

ÆSIR TECHNOLOGIES

NICKEL-ZINC CHARACTERISTICS AND MANUFACTURING

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MPSC NI-ZN BATTERY SYMPOSIUM - APRIL 2022

*When **MISSION CRITICAL ENERGY STORAGE** is more than just a tag line.*

OVERVIEW

- Background
  - Æsir overview
  - What makes Ni-Zn attractive
  - Historical limitations and mitigation strategy
- Basic characteristics of Ni-Zn
  - Electrochemical
  - Cell and battery construction
- Basic performance characterization
  - Cycle life
  - Charge acceptance
  - Rate performance during float stand
  - Severe overcharge characteristics
- Manufacturability
- Conclusion

ÆSIR OVERVIEW

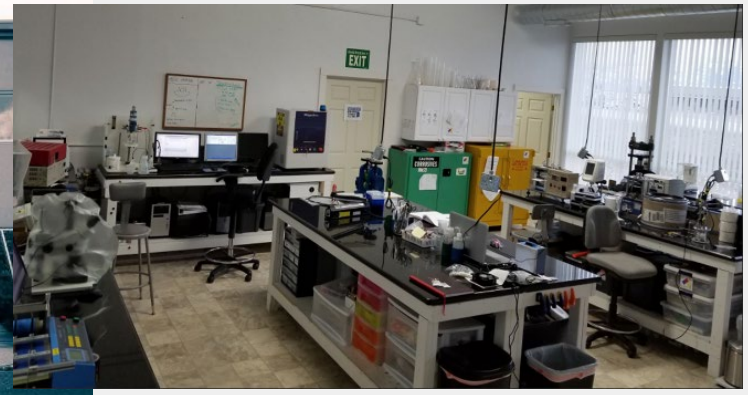
- 10-year-old company
- Focus on Ni-Zn and Zn-Air
  - Pouch cells to G31 format and larger (1000+ Ah)
- Low-rate production facility in Joplin, Missouri
- R&D facility in Bozeman, Montana
- Targeting Lead-Acid market
- Aerospace & Defense, Medical, Critical Infrastructure
  - Lower Volumes
  - Underserved Segments
  - Tight Customer/Supplier Relationships
  - Higher Barriers to Entry due to:
    - Performance Demand
    - Quality Requirements
    - Certification
    - Safety



Joplin, Mo







Bozeman, Mt

WHY NI-ZN?

- Specific energy
  - Transportation example: Anti-idle requirements => Longer run times in smaller packages
- Charge acceptance
  - Industrial power example: Faster turnaround time of equipment => maximize operating hours
- Wide operating temperature range
  - Transportation example: Automotive Stop-Start
- Environmental friendliness - sustainability
  - Recyclability
  - RoHS
- Safety
- Cost
  - Lower life-time cost
    - Cycle life
    - Low maintenance
  - Cost of material – recyclability





Specific energy:

- **60-110 Wh/kg**

Theoretical specific capacity:

- **β-Ni(OH)$_2$: 289 mAh/g**
- **ZnO: 659 mAh/g**

HISTORICAL LIMITATIONS

- Cycle life limitation
  - Accelerated capacity fade due to Zinc migration and dendrite growth
    - Zinc is unstable in potassium hydroxide solutions => becomes soluble ion
      - Wants to migrate to positive electrode on discharge
      - Wants to plate back on negative electrode on charge => shape change
        - => Uneven current density and isolated regions of zinc
      - Drives dendritic growth => creates shorts
  - Cell dry out => increased impedance
    - Electrode gassing
- Manufacturability
  - Traditional processes not easily scaled for high-rate production
    - Manual processes

ÆSIR'S MITIGATION STRATEGY

- Zinc migration and dendritic growth reduction
  - Additives in negative electrode and electrolyte that *stabilize* the zincate ion
    - Contain movement of zincate
  - Additives in negative electrode to control the *nucleation sites* and distribute the zinc evenly
    - Limiting potential growth sites of dendrites
  - Separator design
    - Multicomponent separator system => both zinc barrier and electrolyte reservoir
- Cell dry out
  - Recombination coil => recombines oxygen and hydrogen
  - => sealed and maintenance free design
    - Evercel in early 2000s => Allen Charkey
  - Additives to minimize gassing
- Manufacturability
  - High-rate production – scale for manufacturability
  - Large format cells



