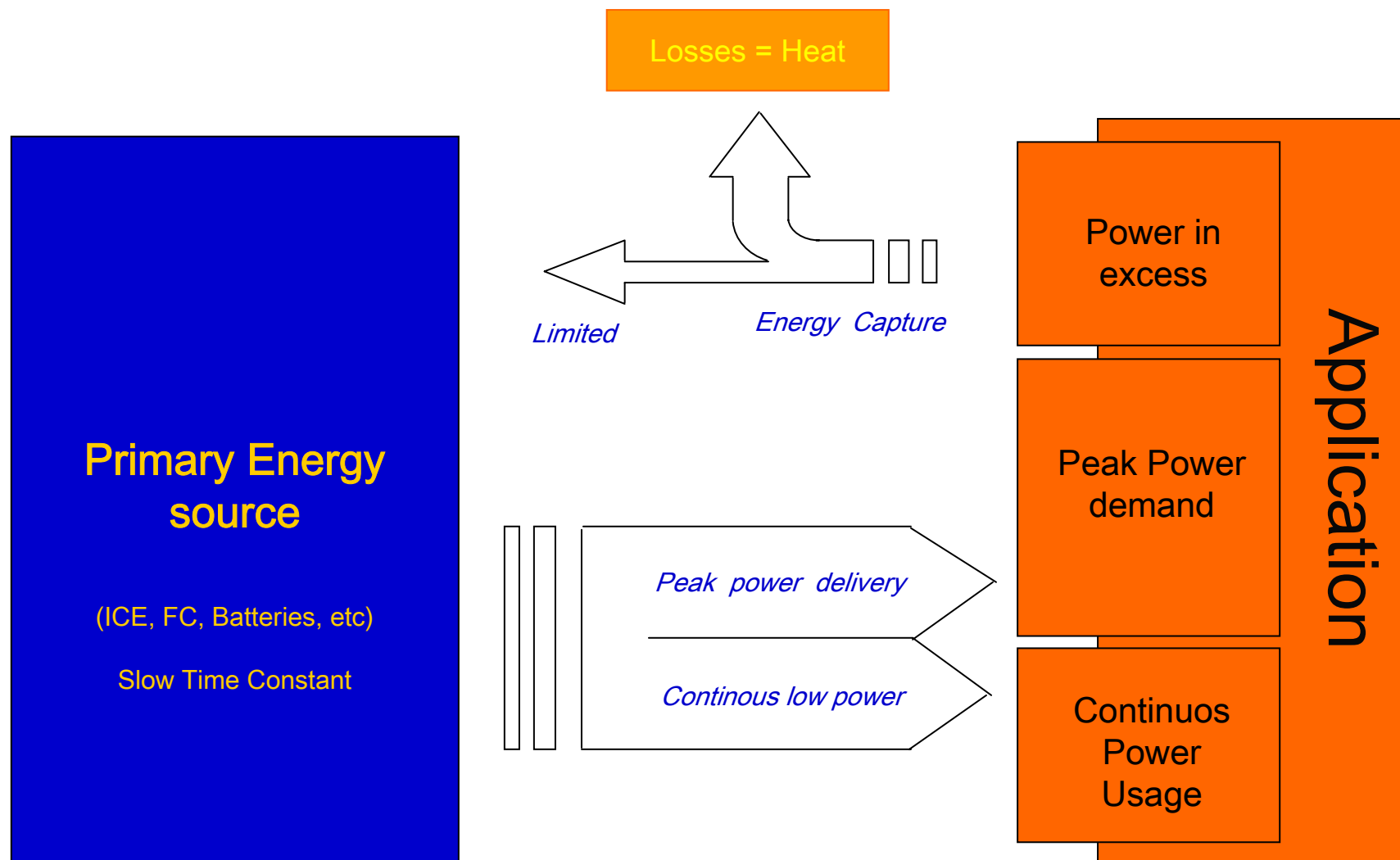


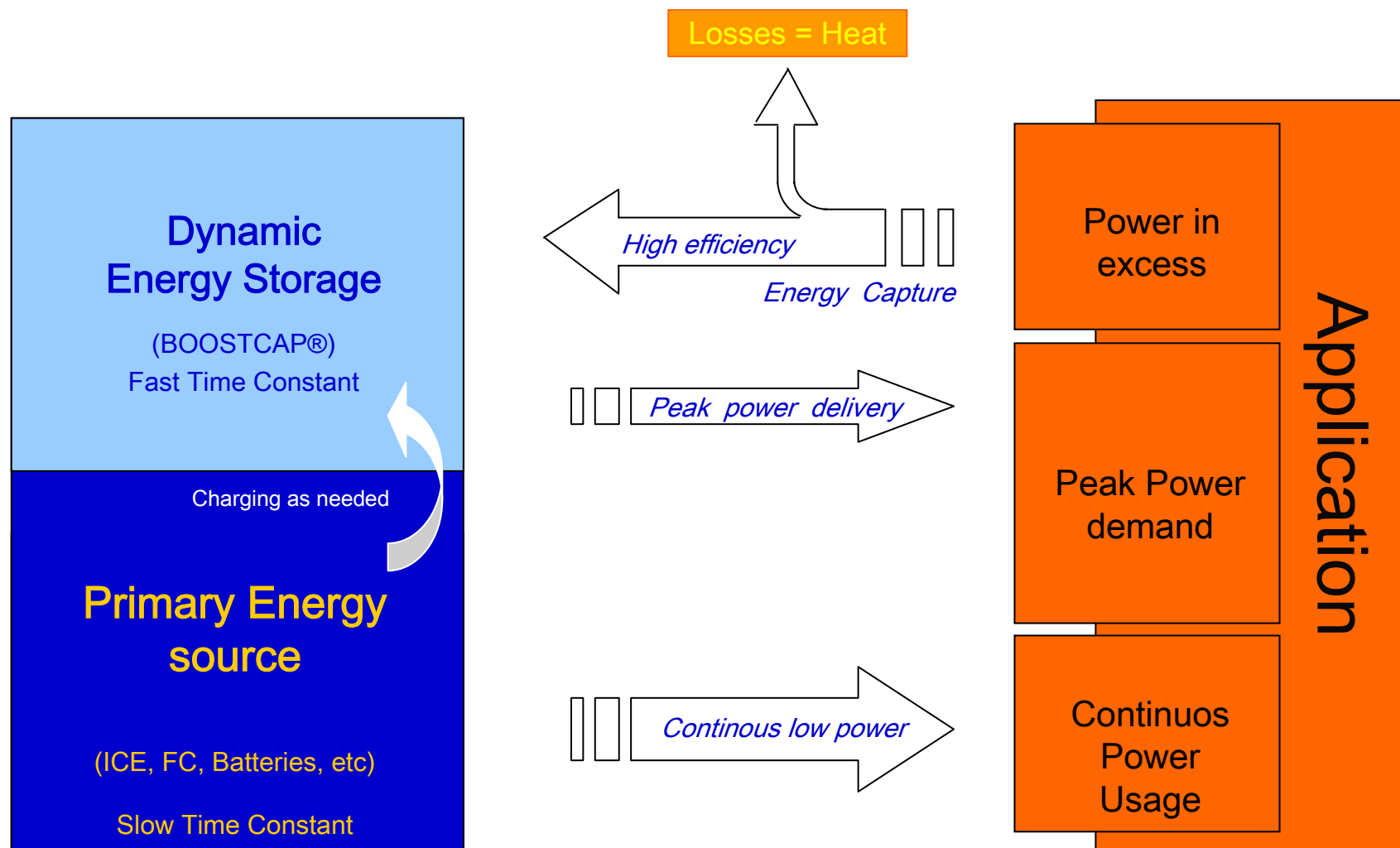
Capacitors up to 3,000F



