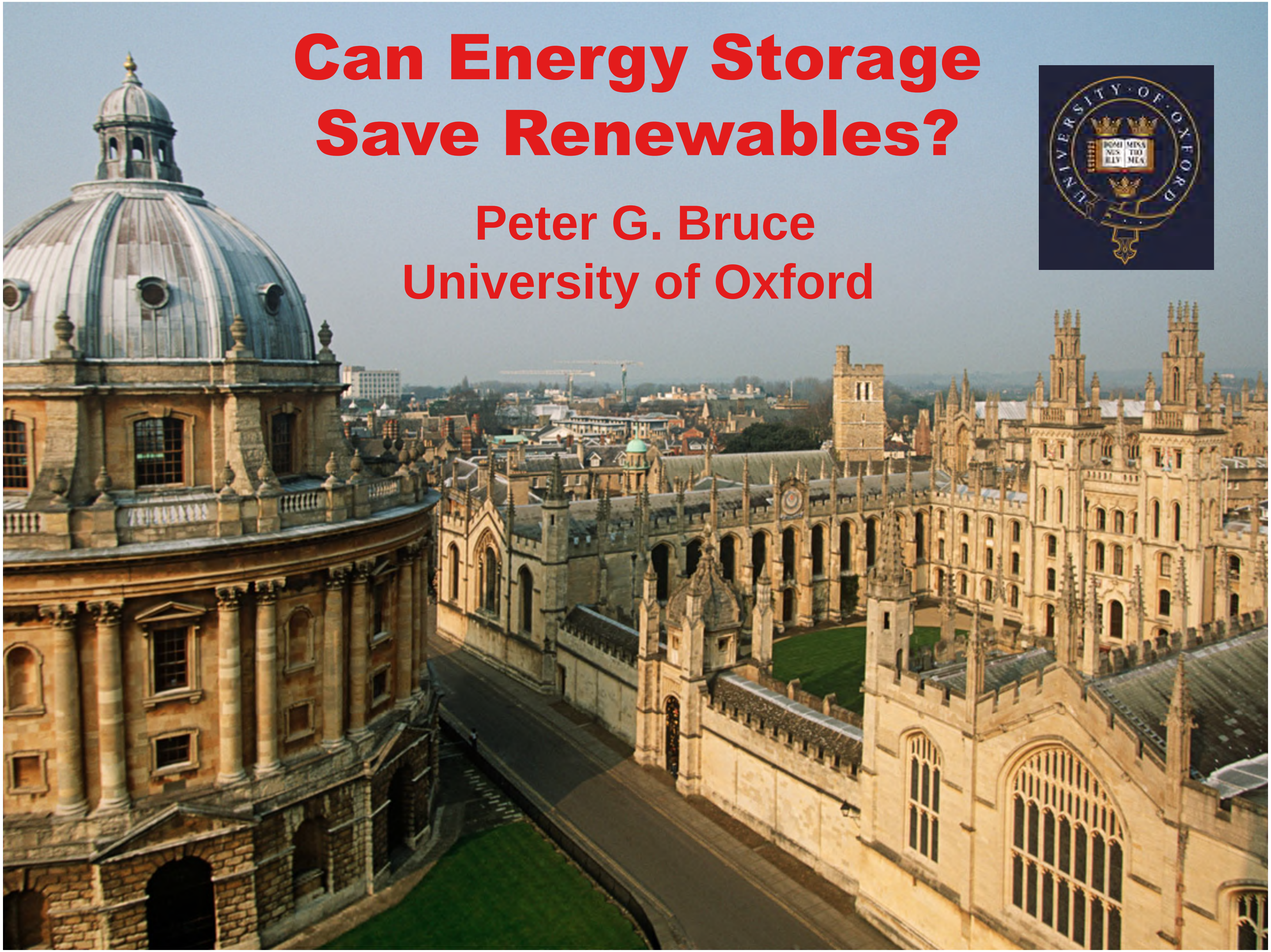
Can Energy Storage Save Renewables?

Peter G. Bruce
University of Oxford



Science in the 20th century

Nature of matter: atom→sub-atomic

Origin of the Universe: Big Bang

Molecular Biology: genetics

etc.

Science in the 21th century

Societal Challenges

- Food
- Water
- Diseases
- Global Warming / Energy

- Climate change – a challenge for science and technology
- New science, new ideas, new materials

Energy storage

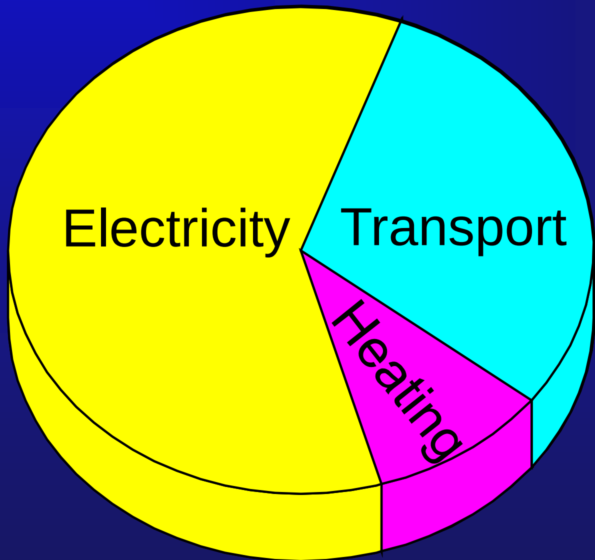
More important today than at any time in history

