Nickel-Zinc Batteries

Zinc Battery Technology Workshop
November 16, 2018

1.
Introduction to Nickel-Zinc Technology

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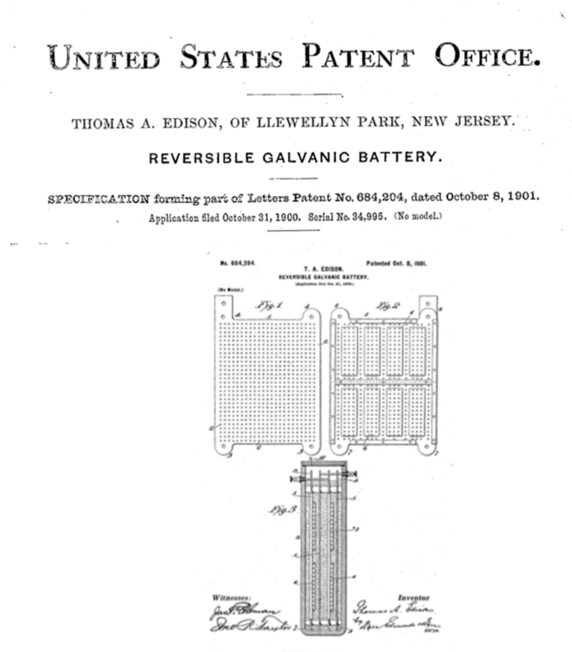
U.S. NAVAL RESEARCH LABORATORY

Nickel-Zinc History

- U.S. Patent 684,201 awarded to Thomas Edison for Ni–Zn battery concept
    - Not commercially viable for decades thereafter
- Some testing in the 1960s for niche applications, but limited cycle life
- Breakthroughs in the 1990s with respect to alkaline electrolyte compositions (*as realized in PowerGenix Ni–Zn cells*)
- Renewed interest in rechargeable zinc batteries on both scientific and commercialization fronts as alternatives to Pb–acid, and even Li-ion

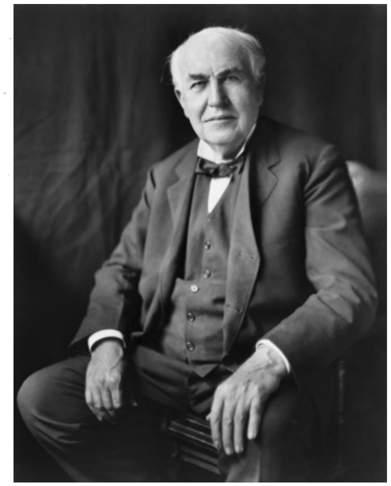

UNITED STATES PATENT OFFICE.

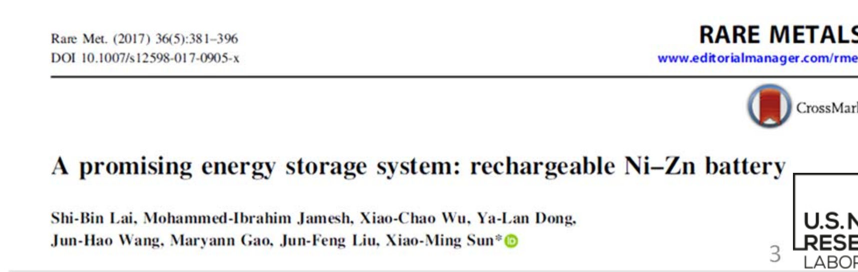
THOMAS A. EDISON, OF LLEWELLYN PARK, NEW JERSEY.

REVERSIBLE GALVANIC BATTERY.

SPECIFICATION forming part of Letters Patent No. 684,204, dated October 8, 1901.

Application filed October 31, 1900. Serial No. 34,995. (No model.)




Rare Met. (2017) 36(5):381–396
DOI 10.1007/s12598-017-0905-x

RARE METALS
www.editorialmanager.com/rmet

CrossMark

A promising energy storage system: rechargeable Ni–Zn battery

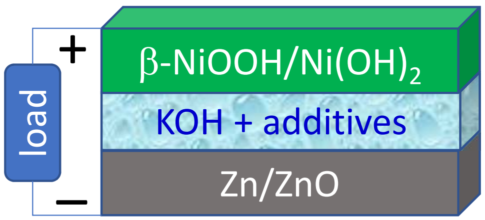
Shi-Bin Lai, Mohammed-Ibrahim Jamesh, Xiao-Chao Wu, Ya-Lan Dong, Jun-Hao Wang, Maryann Gao, Jun-Feng Liu, Xiao-Ming Sun*

Nickel-Zinc Chemistry

$NiOOH + ½H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$ **E = 0.49 V**

Theoretical capacity = 292 mAh g^{-1} NiOOH

✓ *Proven cathode system, used successfully in other Ni-based cells, such as Ni–metal hydride*



E_{cell} = 1.73 V

$Zn + 2OH^- \rightarrow Zn(OH)_2 + 2e^-$ **E = 1.24 V**

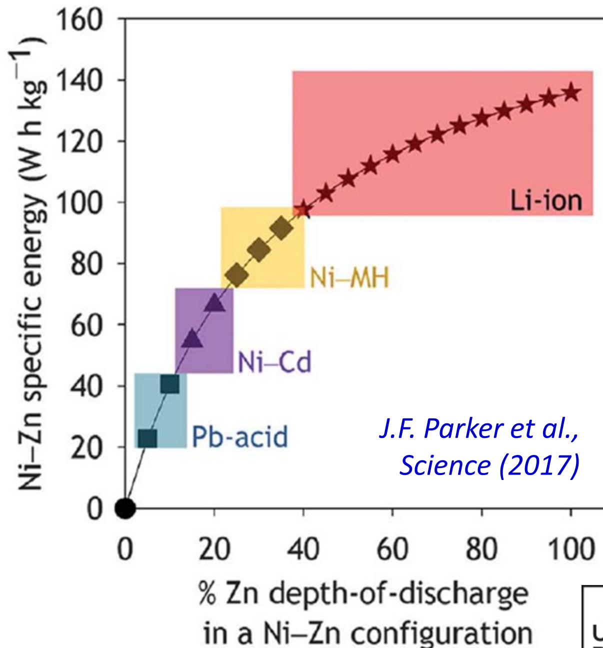
Theoretical capacity = 820 mAh g^{-1} Zn