BASIC ELECTROCHEMICAL CHARACTERISTICS

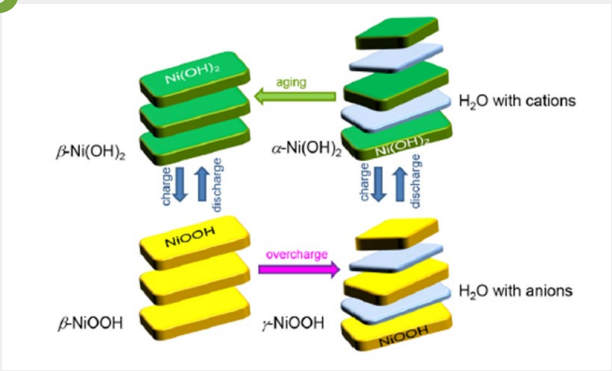
- Basic parameters
  - Nominal voltage: 1.65-1.7V/cell
    - 12V battery contains 7 or 8 cells
  - Float voltage: 1.84-1.86V/cell
  - Typical charge profile: CCCV to 1.94V/cell
  - Discharge cut-off: 1.0-1.3V/cell

Charge:

$$2\ Ni(OH)_2 + ZnO \rightarrow 2\ NiOOH + H_2O + Zn$$

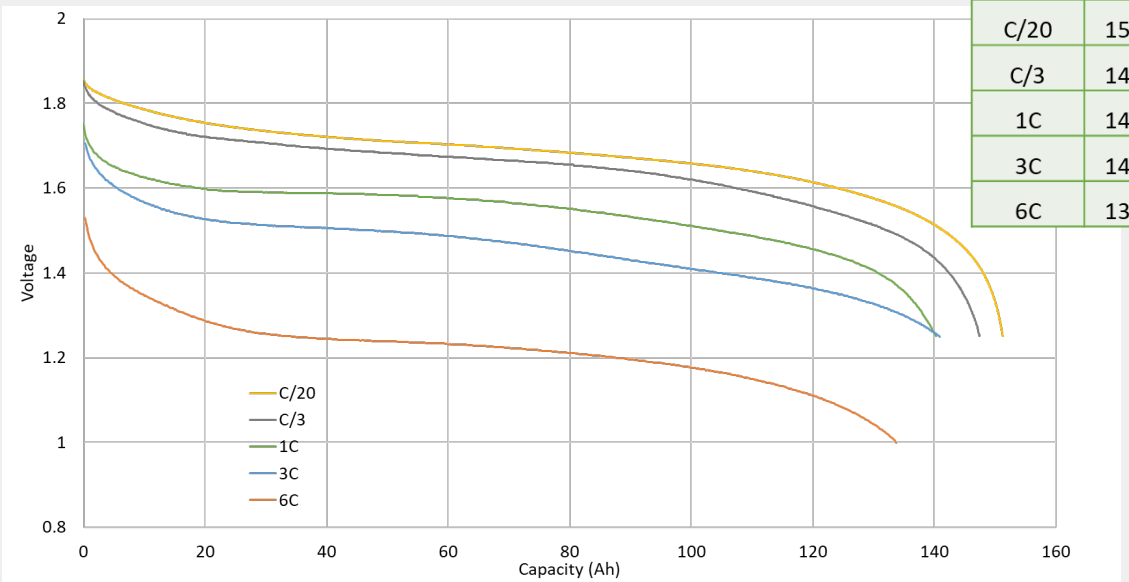
Discharge:

