Energy Storage

Peter G Bruce
School of Chemistry
St Andrews Centre for Advanced Materials
University of St Andrews

John Kilner
Department of Materials
Imperial College London

Energy Storage

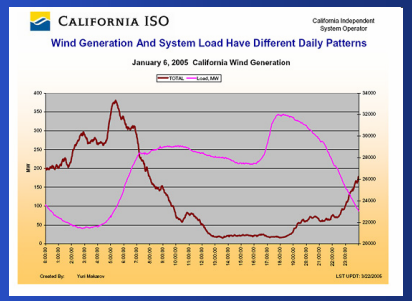
More important now than at any time in history

Electrical Storage

Why?

Static

Wind
Wave
Tidal
Solar
} *Intermittency*



Nuclear — *Constancy of supply*

Micro grids — *Security of supply*

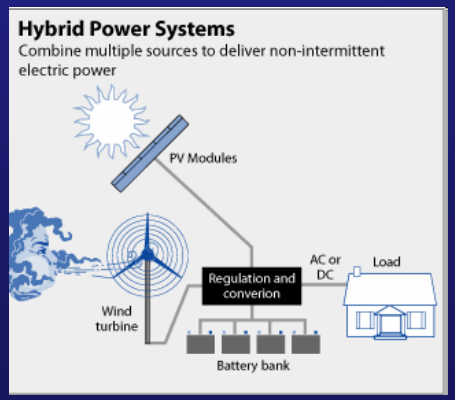
- House
- City
- Developing countries — *Analogous with telephony*

Transport

Electrification

Hybrid vehicles
Plug-in hybrids
} *IC or FC + battery / supercapacitor*

Pure EV — *battery / supercapacitor*



Storage Technologies

What?

- Pumped Hydro (HEP)
- Compressed air
- Chemical (e.g. H_2, others)
- Superconducting magnetic (SMES)
- Flywheels
- Molten salts
- Solar lakes

- Batteries
- Supercapacitors
- Fuel Cells

} *Electrochemical*

Storage Timeline - Static

Based on - estimates when generating technologies available, overcoming technological barriers

2020

Grids

<20% renewables.
Storage desirable but not essential.

HEP

Compressed Air

Microgrids

Batteries

Lead-acid

Established
Cheap

Low efficiency, low energy density, toxic

Redox Flow

Hurdles : Cost, Safety, Membranes.

Zebra Battery

Lithium Battery

Supercapacitor

2050

Grids

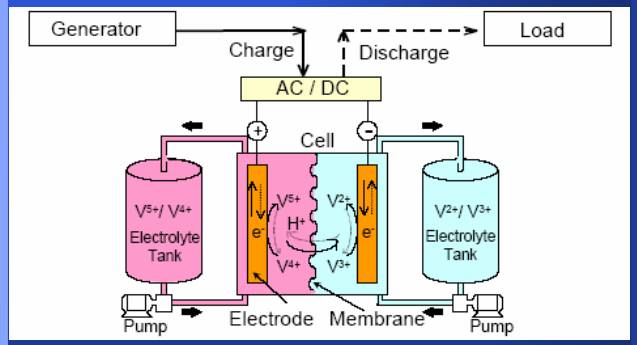
HEP

Compressed air

Chemical (JK)

Redox Flow, Lithium Bat.

Supercap



Microgrids

Redox Flow, Lithium Bat.

Supercap

2100

Grids

HEP

Compressed Air

Chemical (JK)

Supercon (SMES)

Redox Flow, Lithium Bat.

Supercap

Radical

Microgrids

Redox Flow, Lithium Bat.

Supercap

Radical

Storage timeline - Transport

2020

Hybrid Vehicles (IC / Battery)

Batteries

Ni Metal Hydride

Established, High power density. but Low energy density.

