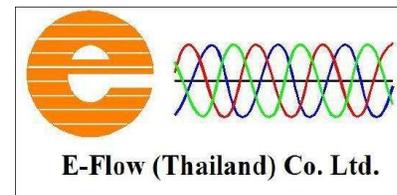


Lithium Batteries/Electric Vehicles

the Good, the Bad and the Ugly

Jay Babin



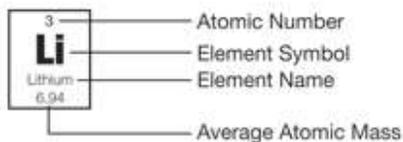
Internet Search-Believe it or not

- California banned EV charging during a recent heat wave
- **Fact check: California didn't require electric car owners to stop charging in heat wave**
 - The California ISO Flex Alert was voluntary and recommended residents curb electricity usage from 5-10 p.m. It encouraged electric vehicle owners to charge their cars before the alert began.
- It did NOT ask electric vehicle owners to stop charging their cars altogether.

<https://eu.usatoday.com/story/news/factcheck/2021/06/25/california-didnt-require-electric-car-owners-stop-charging/5320286001/>

The Periodic Table of the Elements

1 H Hydrogen 1.01																	2 He Helium 4.00						
3 Li Lithium 6.94	4 Be Beryllium 9.01																	5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31																	13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80						
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29						
55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)						
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium 178.49	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (272)	112 Cn Copernicium (285)												



58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium 168.93	102 No Nobelium (259)	103 Lr Lawrencium (262)

Lithium Vs Lead

Lithium-Li

From ancient Greek Lithos (stone)

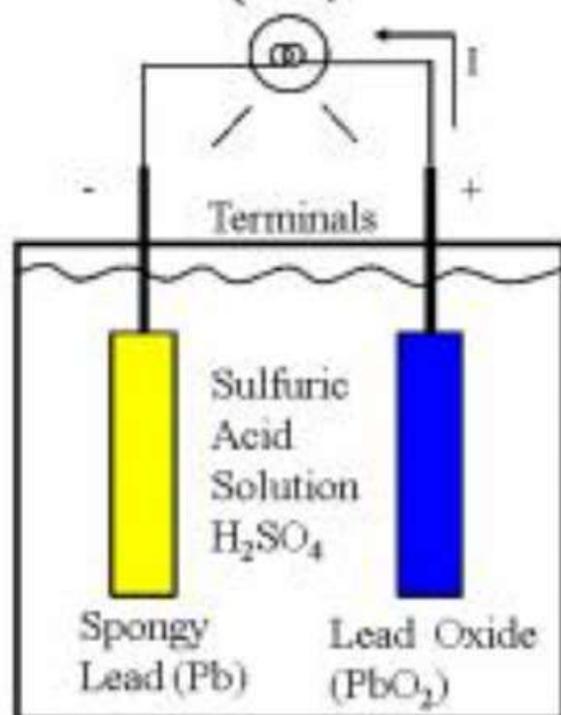
- Atomic number 3 & mass 6.94
- Least dense solid (0.5334 g/ml)
 - Water is 1.0 g/ml
- Highly reactive
- Does not occur freely but occurs mainly as pegmatitic minerals (e.g. quartz)
- Very soluble in water
- Commonly obtained from brines and isolated electrolytically
- Lithium deuteride serves as a fusion fuel in staged thermonuclear weapons
- Used in glass, ceramics, lubricants, flux and batteries
- Used to treat bipolar disorders

Lead-Pb

Latin word plumbum (lead)

- Atomic number 82 & mass 207.2
- Densest of all stable metals (11.34 g/ml)
- Relatively unreactive
- Not very soluble in water
- Easily extracted from ores (Galena)
- Used in Paints, bullets, solder, pewter, batteries
- Very toxic, neurotoxin

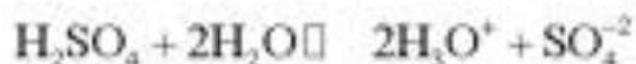
The Lead Acid Electric Battery



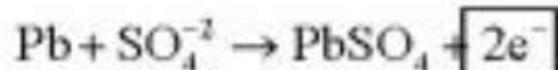
Cell: 2 V

Battery: Multiple cells

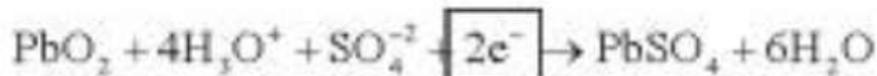
Sulfuric Acid Electrolyte:

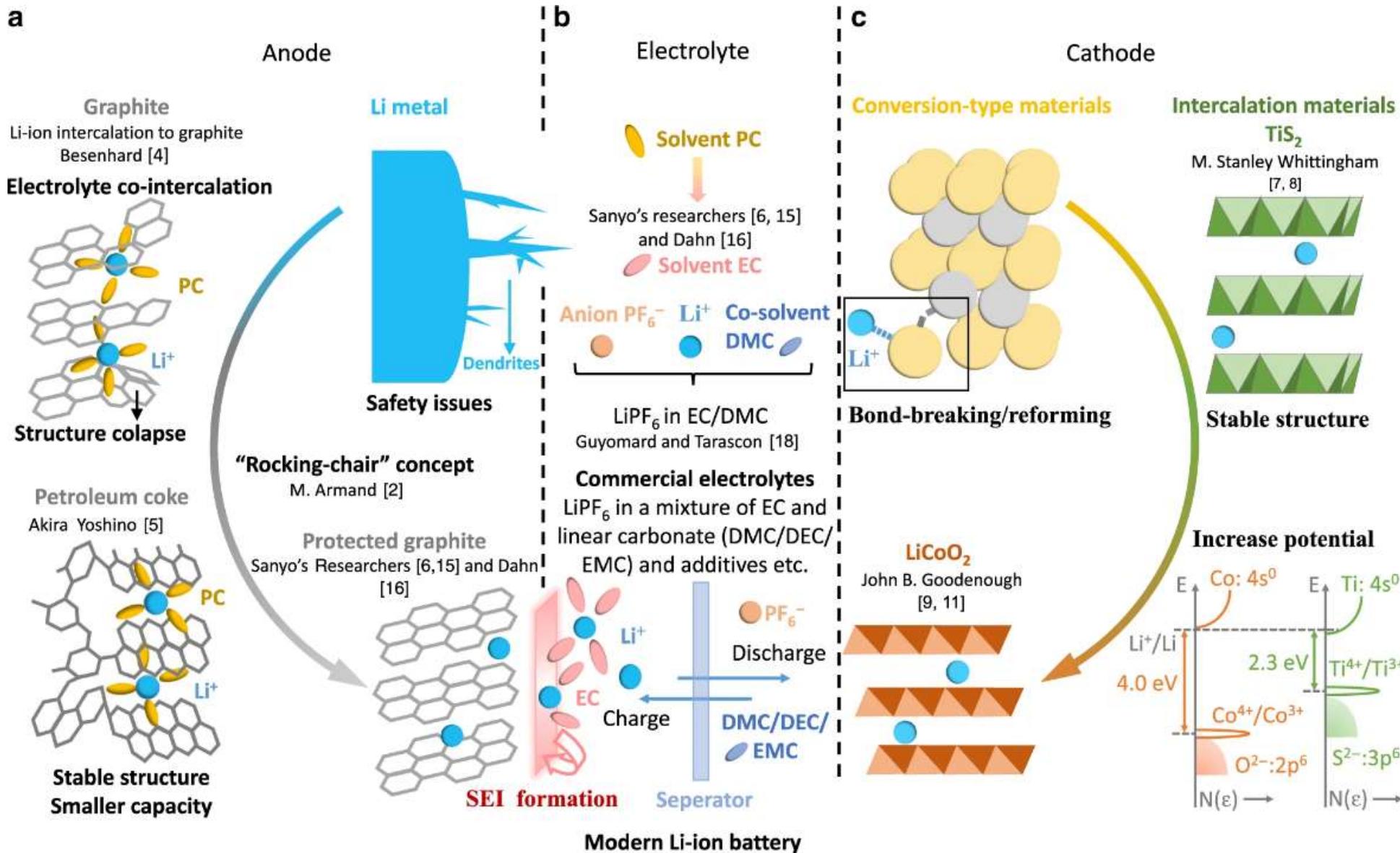


Oxidation at the Negative Plate (Electrode: Anode):

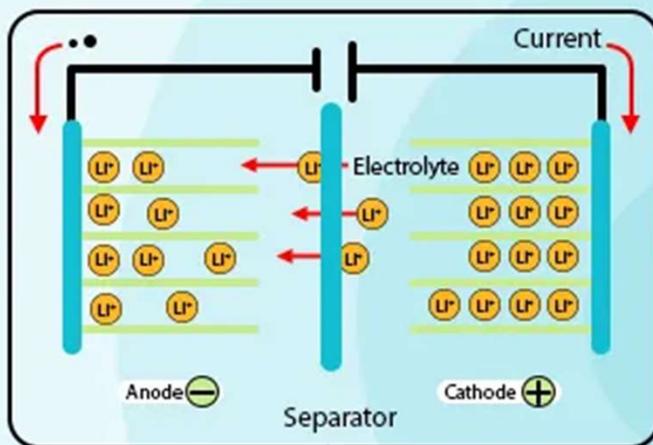


Reduction at the Positive Plate (Electrode: Cathode):

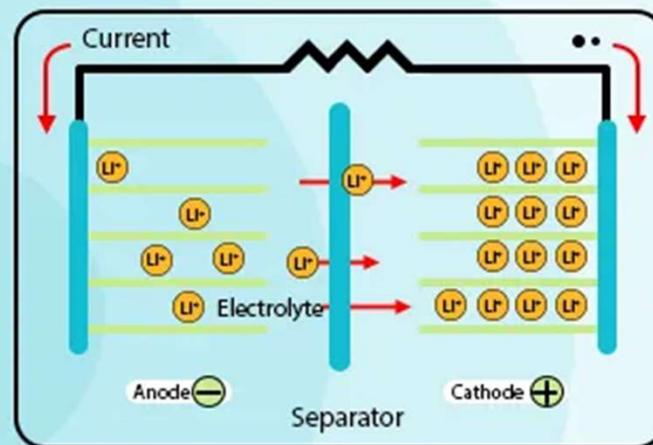




CHEMICAL PROCESS OF A LI-ION



Charging



Discharging

RAVPOWER

Battery composition

	Lead-Acid	Lithium-Ion
Anode	Pb	Carbon
Cathode	PbO ₂	Lithium Oxide (LiFePO ₄ , LiCoO ₂ , LiMn ₂ O ₄ , etc...)
Electrolyte	H ₂ SO ₄ (liquid, gel)	Lithium salt (liquid, solid, gel)

<https://climatebiz.com/lead-acid-vs-lithium-ion/>

The Good



Density and capacity

	Lead-Acid	Lithium-Ion
Storage capacity theory	167 Wh/kg	11,600 Wh/kg
Storage capacity practice	30–40 Wh/kg	110–250 Wh/kg

The theoretical density does not consider the mass of the electrolytes and other components (battery casing, safety equipment...)

	Lead-Acid	Lithium-Ion
Energy density	80-90 Wh/l	250 – 670 Wh/l
Specific power	180 W/kg	250 – 340 W/kg

<https://climatebiz.com/lead-acid-vs-lithium-ion/>

DoD and Charging Efficiency

- Depth of discharge (DoD)
 - LAB manufacturer advises not to discharge the battery below 50% of its full capacity to improve its life duration
 - Recent improvements in lithium technology enable 100% DOD without damaging the battery.
- The charge efficiency is the actual quantity of energy effectively stored in the battery. When charging a 1 kWh battery, you use more than 1 kWh due to internal loss.
 - lithium-ion battery will lose approximately 5-10% of energy
 - lead-acid battery will lose approximately 20-25% of energy

Which is cheaper? Levelized Cost of Storage (LCOS)