$$2\ NiOOH + H_2O + Zn \rightarrow 2\ Ni(OH)_2 + ZnO$$

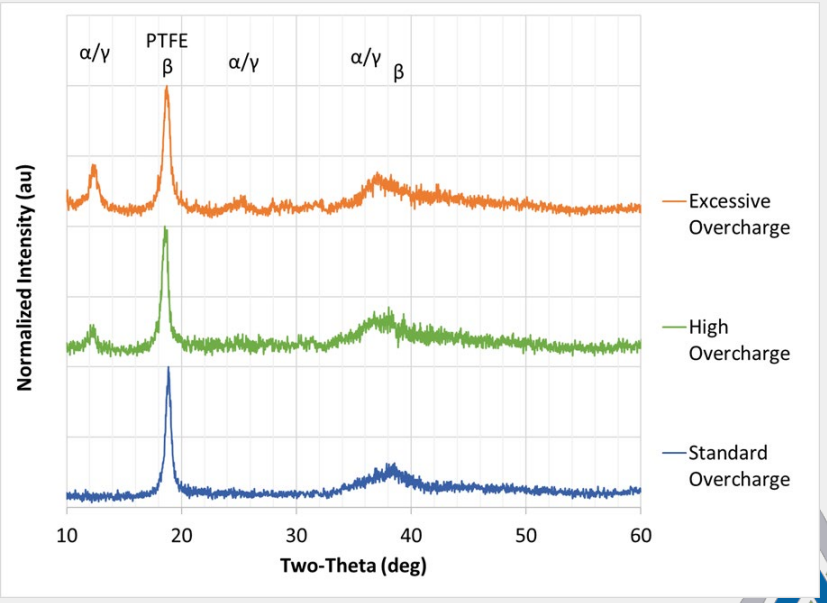


Normally the β-polymorph, will see the γ-polymorph on excessive overcharge

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



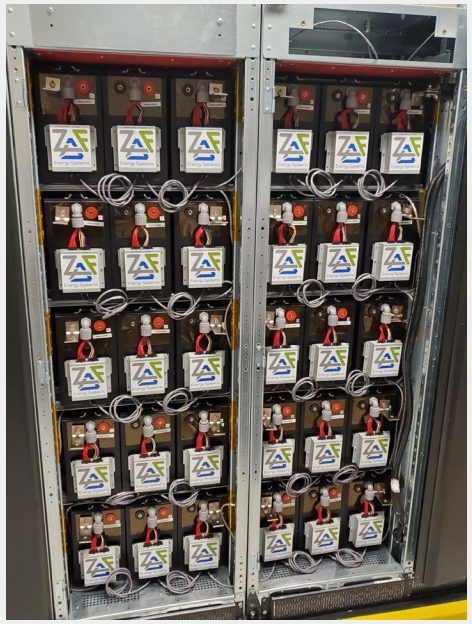
Discharge voltage at various rates for 147Ah G31 hybrid Ni-Zn cell



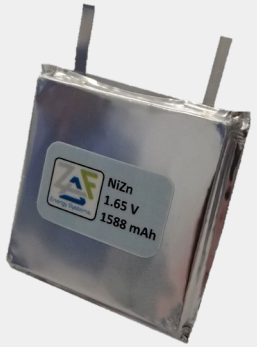
XRD data of Nickel electrodes at various states of overcharge

FLEXIBILITY IN CELL AND BATTERY CONSTRUCTION

- Cell and battery formats
  - Pouch cells: 1.5 Ah
  - Prismatic construction
    - 8 Ah
    - 140 Ah
    - 1500 Ah
  - Monoblocs
    - 9V
    - 12V
    - 48V
  - Large scale stationary
    - 675kW 480V
    - 300s3p configuration
      - 900 cells