Lithium Batteries

High energy density

Supercaps

Carbon / aqueous / Carbon

Battery Management System (BMS)

Plug-in Hybrid

Lithium Batteries
Supercaps
BMS

2050

Hybrid Vehicles (Fuel Cell / Battery)

Lithium Batteries

Supercaps

Fuel Cell / H_2 Storage

BMS

Plug-in Hybrid

Lithium Batteries

Supercaps

BMS

Pure EV

Lithium Batteries

BMS

2100

Hybrid Vehicles (Fuel Cell / Battery)

Lithium Batteries

Supercaps

Fuel Cell / H_2 Storage

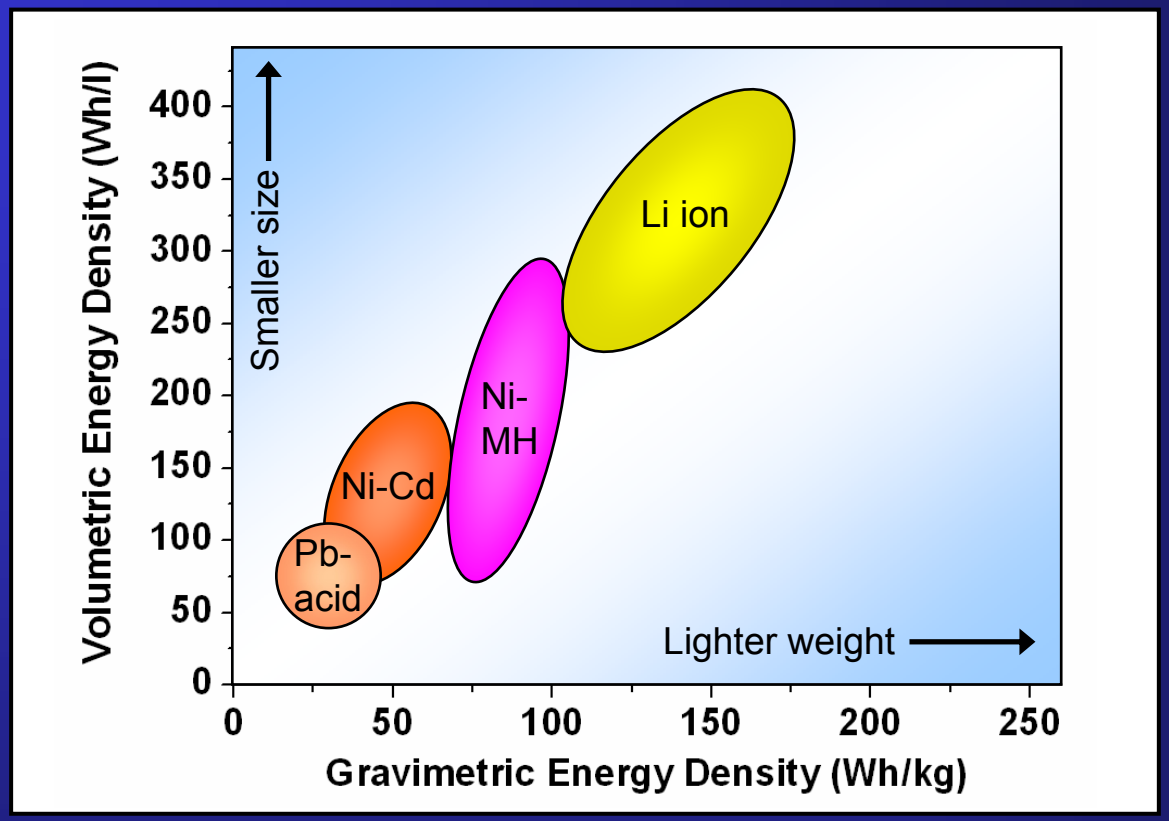
BMS

Pure EV

Lithium Batteries

BMS

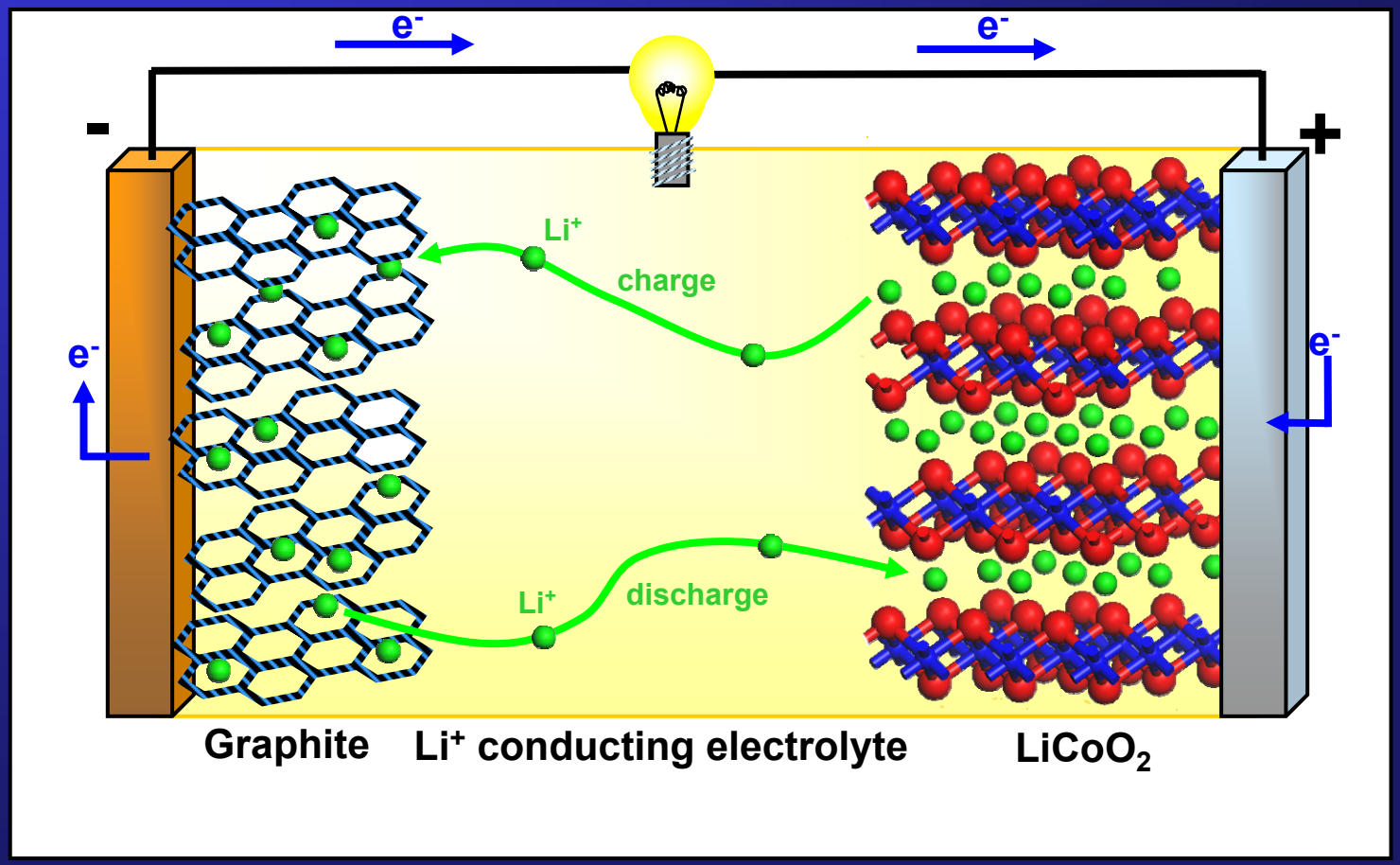
Why Lithium Batteries?



- Transport and static storage
- High coulombic efficiency ⇒ 100%
- Low self-discharge
- Modular – small or large (10m x 10m x10m = 400MWh)
- Green
- Comparable to H_2 storage

Rechargeable Lithium Battery

10^9 cells in 2007, $6-10 billion industry – portable electronics



New generations required for new markets

STEP CHANGE IN SCIENCE and MATERIALS

Lithium Batteries - The Hurdles

Hurdles	2020	2050	2100
Reduce cost - materials (raw and synthesis)	**New Electrodes** Anodes - TiO_2 Cathodes - $LiMn_2O_4$, - Nano-$LiFePO_4$	**New Electrodes** Anodes - Metal alloys Cathodes - Li-Fe-O	**Molecular Electrodes** **Radical new approaches**
Improve safety		**New Electrolytes** - Ionic liquids - Polymer electrolytes	
Cycle life - 300,000 cycles **Calendar life** - 15 yrs (transport)	**LOWER energy density**		
Power Density - HEV, PHEV	**Nanoparticle electrodes**	**Nanostructured Electrodes, e.g. nanowires and mesoporous**	
Energy Density - PHEV, EV, load leveling	**LOWER to obtain cycle life** 80→100Wh/kg	**New Concepts** **Li/S or Li/Air** **200→600→800Wh/kg**	

Japan and USA now investing in lithium battery R and D for transport and load leveling