- Complex reaction pathways involving dissolution, dehydration, precipitation

Theoretical Ni–Zn specific energy = 373 Wh kg^{-1}

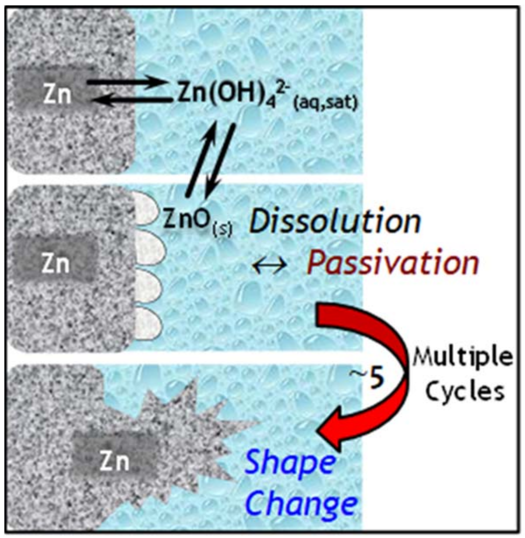
Practical specific energy: 60–100 Wh kg^{-1}

. . . depending on packaging efficiency and materials utilization

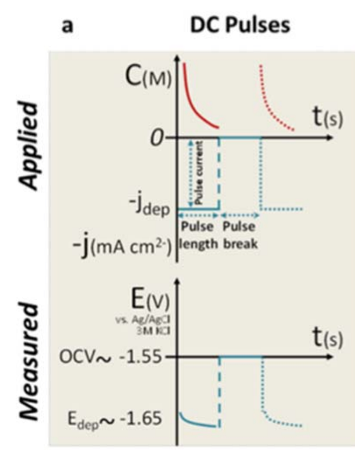


Nickel-Zinc Technical Challenges

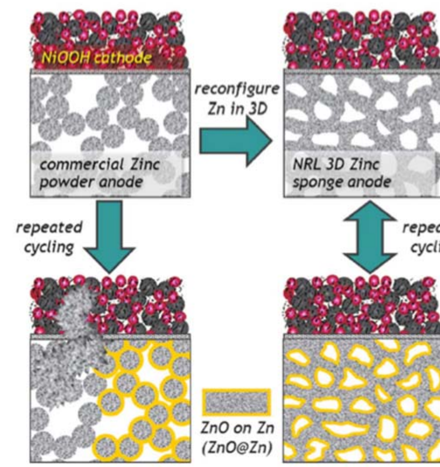
- Major technical challenge: Misbehavior at the anode
  - *Shape change*
  - *Passivation, poor utilization*
  - *Dendrite formation*



- Strategies to tame the "zinc problem" include:
  - Optimized electrolyte formulations to control dissolution/precipitation of zinc species
  - Sophisticated charging protocols to limit shape change and suppress gas evolution (H_2 and O_2)
  - Advanced 3D electrode designs for improving uniform current density and reaction zones



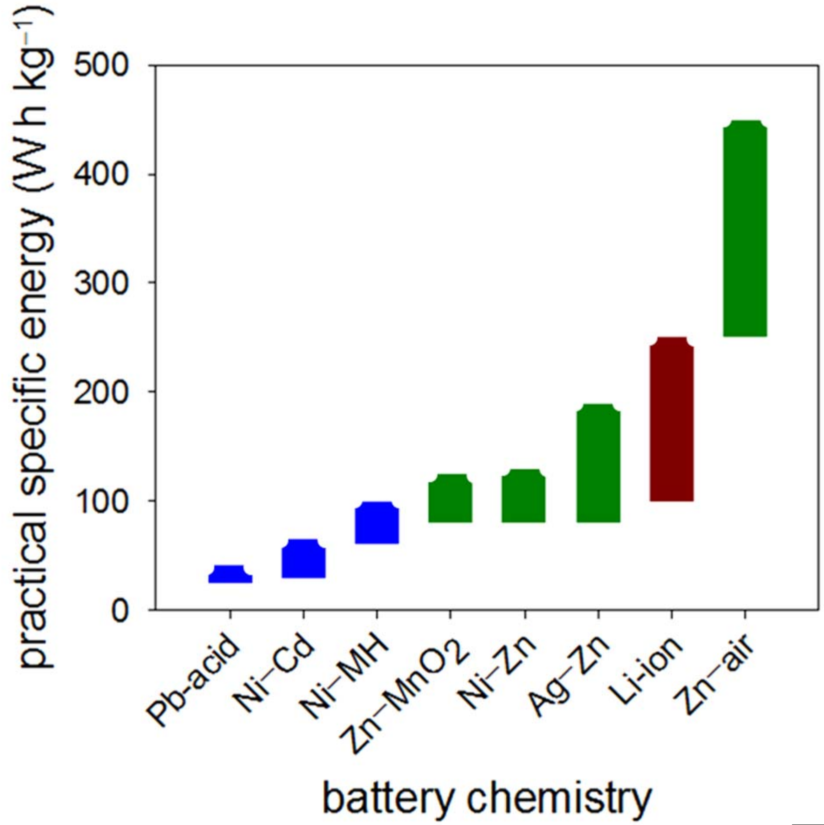
Garcia et al., ACS Appl Mater. & Interfac. (2017)



J.F. Parker et al., Science (2017)