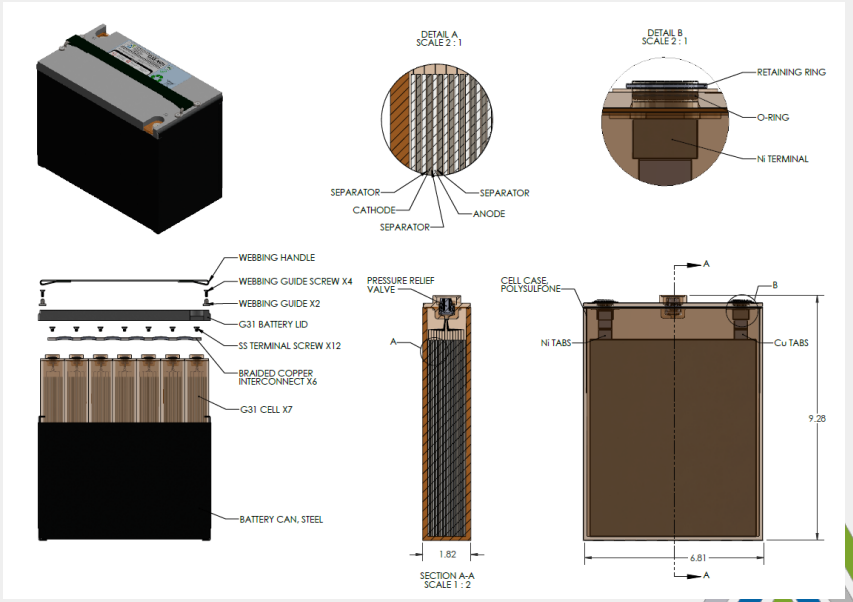
675kW 480V Data Center



1.65V 1.5Ah Pouch cells



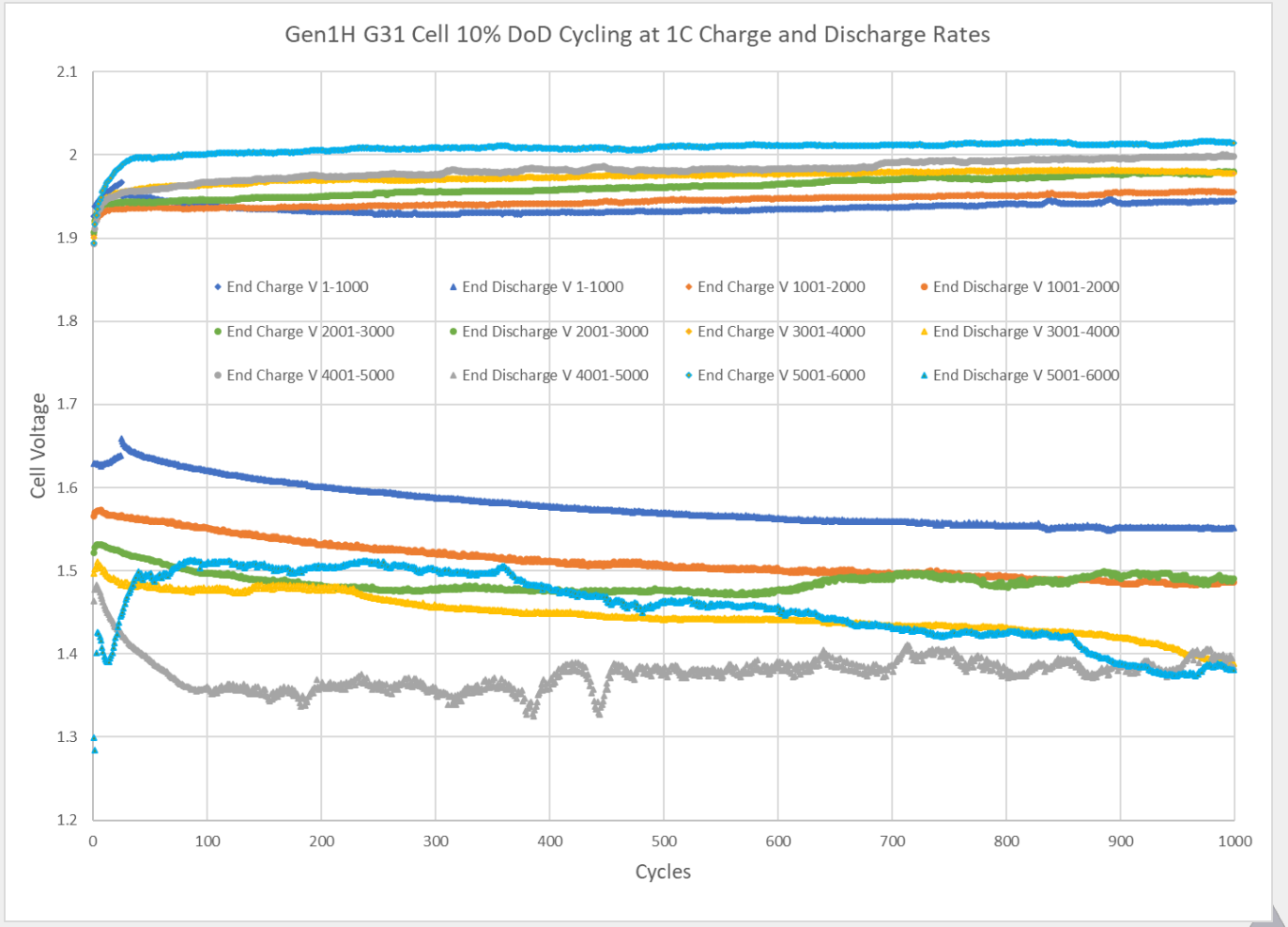
9V 42Ah Monobloc



G31 Cell and Battery Construction

CYCLE LIFE

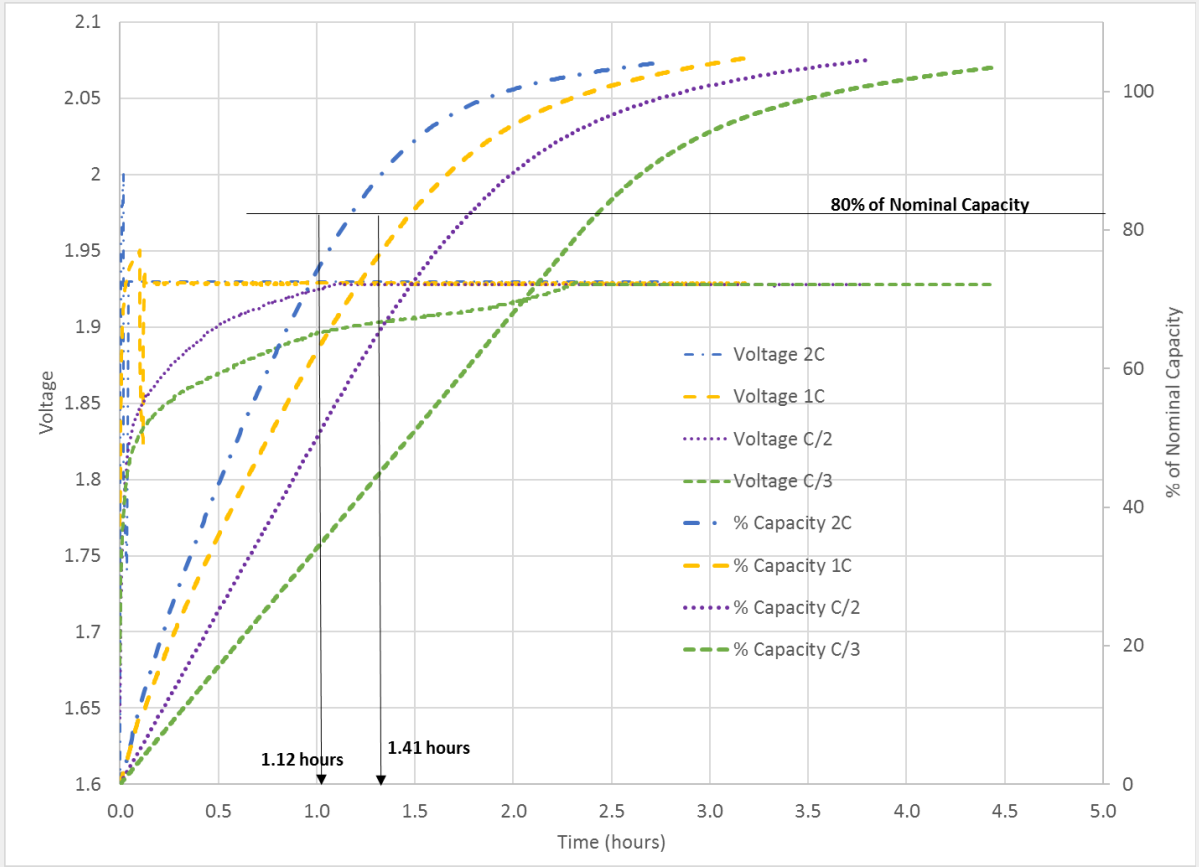
- 100% Depth-of-discharge (DoD)
  - 600 cycles
  - Cycled to the BCIS-06 standard
    - End criteria: 50% of nameplate capacity
- 50% Depth-of-discharge (DoD)
  - 1500 cycles
  - C/3-rate
- 10% Depth-of-discharge (DoD)
  - 6000 cycles
  - 1C-rate