Portable electronics

Power tools

Medical applications

CO_2 emissions



Energy storage

More important today than at any time in history

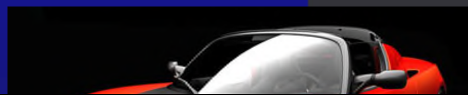
Portable electronics

Power tools

Medical applications

Electrification of transport

Electric
Plug-in
Hybrid



Electricity generation

Renewables

Solar

Wind

Wave

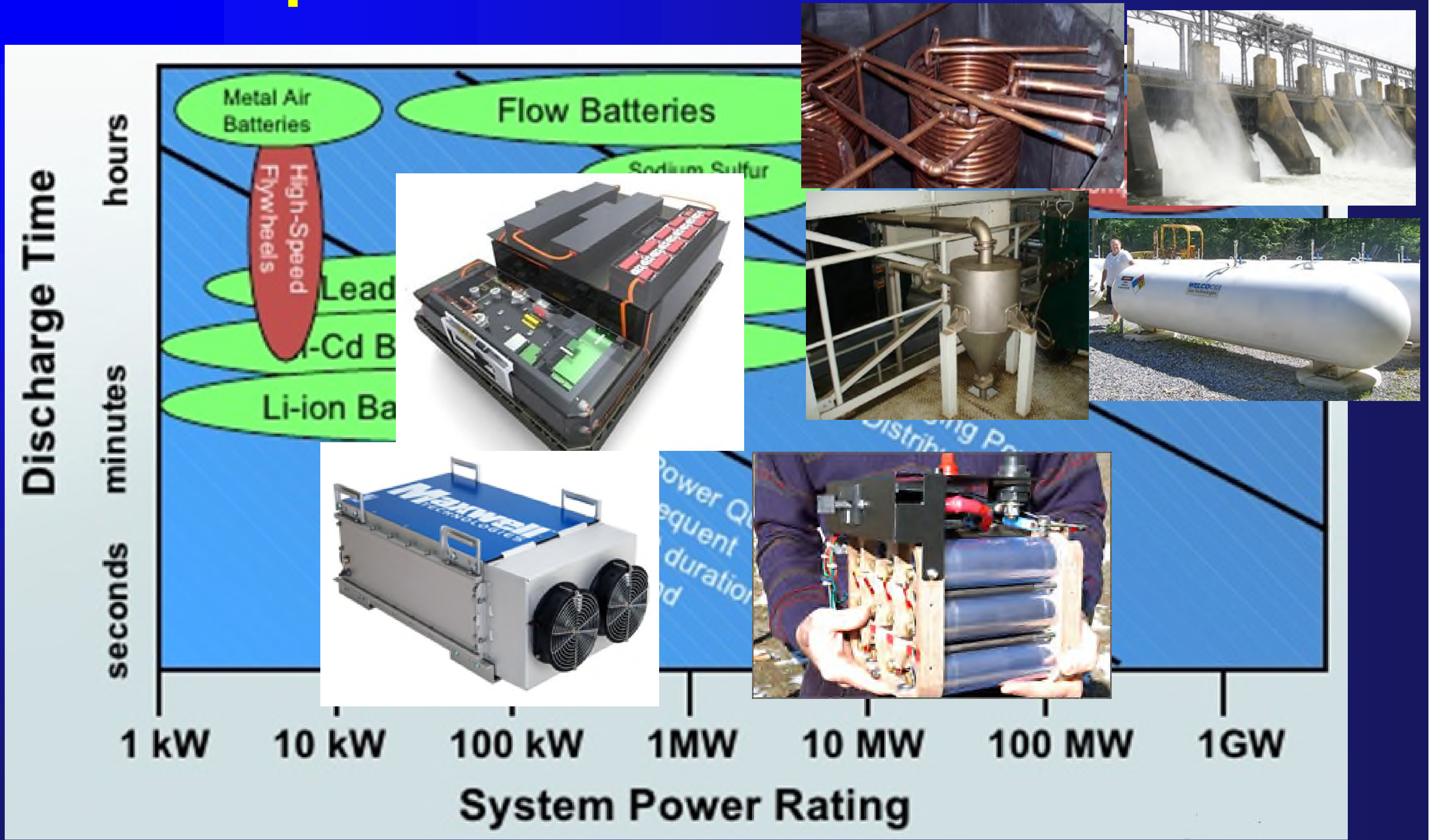
Interm

Nuclear

Continuous

VAST MARKET FOR ENERGY STORAGE
ELECTROCHEMICAL ENERGY STORAGE-BATTERIES

Storage on the Grid
a question of scale and time



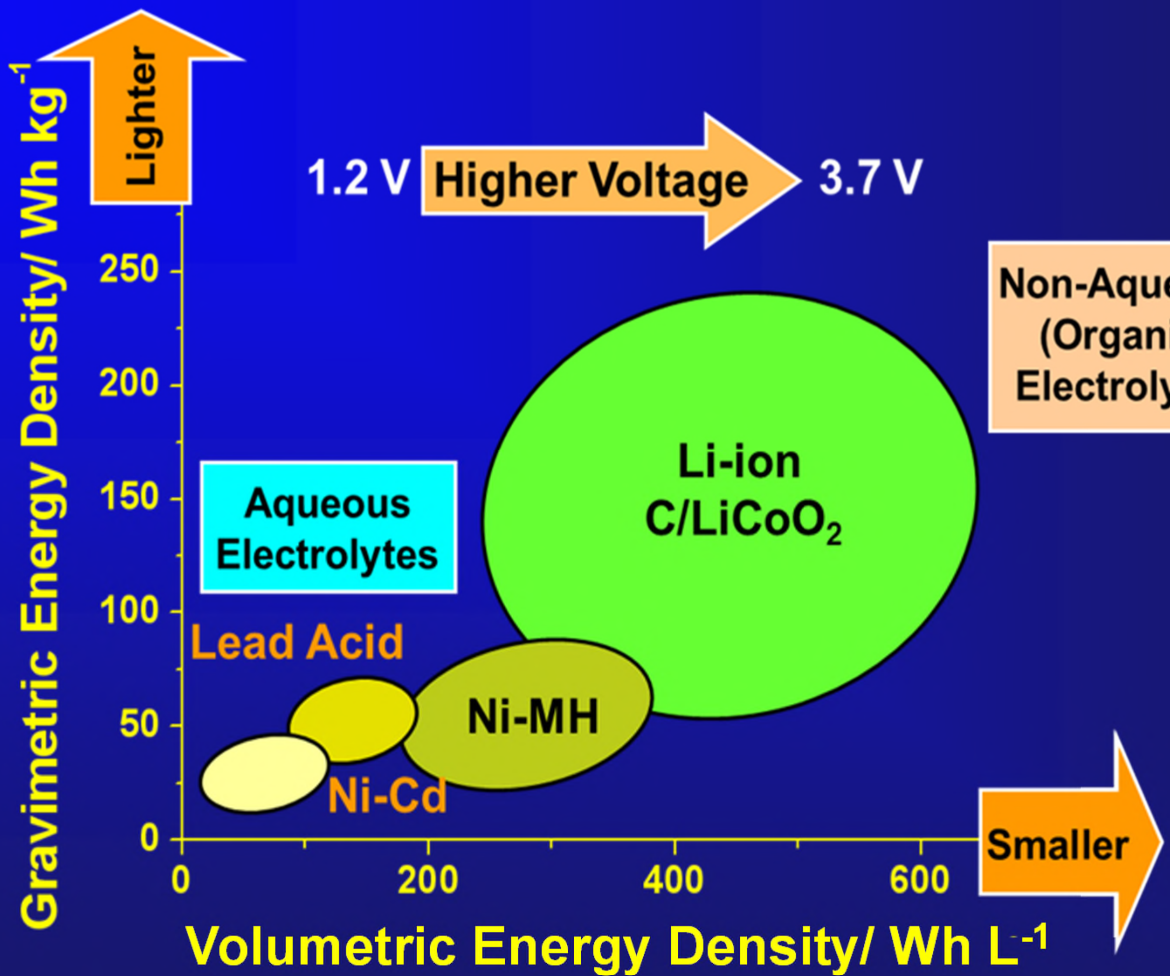
Why Lithium Batteries?

