



# THE REALITY OF NET ZERO

## SEMINAR SERIES





# Battery Energy Storage in Low Carbon Grids

Paul Shearing, ZERO Director:

[paul.shearing@eng.ox.ac.uk](mailto:paul.shearing@eng.ox.ac.uk)

March 2025



# The ZERO Institute

[www.zero.ox.ac.uk](http://www.zero.ox.ac.uk)

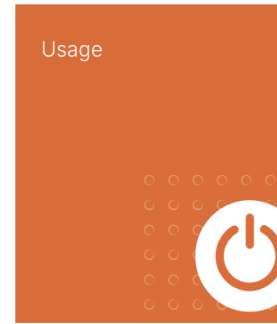
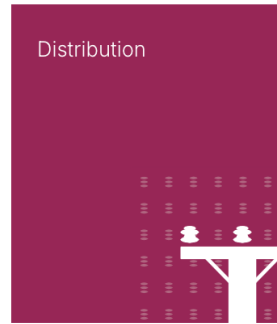
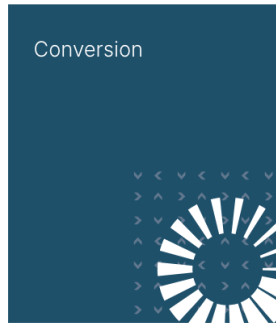
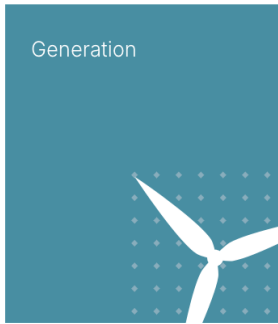
Founded in 2022 our goals are to:

- Establish Oxford as a centre for thought leadership on the zero carbon energy transition and accelerate our research to real world impact.
- Provide leadership in stakeholder engagement, **networking and development** for the community of energy researchers in Oxford.
- Build on existing research based in departments, to address interactions and systems issues across disciplines.
- Provide a single point of contact and a 'shop window' for energy research at Oxford, in partnership with the Oxford Energy Network.



# The ZERO Institute

## ZERO Carbon Energy Systems



## Multi Discipline Strengths



DEPARTMENT OF  
**ENGINEERING  
SCIENCE**



**SoGE** School of Geography  
and the Environment

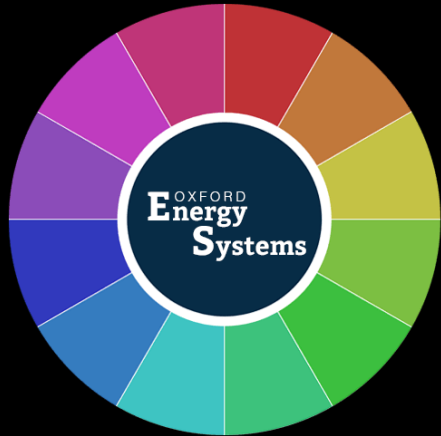


DEPARTMENT OF  
**MATERIALS**

*Vision: We want to shape the transition to a just and fair global zero-carbon energy system, through research that unifies technology, policy, and people.*



# The ZERO Institute and OEN



**ZERO FOUNDERS NETWORK**



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# The ZERO Institute Founders Network



[zero.ox.ac.uk](http://zero.ox.ac.uk)



[ZERO Founders Network](#)



# how?

building the new **home** for climate-tech **founders** and **curious** minds in Oxford

## opportunity

... to **register** and get **involved** later today

tailored support

### 1/ networking activities

**twice** per term

- panel discussions
- fireside chats

### 2/ mentoring programme support network

- accessible to startups and aspiring founders
- open to all career levels

### 3/ business plan competition

**DAY ZERO**

- annual pitch event
- equity-free cash prizes

### 4/ growth funding

**match making**

- access to growth equity financing
- database of venture capital investors



# CONTEXT: NET ZERO AND THE UN SUSTAINABILITY GOALS

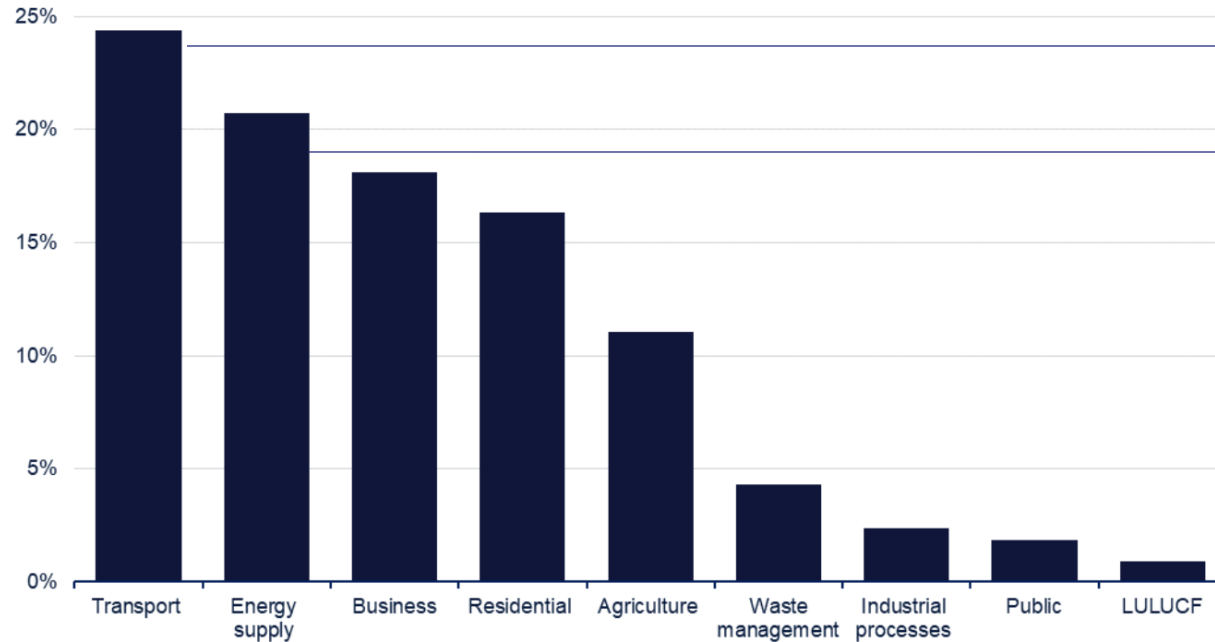




# CONTEXT: THE ROLE OF ENERGY STORAGE



**Figure 5: Net territorial UK greenhouse gas emissions by NC sector, 2020 (%)**



Batteries for EVs

Batteries for the grid

..... Batteries for electric flight?  
.... 'Batteries' for long duration storage?

Source: Table 1.2, Final UK greenhouse gas emissions national statistics 1990-2020 Excel data tables

Note: LULUCF is land use, land use change and forestry.

# CONTEXT: THE ROLE OF ENERGY STORAGE



Renewable  
generation



Electricity  
system




Battery  
storage



17:49

tesla.com



### Order Megapack

Megapack enables low-cost, high-density commercial and utility projects at large scale. It ships ready to install with fully integrated battery modules, inverters, and thermal systems. [View Product Details](#)

**9.6 MW**  
Power

**19.3 MWh**  
Energy

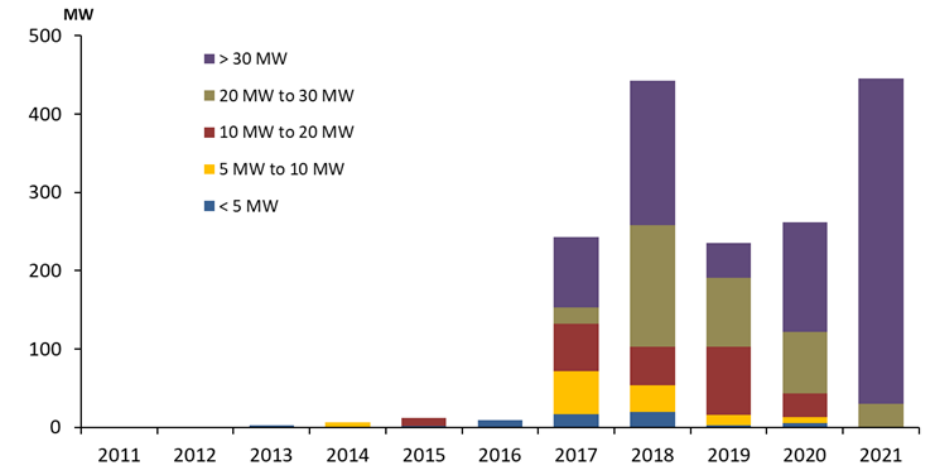
Megapack Quantity:

[Installation Included](#)

Megapack Duration: ☐ 2 hr ☐ 4 hr

Site Location:

UK | Energy Storage | Utility Segment  
Built Capacity by Project Size by Year

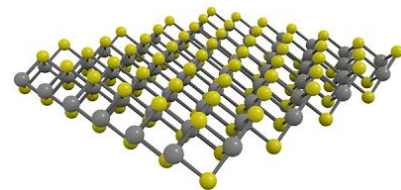
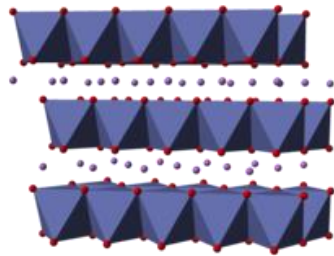
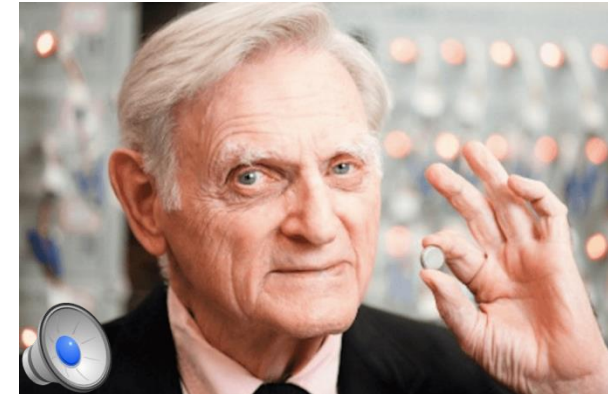
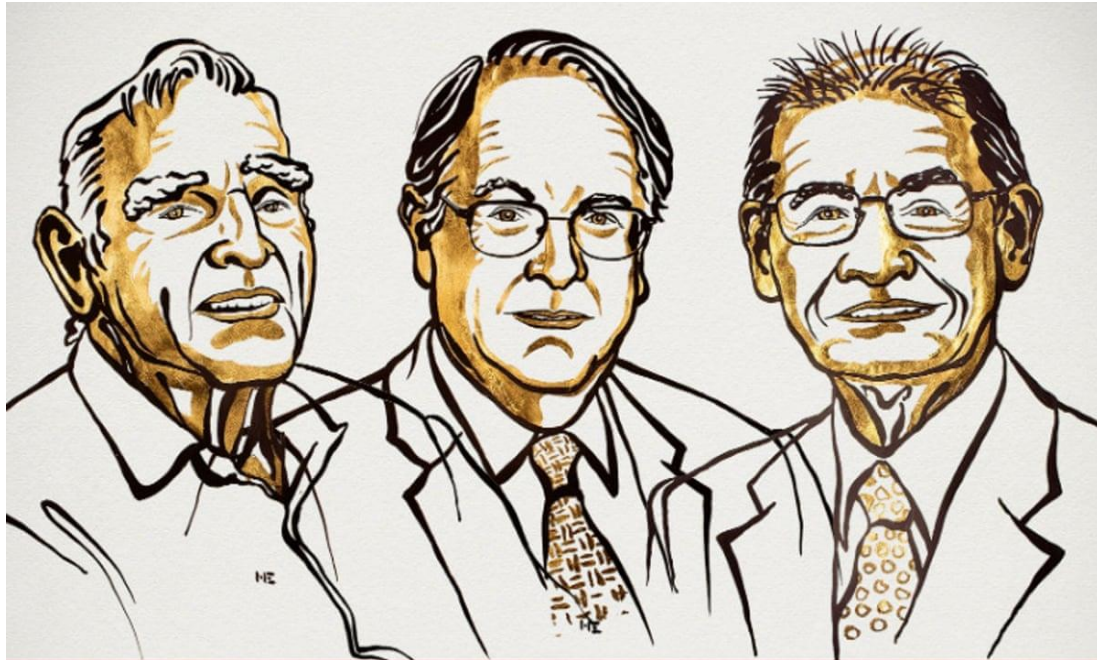


© Solar Media Ltd., 2022

Source: UK Battery Storage Project Database report; March 2022.