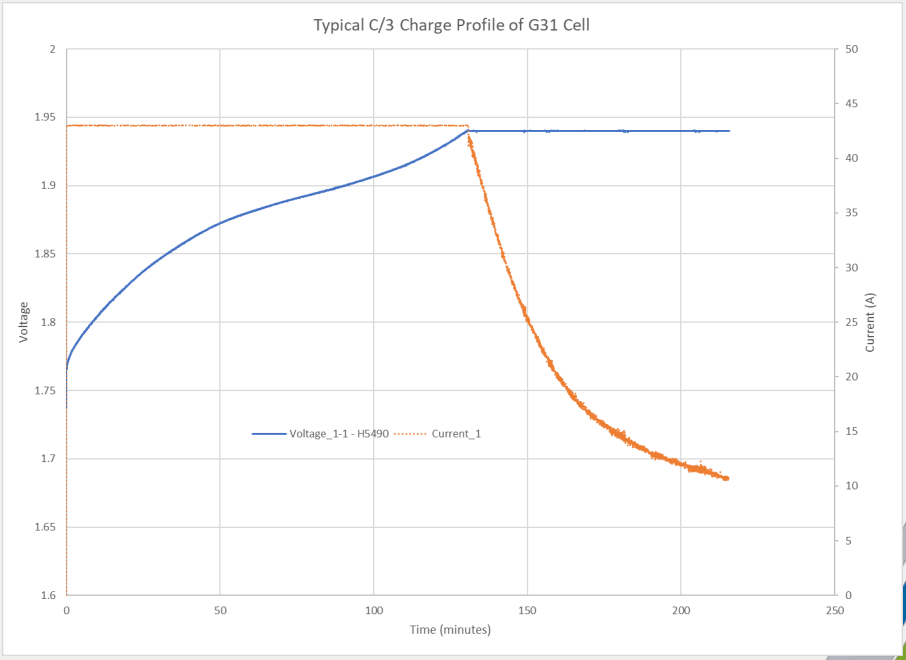


End-of-charge and end-of-discharge voltages during 10% DoD at 1C-rate

CHARGE ACCEPTANCE

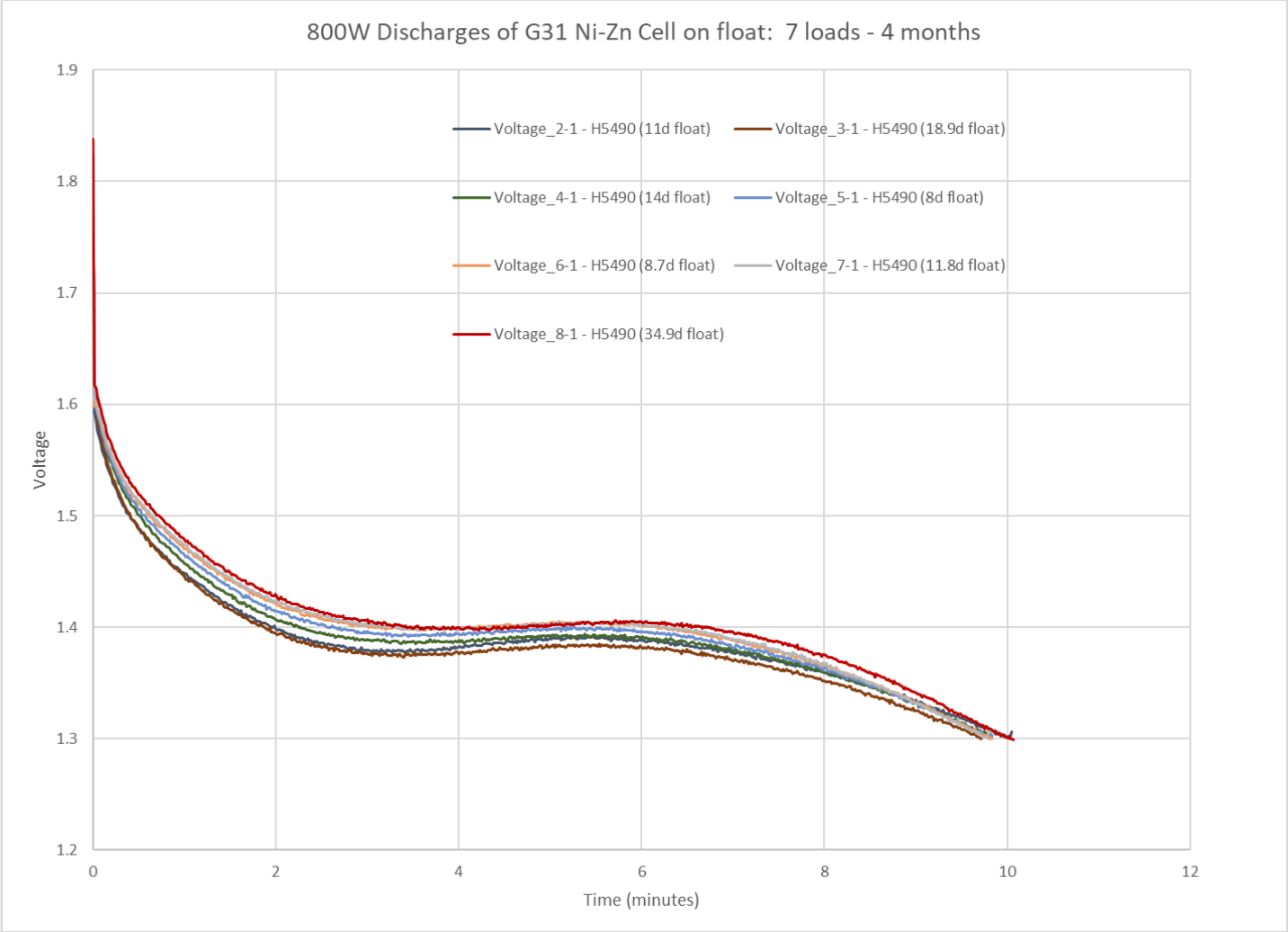
- Typical charge profile is CCCV
  - Constant current- constant voltage
    - Taper current or timed cut-off
  - Recommended 1.94V/cell
- Can also be constant voltage only
  - Float at 1.84V/cell
- Can be charged at up to a 2C-rate
  - 80% of nominal capacity in about 1 hour
- Temperature compensated voltage