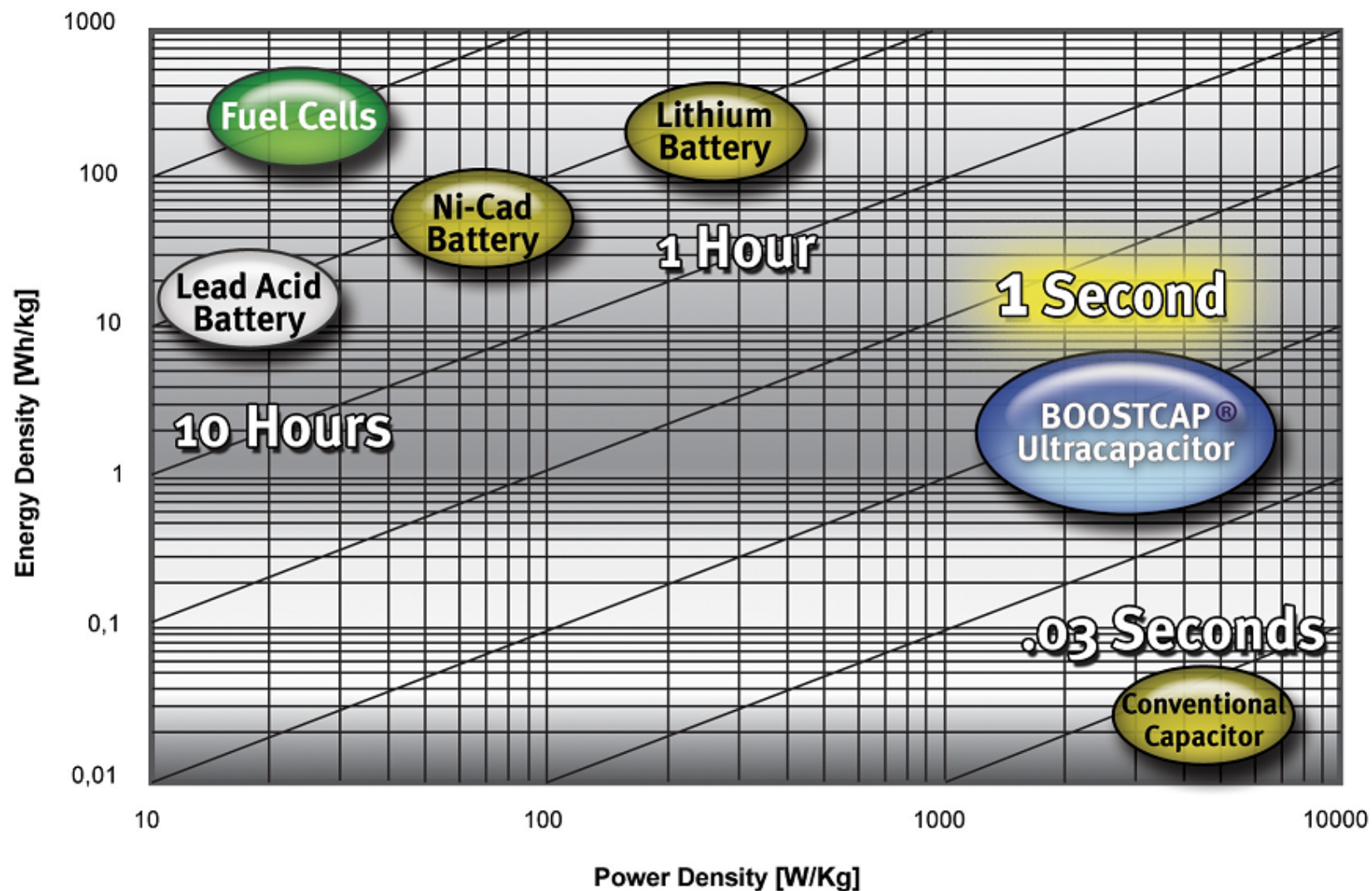
	Size	Scaled	
Carbon electrode	100 μm	10 km	Mt. Everest 
Carbon particle	5 μm	500 m	Petronas Towers 
Micro-pores	2 nm	20 cm	Bucket 
Ions	0.7 nm	7 cm	Grapefruit 
Inter-atomic dist.	0.2 nm	2 cm	Cherry 

Why using supercapacitor?