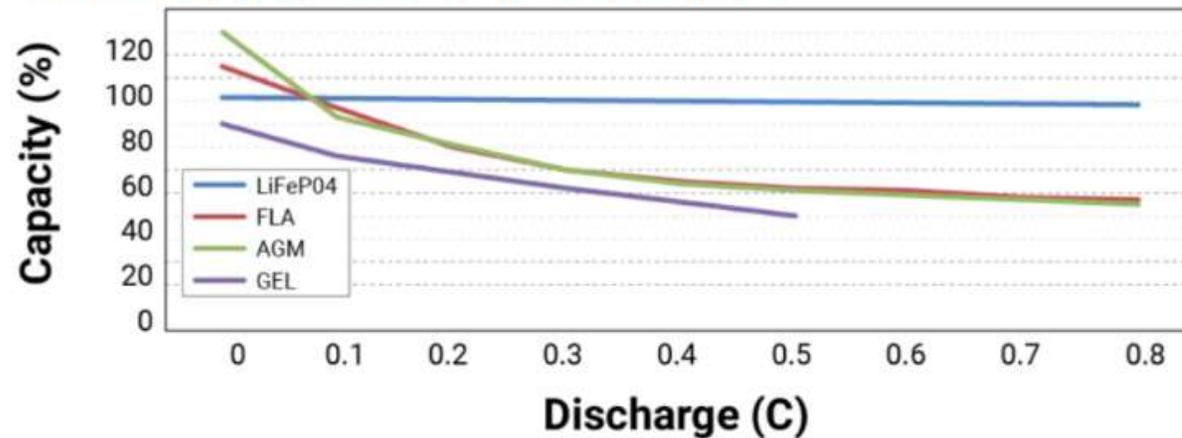
	Expert Power ^{LI}	Expert Power ^{LAB}	Renogy ^{LAB}
Battery type	LiFePO4	VLRA	Hybrid Gel
Capacity	100Ah (1.2 kWh)	100Ah (1.2 kWh)	100Ah (1.2 kWh)
Number of cycles at DOD	3600 cycles @ 80% DOD	500 cycles @ 50% DOD	750 cycles @ 50% DOD
Total kWh over lifetime	3,456 kWh	300 kWh	450 kWh
Total cost	\$399.99	\$139.99	\$206.99
LCOS	0.115 \$/kWh	0.466 \$/kWh	0.459 \$/kWh

<https://climatebiz.com/lead-acid-vs-lithium-ion/>

- Lithium battery capacity is independent of discharge rate
- A lower rated Li battery will have a higher capacity than a LAB

CAPACITY OF LiFePO4 vs. LEAD ACID AT VARIOUS CURRENTS OF DISCHARGE

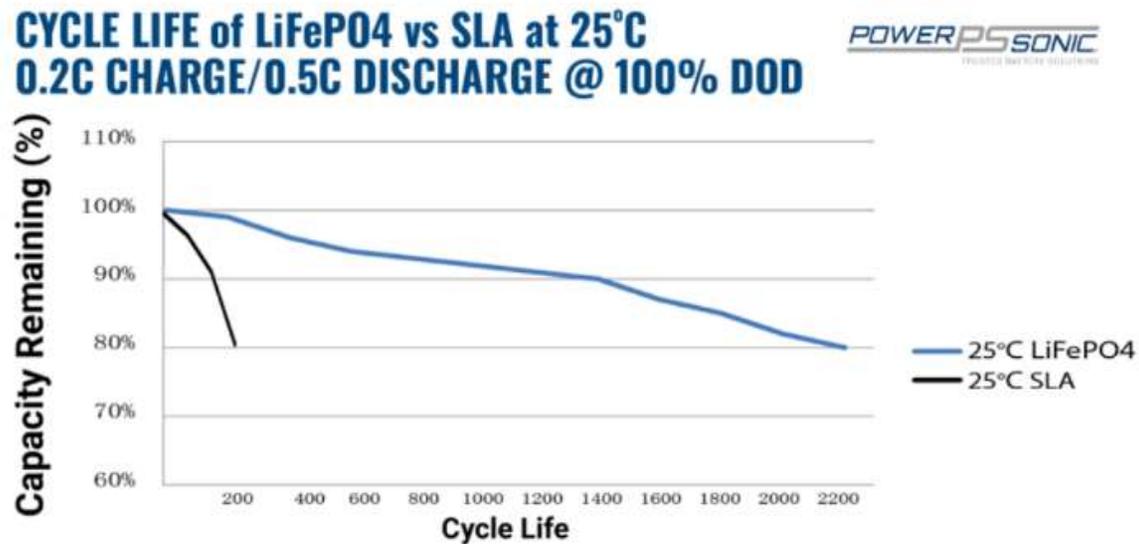
POWERSONIC
INDUSTRIAL BATTERY SOLUTIONS



Capacity of lithium battery vs different types of lead acid batteries at various discharge currents

<https://www.power-sonic.com/blog/lithium-vs-lead-acid-batteries/>

- Li batteries have ~ 11x the cycle life of LAB
- Have to replace LAB sooner/more often