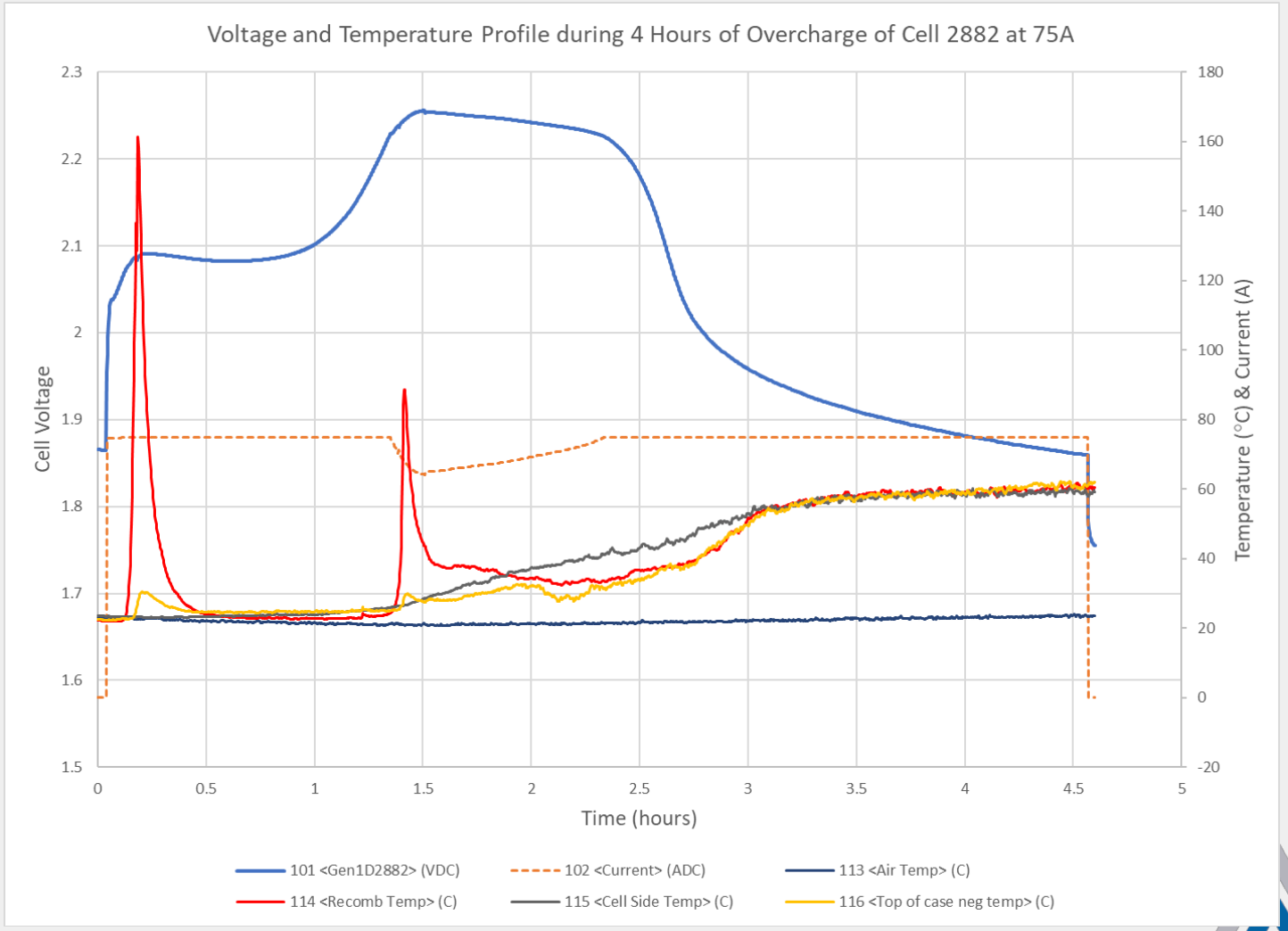
HIGH-RATE PERFORMANCE WHILE ON FLOAT

- Ni-Zn G31 format hybrid cell on float
  - 800W discharge until cut-off at 1.3V
    - 7 loads over 4 months
    - After load, top-off charge, then back on float
      - No deep cycle conditioning