- Direct storage of electrons –

  - high efficiency even higher than convential batteries

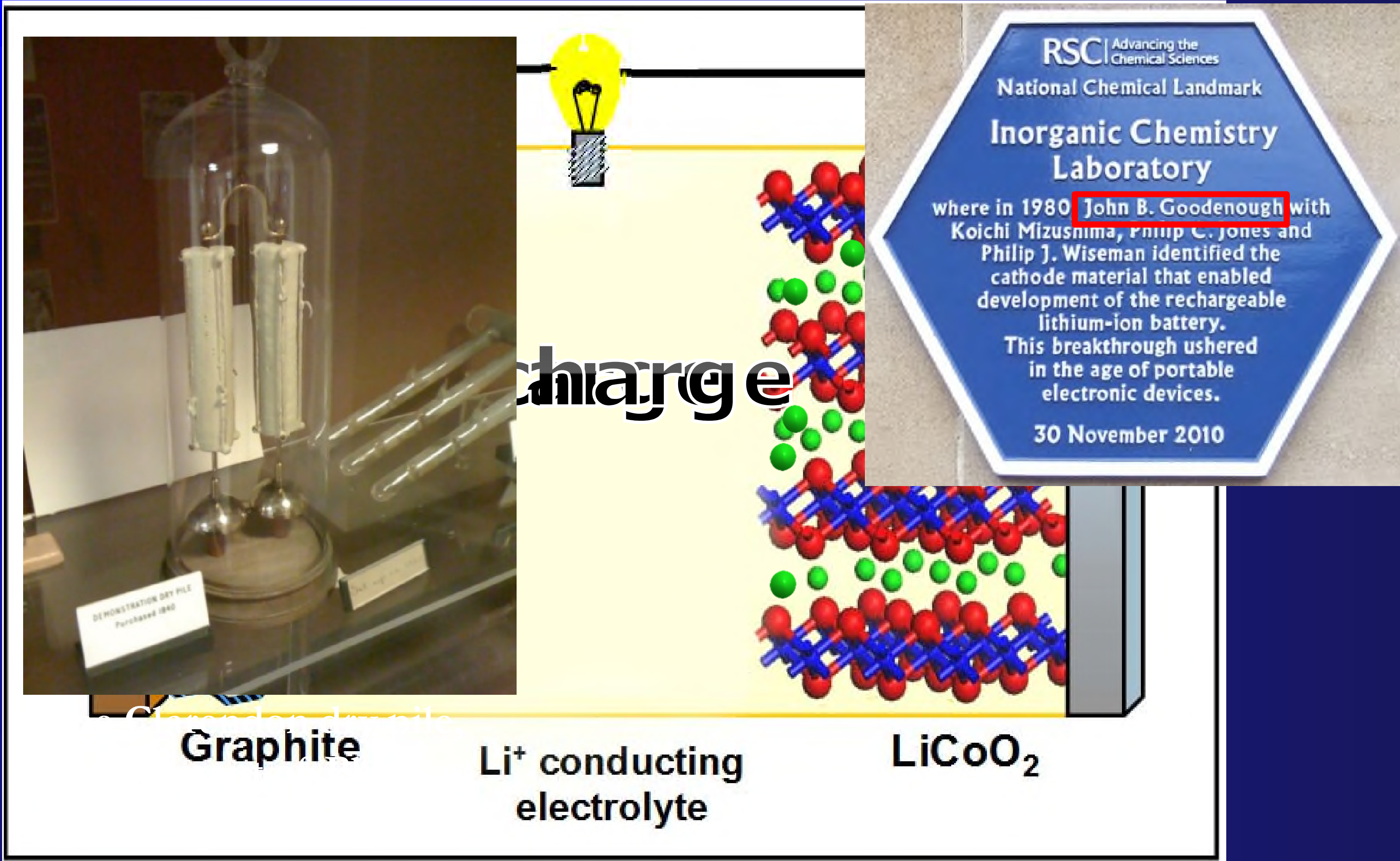
  → 100%
- Modular/scalable
- Store more energy per unit mass and volume than alternatives
- Green (no toxic heavy metals)
- They work
- Potential for advancement

Batteries in context



The Rechargeable Lithium Battery

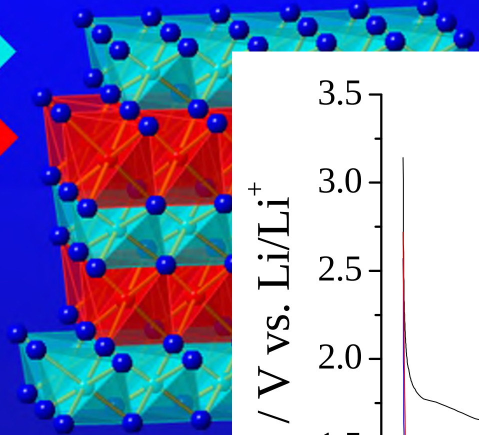
$ 20 billion industry **4 billion cells per year**



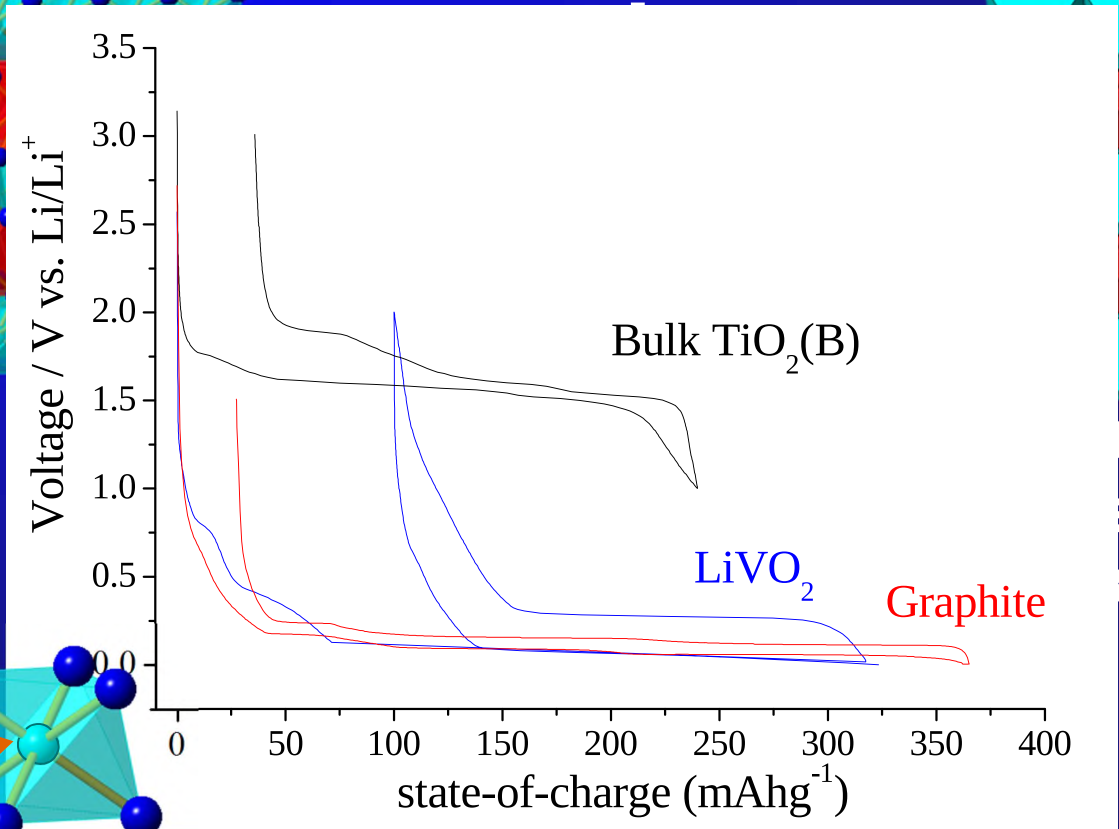
BUT STEP CHANGE ⇨ **new ideas, new science and new materials**

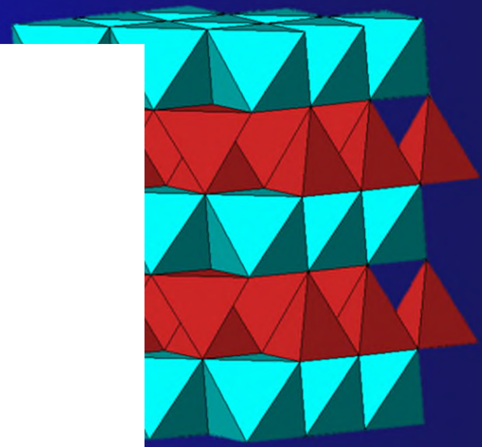
$LiVO_2$:
NEW NEGATIVE ELECTRODE FOR LITHIUM BATTERIES

Energy Density



$LiVO_2$
Cubic





O$_2$
agonal close
ked oxide

Same voltage as graphite BUT

twice the density → DOUBLE ENERGY DENSITY (volumetric)