Power vs. Energy

- Moderately high specific energy among practical battery couples
- Advantages as a replacement for Pb–acid
  - Higher energy content
  - Greater cycle life
- Applications include:
  - Micro-hybrid vehicles
  - “Hotel load” power (e.g., for tractor-trailers)
  - Uninterruptible Power Supplies
  - Grid storage



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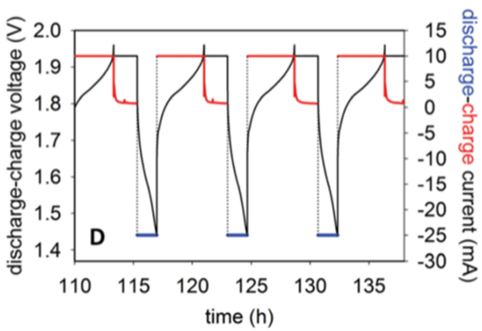
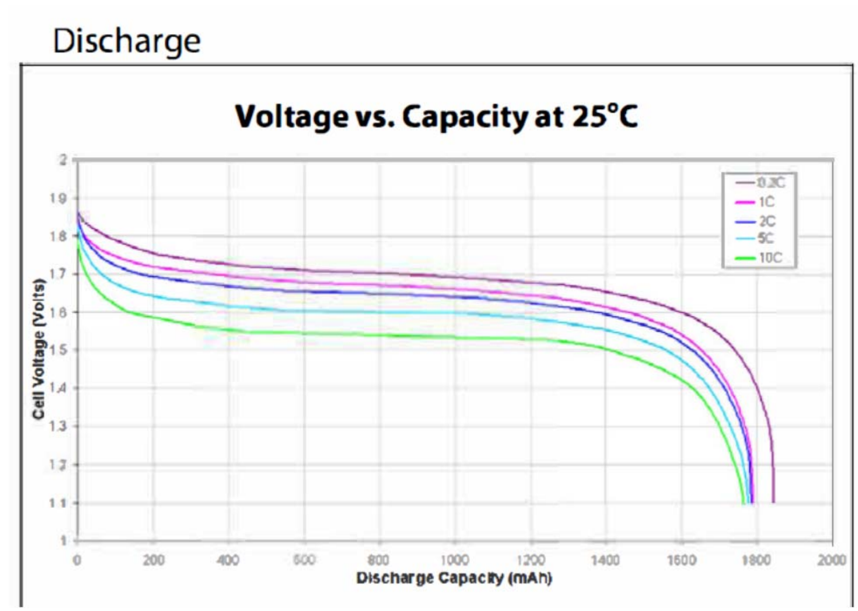
Nickel-Zinc Performance Testing

Coin Cells → **Packaged Cells** → **Modules**





2.

Nickel-Zinc Comparison with Other Chemistries

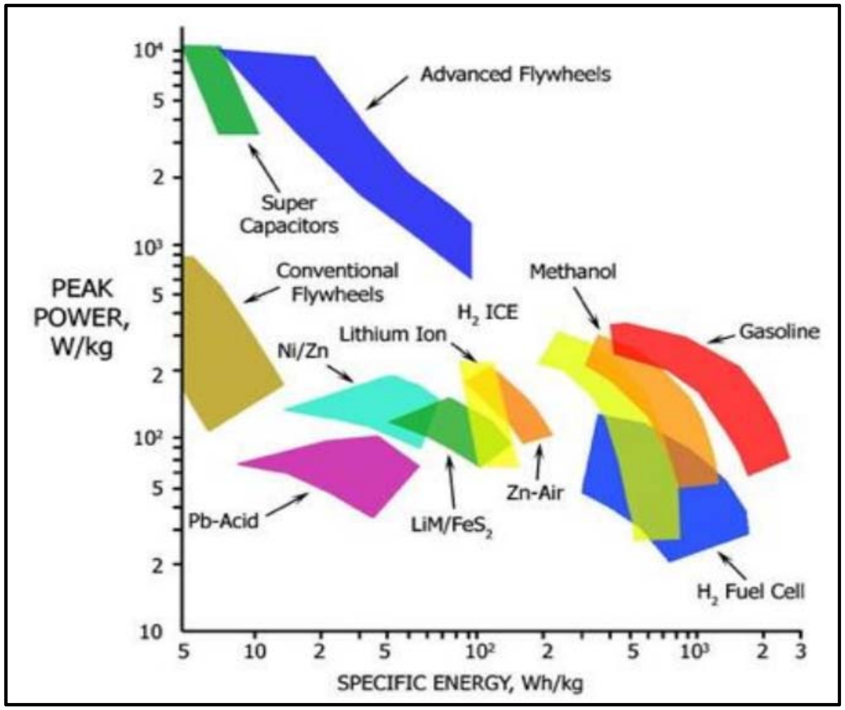
Randy A. Moore
President & CEO
ZAF Energy Systems, Inc.

Energy Systems

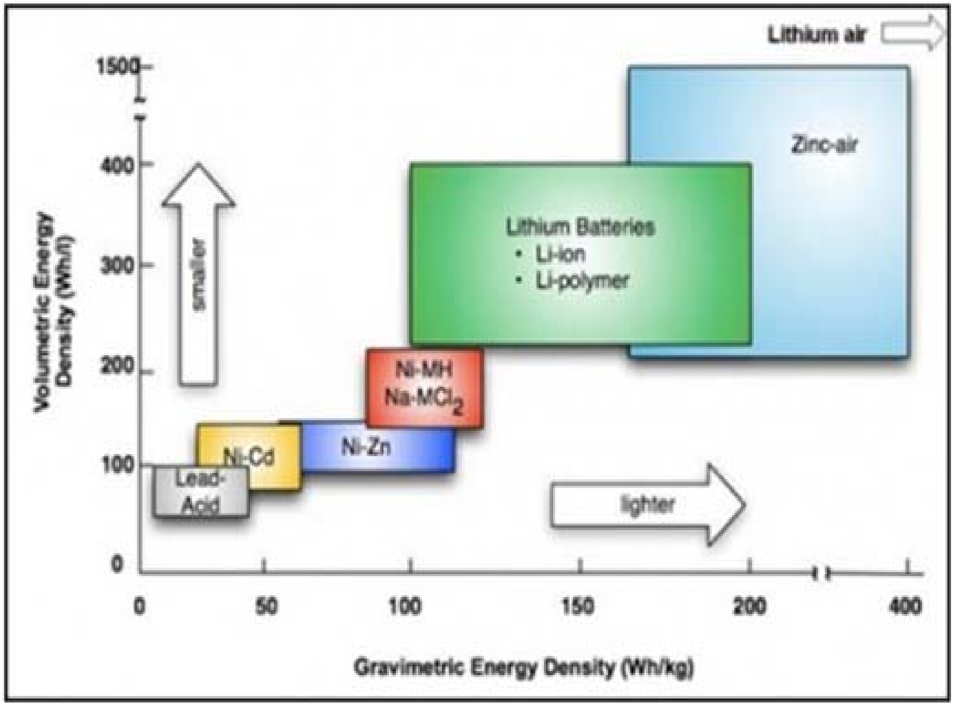
Overview – Comparison to Other Chemistries