Ultracapacitor vs Battery



Cycling capabilities Ucap's Vs Batteries

Lead acid



3'000 load cycles (20% DOD)

Nickel Cadmium



10'000 load cycles (40% DOD)

Lithium Ion



20'000 load cycles (40% DOD)

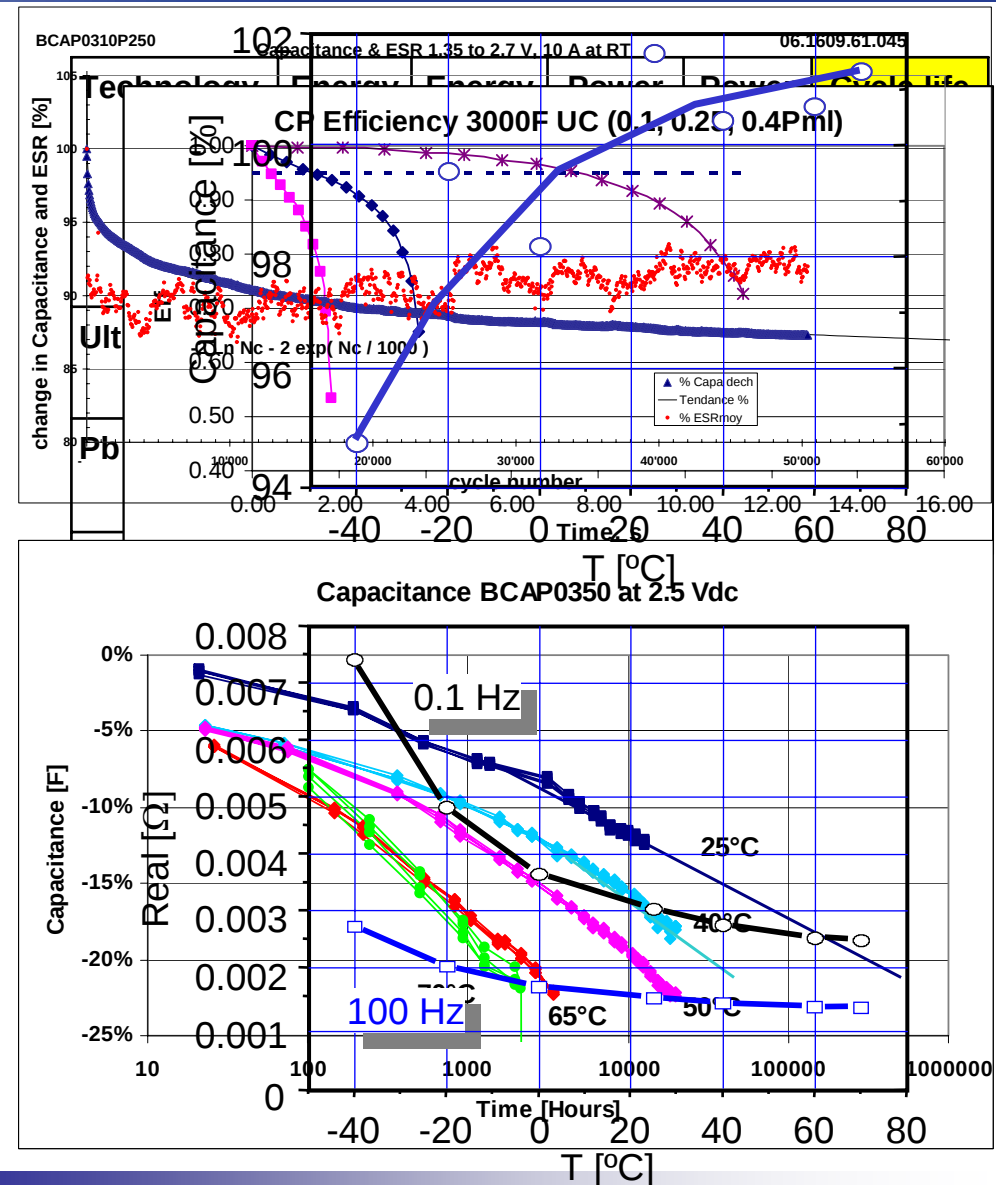
Ultracapacitors



More than

1'000'000 load cycles (75% DOD)