A. R. Armstrong, C. Lyness, P. M. Panchmatia, M. S. Islam & P. G. Bruce, *Nature Materials*, March 2011

New positive electrodes: Li_2FeSiO_4

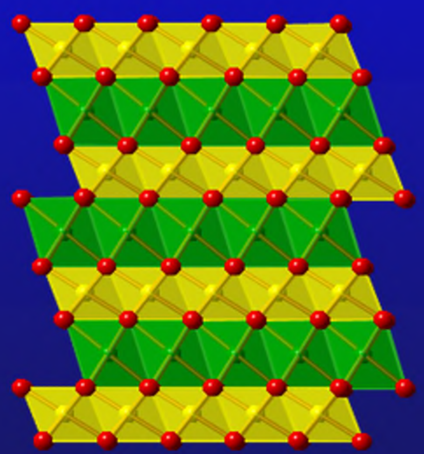
Cost + safety

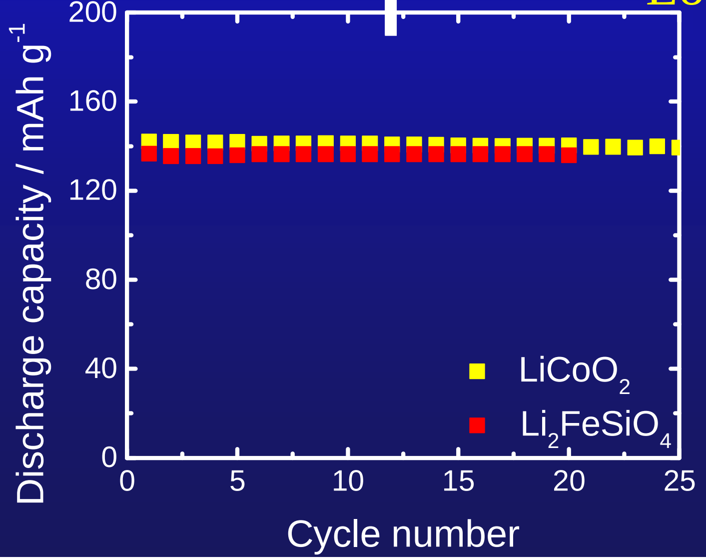
$LiCoO_2$	Li_2FeSiO_4
Expensive	made from rust Fe_2O_3 and sand SiO_2
Safety problems	Safe: oxygen locked into SiO_4
	Non-toxic
Limited availability	Available anywhere

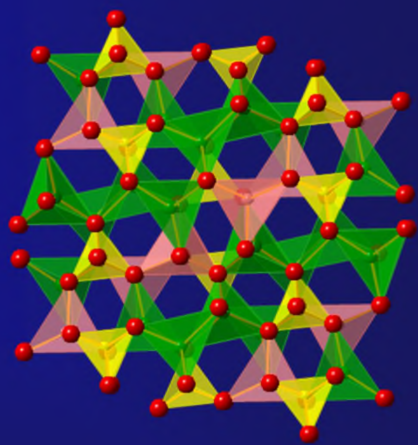
<u>Limitations:</u>

Lower voltage

Lower rate



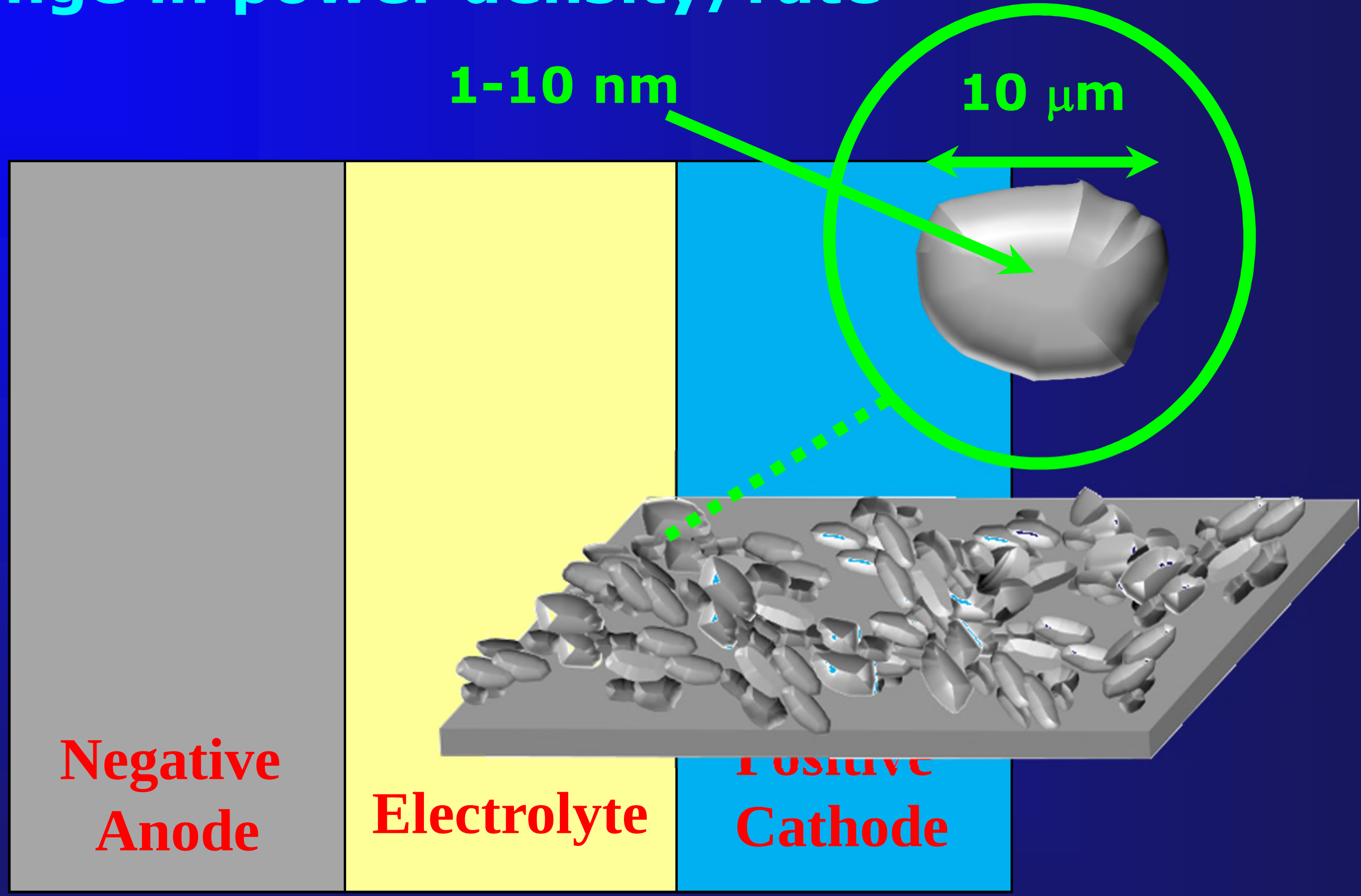




A.R. Armstrong, N. Kuganathan, M.S. Islam & P.G. Bruce, *J. Am. Chem. Soc.*, 2011

