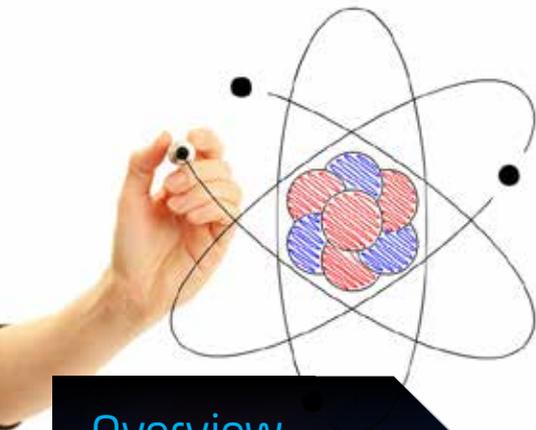


The Power of 3

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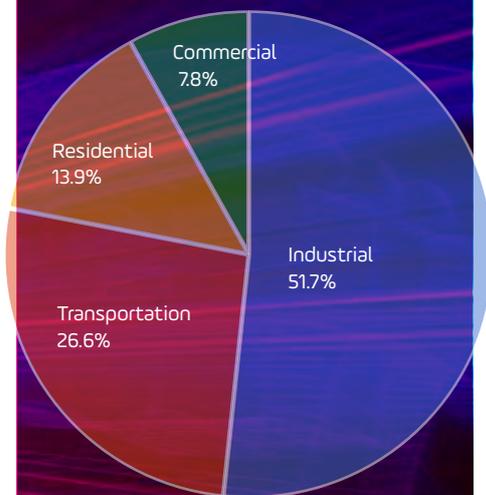
Driving the future further

Is the 'nickel/graphite' battery good enough?



Overview

With all the world's major automotive producers committing to the production of electric vehicles (EVs) now or in the near future, and with those who govern roughly half the world's population putting the legislative nail in the coffin of the internal combustion engine (see *The Power of 3*, issue 17), which energy storage device can best power transportation (currently around 27% of all energy consumed) globally?

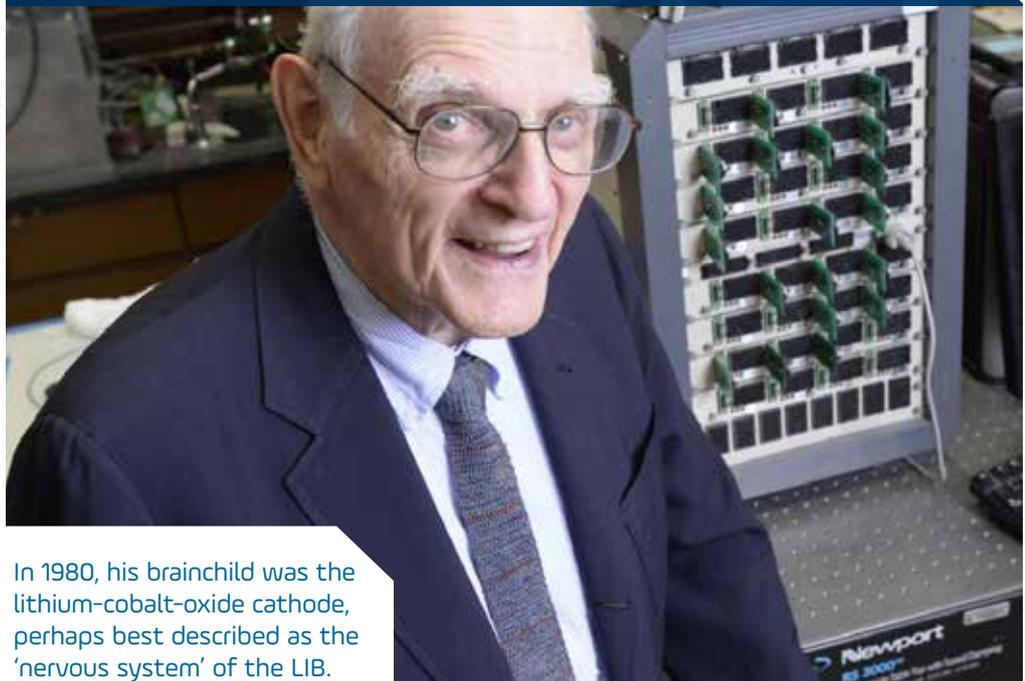


World energy consumption by sector, 2012

[Source: EIA Data]

What says John Goodenough?

At 95 years of age, Professor John Bannister Goodenough can justifiably be described as the father of the modern lithium-ion battery (LIB).



In 1980, his brainchild was the lithium-cobalt-oxide cathode, perhaps best described as the 'nervous system' of the LIB.

By 1991, Sony had combined Goodenough's cathode and a carbon anode to create the world's first commercial rechargeable LIB (see *The Power of 3*, issue 4).

Goodenough's cathode – or a variation of it – can be found in almost every portable device ever sold, and to this day no competitor has managed to improve on it. Seemingly not content with that, however, Goodenough has now teamed with physicist Maria Helena Braga in a bid to jump-start the EV revolution with more disruptive battery technology, lodging new patents (and clearly seeking royalty revenues) as he prepares to embrace a second century spent on planet Earth.

And that technology is ... ?

Braga and Goodenough have managed to dumbfound electrochemists worldwide by inventing a solid-state battery (one in which both the electrolyte and electrodes are solid) with an electrolyte of glass and both the anode and cathode composed of graphite.

Although solid-state batteries are considered safer than most LIBs, and may have the potential for higher energy density, to date issues of cost and lifecycle have proved problematic with this type of technology.