- Discussion of Various Possible Chemistries
- Specific Energy & Energy Density → Batteries & Other Energy Storage
- Materials → Availability/Abundance & Economics/Cost
- Safety/Environmental/Recycling
- Conclusion

Nickel-Zinc Comparison

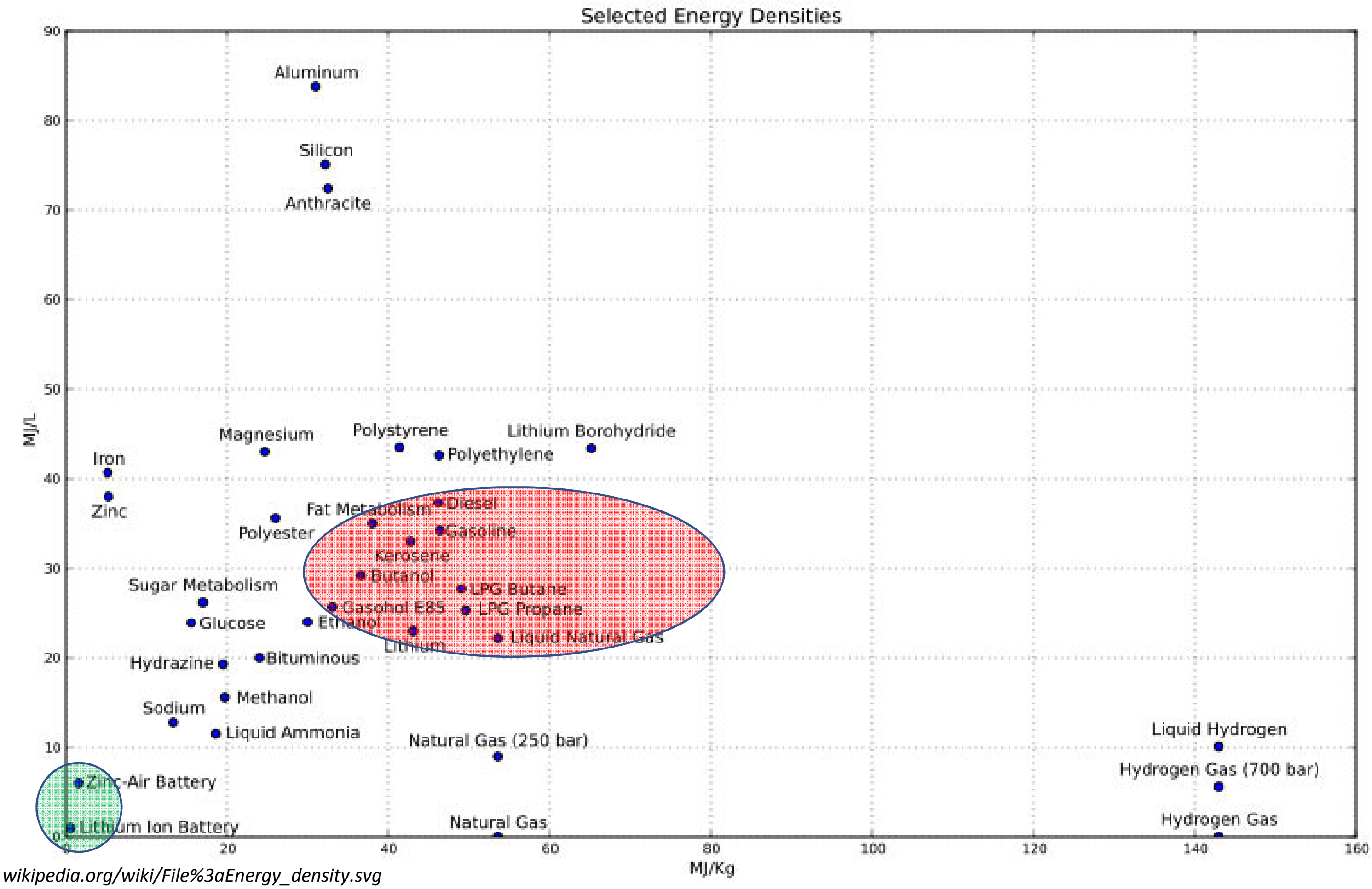


Source: Ghoniem 2011



Source: NASA

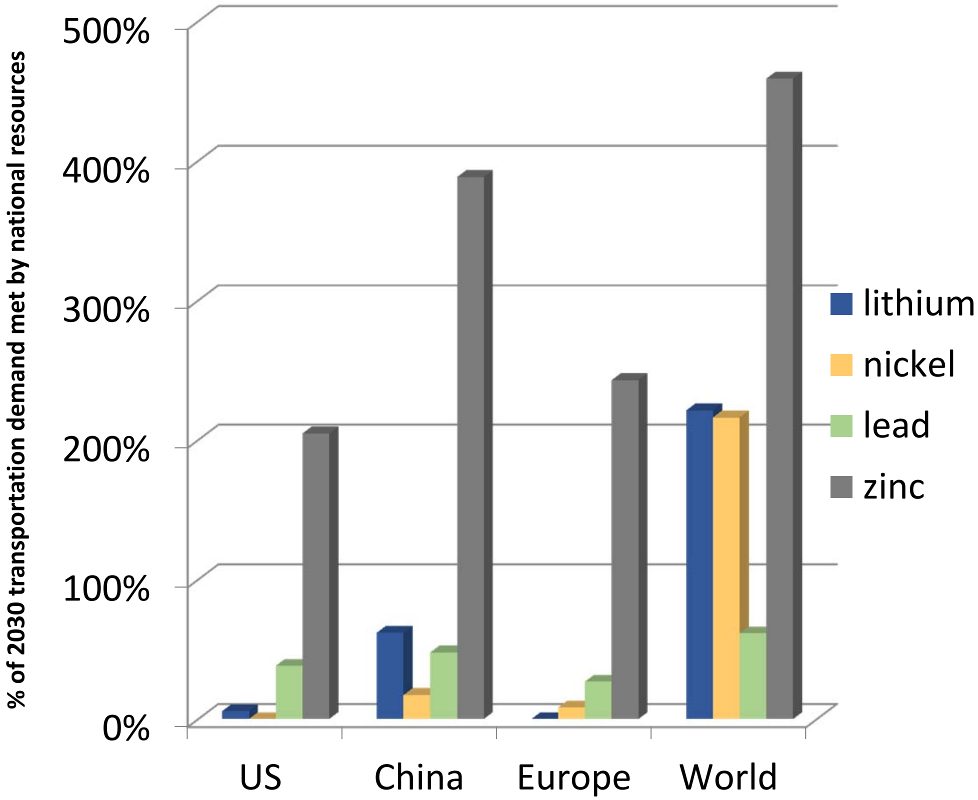
Batteries – Other Energy Storage Comparison



Source: https://en.wikipedia.org/wiki/File%3aEnergy_density.svg

Energy Systems

Why Zinc? → Abundant Supply



Zinc Production
and
Reserves (2016)

	Mine production[9] 2015	2016[e]	Reserves[10]