Nanostructured materials controlling nano size and shape

Step-change in power density/rate

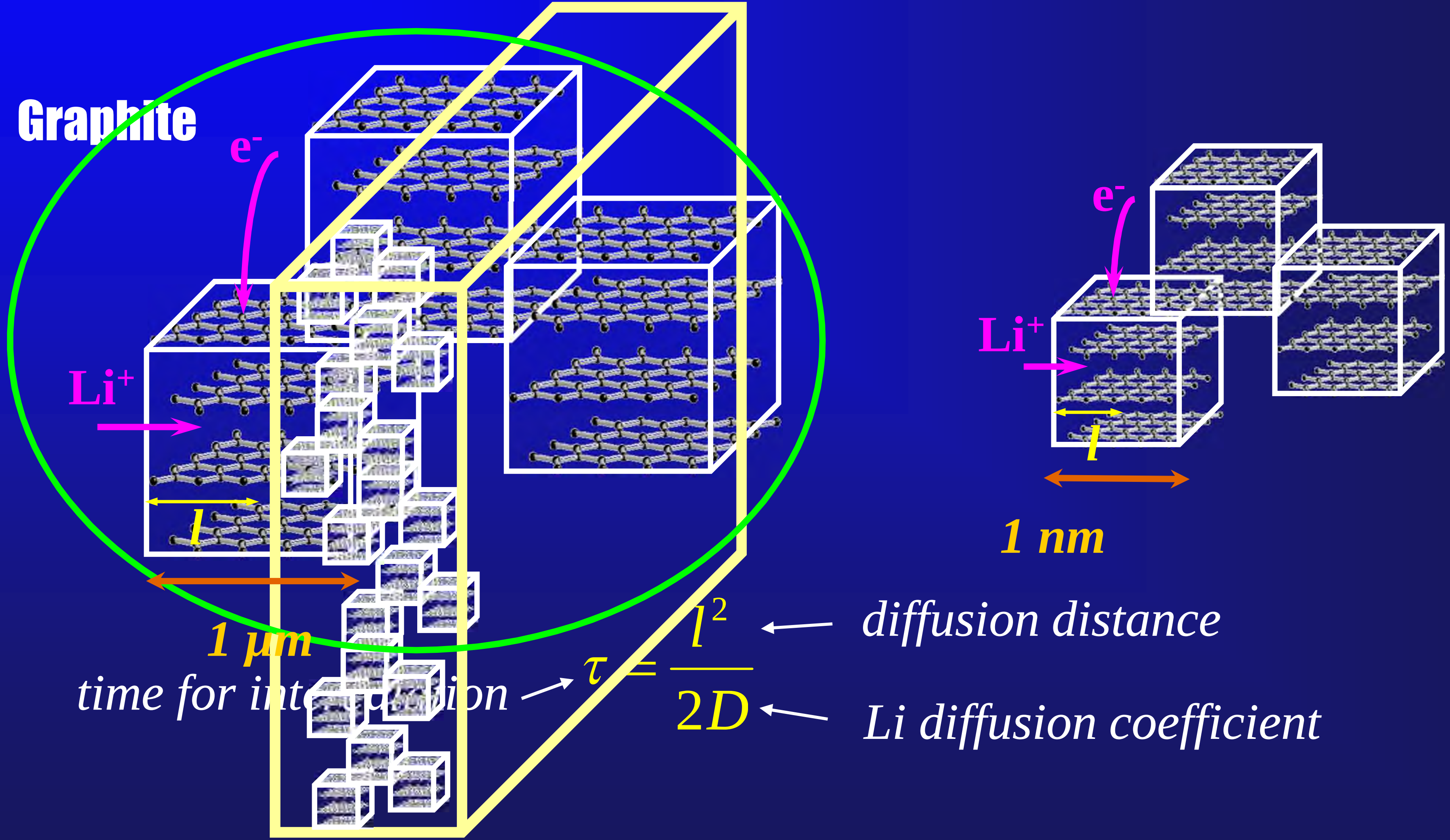


nanomaterials

High Power Lithium Batteries → NANOMATERIALS

Requires solid state intercalation reaction rates 10^3 faster

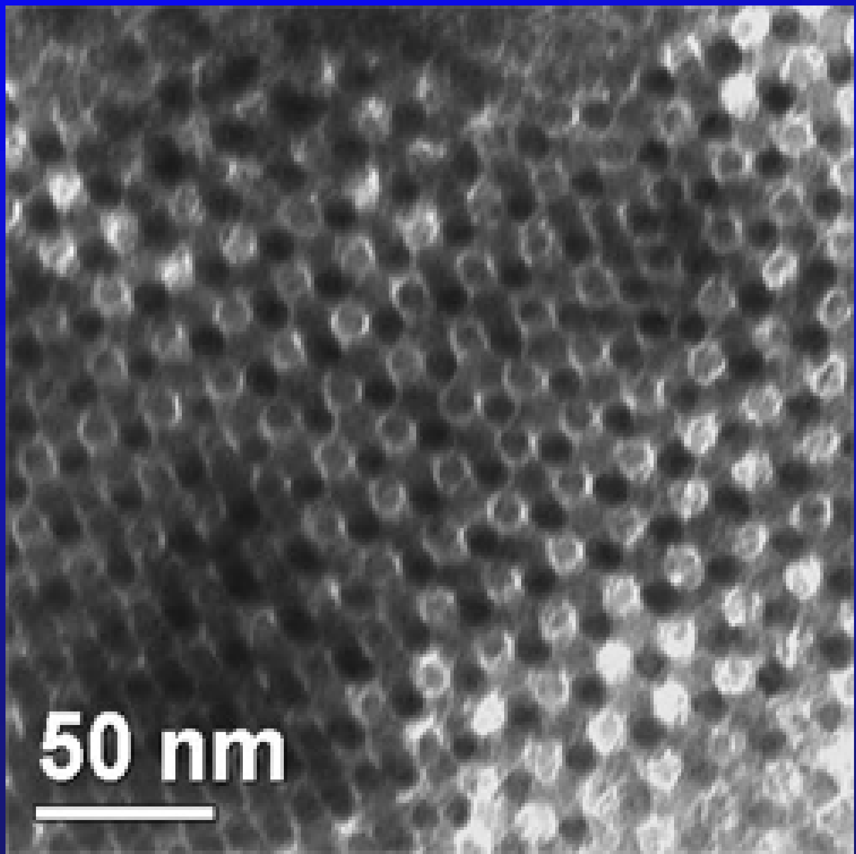
From	Micron	to	Nano



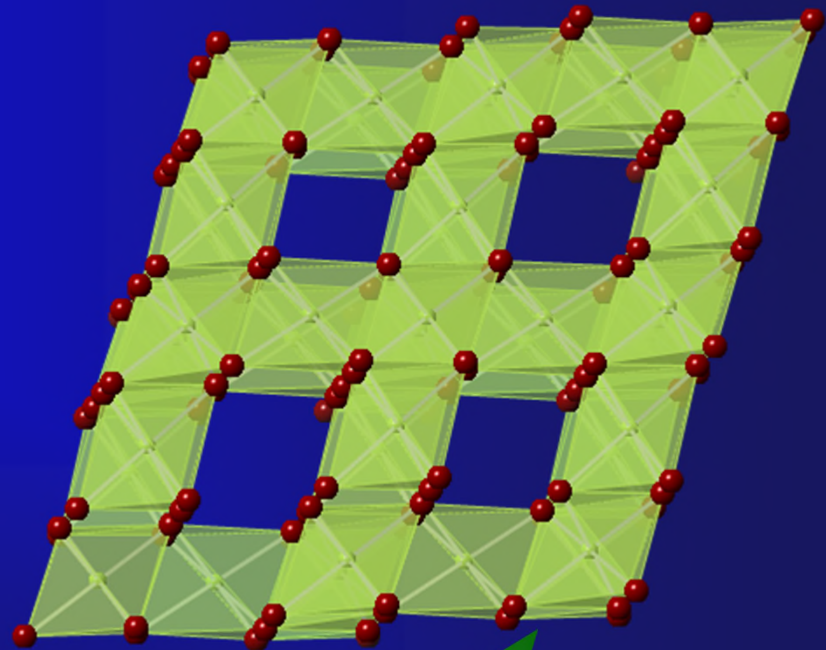
Mesoporous $LiMn_2O_4$ cathode (positive electrode) for lithium batteries