- Excellent power density
- Highly efficient energy transfer
- High durability and lifetime
 - 1 Mio cycles
 - 10 years lifetime
- Stable performance over large temperature range
- Cost effective



Heavy Transportation Module
HTM125



MC Line 650F to 3000F



PC Line - From 2F to 10F



48 V Module Series



BC Line 140F to 350F

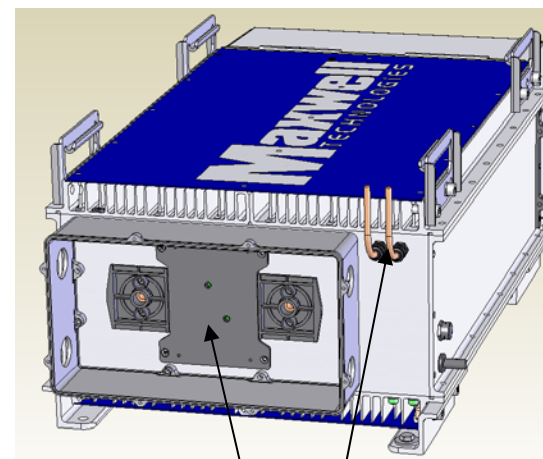
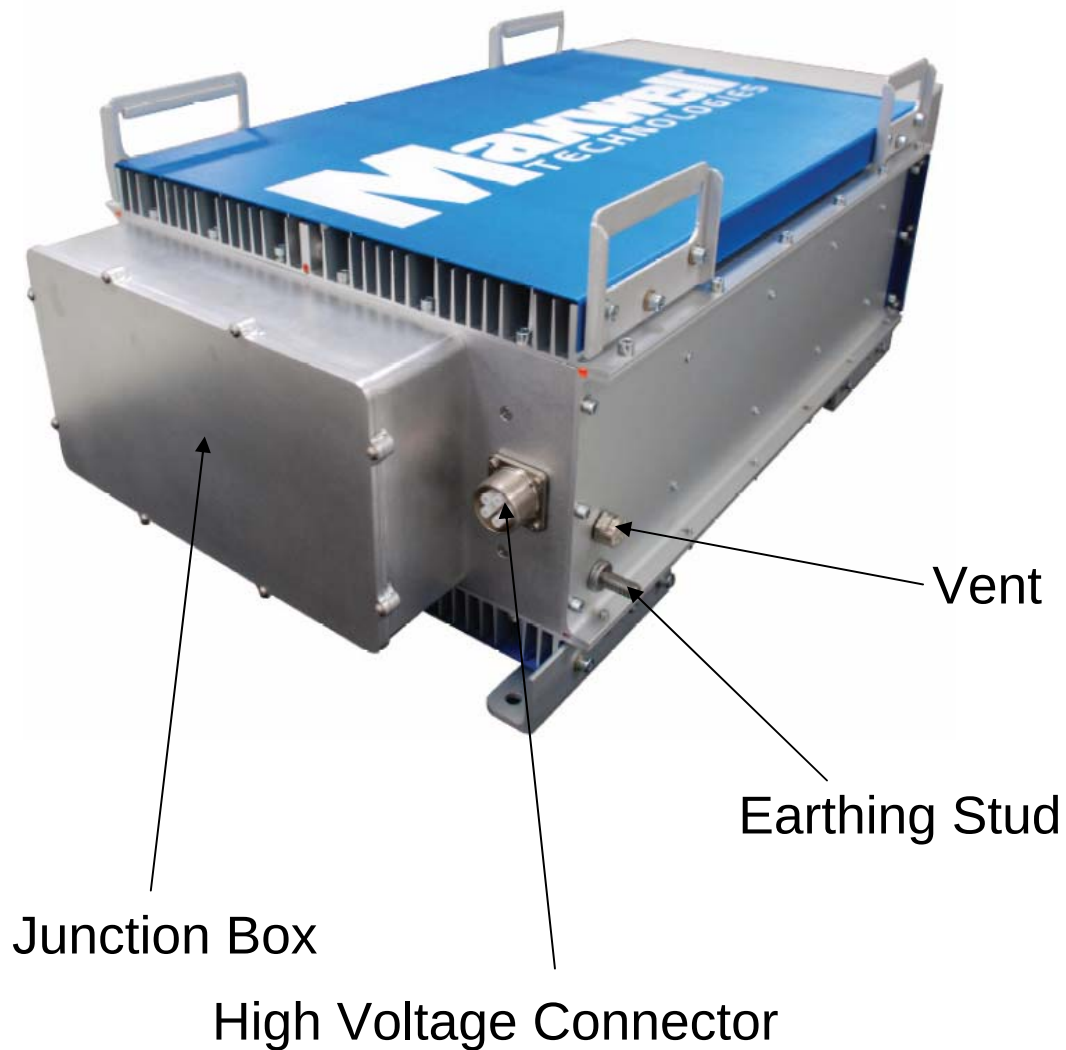