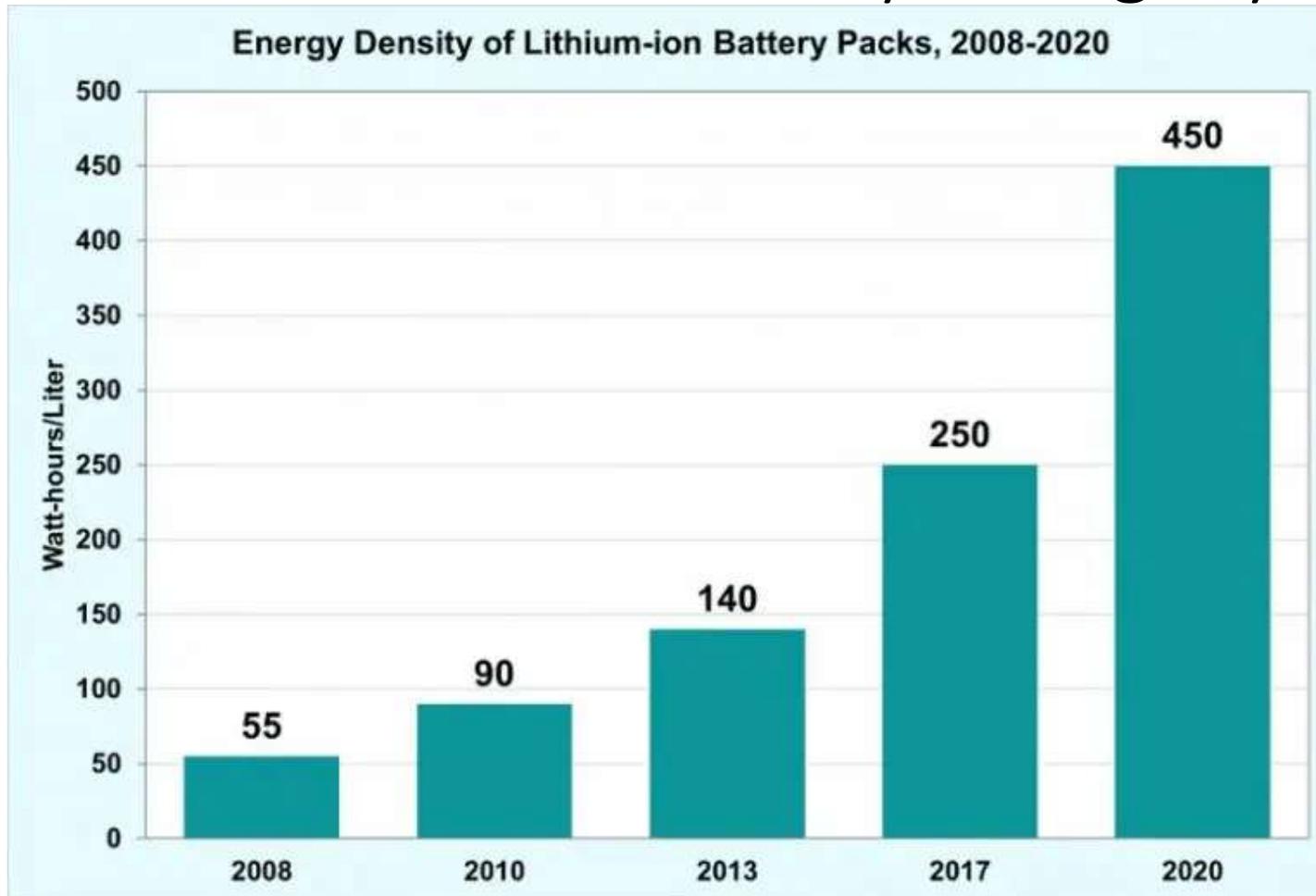
Comparing LiFePO4 vs SLA battery cycle life

<https://www.power-sonic.com/blog/lithium-vs-lead-acid-batteries/>

	Lead Acid Batteries	Lithium-Ion Batteries (LiFePO4)
Power Density	40 watts per kilogram	125 watts per kilogram
Cycle Life	200 @ 100% DoD	2800 @ 100%DoD
Usable Energy	50%	80%
Temperature sensitivity	Degrades significantly above 76° F (25° C)	Degrades above 95° F (45° C)
Voltage Per Cell	2 V	3.2 V
Maintenance Requirements	Regular maintenance, every 3 months	Basic annual maintenance

<https://www.eTechnophiles.com/lithium-ion-vs-lead-acid-battery/>

Li Battery Ontogeny



<https://www.eTechnophiles.com/lithium-ion-vs-lead-acid-battery/>

Life span & other benefits

- Lithium-ion batteries admit 10,000 charge cycles and a life of 10 years when discharged up to 70% of their initial capacity. Compared to lead acid batteries since they only offer 350 cycles and a life of 1 year when discharged up to 70%.

	Lead Acid	Lithium-Ion
Charging Time	8 hours	1 - 2 Hours
Cool-Down Period	8 Hours	Not Needed
Charging Method	Removed from forklift, placed in charging base and taken to special charging storage room	Plugged directly into the wall, even while the battery is installed in the forklift
Safe Discharge	Down to 30% - 50% capacity	Down to 20% capacity
Opportunity Charge	No	Yes

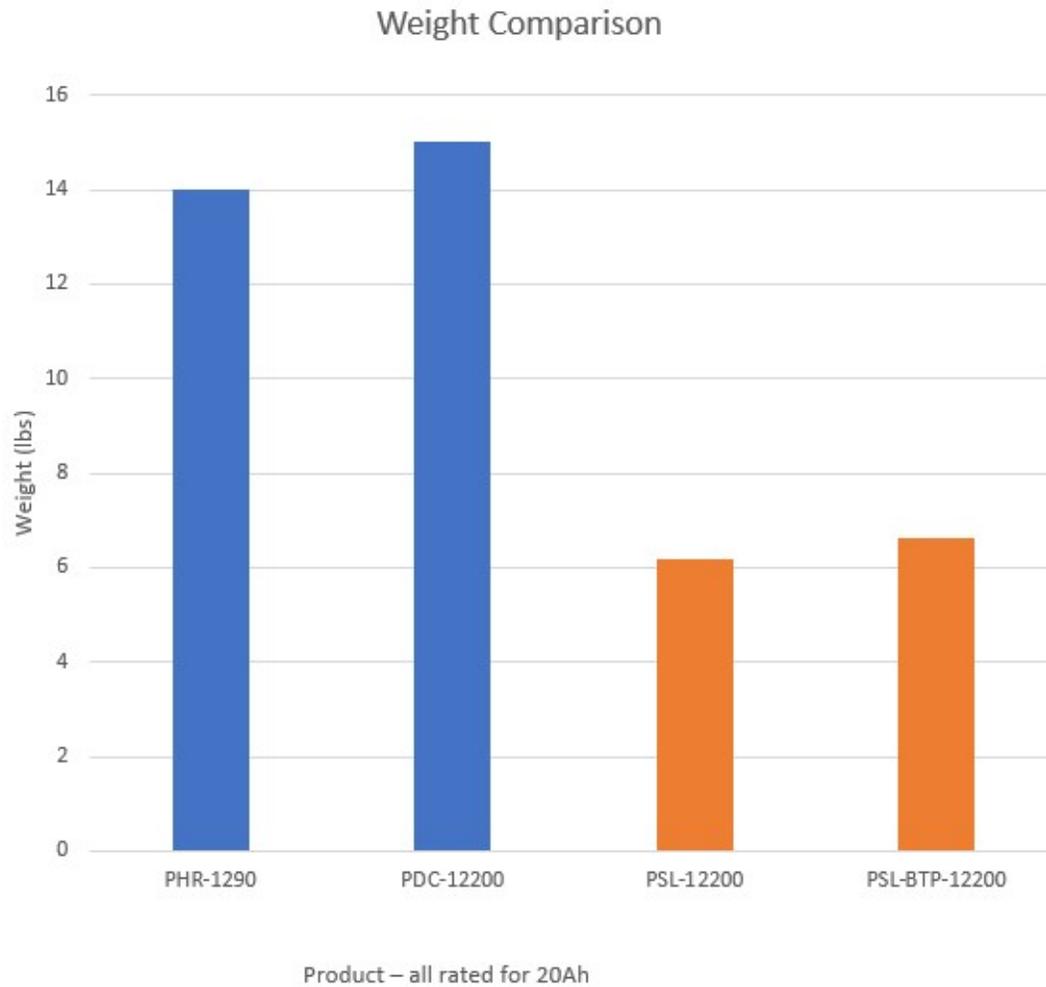
<https://www.etechnophiles.com/lithium-ion-vs-lead-acid-batterv/>