ROYAL SOCIETY DISCUSSION

ENERGY MATERIALS TO COMBAT CLIMATE CHANGE

June 8-9, 2009,
Royal Society London

Organises

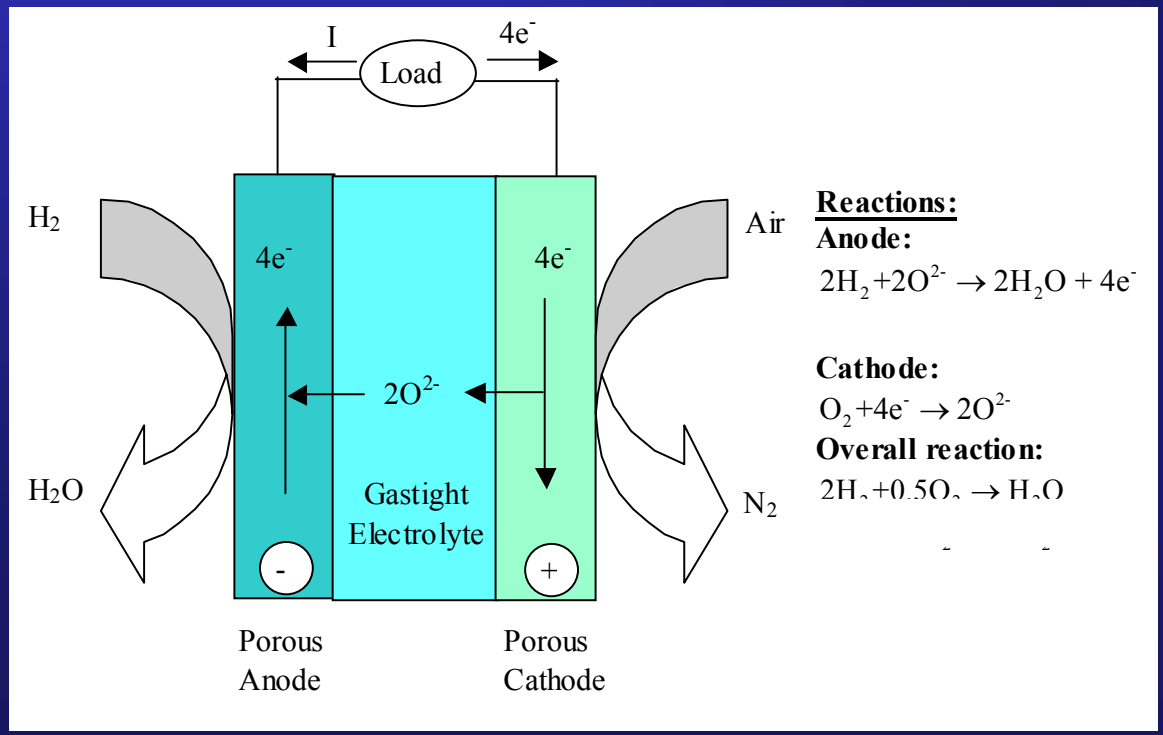
Peter G Bruce FRS, St Andrews
Richard Catlow FRS, UCL
Peter Edwards FRS, Oxford