## CONTEXT: 2019 NOBEL PRIZE





# CONTEXT: SEVEN YEARS OF THE FARADAY CHALLENGE

## Technical Targets – 2018



### Cost

2/3 cost reduction

Now	2035
\$130/kWh (cell)	\$50/kWh (cell)
\$280/kWh (pack)	\$100/kWh (pack)



### Energy Density

2x energy density

Now	2035
700Wh/l, 250Wh/kg (cell)	1400Wh/l, 500Wh/kg (cell)



### Power Density

4x power density

Now	2035
3 kW/kg (pack)	12 kW/kg (pack)



### Safety

Battery packs 'inherently safe'

2035
Eliminate thermal runaway at pack level to reduce pack complexity



### 1st Life

Pack life equivalent to life of the car

Now	2035
8 years (pack)	15 years (pack)



### Temperature

50% increase in operating temp. range (°C)

Now	2035
-20° to +60°C (cell)	-40° to +80°C (cell)



### Predictability

Full predictive models

2035
Full predictive models for performance and aging of battery

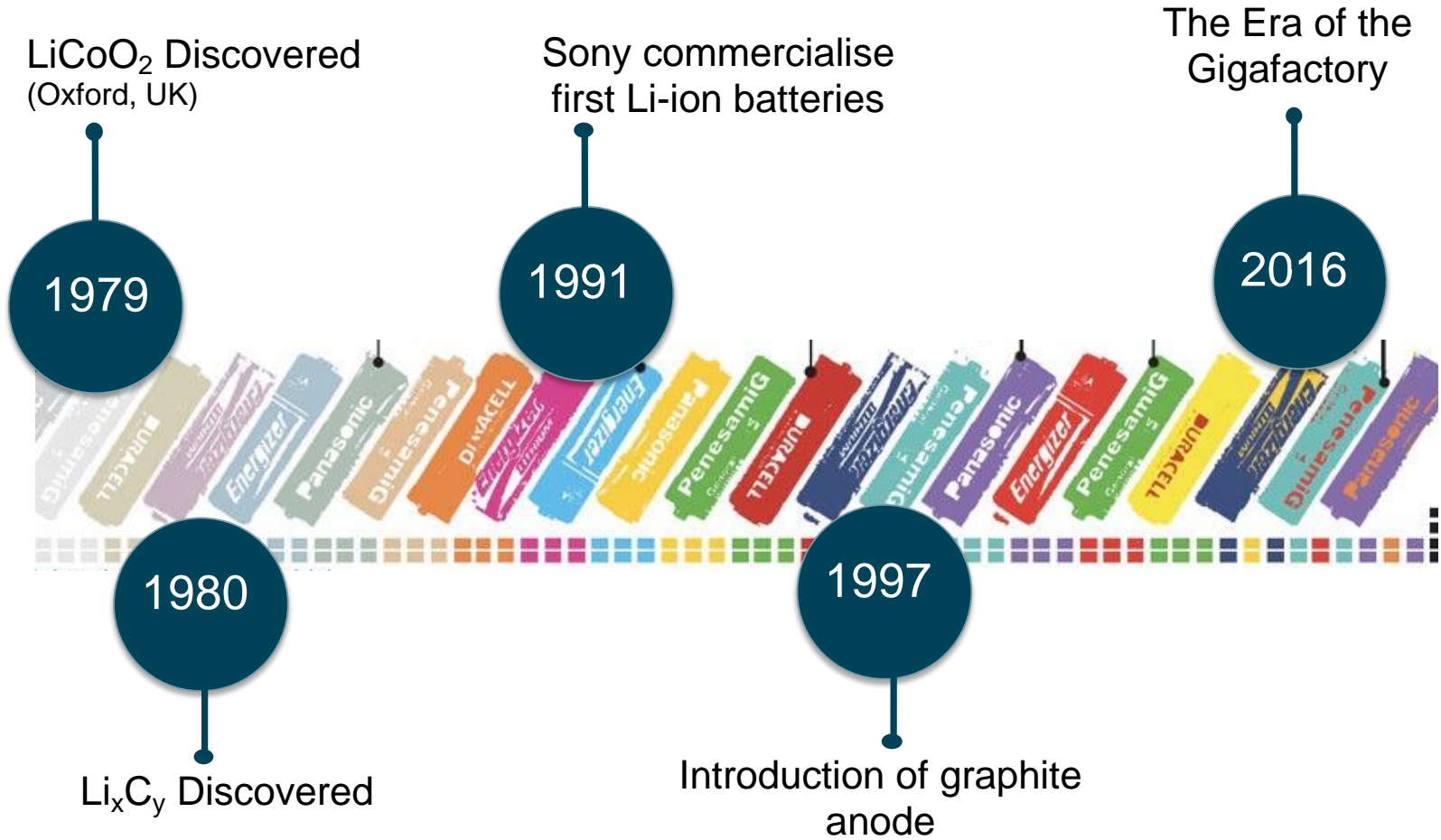


### Recyclability

Closed-loop recycling system in place

Now	2035
10-50% (pack)	95% (pack)

# PERSPECTIVE: TIME TO COMMERCIALISATION



# CONTEXT: THE CONTINUED CHALLENGE FOR BATTERIES



Fit for  
Purpose

Optimised  
for Better  
Performance

Cheaper and  
Mass  
Producible

Increasingly Safer,  
Sustainable and  
Recyclable



**Power Density**  
4x power density

Now	2035
3 kW/kg (pack)	12 kW/kg (pack)



**Energy Density**  
2x energy density

Now	2035
700Wh/l, 250Wh/kg (cell)	1400Wh/l, 500Wh/kg (cell)



**1st Life**

Pack life equivalent  
to life of the car

Now	2035
8 years (pack)	15 years (pack)



**Temperature**

50% increase in  
operating temp. range (°C)

Now	2035
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**Cost**

2/3 cost reduction

Now	2035
\$130/kWh (cell) \$280/kWh (pack)	\$50/kWh (cell) \$100/kWh (pack)



**Predictability**

Full predictive models

2035  
Full predictive models for  
performance and aging of battery



**Safety**

Battery packs 'inherently safe'

2035  
Eliminate thermal runaway at pack  
level to reduce pack complexity

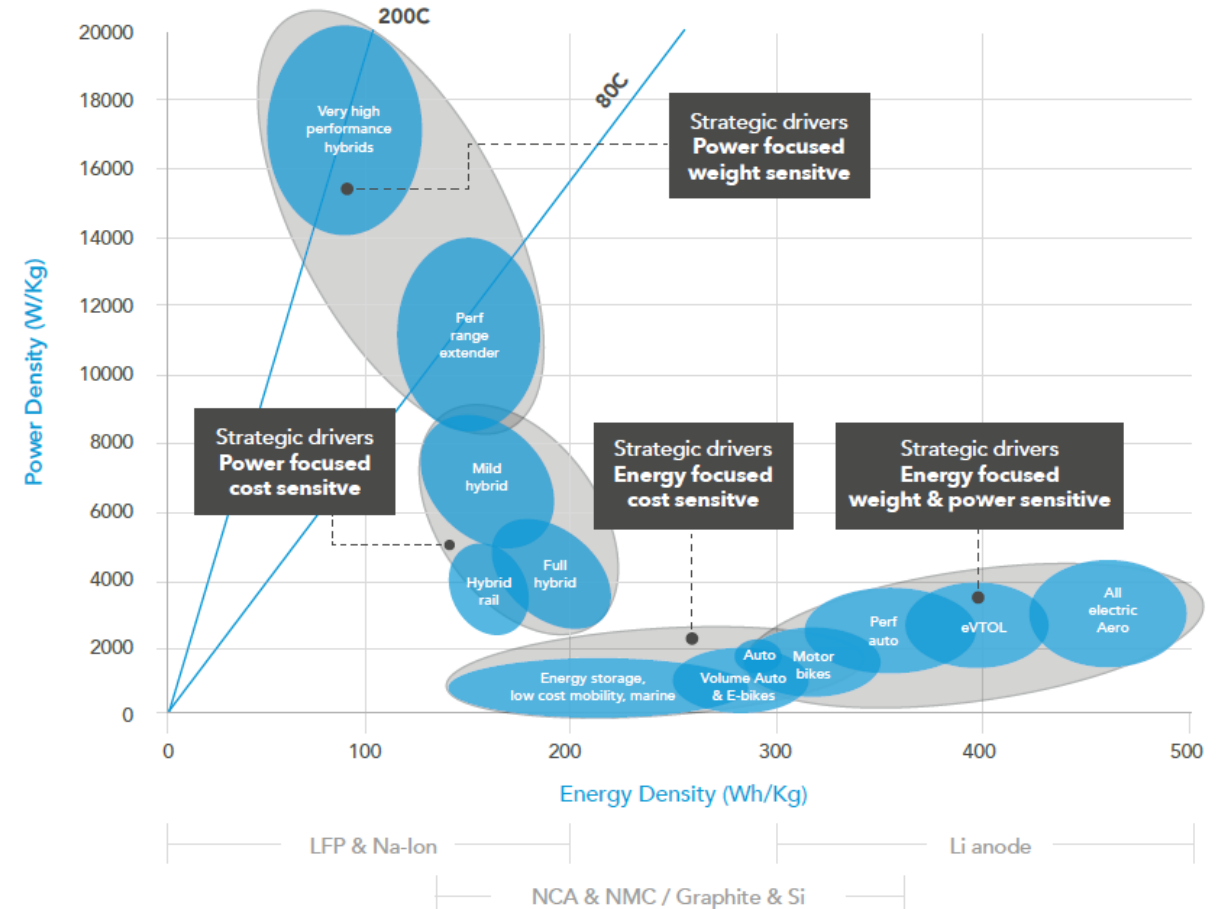


**Recyclability**

Closed-loop recycling  
system in place

Now	2035
10-50% (pack)	95% (pack)

## The Great Application Power/Energy/Chemistry Trade-off



Ref: WMG Discussion Document for the UK Battery Community



# PERSPECTIVE: ROLLS ROYCE 'BACK TO THE FUTURE'?



2/3 In 1900 Charles Rolls said: "The electric car is noiseless and clean. There is no smell or vibration; they should become very useful when charging stations can be arranged. For now, they will not be very serviceable – at least for many years to come."

[#SpiritElectrified](#)



1:01 PM · Sep 27, 2021



# PERSPECTIVE: AGRATAS, BMW, STELLANTIS...



## Jaguar Land Rover-owner to spend £4bn on UK battery factory

🕒 19 July · 💬 Comments



## Vauxhall UK plant safe with electric vehicle plan

🕒 6 July 2021 · 💬 Comments



## BMW investment secures future of Mini factories

🕒 1 day ago · 💬 Comments




Image Credits: BBC




# PERSPECTIVE: AND IT'S NOT JUST THE OEMS....

Latest News



**Nexeon Signs Agreement for First Commercial Volume Production Site and Secures Raw Material Supply Chain for Silicon Anodes**

August 3, 2023




06/09/2023

**Echion secures significant investment from Volta Energy Technologies**

[Read More](#)

Nyobolt Closes £50m Series B Funding to Bring Tungsten Batteries to Market

By Sam Feggetter July 15, 2022



**Nyobolt Closes £50m Series B Funding to Bring Tungsten Batteries to Market**

British fast-charging battery manufacturer Nyobolt has closed its Series B funding round, which will see £50 million pumped into the company.

[READ MORE »](#)


15 July 2022



Reliance New Energy Solar to Acquire Faradion Limited

**BGF**

What we do ▾ Portfolio ▾ News Insights About us ▾ Contact ▾ [Looking for funding?](#)



News


**Fast-charging battery startup Gaussion powers up with new investment**

[Back to News](#)

**ABOUT:ENERGY**

**SEED ROUND**

£1.5 million



About:Energy  
Jun 8 · 4 min

[Press releases](#)

**About:Energy Secures £1.5m Seed Investment to Position UK as Battery Data Leader**



# PERSPECTIVE: BUT NO ONE SAID IT WOULD BE EASY...



The Economist

Menu Weekly edition The world in brief Search

Business | Electric shock

## Northvolt announces more cuts, worrying investors

Europe's battery-making champion has overstretched itself



## NEWS

Home | InDepth | Israel-Gaza war | War in Ukraine | Climate | UK | World | Business | Politics | Culture

Business | Economy | Technology of Business | AI Business

## Vauxhall owner to close Luton factory



GETTY IMAGES

Theo Leggett & Michael Race  
Business correspondent & Business reporter, BBC News