Goodenough says of his latest findings, though, that:

Cost, safety, energy density, rates of charge and discharge and cycle life ... all [are] critical for battery-driven cars to be more widely adopted. We believe our discovery solves many of the problems inherent in today's batteries.

Like father like son?

If Goodenough is the father of the LIB, then Elon Musk must surely be its son, given that he's taken the product invented by the former and hugely popularised its application in EVs in particular. In fact, at this moment in time Musk's company Tesla is the world's biggest consumer of LIBs, no mean feat given the time frame in which he's achieved it.



LIBs also feature in Musk's Powerwall energy storage systems, which might just be used in the first colony on Mars, which Musk plans to establish by catapulting humans across the solar system in his own SpaceX rocket ships.

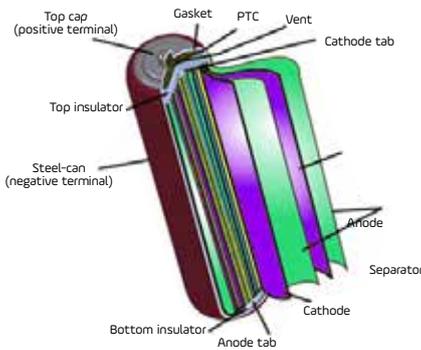
It's Musk, too, who is credited with the statement that the device he's popularised to such an extent, the LIB, is actually a 'nickel/graphite battery' – not a LIB at all!

Other entrepreneurs have made similar statements, but emphasising other components (such as cobalt and copper) to benefit their promotional thrusts.

But why can the now-ubiquitous LIB be described in so many ways? Two answers spring to mind.

1. LIBs incorporate a range of chemistries, each combination having specific properties and hence specific applications.
2. By weight, the lithium content of a LIB is generally quite small, with other metals (in varying concentrations) making up most of the mass.

Examining the anatomy of a LIB makes it easier to understand.

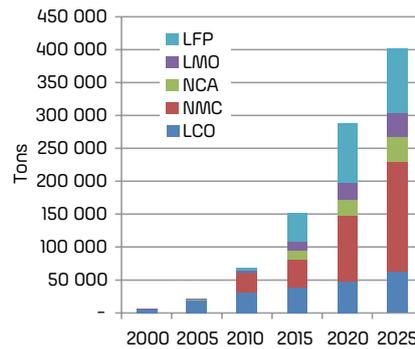


Cylindrical LIB

Most of the metal in a LIB is consumed in the manufacture of the cathode, which generally takes the form of mixed metal oxides, including lithium, or mixed metal

phosphates. The anode is generally graphite, manufactured to a stringent particle size, shape and porosity standards. In the most common LIB type – the cylindrical 18650 (18 mm in diameter and 65 mm long) – the anode and cathode are manufactured as thin films, rolled together then inserted into a metal canister to protect the fragile components. In other words, it's the cathode that, to a large extent, determines the unique properties of the various types of LIB ... and it's those properties that will determine market demand going forward.

Avicenne Energy has estimated demand for the various battery chemistries as follows.



Cathode active materials 2000-2025

The cathode chemistries (the *anodes* are graphite) can be characterised as follows.

LFP	Lithium-iron-phosphate
LMO	Lithium-manganese oxide
NCA	Lithium-nickel-cobalt-aluminium oxide
NMC	Lithium-nickel-manganese-cobalt oxide
LCO	Lithium-cobalt oxide

In general, cathodes containing cobalt store more energy per unit of mass, meaning that NCA/NMC chemistries are more suitable for EVs. LFP batteries, on the other hand, have a much greater service life than their cobalt counterparts, being capable of very high

current delivery, but store less energy per unit of mass. Moreover, LFP batteries are not at risk of thermal runaway (meaning they can power a hover board without it catching alight) and are generally considered the 'safe' LIB. LFP batteries have found their niche in hybrid EVs, as storage mechanisms for renewable power and in other applications where longevity is more important and size and mass less critical.

But back to Musk's statement about the 'nickel/graphite battery' and why he made it. Tesla has adopted NCA technology in its EVs, to provide maximum power storage with minimal weight – and in that way minimise 'range anxiety'. Published estimates of the metal imports required to produce them may provide the key to Musk's assertion.

The figures look something like this.

	NCA batteries	Graphite	Cobalt	Nickel	Lithium	Total
Tesla '000 tpa	42.00	5.00	12.92	4.60	64.52	
% by mass	65.10	7.75	20.02	7.13	100	
Molecular %	78.27	1.90	4.92	14.91	100	

If viewed in terms of mass, the batteries that propel Musk's EVs are indeed dominated by nickel and graphite. However, if they're viewed in terms of molecular proportions, then lithium is the dominant metal – with a molecular weight of only 6.9, that small mass packs a lot of atoms, and it's the charge carried by the lithium ions that drives the battery.

As the planet relinquishes its dependence on fossil fuels and renewable sources of power become the norm, the requirement for reliable energy storage will increase ... and that's the domain of the LFP, the *safe* LIB.

Goodenough's innovations notwithstanding, demand for lithium, graphite, nickel and cobalt is set to skyrocket, with lithium remaining a vital ingredient of EV battery technology.

And finally ... Fancy a device you can see through? As [New Atlas](#) reports, Stanford University researchers say they've developed a see-through, flexible LIB for powering fully translucent mobile gadgets like cell phones, tablets and e-readers.



Although their prototype see-through battery is only about half as powerful as a standard LIB of the same size (it's comparable to the nickel-cadmium battery used in some less-energy-intensive devices), the researchers hope that "by aligning multiple electrodes together, the amount of energy stored can be increased without sacrificing the transparency." Wait and see ...

Which [Perth-based company](#) has a vested interest in LFP, the 'safe' LIB and emphatically NOT a 'nickel/graphite' battery?



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