United States	825	780	11,000
Australia	1,600	850	[11]63,000
Bolivia	440	460	4,000
Canada	277	310	5,700
China	4,300	4,500	40,000
India	821	650	10,000
Ireland	236	150	1,100
Kazakhstan	339	340	11,000
Mexico	680	710	17,000
Peru	1,420	1,300	25,000
Sweden	247	250	3,000
Other countries	1,610	1,600	32,000
World total (rounded)	12,800	11,900	220,000

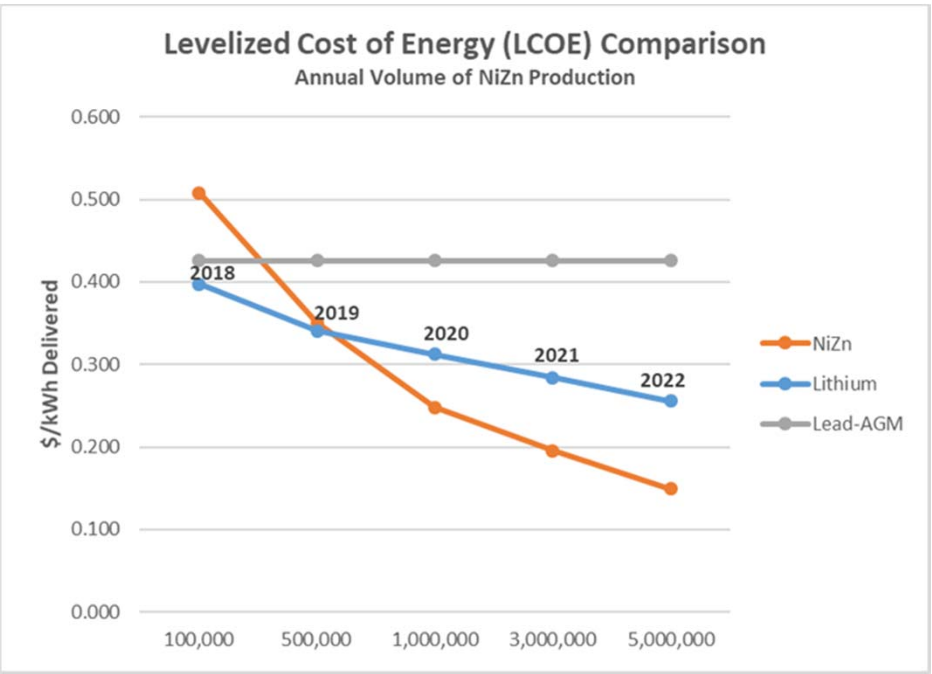
World Resources: Identified zinc resources of the world are about 1.9 billion tons.

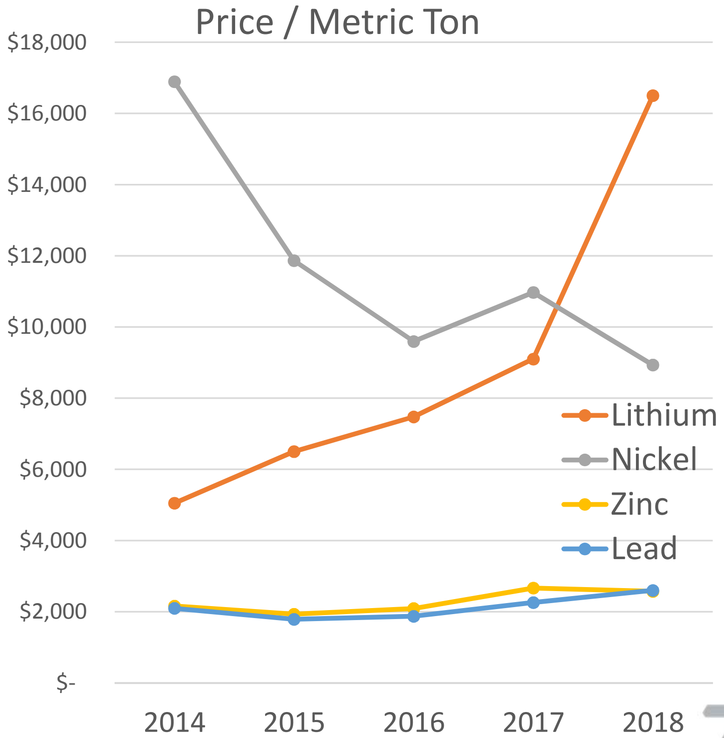
The Economics

Material abundance translates into lower cost and greater price stability.