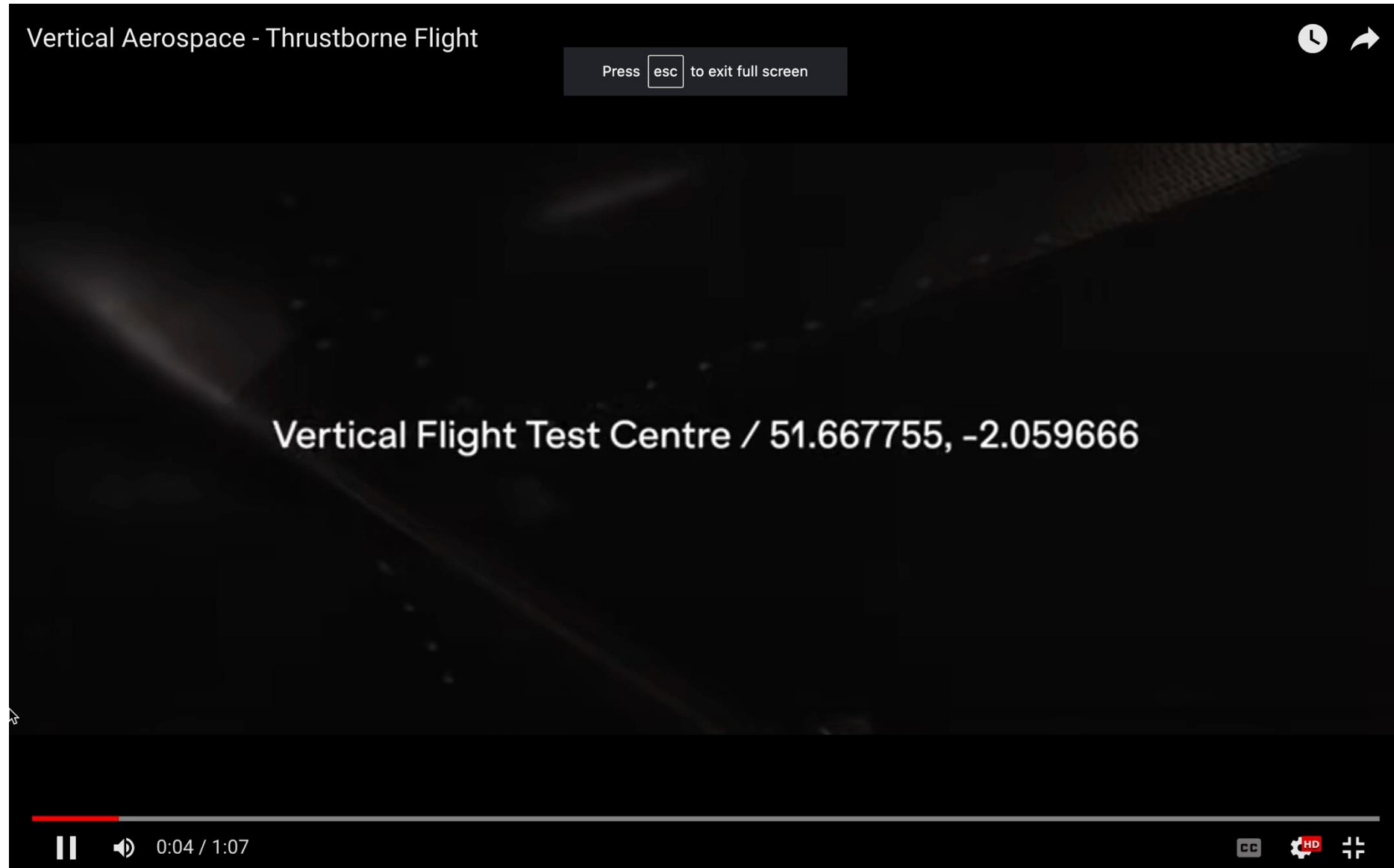
## BMW delays electric Mini over 'uncertainty'



BMW MINI

BMW said "multiple uncertainties facing the automotive industry" had led to its decision

# PERSPECTIVE: THE OPPORTUNITIES FOR ELECTRIC FLIGHT



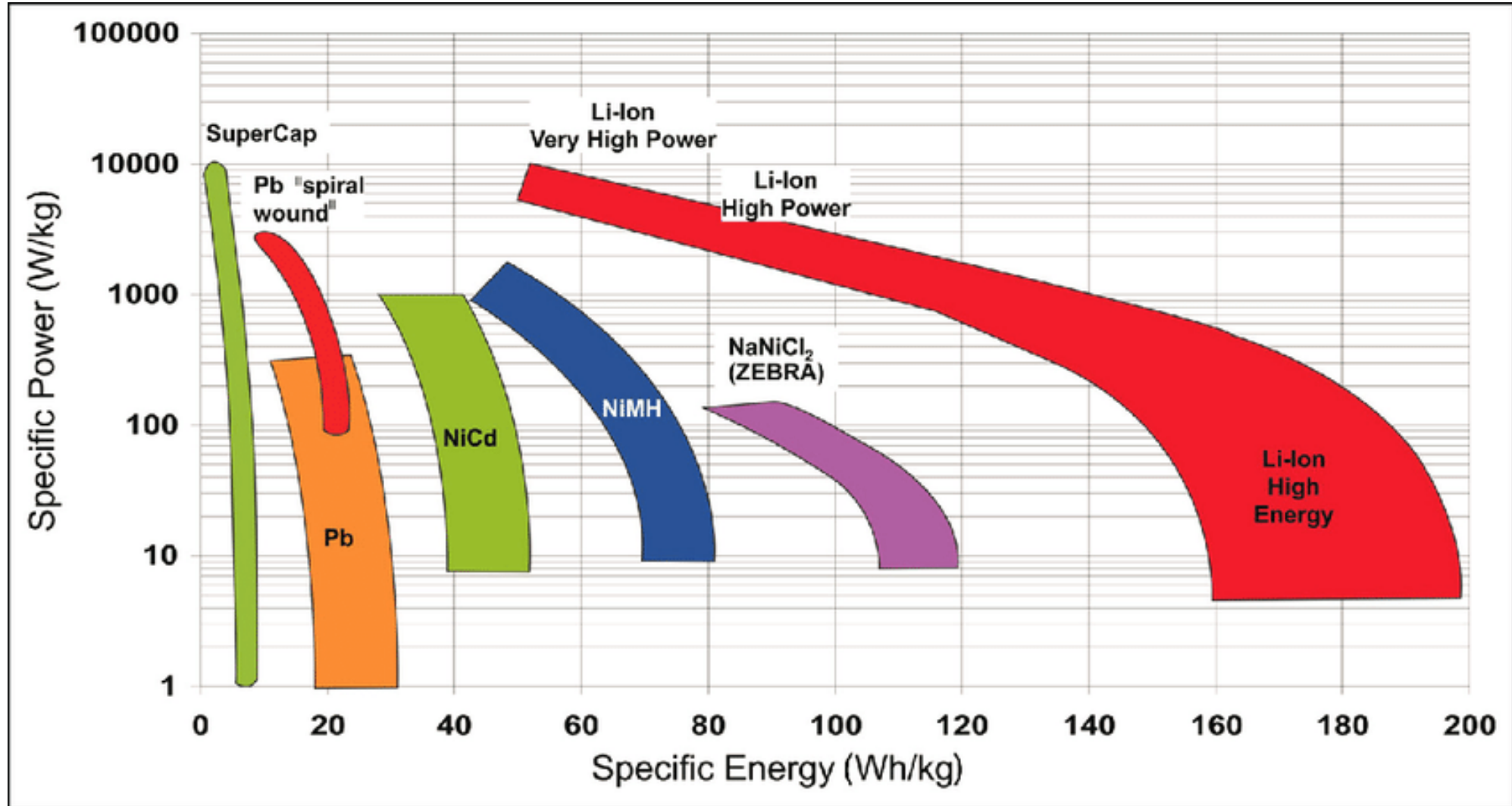


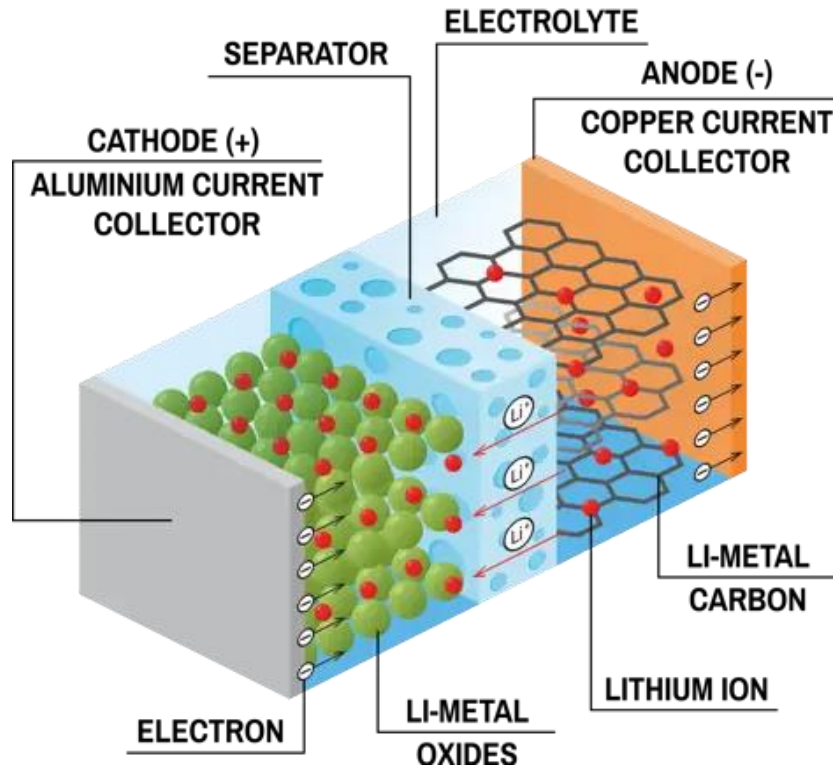
Image Credit: Dirk Uwe Sauer et al





# LITHIUM-ION BATTERY

## DISCHARGE



## CHARGE

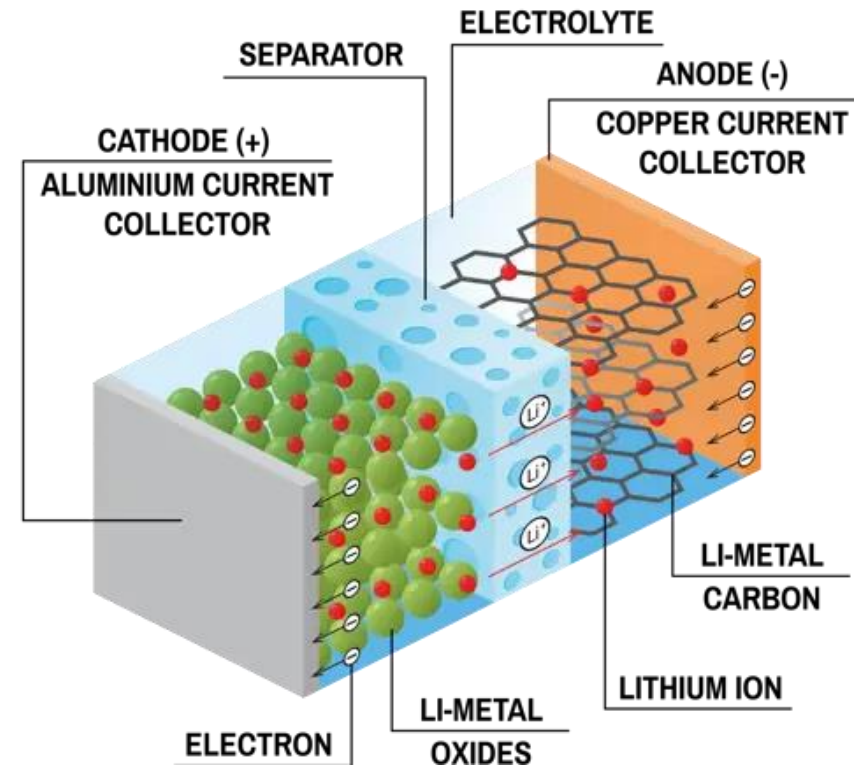
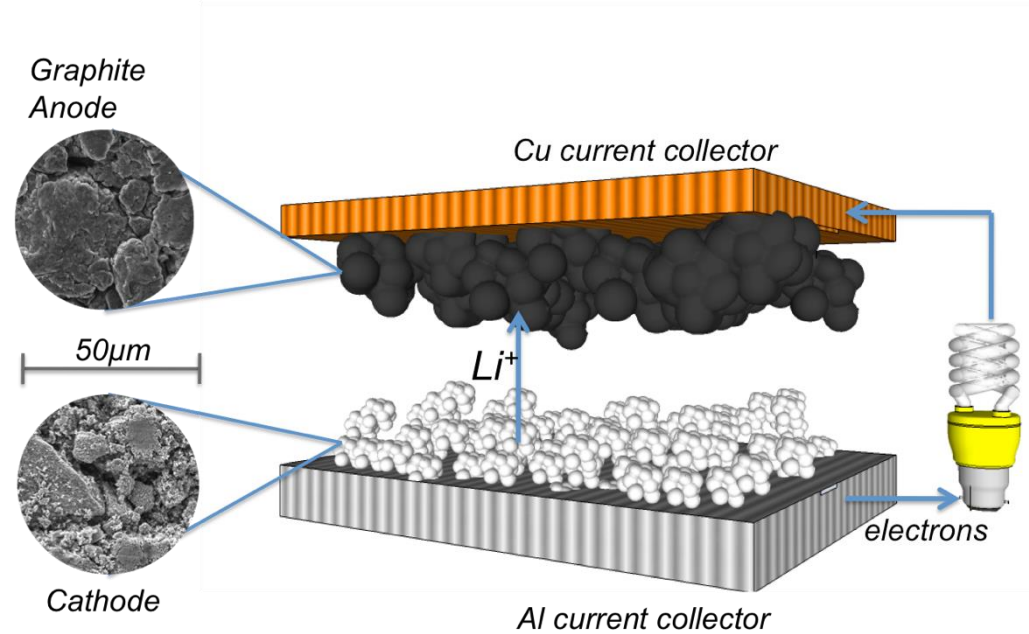