Battery Installation & Weight

- Li batteries can be installed in any orientation
- Lead batteries cannot be installed on an angle or inverted

<https://www.power-sonic.com/blog/lithium-vs-lead-acid-batteries/>

LA vs Li: Weight for 200 Ah



<https://www.power-sonic.com/blog/lithium-vs-lead-acid-batteries/>

- Many differences between Li and LA batteries
- Most instances Li is the better/stronger battery
- LA batteries are better for some applications
 - long strings-serial/parallel orientation
 - low charging temperatures
 - high discharge rates

<https://www.power-sonic.com/blog/lithium-vs-lead-acid-batteries/>

No exhaust pipe emission













2019-07-01 The worlds largest floating solar farm in Chinas' Huainan Anhui Province









The Bad



Cold temperatures & charging

- Li battery will not accept a charge at temp $< 0^{\circ}\text{C}$ (32°F)
- @ 0°F Li is discharged at 70% of its rated capacity,
lead acid battery is only 45% of its rated capacity

<https://www.power-sonic.com/blog/lithium-vs-lead-acid-batteries/>

How Many Miles Can an EV Drive on a Full Charge?

- The average figure for how far a single charge can get you is 250 miles (June 2022)
 - Smart EQ forfour with an average real-world range of 55 miles (16.7kWh battery)
 - Lucid Air Dream Edition R has an estimated average range of 430 miles (118kWh battery)
 - *UC Davis Plug In Hybrid and Electric Vehicle (PHEV) Research Center*
- Battery size, vehicle weight, vehicle age,
- Driving behavior, weather (AC/Heater), driving conditions (traffic)

What's The Real World Highway Range Of Today's Electric Cars? (June 2023)

Vehicle	Price	Real Range (Miles)	EPA Range (Miles)	Difference	Efficiency (mi/kWh)
2022 Lucid Air Dream Edition Range	\$169,000	500	520	-4.0%	4.30
2022 Mercedes EQS 450+	\$102,310	395	350	+13.0%	3.67
2022 BMW iX xDrive50 w/20" Wheels	\$83,200	345	324	+6.5%	3.25
2023 Cadillac Lyriq RWD w/20" Wheels	\$62,990	330	312	+5.8%	3.15
2021 Tesla Model 3 AWD	\$48,990	310	353	-12.2%	4.25
2023 Porsche Taycan RWD 93 kWh Battery (New Software)	\$81,150*	305	225	+35.8%	3.66
2021 Tesla Model S Plaid w/21" Arachnid	\$134,490	300	348	-12.0%	3.30
2021 Porsche Taycan RWD 93 kWh Battery	\$85,470*	293 297	225 225	+30.0% +32.0%	3.49 3.50
2019 Tesla Model 3 AWD	\$47,990	290	322	-10.0%	4.25
2021 Ford Mustang Mach-E California Route 1 Edition	\$50,400	287	305	-6.0%	3.30

<https://insideevs.com/reviews/443791/ev-range-test-results/>

Vehicle	Price	Real Range (Miles)	EPA Range (Miles)	Difference	Efficiency (mi/kWh)
2022 Hyundai Ioniq 5 AWD Limited w/20" Wheels	\$54,500	195	256	-24.0%	2.70
2022 Jaguar I-Pace EV400 w/22" Wheels	\$69,900	195	234	-16.7%	2.37
2020 Nissan LEAF SL +	\$43,900	190	215	-11.6%	3.40
2022 Ford Lightning Pro Standard Range	\$39,974	214	230	-7.0%	2.20
2019 Audi e-tron	\$74,800	188	204	-7.9%	2.30
2020 Hyundai Ioniq EV	\$33,045	171	170	+0.6%	4.50
2019 BMW i3s BEV	\$47,650	141	153	-7.8%	3.60
2020 BMW i3s REx	\$51,500	126	126	0.0%	3.50
2020 MINI Cooper SE	\$29,990	108	110	-1.8%	3.70
2015 Chevy Spark EV	\$25,995	63	82	-23.2%	3.50
2018 smart Electric Drive	\$28,750	51	57	-10.5%	3.40

Operating cost

	Range (mi)	KWH/mi	Bt/mi	KWH Full Tank	Cost to fill it up Bt.
mean	244 (389 km)	0.315	1.556	76.01	375.6
med	245 (392 km)	0.303	1.498	81.02	400.4
max	500 (800 km)	0.493	2.434	128.57	635.4
min	51 (82 km)	0.222	1.098	15.00	74.1

2018 Toyota Hilux diesel 3.8 Bt/mi

<https://insideevs.com/reviews/443791/ev-range-test-results/>

How does air conditioning affect EV distance?