Five-year trend data displayed.

- 2018 Datapoint: at one point, zinc slightly lower than lead
- Future prices based on volume and material cost





Source: www.metalary.com

ZAF Energy Systems

Safety Matters

RoHS Restricted Substance

- Li-Ion
- Ni-Metal Hydride Nickel, KOH
- Lead Acid Lead, HSO_4
- Ni-Cadmium Cadmium, KOH
- ZAF NiZn Nickel, Zinc, KOH
- ZAF Zinc-Air Zinc, KOH

When "Recycling" Isn't a Good Thing . . . and, When It Is

Lead-acid batteries are the most recycled commodity in the history of mankind—about 99% of all lead acid batteries are recycled. Experts say that the recycling of lead batteries is the #1 world's worst pollution problem with the lead smelting that follows being the #3 world's worst problem.

A man in Indonesia uses an axe to break up old batteries by hand in order to extract the valuable lead within. In the "breaking" process toxic lead is spilled everywhere and spills into the water table. (#1)

Source: "2016 World's Worst Pollution Problems"

PURE EARTH

GREEN CROSS

A child pours lead into an open-air crucible for smelting. Lead particle emissions drift into the air where some are breathed in and some come back down to pollute the ground surface. (#3)

Lithium Ion → $1 → Recycled → $1.25

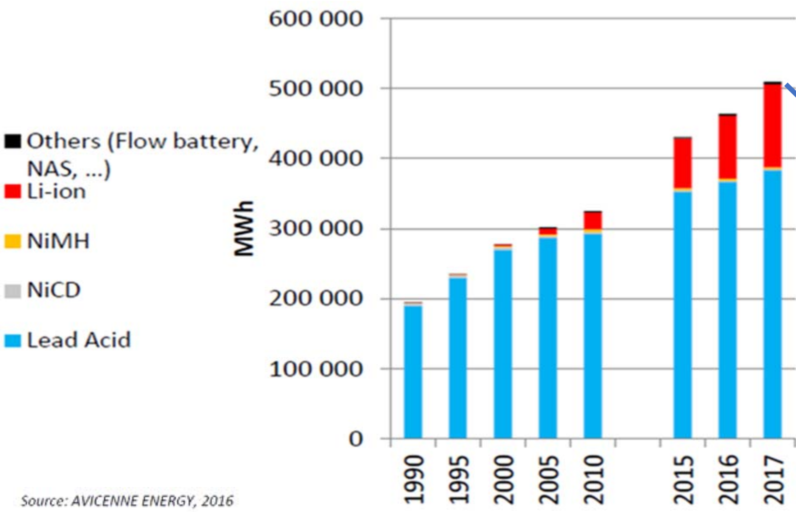
Lead Acid → $1 → Recycled → $0.90

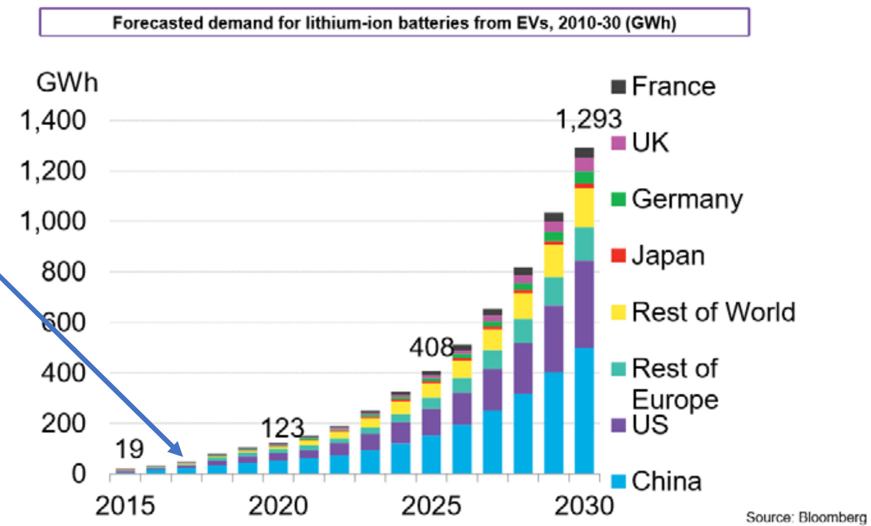
Nickel Zinc → $1 → Recycled → $0.85

- No battery can be successful without a recycling solution—it is one of the largest barriers to commercializing new battery technology.
- The NiZn chemistry starts out environmentally safe and remains so.
- NiZn battery recycling has an economically positive value proposition.
- NiZn systems do not require large decommissioning costs.
- The recycling process does not require smelting.
- The recycled nickel output is "battery-grade" and ready for use in a new battery.