Image Credit: Shearing/RAENG

# LI-ION BATTERIES – JARGON BUSTING....



Term	Characteristic Units	Unit Abbreviation
Electromotive force (emf) Potential Voltage	volt	V
Current	ampere or amp	A
Resistance	ohm	$\Omega$ or ohm
Capacity	ampere-hour or amp-hour coulomb	Ah C
Power	watt	W
Power density (weight basis)	watts per kilogram	$\text{W kg}^{-1}$
Power density (volume basis)	watts per cubic decimeter	$\text{W dm}^{-3}$
Energy	watt-hour joule	Wh J
Energy density (weight basis)	watt-hours per kilogram	$\text{Wh kg}^{-1}$
Energy density (volume basis)	watts-hours per cubic decimeter joules per cubic centimeter	$\text{Wh dm}^{-3}$ $\text{J cm}^{-3}$

# BATTERIES & THE ELECTRIC MOTOR



Image Credit: Hubsan

0.9Wh



Image Credit: Dyson

Ca. 44Wh



Image Credit: Van Moof

504Wh



# BATTERIES & THE ELECTRIC MOTOR



Image Credit: JLR

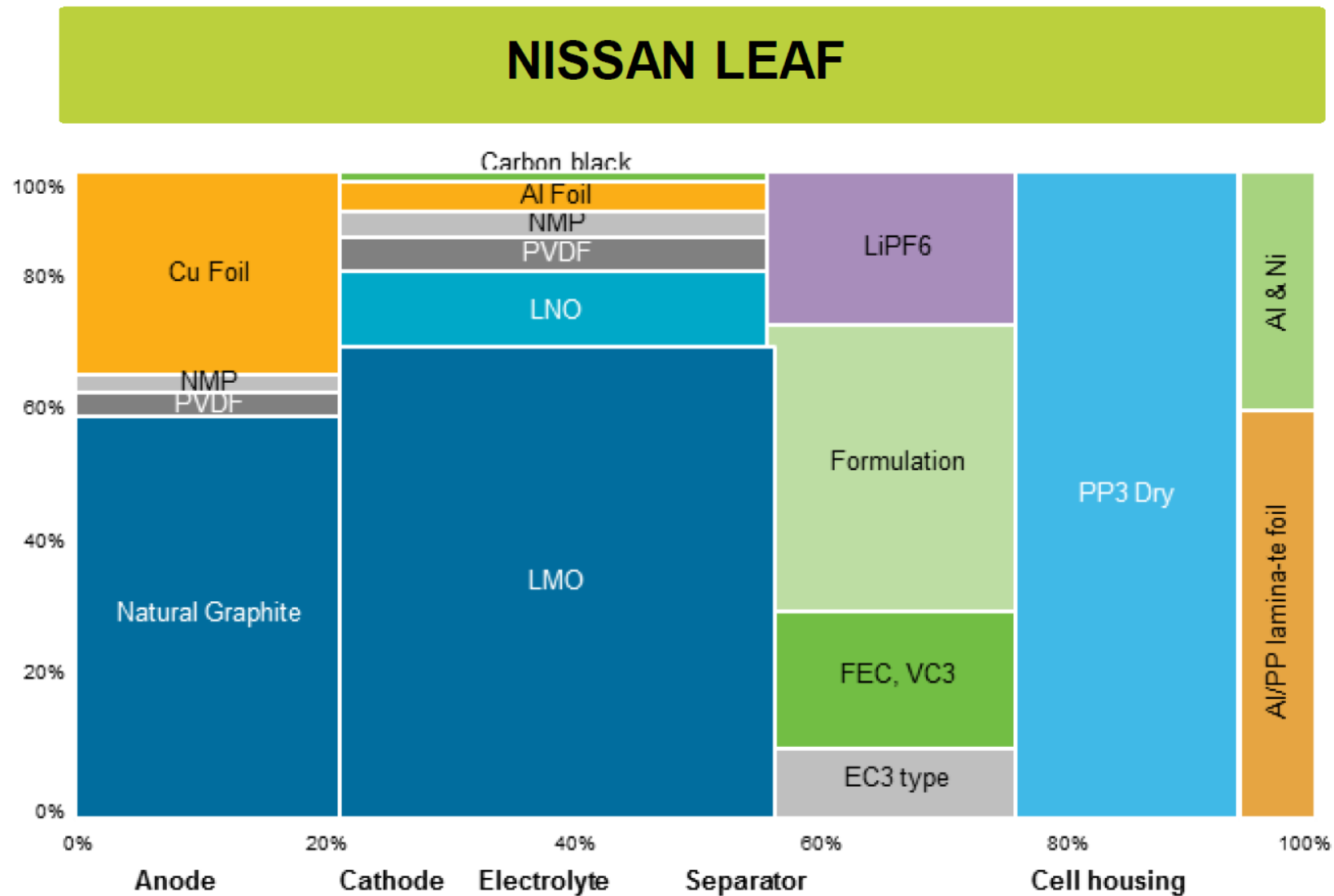
90 kWh



Image Credit: Tesla

100 MWh+

# COST BREAKDOWN: GEN 1 NISSAN LEAF



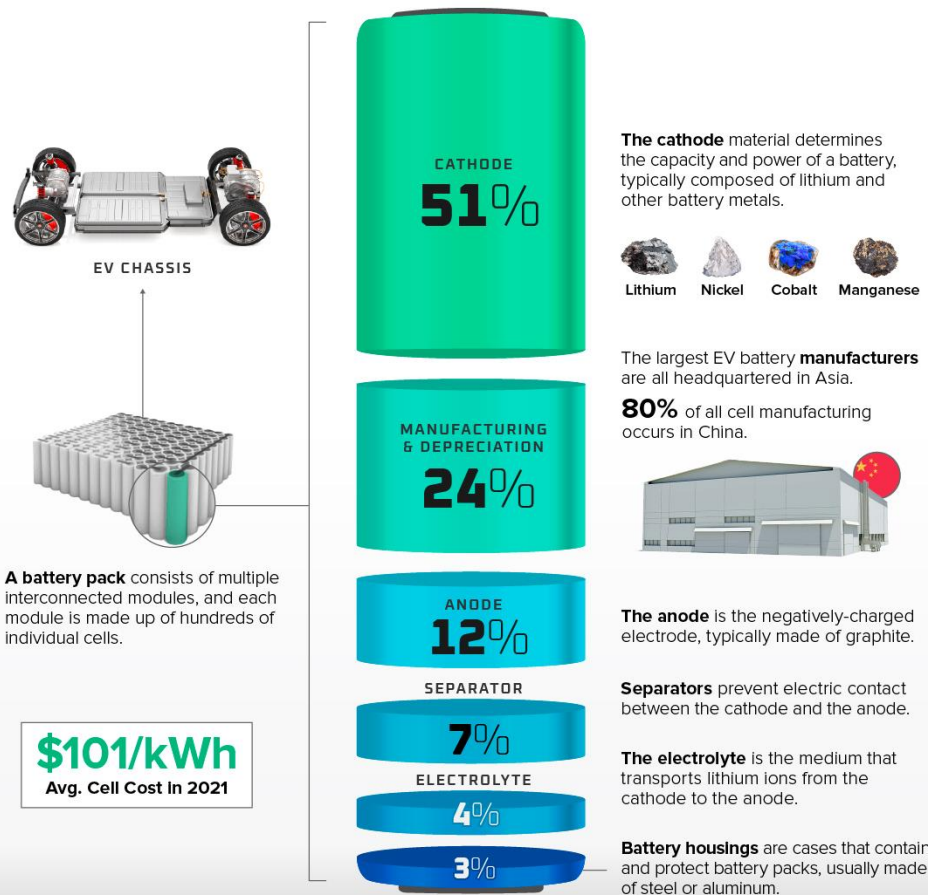
# LITHIUM METAL ELECTRODES



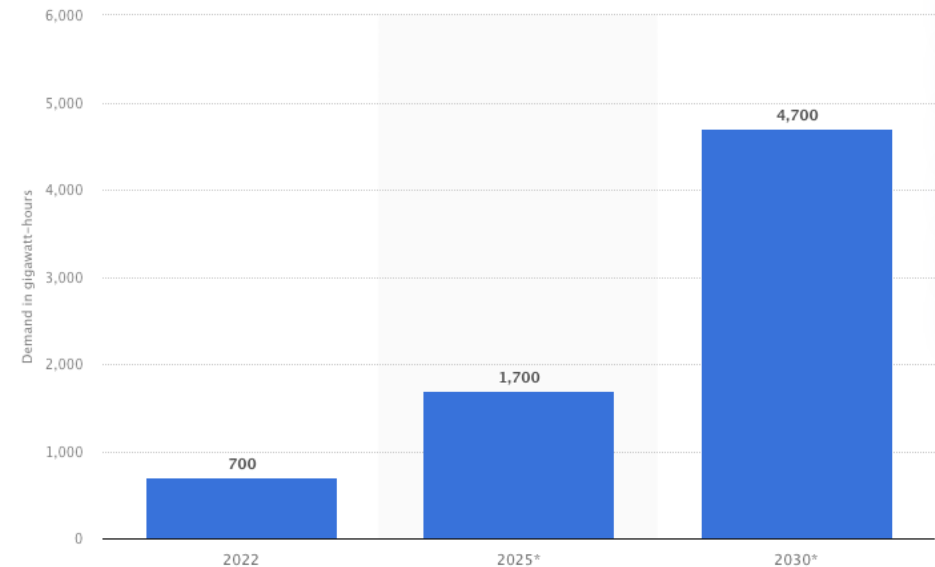
# Breaking Down the Cost of an EV BATTERY CELL

The average cost of lithium-ion batteries has declined by 89% since 2010.

What makes up the cost of lithium-ion cells?



Percentages may not add to 100 due to rounding.  
Source: BloombergNEF



[Additional Information](#)

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Image Credit: Statista

Image Credit: The Visual Capitalist

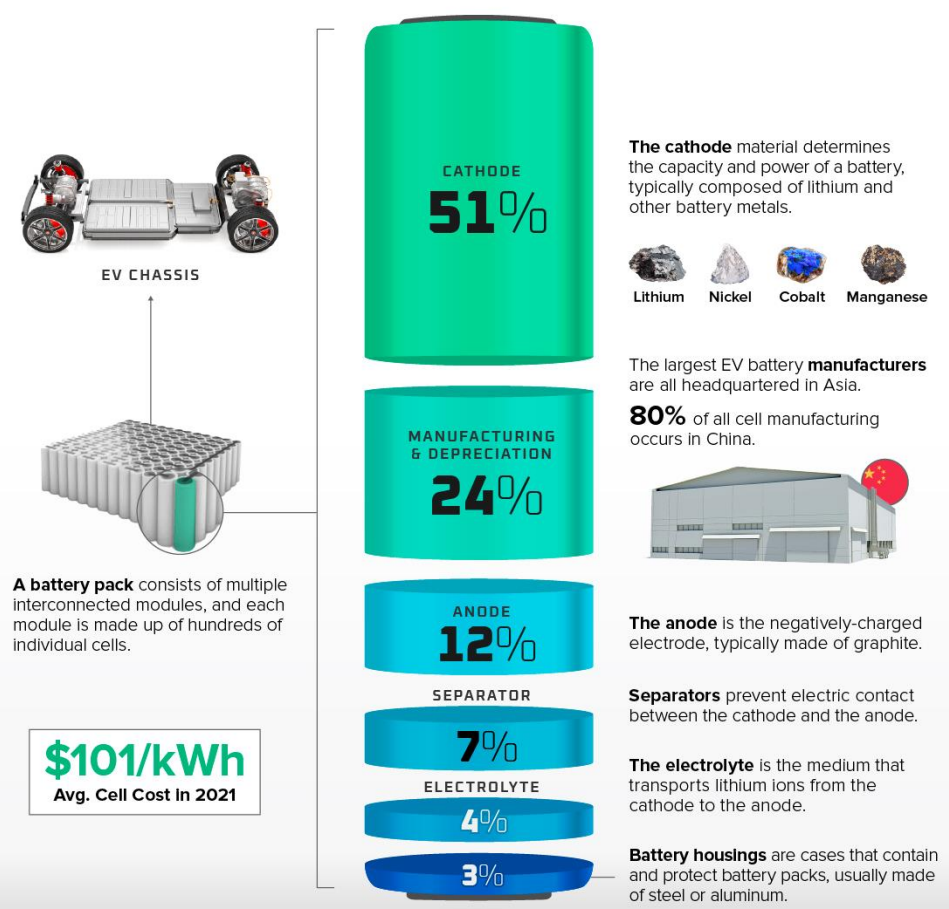




# Breaking Down the Cost of an EV BATTERY CELL

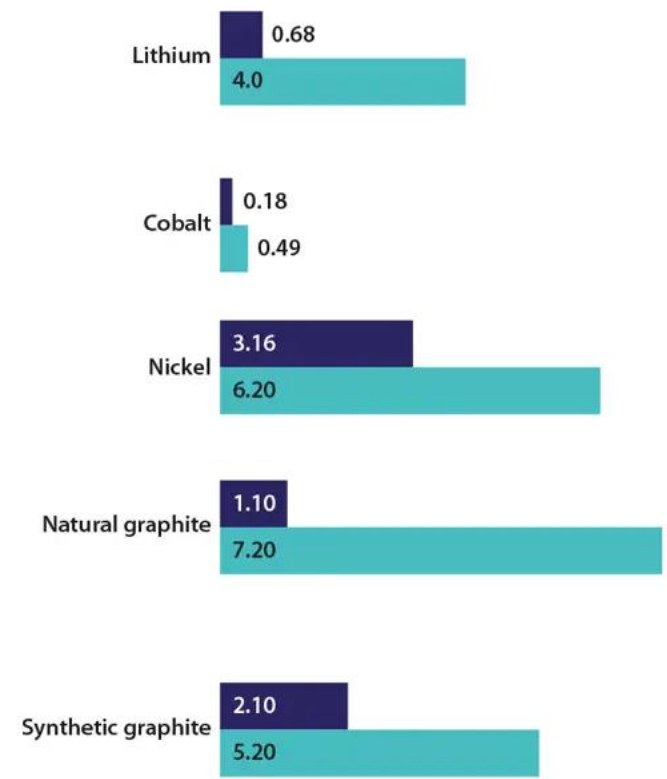
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What makes up the cost of lithium-ion cells?