Power + cost + cycle life

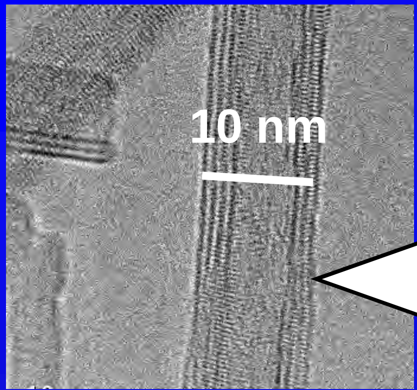
Mn_2O_4 (MnO_2) $\leftrightarrow$ $LiMn_2O_4$: intercalation



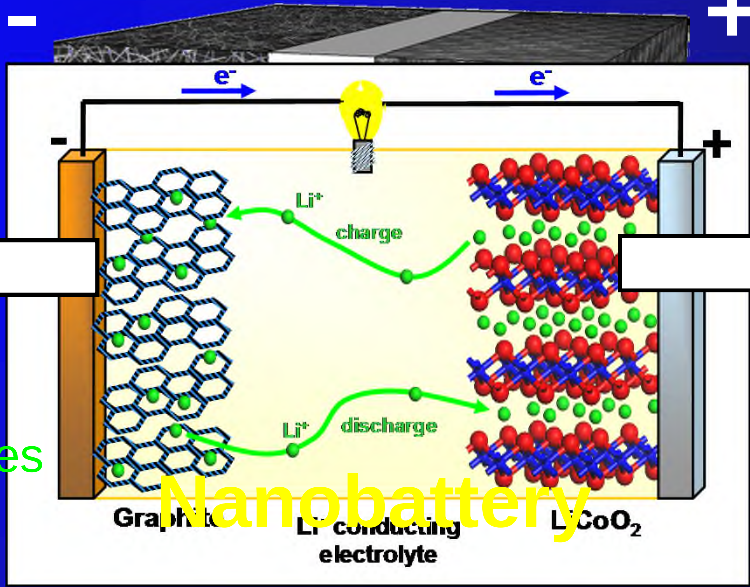
$LiMn_2O_4$



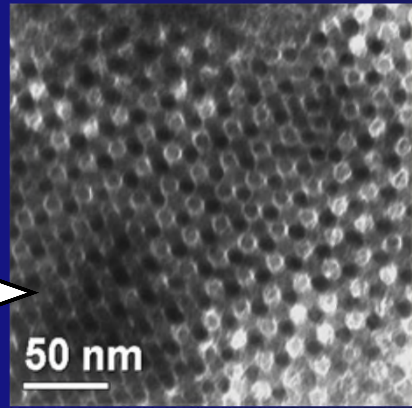
Lithium Batteries



Titanium dioxide nanotubes

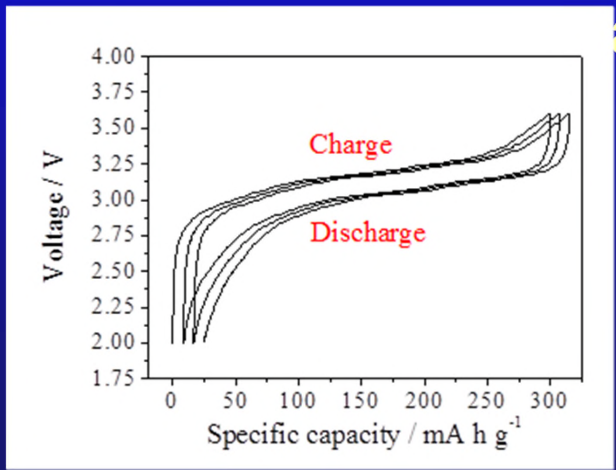


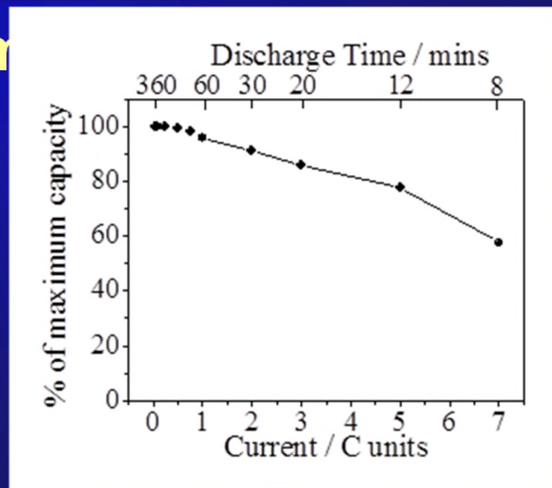
Nanobattery



Mesoporous
Lithium manganese oxide

able lithium

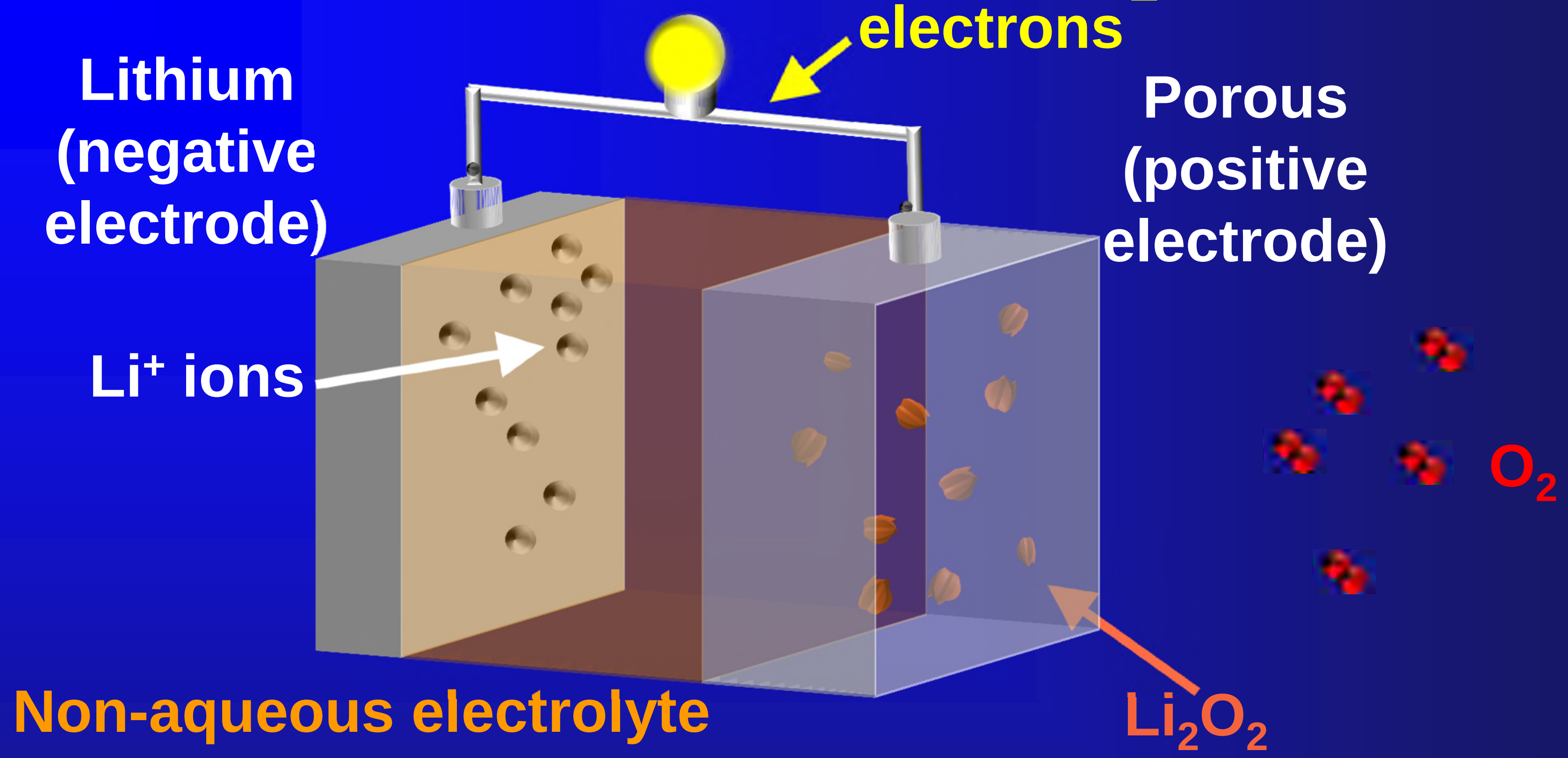




Electrical energy storage – rechargeable batteries

Bruce, Freunberger, Hardwick & Tarascon *Nature Materials* **11**, 19-29 (2011)