85% Material Recovery Yields
40% Reduction in Battery Cost

Batteries – $70B Market and Growing





Battery Growth

- 135% growth in last 25 years
- 22% CAGR projected through 2030
- Lead acid growth = 5% CAGR
- **Lead acid global sales = $50B**
- **Lithium sales = $20B with significant growth expected**

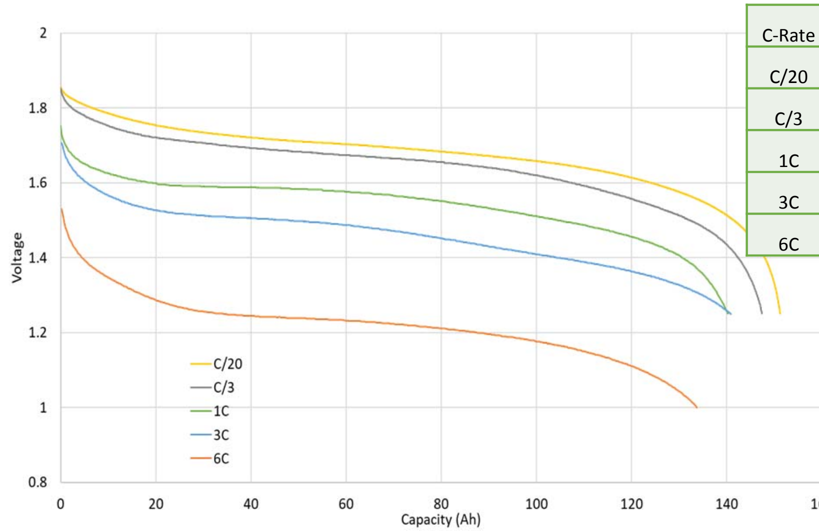
Global battery market expected to exceed 1 TWh by 2025

NiZn is Ready for Market – Scaled Production

G31 Single Cell Performance Characteristics	
Typical Capacity (Rated @ C/3)	147 Ah
Voltage (Nominal)	1.7V
Discharge Energy (C/3)	250 Wh
Weight	3.42 kg
Specific Energy (Cell Only)	73 Wh/kg
Length	4.64 cm
Height	23.7 cm
Width	17.1 cm
Volume	1.82 L
Volumetric Energy Density (Cell Only)	137 Wh/L

G31 Single Cell Performance Characteristics	
Typical Capacity (Rated @ C/3)	163 Ah
Voltage (Nominal)	1.7V
Discharge Energy (C/3)	277.1 Wh
Weight	3.42 kg
Specific Energy (Cell Only)	81 Wh/kg
Length	4.64 cm
Height	23.7 cm
Width	17.1 cm
Volume	1.82 L
Volumetric Energy Density (Cell Only)	152.3 Wh/L

- ZAF Ni-Zn Generation-1 G31 147Ah/163Ah cells
- Cells show only a 13% change in utilization from C/20 to 6C (882A).
- This indicates that Ni-Zn technology can be used in many applications, over a vast range of C-rates
- Tested at Eclipse Energy, LLC



C-Rate	Capacity	% Utilization
C/20	151.13	102.81
C/3	147.70	100.48
1C	141.42	96.20
3C	140.87	95.83
6C	133.74	90.98

Conclusion: NiZn is the Ideal Chemistry to Meet Expected Growth

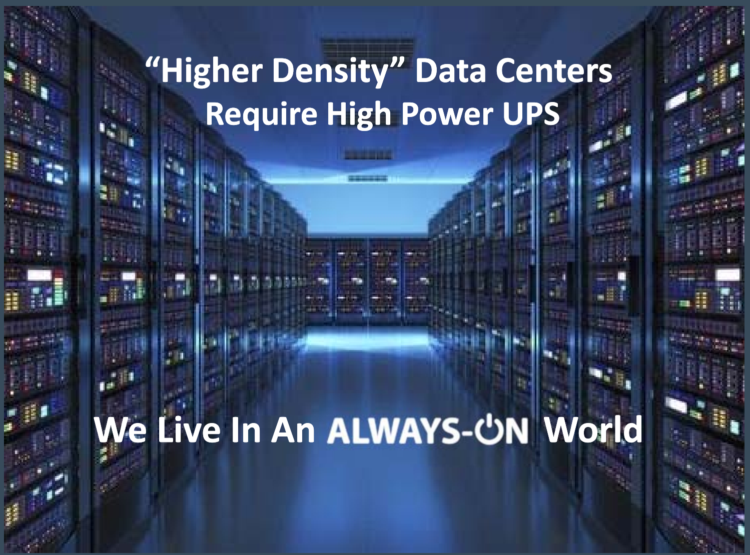
- ✓ **Cost** – Chemistry and materials in construction are inexpensive and meet cost/benefit threshold of the targeted markets
- ✓ **Safe** – Chemistry is safe and free from toxic materials
- ✓ **Environmental** – Most “green” battery viable today
- ✓ **Energy Independence** – Chemistries are globally abundant in quantities sufficient to meet industry growth demands
- ✓ **Scale** – Cells, manufacturing and chemistry are scalable
- ✓ **Robust** – Chemistry and systems are flexibility to provide wide variety of power and energy services to drive the greatest economic benefit

3.
Nickel-Zinc Case Studies

Tod Higinbotham
President, Systems Division
ZincFive

ZincFive


Integrated Intelligent Transportation Systems
Require 100% Uptime
ITS Without Power Is Chaos


"Higher Density" Data Centers
Require High Power UPS
We Live In An ALWAYS-ON World


New Military Technologies
Require Safety & Reliability
Meeting Threats With Energy Advances


High Efficiency Anti-Idle Solutions
Require On-Line Time & TCO
Hybrid Solutions Key to "CO2" Reduction