Percentages may not add to 100 due to rounding.  
Source: BloombergNEF

2022 supply 2035 demand  
by mineral (million tonnes)



Number of mines/plants needed

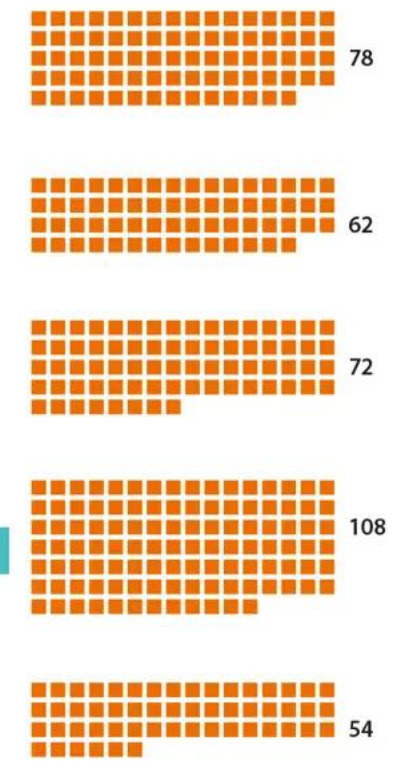


Image Credit: Shearing/RAENG

Image Credit: The Visual Capitalist



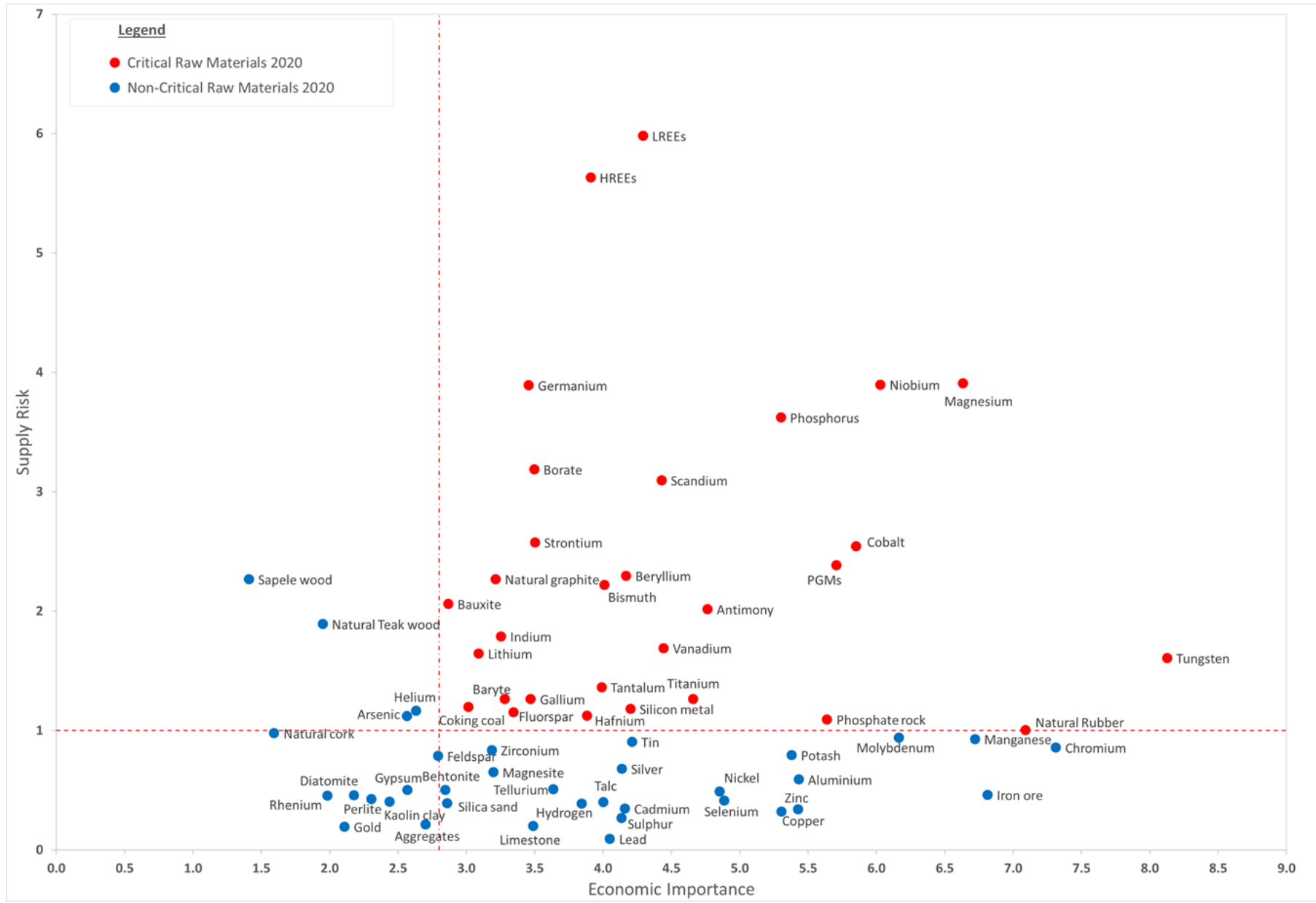


Image Credit: EU RMIS



EU Critical Raw Materials Act																																																																																																																																																																																			
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Image Credit: <https://mobilitynotes.com/european-critical-raw-materials-act/>

# PERIODIC TABLE OF ELEMENTS

## Chemical Group Block



1

1.0080

H

Hydrogen

Nonmetal

2

4.00260

He

Helium

Noble Gas

3

7.0

Li

Lithium

Alkali Metal

4

9.012183

Be

Beryllium

Alkaline Earth Metal

5

10.81

B

Boron

Metalloid

6

12.01

C

Carbon

Nonmetal

7

14.007

N

Nitrogen

Nonmetal

8

15.999

O

Oxygen

Nonmetal

9

18.9984...

F

Fluorine

Halogen

10

20.180

Ne

Neon

Noble Gas

11

22.989...

Na

Sodium

Alkali Metal

12

24.305

Mg

Magnesium

Alkaline Earth Metal

13

26.981...

Al

Aluminum

Post-Transition Metal

14

28.085

Si

Silicon

Metalloid

15

30.973...

P

Phosphorus

Nonmetal

16

32.07

S

Sulfur

Nonmetal

17

35.45

Cl

Chlorine

Halogen

18

39.9

Ar

Argon

Noble Gas

19

39.0983

K

Potassium

Alkali Metal

20

40.08

Ca

Calcium

Alkaline Earth Metal

21

44.95591

Sc

Scandium

Transition Metal

22

47.867

Ti

Titanium

Transition Metal

23

50.9415

V

Vanadium

Transition Metal

24

51.996

Cr

Chromium

Transition Metal

25

54.93804

Mn

Manganese

Transition Metal

26

55.84

Fe

Iron

Transition Metal

27

58.93319

Co

Cobalt

Transition Metal

28

58.693

Ni

Nickel

Transition Metal

29

63.55

Cu

Copper

Transition Metal

30

65.4

Zn

Zinc

Transition Metal

31

69.723

Ga

Gallium

Post-Transition Metal

32

72.63

Ge

Germanium

Metalloid

33

74.92159

As

Arsenic

Metalloid

34

78.97

Se

Selenium

Nonmetal

35

79.90

Br

Bromine

Halogen

36

83.80

Kr

Krypton

Noble Gas

37

85.468

Rb

Rubidium

Alkali Metal

38

87.62

Sr

Strontium

Alkaline Earth Metal

39

88.90584

Y

Yttrium

Transition Metal

40

91.22

Zr

Zirconium

Transition Metal

41

92.90637

Nb

Niobium

Transition Metal

42

95.95

Mo

Molybdenum

Transition Metal

43

96.90636

Tc

Technetium

Transition Metal

44

101.1

Ru

Ruthenium

Transition Metal

45

102.9055

Rh

Rhodium

Transition Metal

46

106.42

Pd

Palladium

Transition Metal

47

107.868

Ag

Silver

Transition Metal

48

112.41

Cd

Cadmium

Transition Metal

49

114.818

In

Indium

Post-Transition Metal

50

118.71

Sn

Tin

Post-Transition Metal

51

121.760

Sb

Antimony

Metalloid

52

127.6

Te

Tellurium

Metalloid

53

126.9045

I

Iodine

Halogen

54

131.29

Xe

Xenon

Noble Gas

55

132.90...

Cs

Cesium

Alkali Metal

56

137.33

Ba

Barium

Alkaline Earth Metal

57

138.9055

La

Lanthanum

Lanthanide

58

140.116

Ce

Cerium

Lanthanide

59

140.90...

Pr

Praseodymium

Lanthanide

60

144.24

Nd

Neodymium

Lanthanide

61

144.91...

Pm

Promethium

Lanthanide

62

150.4

Sm

Samarium

Lanthanide

63

151.964

Eu

Europium

Lanthanide

64

157.2

Gd

Gadolinium

Lanthanide

65

158.92...

Tb

Terbium

Lanthanide

66

162.500

Dy

Dysprosium

Lanthanide

67

164.93...

Ho

Holmium

Lanthanide

68

167.26

Er

Erbium

Lanthanide

69

168.93...

Tm

Thulium

Lanthanide

70

173.05

Yb

Ytterbium

Lanthanide

71

174.9668

Lu

Lutetium

Lanthanide

72

178.49

Hf

Hafnium

Transition Metal

73

180.9479

Ta

Tantalum

Transition Metal

74

183.84

W

Tungsten

Transition Metal

75

186.207

Re

Rhenium

Transition Metal

76

190.2

Os

Osmium

Transition Metal

77

192.22

Ir

Iridium

Transition Metal

78

195.08

Pt

Platinum

Transition Metal

79

196.96...

Au

Gold

Transition Metal

80

200.59

Hg

Mercury

Transition Metal

81

204.383

Tl

Thallium

Post-Transition Metal

82

207

Pb

Lead

Post-Transition Metal

83

208.98...

Bi

Bismuth

Post-Transition Metal

84

208.98...

Po

Polonium

Metalloid

85

209.98...

At

Astatine

Halogen

86

222.01...

Rn

Radon

Noble Gas

87

223.01...

Fr

Francium

Alkali Metal

88

226.02...

Ra

Radium

Alkaline Earth Metal

89

227.02...

Ac

Actinium

Actinide

90

232.038

Th

Thorium

Actinide

91

231.03...

Pa

Protactinium

Actinide

92

238.0289

U

Uranium

Actinide

93

237.04...

Np

Neptunium

Actinide

94

244.06...

Pu

Plutonium

Actinide

95

243.06...

Am

Americium

Actinide

96

247.07...

Cm

Curium

Actinide

97

247.07...

Bk

Berkelium

Actinide

98

251.07...

Cf

Californium

Actinide

99

252.0830

Es

Einsteinium

Actinide

100

257.0...

Fm

Fermium

Actinide

101

258.0...

Md

Mendelevium

Actinide

102

259.1...

No

Nobelium

Actinide

103

266.1...