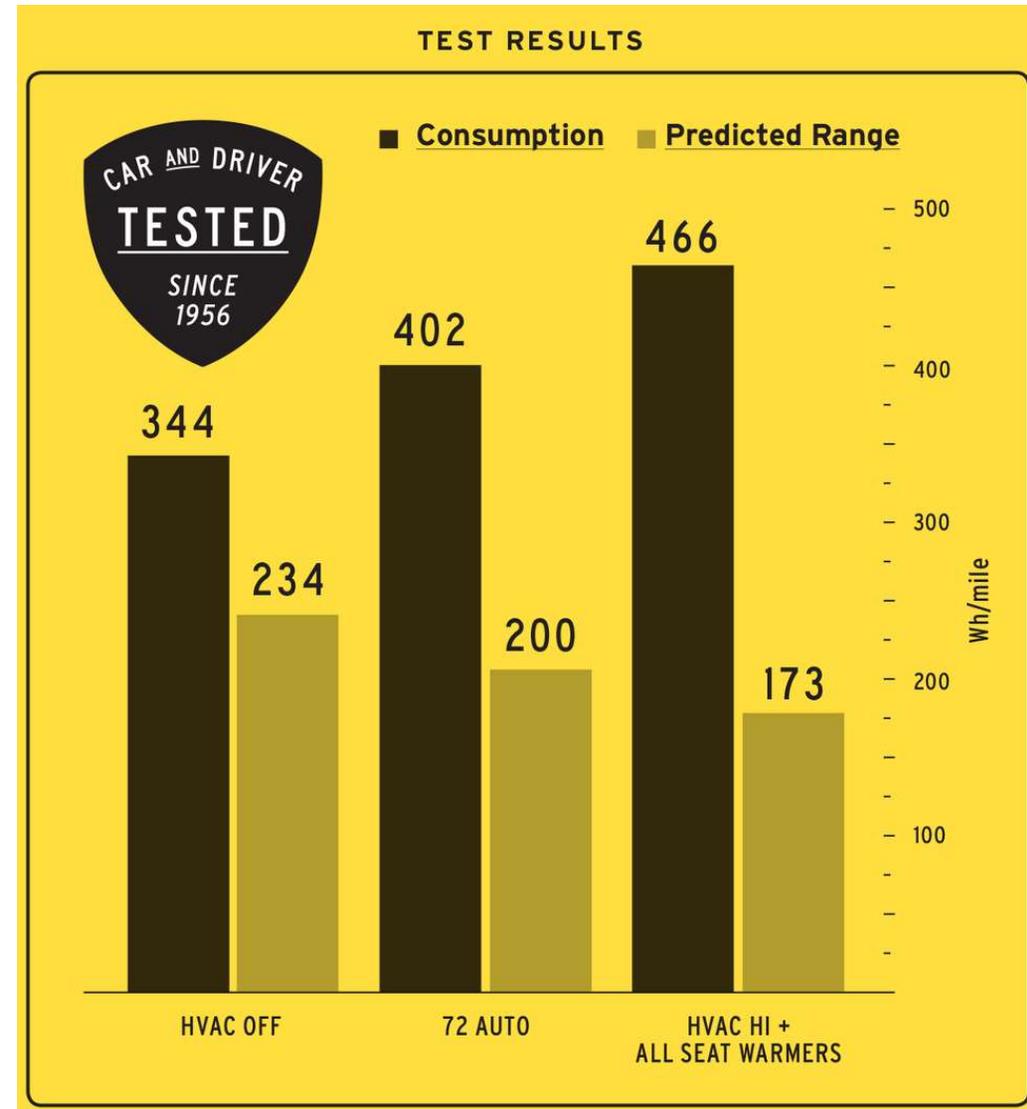
Air conditioning can affect EV range significantly, depending on the ambient temperature, the type of refrigerant used, and the settings of the system. Some studies have found that air conditioning can consume **30 to 50%** of the total stored energy in electric cars¹, or reduce the range by **17 to 41%** in extreme hot or cold conditions²³. However, some manufacturers claim that their EVs have minimal range loss due to air conditioning, such as Tesla, which reported only a **1%** drop in range in 95-degree conditions⁴. A new refrigerant developed by Daikin Industries is said to extend the range by **50%** when using air conditioning in an urban area of Japan⁵.

Hello, this is Bing! I'm the new AI-powered chat mode of Microsoft Bing

Heating decreases range

- Tesla Model 3
- 234 mile range & 344 Wh/mi
- 200 mile range & 402 Wh/mi
- 173 mile range & 466 Wh/mi

<https://www.caranddriver.com/news/a31739529/how-much-does-climate-control-affect-ev-range> March 2020



Capital cost (in the US before taxes/rebates)

- Mean=\$66,293 (Bt 2,320,000)
- Med=\$55,450 (Bt 1,941,000)
- Max= \$169,000 (Bt 5,915,000)
- Min= \$25,995 (Bt 910,000)

<https://insideevs.com/reviews/443791/ev-range-test-results/>

Maintenance Costs

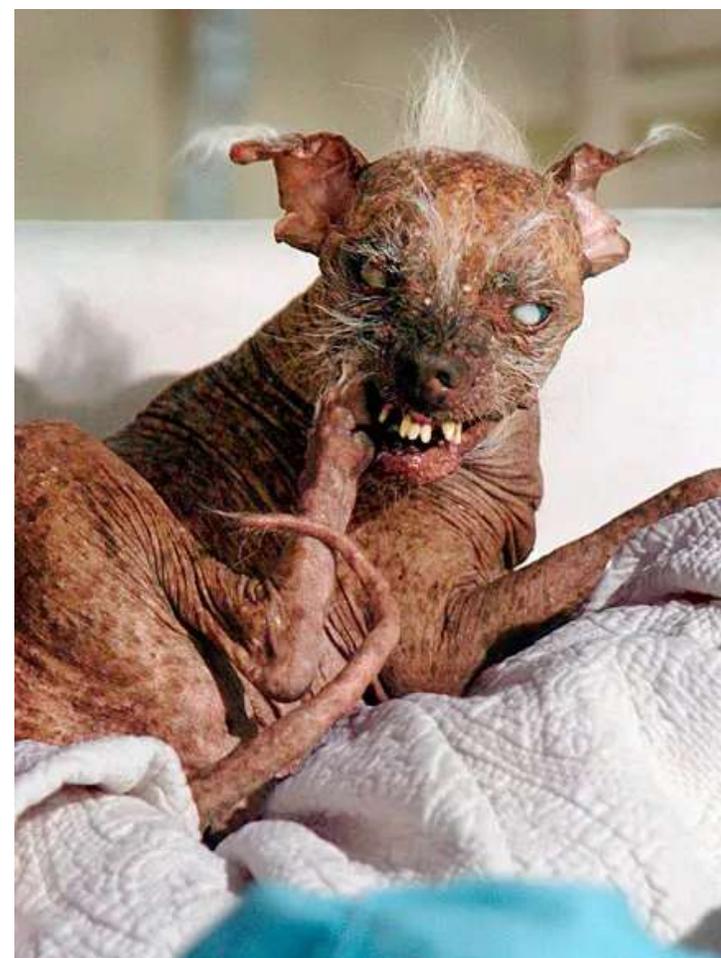
- An October 2021 report by analytics firm ***We Predict*** stated that while service costs are initially higher, after three years of ownership, an EV costs 31% less to maintain than a gasoline vehicle.
- According to the Department of Energy, the cost of an EV's lithium-ion battery fell 89% from \$1,355/kilowatt-hour in 2008 to \$153/kWh in 2022. <https://www.cars.com/articles/how-much-do-electric-car-batteries-cost-to-replace-465308/>