Wind Mills 75V Module



16 V Modules Series

15 V Modules and Packs



CAN

More than one million charge/discharge cycles

- Long life of the module that reduces down time and total cost of ownership

IP65 compliance, high grade components

- Dust and splash proof, resistance to harsh conditions
- Designed and tested for SAE J1455, J2380 and EN61373

Uncompromised safety

- Designed and tested for 4000VAC isolation voltage
- Junction box preventing accidental contact with power elements

Trolleybus and supercapacitors?

A question of efficiency

Von Siemens (1882)



Von Helmholtz (1879)



Van Hool / Vossloh Kiepe / Maxwell (2008)



Trolleybus efficiency is not to prove, but end-users still face challenges

- Control of energy flux within a delimited electrical network
=> **Grid stabilisation**
- Mitigation of visual impact and autonomous vehicle
=> **Overhead line free run**



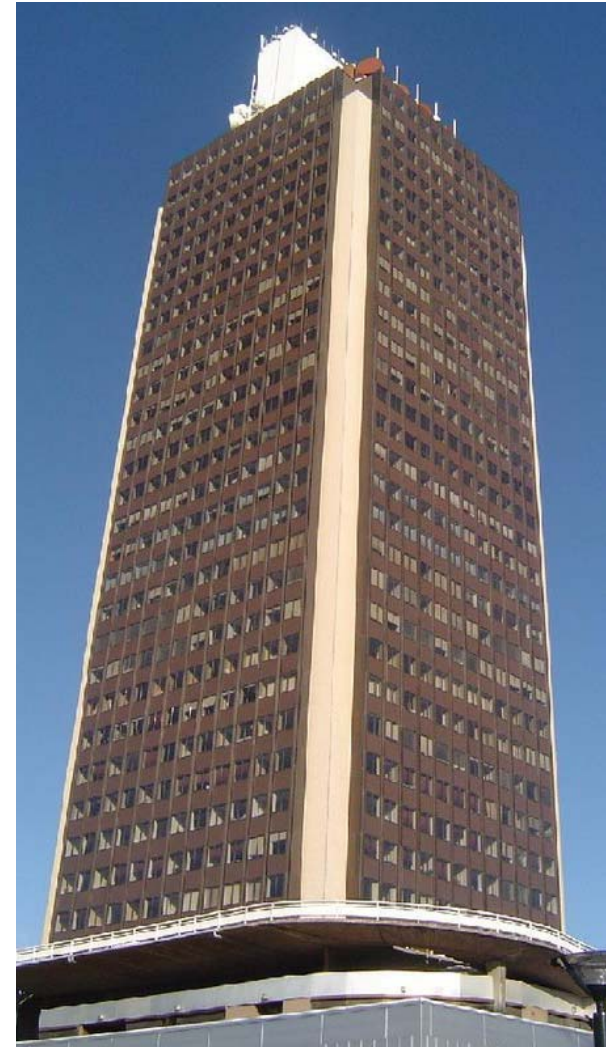
Source: EDF