Lr

Lawrencium

Actinide

Atomic Number

17

35.45

Atomic Mass, u

Name

Chlorine

Halogen

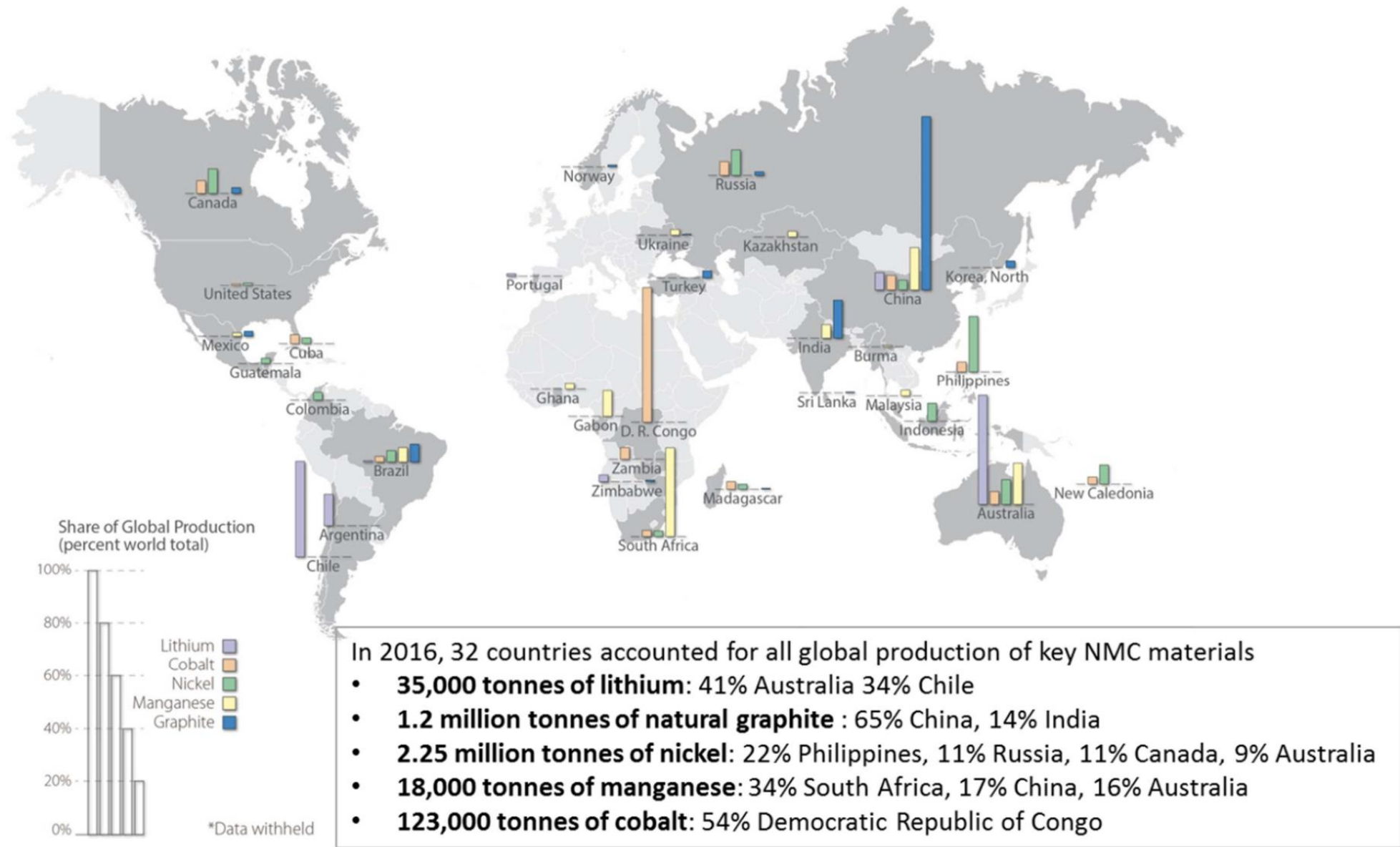
Symbol

Cl

Chemical Group Block

PubChem





**Figure 1. World mining industry production for materials used in LIB in 2016 (data source: USGS 2016 [131])**

# GLOBAL LIB PRODUCTION GWH

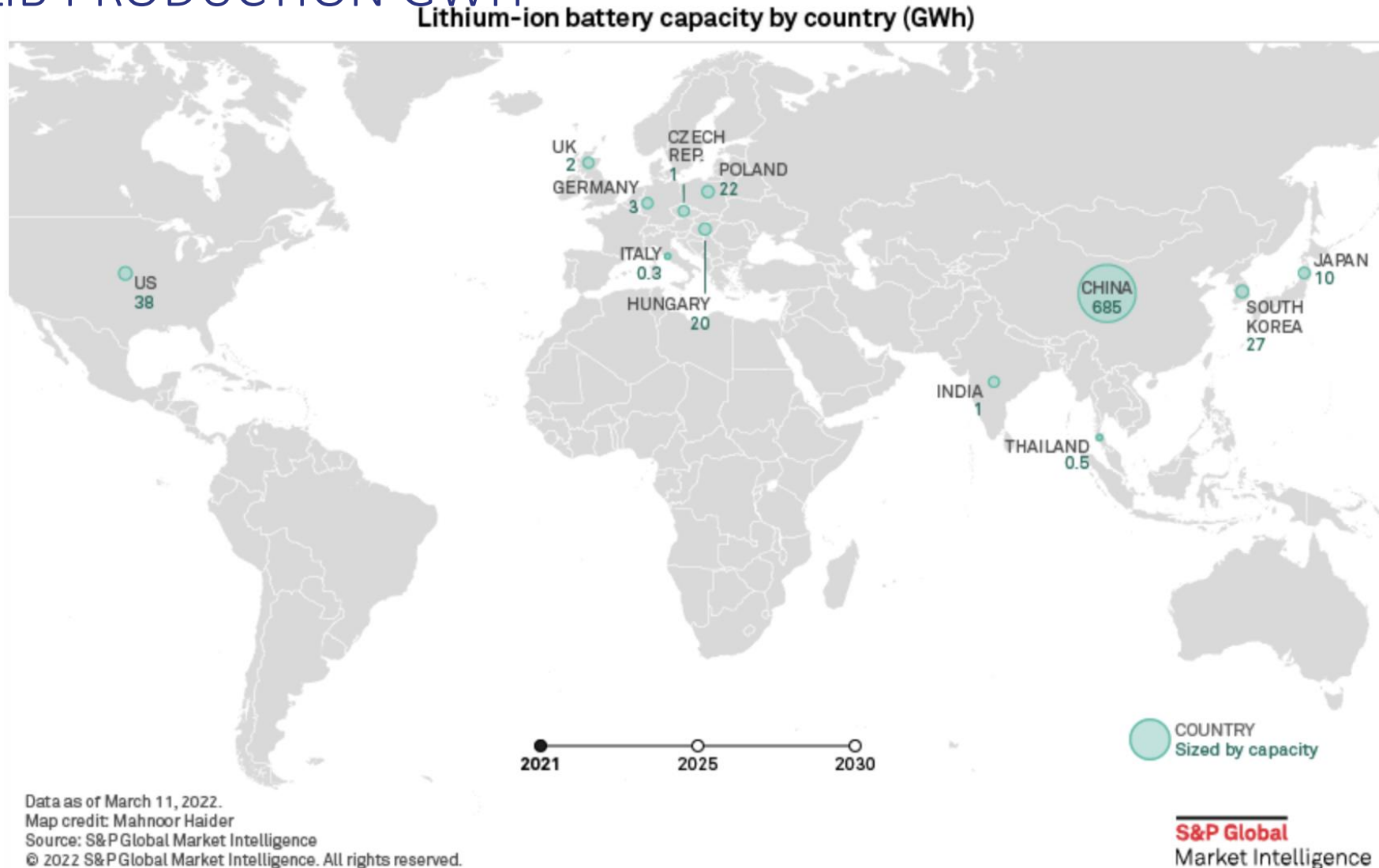


Image Credit: S&P Global

# GLOBAL LIB PRODUCTION GWH

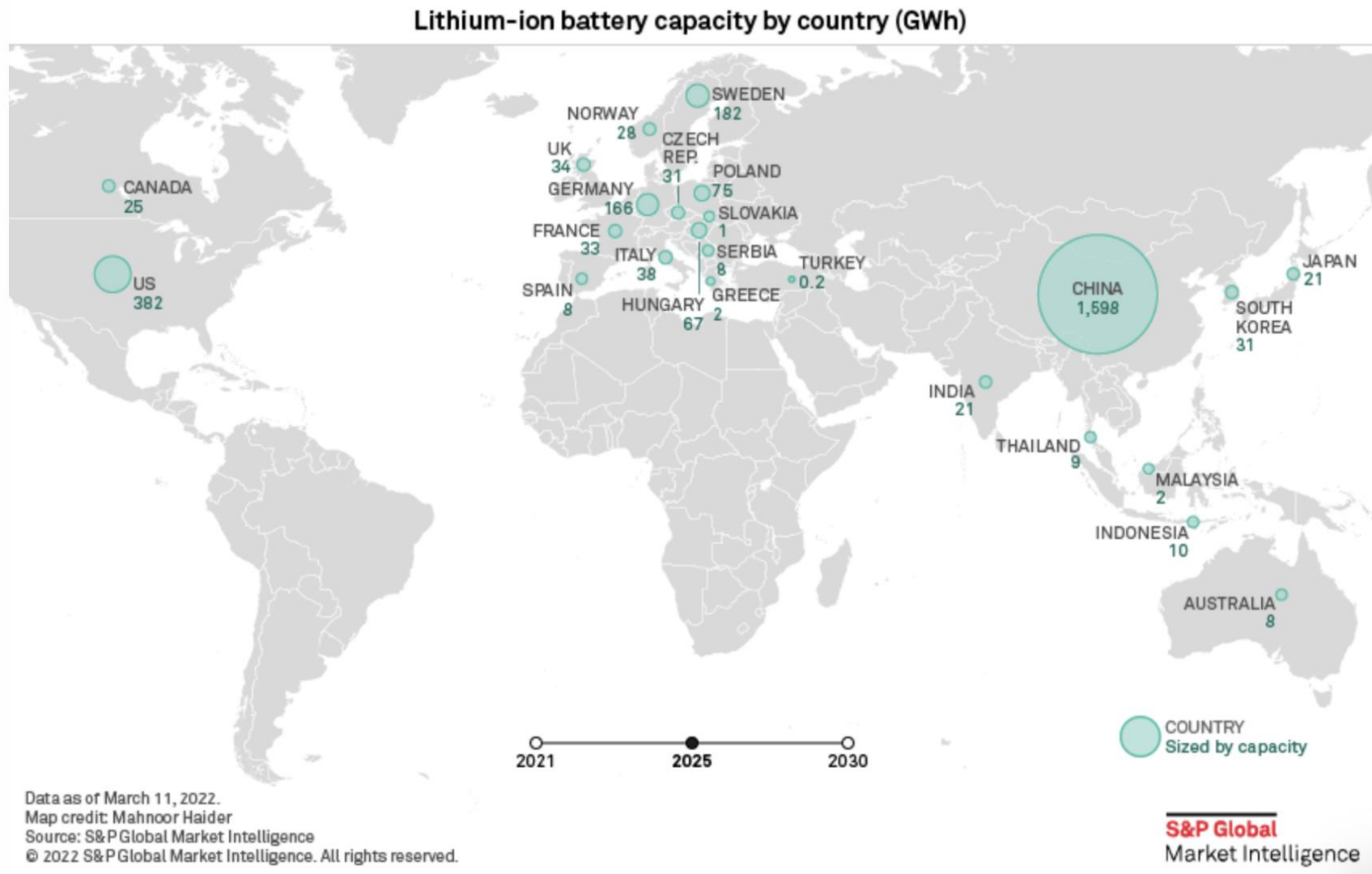


Image Credit: S&P Global

# GLOBAL LIB PRODUCTION GWH

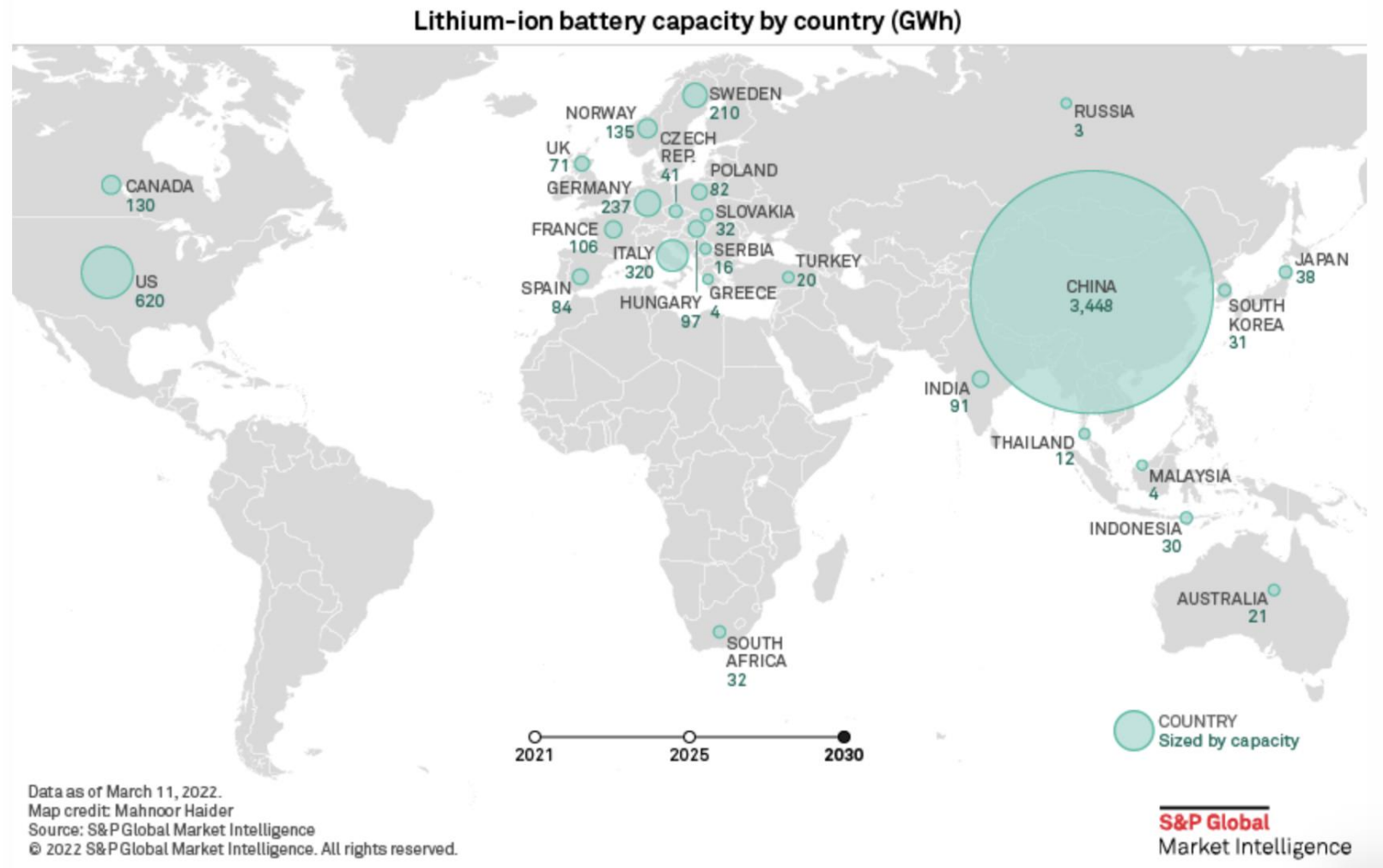


Image Credit: S&P Global





# Australia's lithium mining boom hit by sagging prices



GETTY IMAGES

Australia is the world's largest producer of lithium ore