Battery Replacement Costs

- Labour \$1,200 to \$3,000 (42,000 to 105,000 Baht)
- Chevrolet Bolt \$990/cell, 10 cells, \$9,900
- Hyundai Ioniq Electric \$17,845
- BMW i3 \$3,054/cell, 8 cells, \$24,432
- Nissan Leaf \$10,000 list price actual is cheaper
- Volkswagen e-Golf \$27,000
- Ford Mustang Mach-E \$17,588
- Tesla Model 3 \$13,000 to \$20,000 (<https://www.way.com/blog/tesla-battery-replacement-cost/>)

<https://www.thedrive.com/guides-and-gear/these-replacement-battery-costs-for-these-six-normal-evs-is-staggeringly-high>

The Ugly



Recycling

- Lead-acid batteries are the most recycled product in the world. The recycling rate is 99% in the U.S. as nearly all parts (sulfuric acid, casing, lead) can be recycled. Additionally, new lead-acid batteries usually contain more than 80% recycled material.
- Only 5% of Li batteries are recycled
- Lithium-ion batteries is a new technology; recycling this material still proves to be challenging.

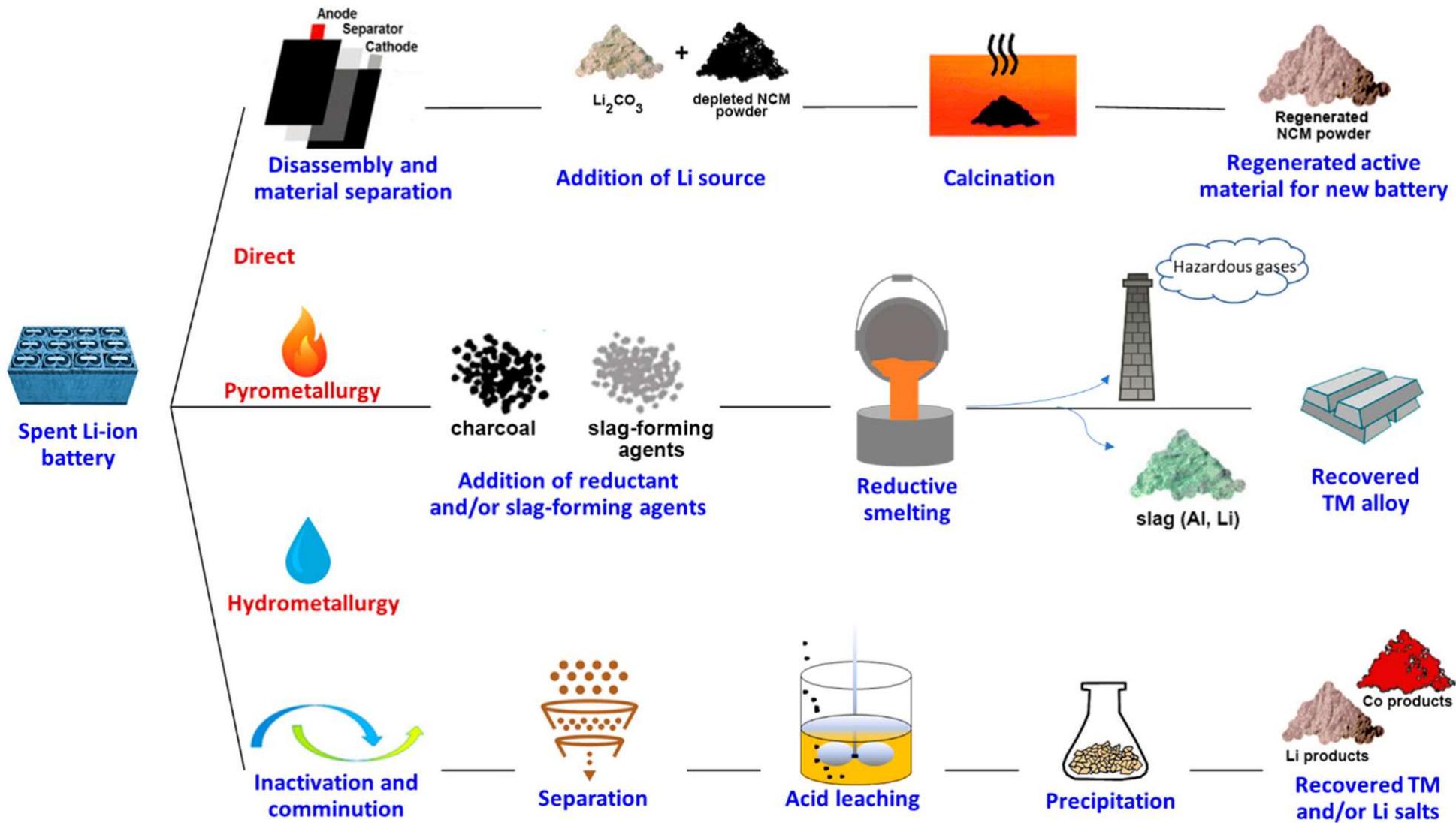
<https://climatebiz.com/lead-acid-vs-lithium-ion/>

Recycling Li Batteries

- Current method is shredding everything and trying to purify a complex mixture
- Results in expensive processes with low value products," *Andrew Abbott, a physical chemist at the University of Leicester.*
- It costs more to recycle than to mine more lithium to make new ones.
- Only about 5% of Li batteries are recycled globally.