Hydrogen Fuel Cell: Schematic

Electrolysis

$$2H_2O \rightleftarrows H_2 + O_2$$

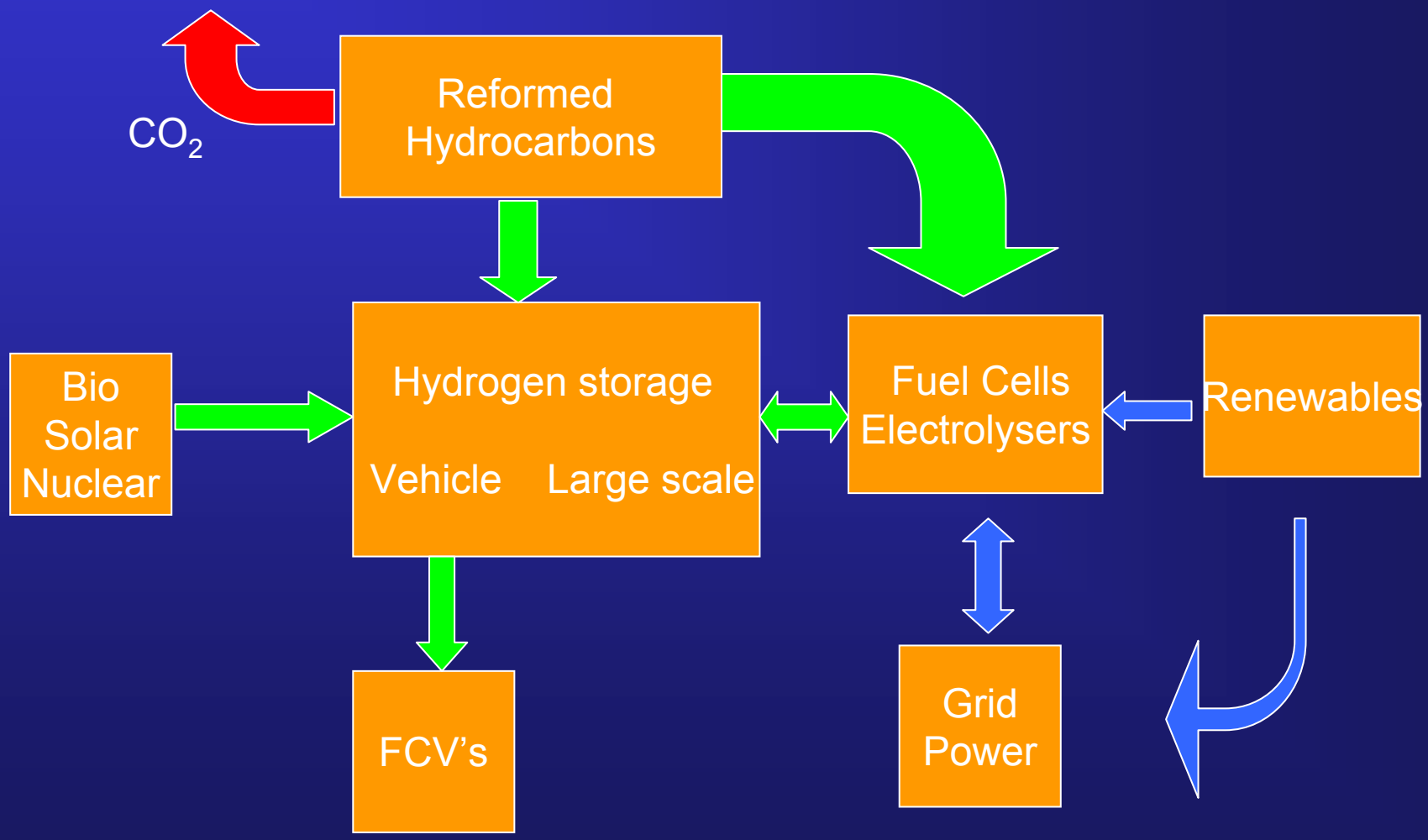
Hydrogen fuel cell



Hydrogen and Fuel cells

- Two major types of fuel cells to be developed
- Proton Exchange Membrane (PEM)
  - Transport applications: Buses, fleet vehicles
  - Hybrids FCV's
- Solid Oxide Fuel Cells (SOFC's)
  - Stationary power generation
  - kW to MW

Hydrogen /Fuel Cell Economy



Fuel Cells - The Hurdles

hurdles	2020	2050	2100
SOFC *Improve performance* Electrolytes Electrodes *Improve durability* *Reduce cost* –	New Electrolytes Apatites Chromium tolerant cathodes Redox + Sulphur tolerant anodes kW Mobile, CHP MW distributed	Epitaxial nanostructures Micro SOFC's Controlled porous nanostructures High volume production High efficiency reversible systems	Low T SOFC T convergence High T PEM New FC concepts Bio FC's
PEM Improve performance Electrolytes Electrodes Improve durability Reduce cost –	High T membranes Metal interconnects MeOH Crossover CO Tolerance Low PGM content	Organic inorganic hybrids Nanostructured Electrodes	