## Nickel prices have

Nickel open prices, US dollars per

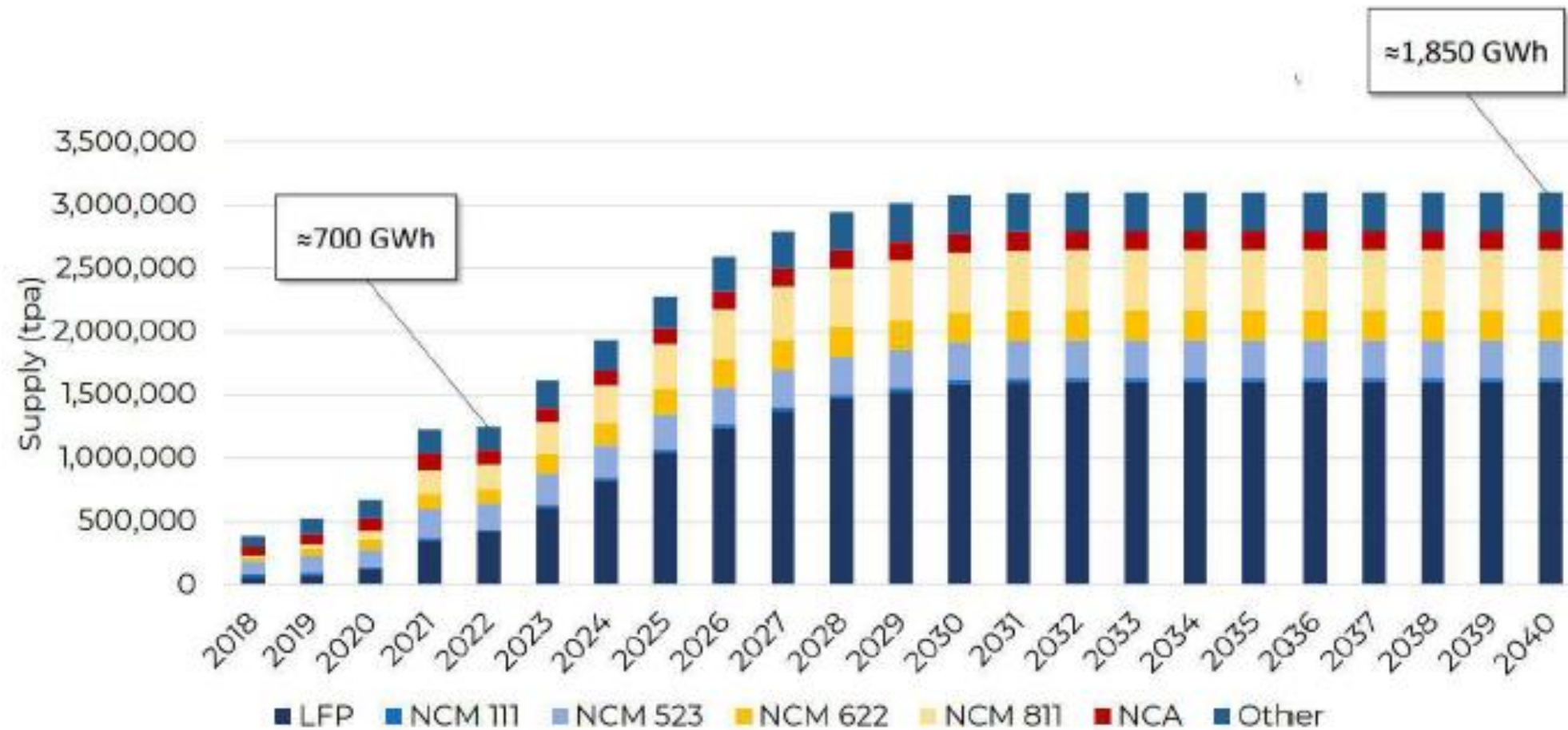


Source: Trading Economics

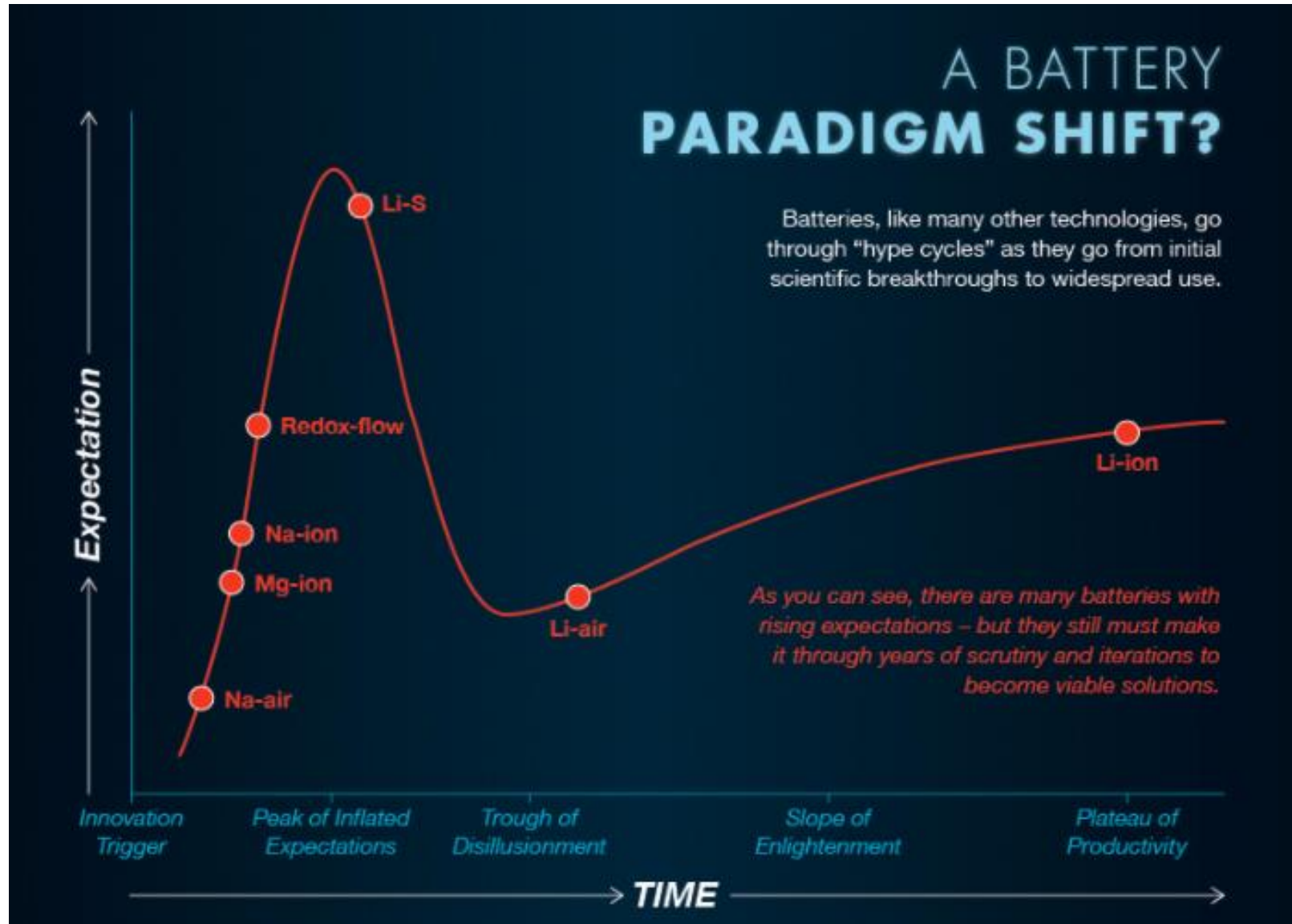
Image Credit: Tr



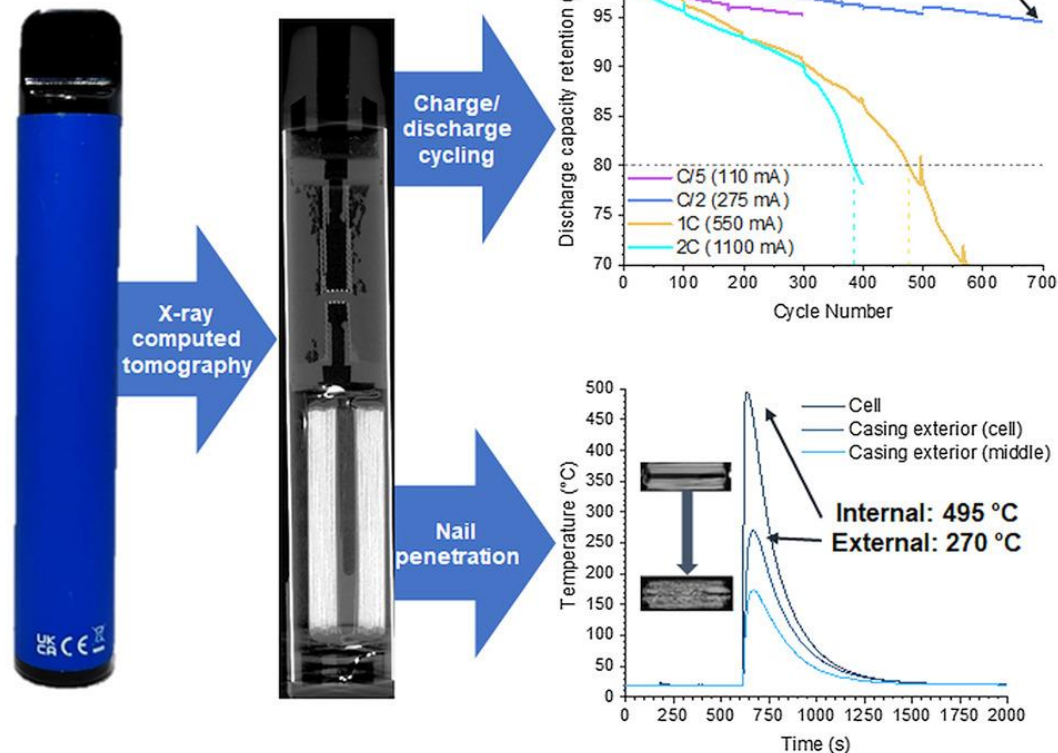
# PERSPECTIVE: THE RENAISSANCE OF LFP



Source: Benchmark Mineral Intelligence 2022 | Q2 2022 Forecast



# CASE STUDY 1: DISPOSABLE VAPE BATTERIES



## 'Disposable Battery'

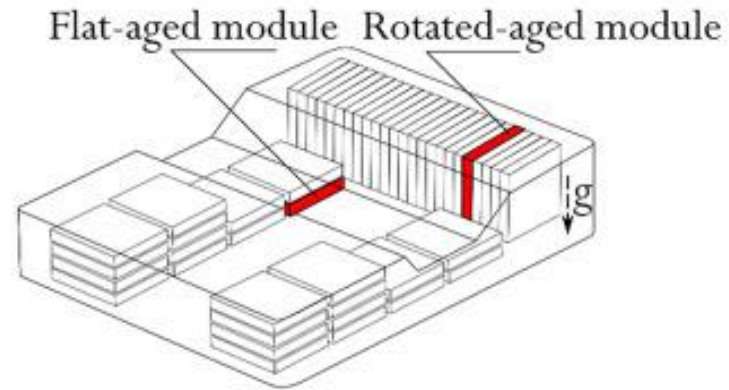
- 550 mAh, 3.7V
- 1.3 million batteries disposed of **every week** UK
- **How many Teslas could be made every year from discarded UK Vape batteries?**  
**1965 Tesla Model S vehicles...**  
**(or more than 5 million iPhones)**