Recycling Li Batteries-2 main methods

- LIBs must be first classified and most often pretreated through discharge or inactivation, disassembly, and separation after which they can be subjected to direct recycling or
- pyrometallurgy,
- hydrometallurgy,
- or a combination of methods,



LITHIUM PRODUCTION

Global lithium production has quadrupled since 2010.

Which countries produce the most lithium, and how have they changed over time?

Mine Production of Lithium 1995-2021

Tonnes

1995 TOTAL PRODUCTION

9.5k Tonnes

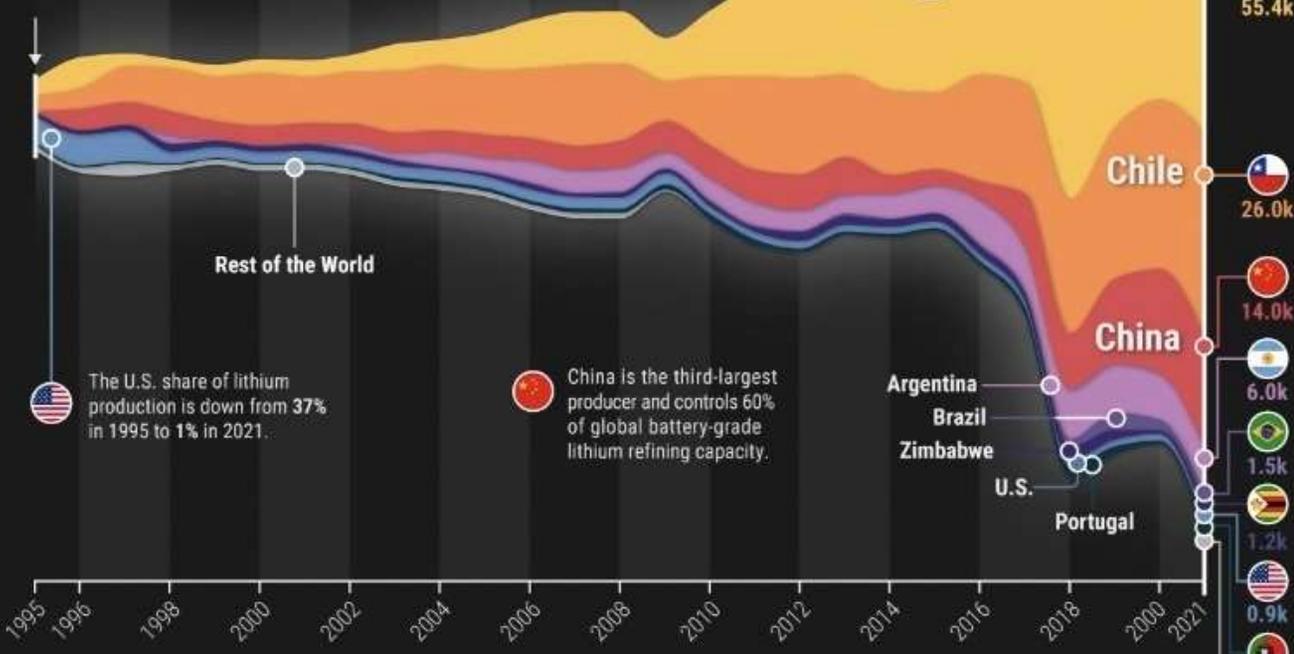
2021 TOTAL PRODUCTION

106k Tonnes

Australia produces more than 50% of the world's lithium, and China accounts for over 90% of Australian lithium exports.

The U.S. share of lithium production is down from 37% in 1995 to 1% in 2021.

China is the third-largest producer and controls 60% of global battery-grade lithium refining capacity.



<https://www.weforum.org/agenda/2023/01/chart-countries-produce-lithium-world/>
Jan 2023

Li Use



<https://www.weforum.org/agenda/2023/01/chart-countries-produce-lithium-world/>
Jan 2023

Li Demand and Mining

- The world produced 540,000 tonnes of lithium carbonate equivalent (LCE) in 2021
- The demand for lithium is projected to reach 1.5 million tonnes of LCE by 2025 and over 3 million tonnes by 2030.
- Based on the above demand projections, production needs to triple by 2025 and increase nearly six-fold by 2030.

- Extracted from brine (Chile)
- Hard rock mining (Australia)

Li Mining

- Chile supplies 25% of the world's Li
- In Chile mining is linked to human rights abuses, respiratory ailments, dispossession of indigenous territory and labour exploitation. Once the minerals are wrested from the ground, mining companies tend to accumulate profits and leave behind poverty and contamination. These profits only multiply along the vast supply chains that produce electric vehicles and solar panels

<https://www.theguardian.com/commentisfree/2021/jun/14/electric-cost-lithium-mining-decarbonasation-salt-flats-chile>

Li Mining

- According to Benchmark Mineral Intelligence, spodumene sold for \$415 (£360) a tonne in January 2021 and \$4,994 (£4,300) in October 2022.
- By 2040 the International Energy Agency expects demand for lithium to grow more than 40 times current levels if the world is to meet its Paris Agreement goals. <https://www.bbc.com/future/article/20221110-how-australia-became-the-worlds-greatest-lithium-supplier>
- 500,000 gallons (2,273,000 litres (2,273 tonne)) of water to mine one tonne of Li <https://www.bbc.com/future/article/20220105-lithium-batteries-big-unanswered-question>

Li Mining and the Environment

- South America's Lithium Triangle, which covers parts of Argentina, Bolivia and Chile, holds more than half the world's supply of Li beneath its salt flats. But it is also one of the driest places on earth. In Chile's Salar de Atacama, mining activities consumed 65 percent of the region's water

- <https://www.instituteforenergyresearch.org/renewable/the-environmental-impact-of-lithium-batteries/> Nov 2020

Li Brine ponds in Chile



Brine Ponds in Chile



Summary

- Do cut emissions depending on electricity sources
- Cost/mi can be significantly cheaper than fossil fuels (dependent on elec. source and timing)
- Range is limited
 - Infrastructure challenge
 - Better technology will improve the range
- Replacement batteries are very expensive (offset by mileage savings?)
- Cost of Li is going to increase
 - Offset by better technology/longevity?
- Mining has serious environmental and social impacts
- Recycling is expensive but in its infancy

Summary

95% of all electric cars are still on the road

The other 5% made it home