Recuperating 80% of the kinetic energy of a 15 tons bus running at 20km/h (average city bus speed), represents the energy necessary to lift a piano of 200kg to the top of a 30 floor building within a few seconds!

Peaks due to absorption or restitution of the kinetic energy introduce instability in the voltage grid.

To reduce or avoid those, the energy must be transferred rapidly. It can be either burnt (looses) or recuperated and reused in energy storage.



Substation solution from Siemens (Sitras, in function since 2003) for trams shows following reductions:

- Energy consumption up to 30%
- Peak power demand up to 50%

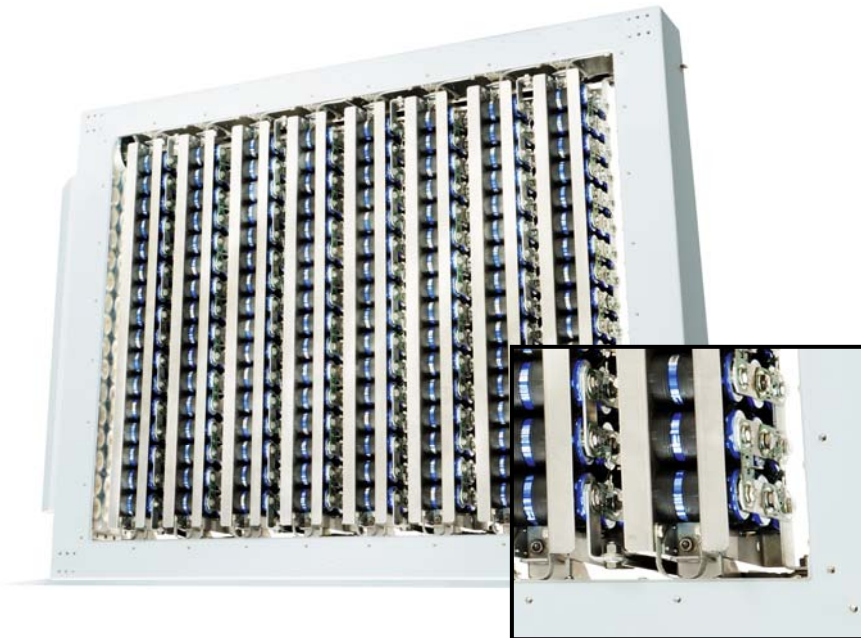
Other advantages

- More trains in the same network
- Less sub-station (factor 1.7)



Supercaps can be used to join 2 stops without using the pole. With a well designed supercaps system, the trolleybus can run up to 500m (or more) on its embedded energy source.