## CASE STUDY 2: EOL AUTOMOTIVE BATTERIES



A



A Gen 1 Nissan Leaf Cell has a capacity of 32Ah (nominal voltage 3.7V)  
At end of life its capacity retention is 80%

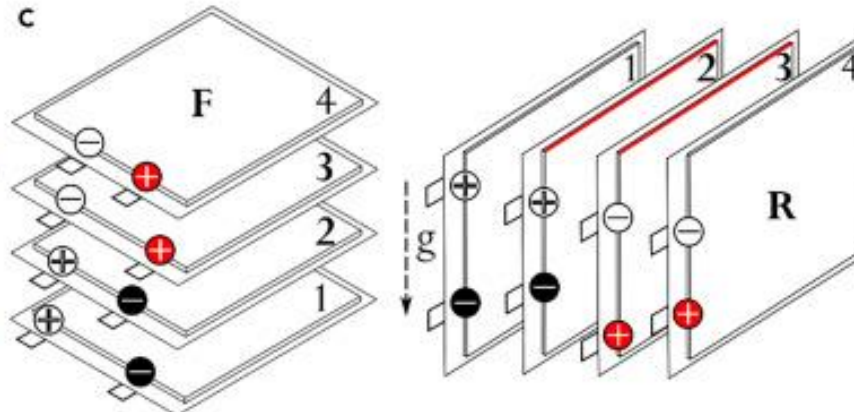
Each vehicle contains 192 cells

The Roosecote storage battery is 49MW/24.5MWh

B



C



**How many end of life Nissan leaf vehicles would need to be recycled to service these needs?**

**1347 cars worth...**

## CASE STUDY 3: TESLA MEGA-PACK



The Victoria Big Battery provides 300MW and 450MWh of grid services

It is likely constructed from 21700 cells

Assuming a capacity of 4.5Ah and nominal voltage of 3.7V

**How many individual cells make up the big battery?**

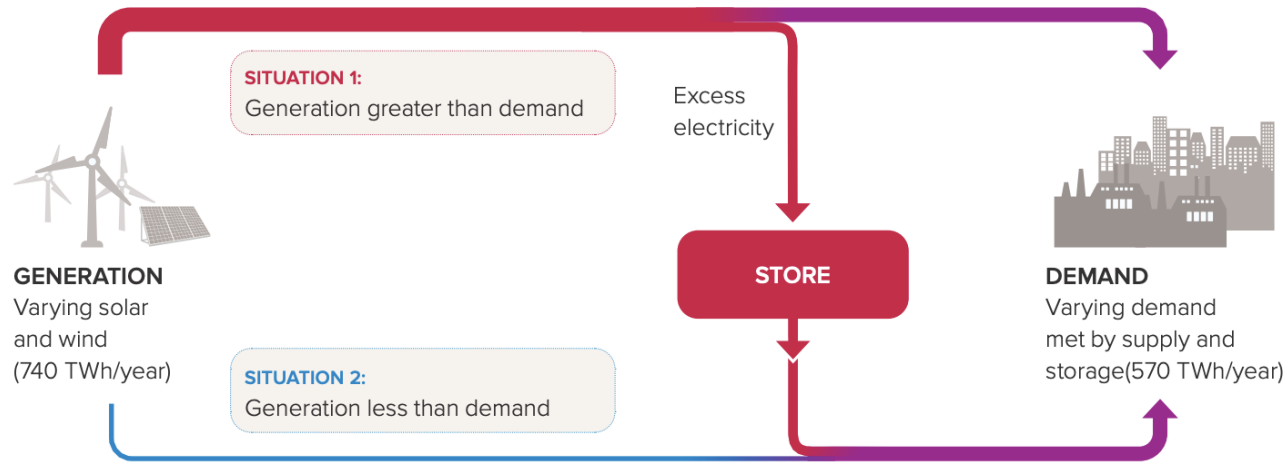
**Ca. 27 million!!**

# CASE STUDY 4: LONG DURATION STORAGE

FIGURE 1

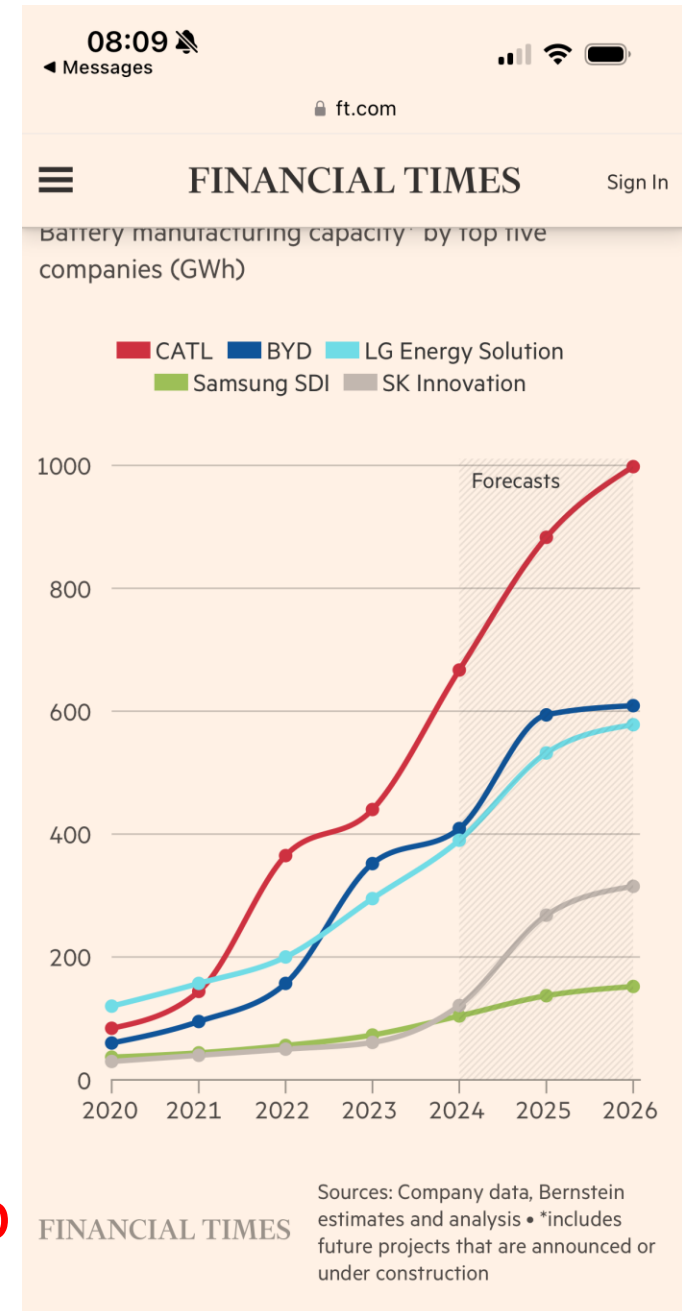
Energy store operation.

Demand must always be balanced by generation and / or storage.



To balance intermittent renewables over long periods (eg seasonal low wind) – the UK could require up to 120TWh of energy storage

**Related to 2023 global battery manufacture from the 'Top 5' – how many years production does this equate to? 2023 production of ca. 1.2TWh... so about 100 years**





# THE ERA OF THE GIGAFACTORY

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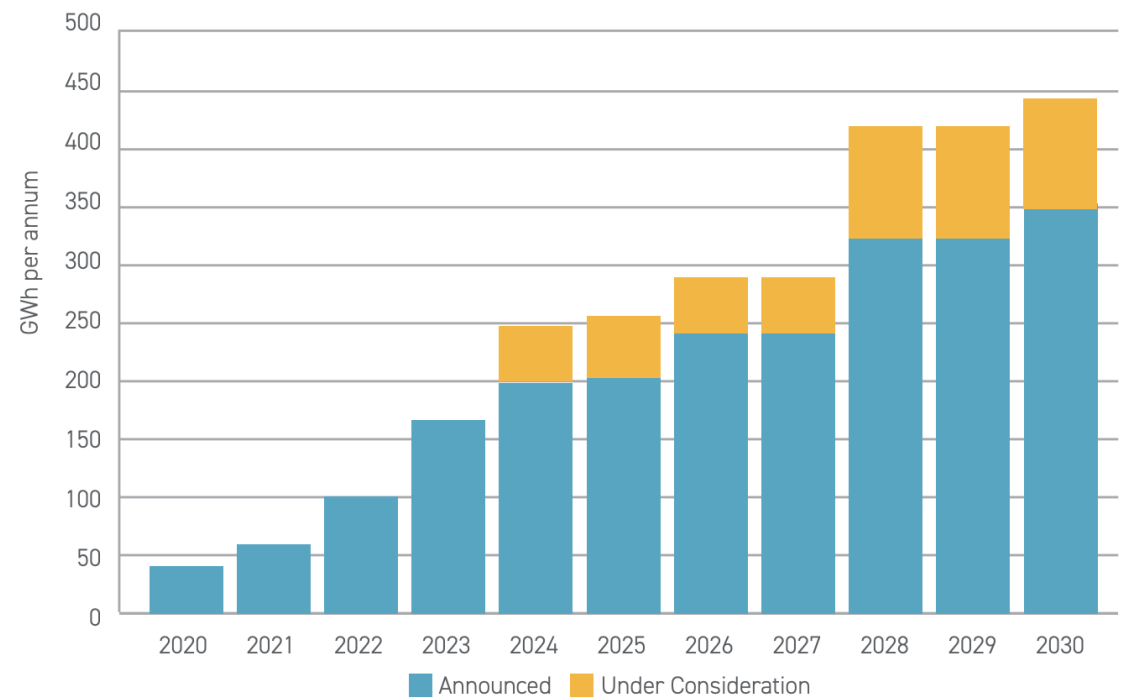




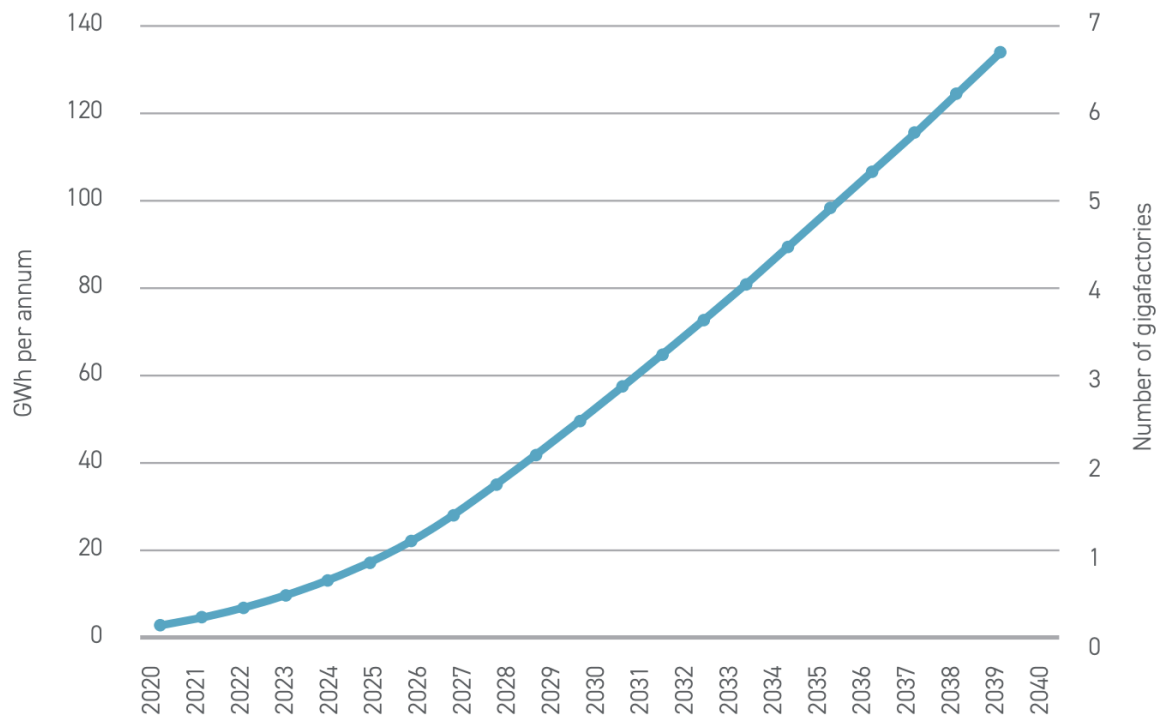
# BATTERIES: SUPPLY & DEMAND



European lithium-ion gigafactory battery manufacturing capacity to 2030



Projected demand for UK-produced batteries



Source: Faraday Institution, UK electric vehicle and battery production potential to 2040

# GIGA- FACTORIES IN THE UK

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THE ROYAL  
INSTITUTION  
'GIGAFACTORY'  
1807





# Thank You

Paul Shearing,  
ZERO Director:

[paul.shearing@eng.ox.ac.uk](mailto:paul.shearing@eng.ox.ac.uk)