The Aprotic Lithium-Air (O_2) Battery

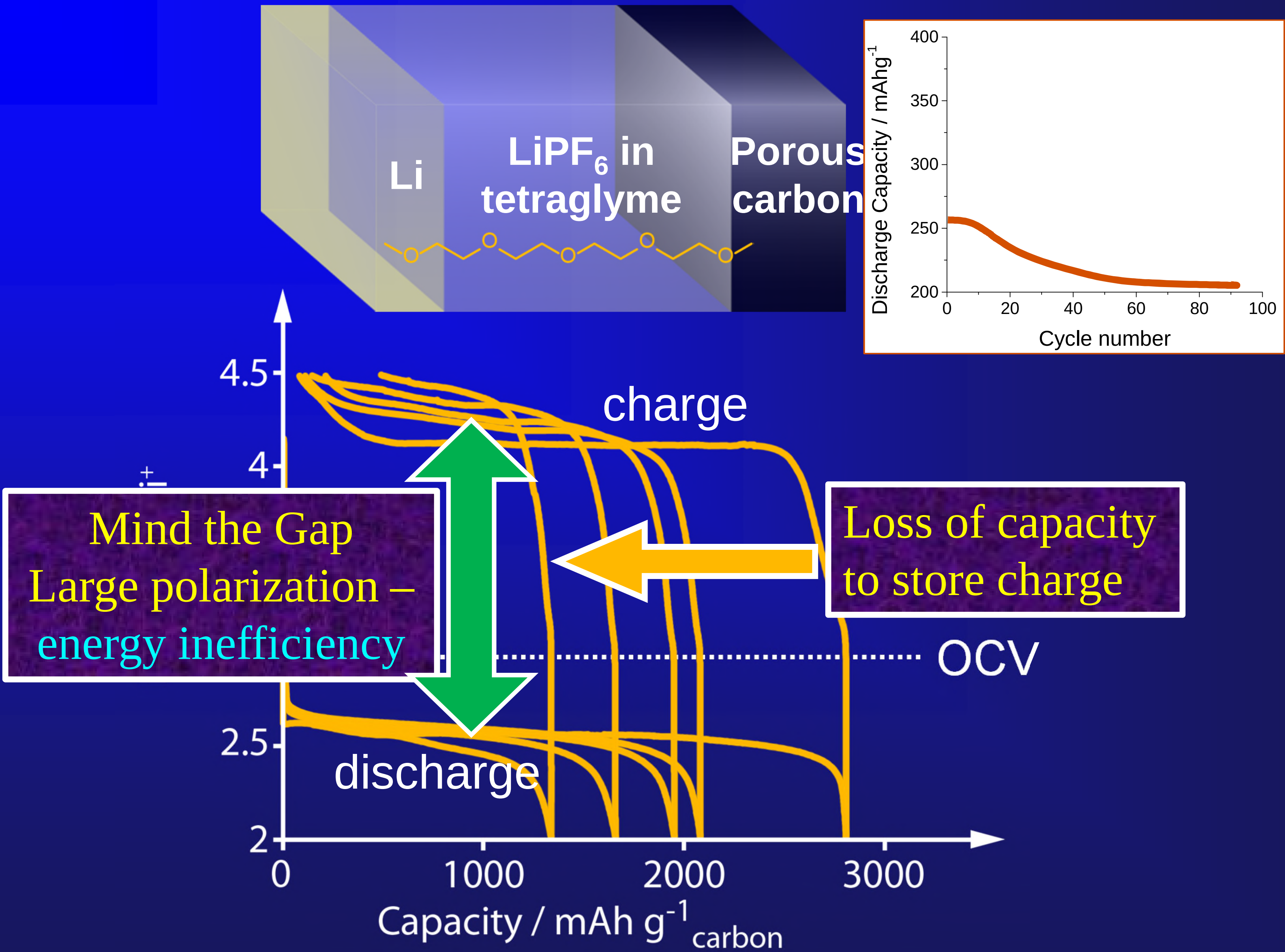


Discharge
Charge

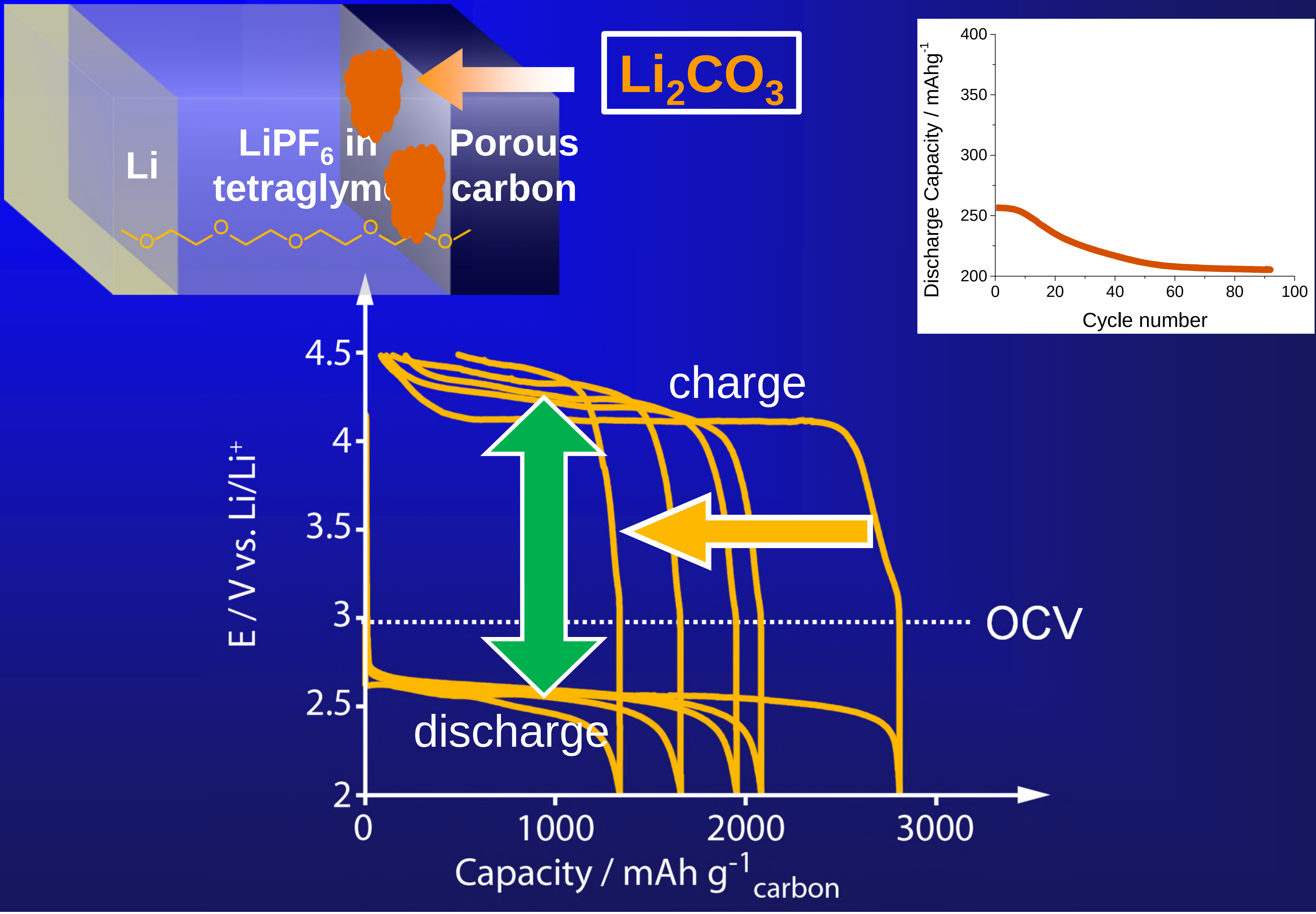
Predicted practical specific energies / Wh kg^{-1}

$Li-O_2$	Li-ion
700-1000	400

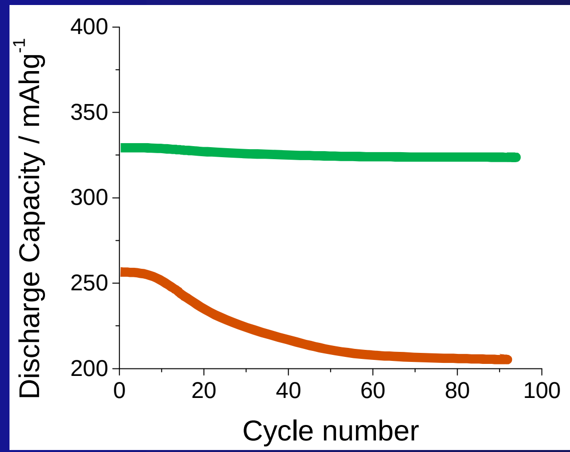
Discharge and Charge Cycling

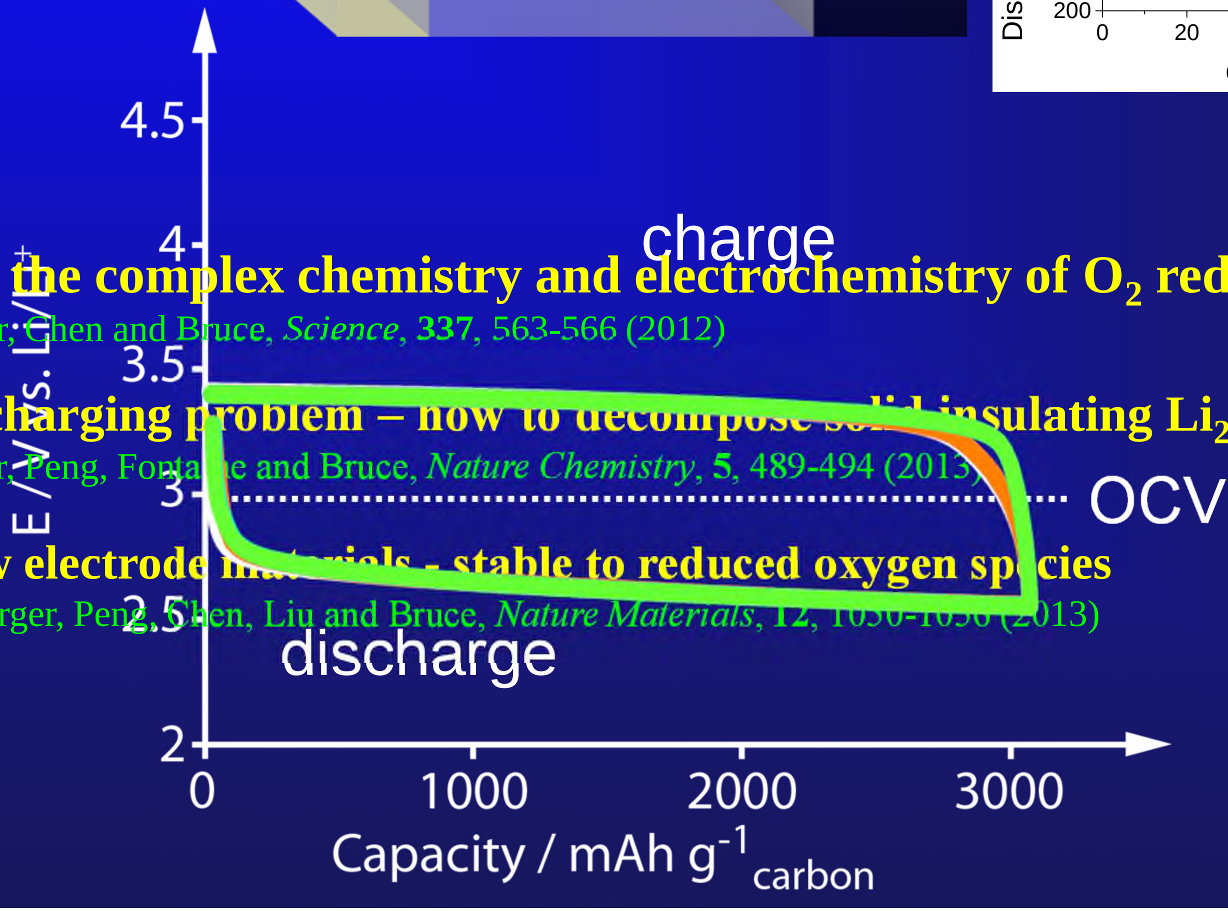


Discharge and Charge Cycling



Discharge and Charge Cycling





- **Understand the complex chemistry and electrochemistry of O_2 reduction**
  Peng, Freunberger, Chen and Bruce, *Science*, **337**, 563-566 (2012)
- **Solving the charging problem – how to decompose solid insulating Li_2O_2 on charging**
  Chen, Freunberger, Peng, Fontaine and Bruce, *Nature Chemistry*, **5**, 489-494 (2013)
- **Discover new electrode materials - stable to reduced oxygen species**
  Ottakam, Freunberger, Peng, Chen, Liu and Bruce, *Nature Materials*, **12**, 1050-1056 (2013)