- mitigation of overhead lines and switches visual impact
- temporary re-routing

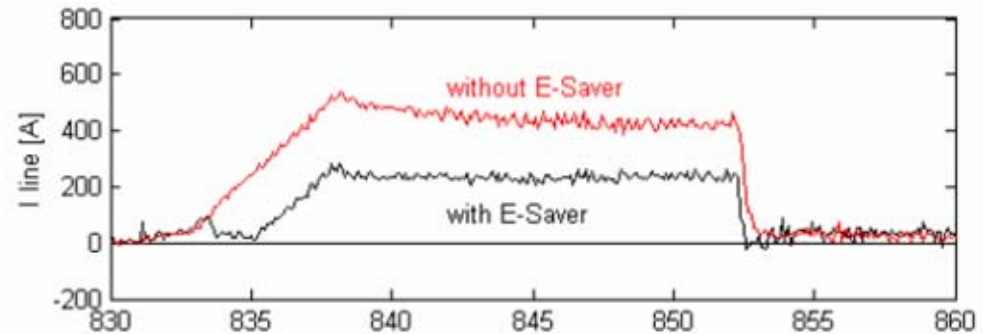


BCAP3000 based Bombardier DMU Mitrac system

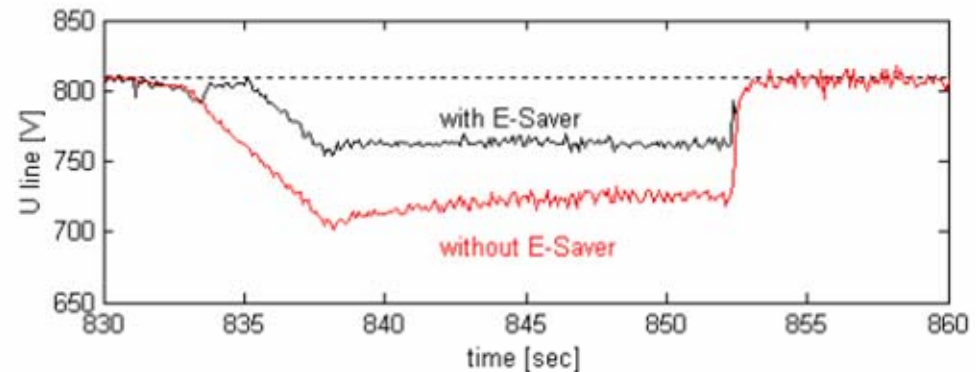


HTM125 based Siemens Sitras® mobile

Drastic reduction of line power demand possible



Drastic reduction of line voltage drop



Advantages: On new lines, less substations
On existing lines, more vehicles

Source: Bombardier Transportation

Hybrid bus/trolleybus

- Production: Over 100 buses per year, 30'000 caps
- Ultracapacitor bus fleets in service since 2005



- Miland project



- First 24m double articulated hybrid bus







Volume and weight comparison



Battery compartment with lead batteries.
Total weight more than 300 kg



Battery compartment with Uc's module
Total weight less than 30 kg

Safety



Abuse Tolerance Tests HCN Measurement

- ☐ Hydrogen cyanide (HCN) released from ACN-based cells following O/V, O/T, & S/C abuse tests were measured at Sandia National Lab
- ☐ The observed readings are shown in the table below

<u>Gas Analysis Test Data</u>	<u>HCN Analysis (μg)</u>
Over Voltage Test #1	0.0139
Over Voltage Test #2	0.0244
Over Temperature #1	0.0124
Over Temperature #2	0.0340
Short Circuit #1	0.0000

A Worse Case Scenario

- ☐ 200 cells (~600V Max)
- ☐ 4 m³ volume of cabin space – Larger cabin advantageous
- ☐ Worse case emission of 0.034 μg of HCN per cell
- ☐ Total HCN emissions from pack 200x0.034 μg
- ☐ Emissions completely sealed & trapped in the cabin
- ☐ Passenger trapped in the cabin for 8-hours
- ☐ HCN concentration per cubic meter 200X0.034/4 $\mu\text{g}/\text{m}^3$
- ☐ NIOSH exposure index over 8 hours:

$$(200 \times 0.034 / 4) \times 8 = 13.6 \mu\text{g-hrs}/\text{m}^3$$
- ☐ Guideline exposure limit is 5,000 $\mu\text{g-hrs}/\text{m}^3$



14

ACN- or PC-Based Ultracaps?

- ☐ In light of recent findings, previous industry concerns over toxicity potential of ACN-based ultracaps are unfounded
- ☐ Given significant advantages of ACN over PC-based ultracaps, particularly in the area of power & cold-

Customer involuntary shortcut test



After changing melted connectors, the module was still fully functional!

Customer home made fire test



This one not...

Many thanks!

Fabrice Bugnon
Key Account Manager
Heavy Transportation Europe
fbugnon@maxwell.com