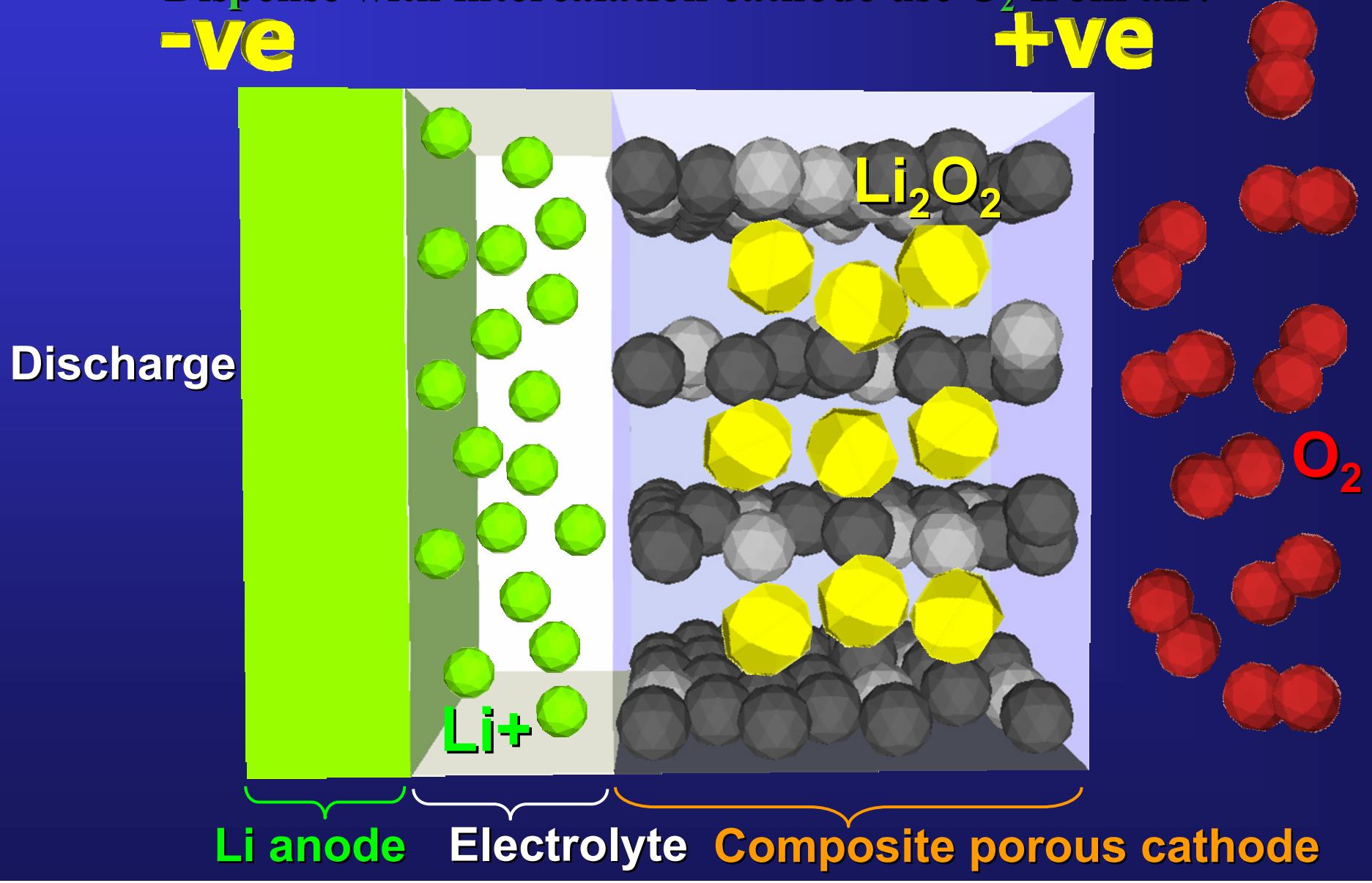
US SECA programme started in 1999 to meet cost and performance goals

Hydrogen storage/distribution - The Hurdles

hurdles	2020	2050	2100
Hydrogen storage Targets for mobile applications **DOE targets for 2010 and 2015** Solid state storage Gaseous storage Liquid hydrogen	9wt% solid state storage Light metal hydrides Improved composite high pressure cylinders Low boil off liquid	High capacity storage Metal organic framework materials Storage in engineered nanostructures Nanotubes etc. Cost target 2$ Kwh^{-1}	Novel storage concepts
Hydrogen production Improved Hydrocarbon reforming Costs Infrastructure Current US 8-9Mt	Improved catalysis Shortage of natural gas CO_2 sequestration Capital investment	Improved gas separation membranes Reversible SOFC's Capital investment 300M Light duty vehicles in USA 65Mt 600-700 new plants	Fission Fusion Bio Solar (1974 levels ~400 reactors)

Development of infrastructure

Lithium / Air Battery Schematic

Store 8X energy – a radical advance

Dispense with intercalation cathode use O_2 from air!