SAFETY TESTING: EXTENDED OVERCHARGE

- Ni-Zn G31 format hybrid cells on extended overcharge
  - Capacity: 122 Ah
  - At 100% SoC at beginning of charge test
  - 75A charge for 4 hours
    - 300 Ah of overcharge => 246% Overcharge
  - No voltage limit
  - Cell temperature levels out at about 60°C
    - Ohmic heat
    - Cell dry out
  - Extensive gassing
    - Recombination coil temperature increase



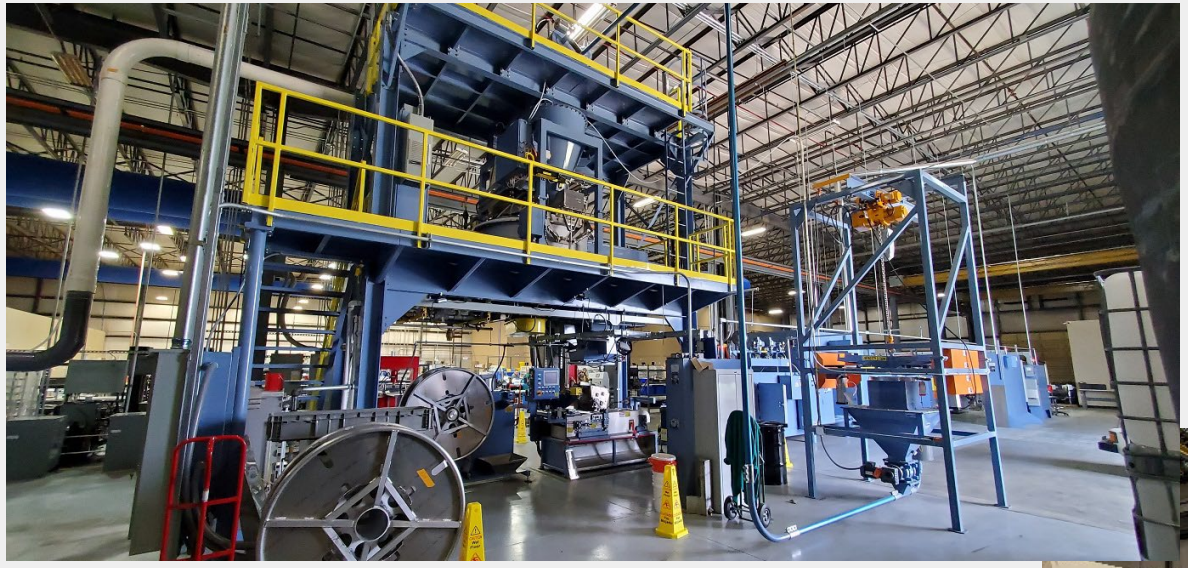
MANUFACTURING OF NI-ZN ELECTRODES

- Historical limitation on lowering cost and market adoption
  - Manufacturing of electrodes => bottleneck
- Æsir has developed low-rate tape cast method
  - Coating $Ni(OH)_2$ slurry on various nickel substrates
  - Automated feedback controls to ensure uniform loading and thickness
  - < 1 ft/min
    - Limited by dryer length
  - In process of adding line for anode slurry



Tape cast manufacturing line of Ni-Zn electrodes

HIGH VOLUME MANUFACTURING OF NI-ZN ELECTRODES



Mixer, mix platform, and paster

- Æsir is collaborating with Lead-Acid equipment manufacturer Wirtz Mfg. Co.
- Built a high-volume Ni-Zn electrode pasting line
- 100 ft/min

QC Stations **Calendar** **Dryer**



SUMMARY

- Ni-Zn has an energy density range between PbA and Li-Ion
- Deep cycle life has improved well past Lead-Acid
- Safe, recyclable, and environmentally friendly
- Suitable in extended float stand applications
- Moving to high volume manufacturing