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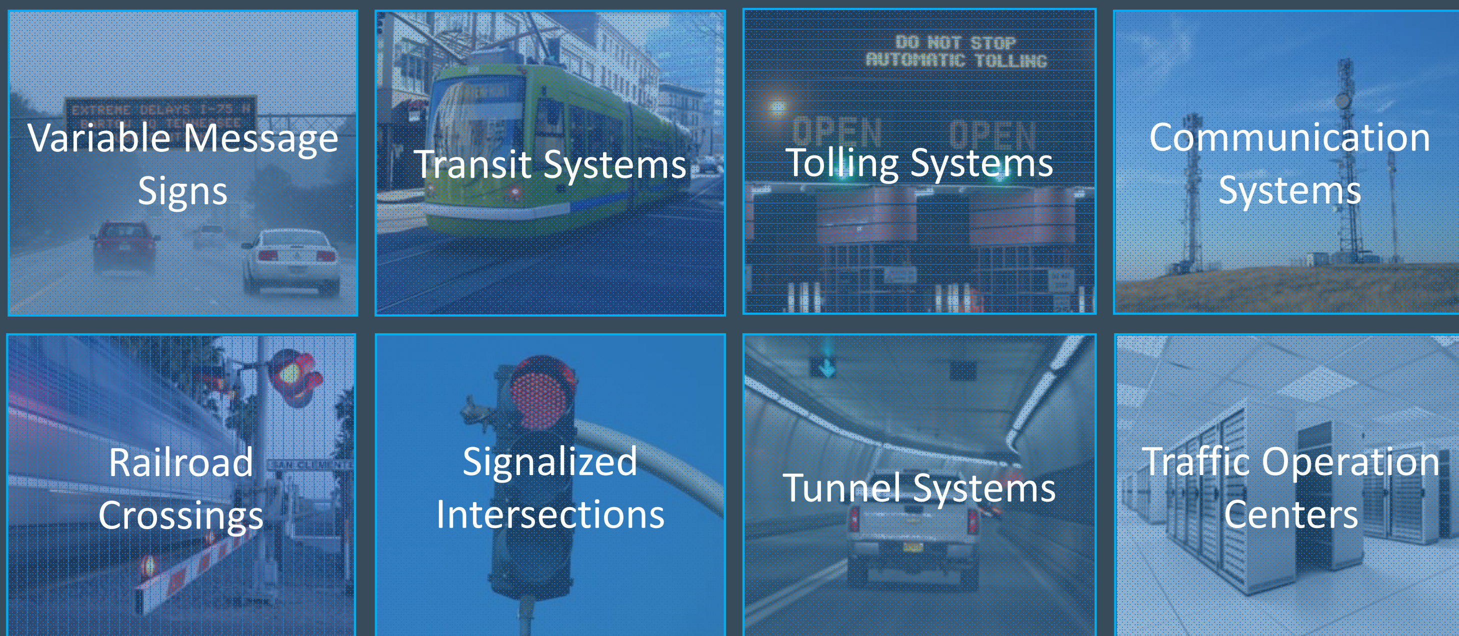
ITS Market

Challenge: ITS is Shifting

Integration Creates Dependent Systems Requiring Full Availability, Safety, and Intelligence



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NiZn ITS Solution

Traffic UPS:
- Safe and reliable NiZn battery
- Advanced power monitoring
- Unique form factor

Benefits:
- 2-5X lifetime over lead-acid
- No maintenance
- Lower TCO
- Safe and recyclable
- Wide temperature tolerance

Status:
- 1,000s of units installed
- Over 15 million battery operational hours logged
- NiZn batteries in Caltrans standard

Data Center Market

Challenge: Rapidly increasing data density is driving need for high power density UPS solutions

- Massive Footprint Reduction
- TCO Reduction
- Power efficiency increase
- Efficient use of capital

Needs:
- High power density
- Very safe and stable at high rates
- Long life (>10 years)
- Recyclable

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NiZn Data Center Solution

Tower UPS/OCP Battery Unit:
- High power solution, 10C rates and over 150 cycles (>10 years)
- Safe and reliable
- Stable at high temperatures

Benefits:
- 3-5X lifetime over lead-acid
- No maintenance
- Lower TCO
- Safe and recyclable
- Wide temperature tolerance

Status:
- First units sold on 2018
- Large data center customer in qualification

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Defense Market

Challenge: Submarines adding electrical load and require higher density, safe, and reliable solution

Opportunity:

- Ohio and Virginia Class Retrofits and development program for Columbia class
- Navy requires >2X longer run cycle and service life
- The safety requirement is paramount
- Lithium safety problems are unacceptable for this application

NiZn Defense Solution

Group 31, 150Ah Prismatic

- Safe and reliable- no thermal runaway
- Stable at high temperatures

Benefits:

- 2-3X lifetime over lead-acid
- No maintenance
- Lower TCO
- Safe and recyclable
- Wide temperature tolerance

Status:

- Retrofit program for Ohio and Virginia Class
- Development program for Columbia Class

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Commercial Trucking Market

Challenge: Anti-idle regulations and desire for CO_2 reductions require new solution

Opportunity:

- New legislation requires truckers to turn-off their engine when at rest; 10 hours rest required for every day
- Hotel loads for electronics is increasing
- HVAC is often required for full 10 hours
- Location of the batteries requires tolerance to high heat
- Lead acid solution does not have the run time and requires very long charge times
- Lithium not a good choice for safety and heat tolerance

NiZn Solution

Group 31, 48V Battery Packs
- Meet full 10 hour run time
- Can be rapidly charged and available
- Also capable of supporting Start-Stop cycling
- Safe and reliable - no thermal runaway
- Stable at high temperatures

Benefits:
- 2-3X lifetime over lead-acid
- No maintenance
- Lower TCO
- Safe and recyclable
- Wide temperature tolerance

Status:
- Being qualified at multiple major manufacturers

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Nickel-Zinc Summary

Commercially Available in Volume!

Superior Performance

- "Power" batteries outperform other chemistries in many applications
- Rapid charge/discharge rates improve battery use cases

Significant Safety Advantages

- Fail-safe and thermally stable

Environmental Advantages

- Fully recyclable with >90% recyclable materials
- No hazardous materials

Long Operating Life

- Low self-discharge, long shelf-life and high cycle count

Low Maintenance

- No periodic maintenance required

Wide Operating Temperature Range

- Suitable for indoor and outdoor environments

4.
Q & A Session