Intracell Thermal Management System for Batteries: Architecture, Advantages, and Applications

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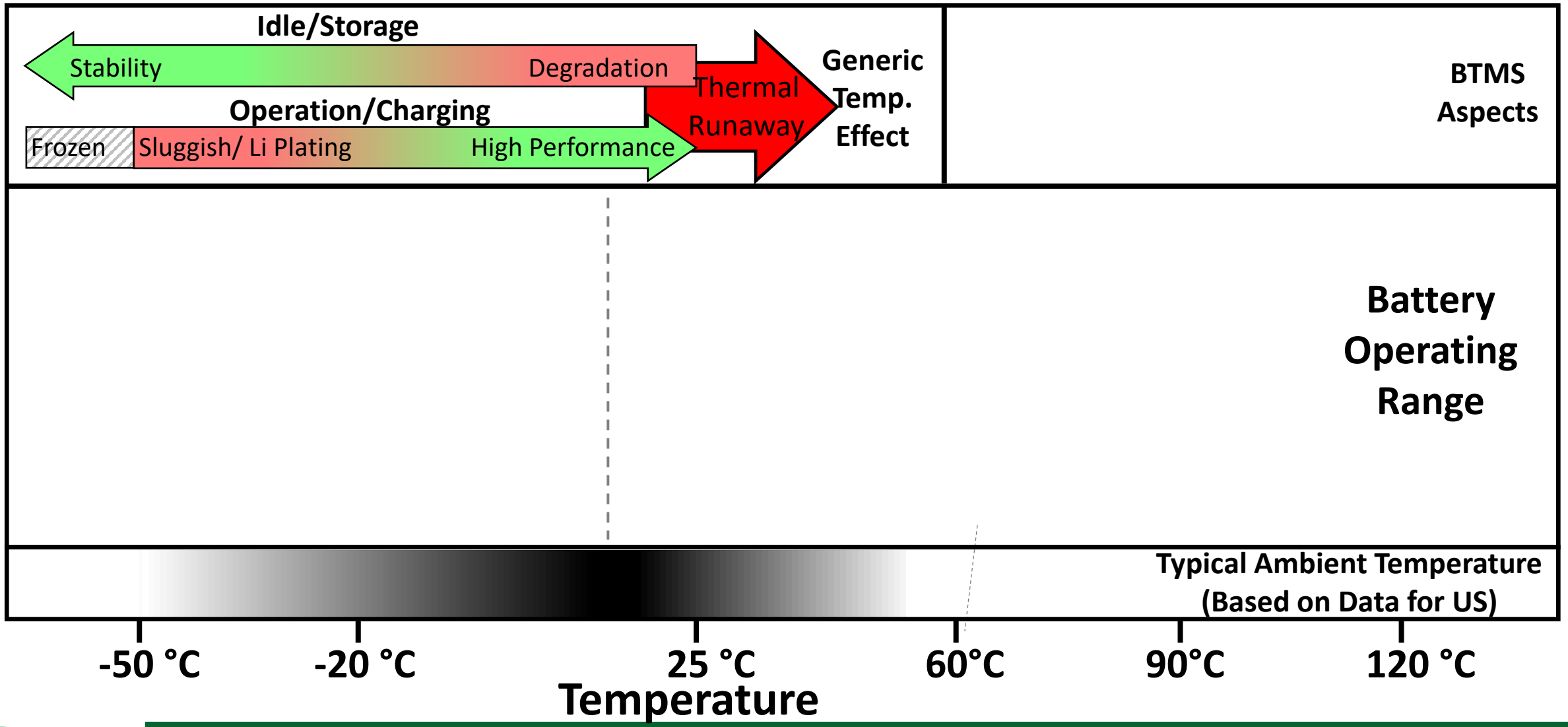
Battery Thermal Management



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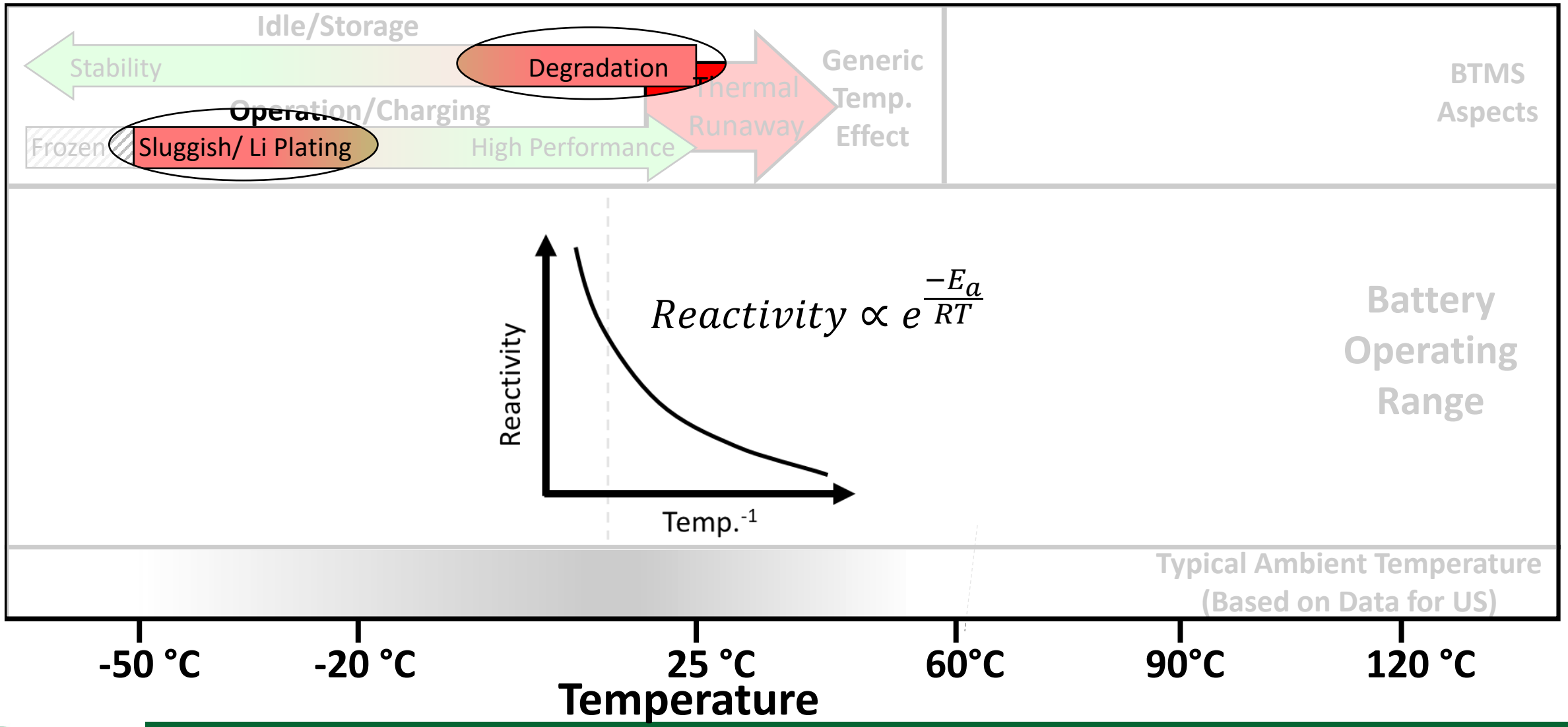

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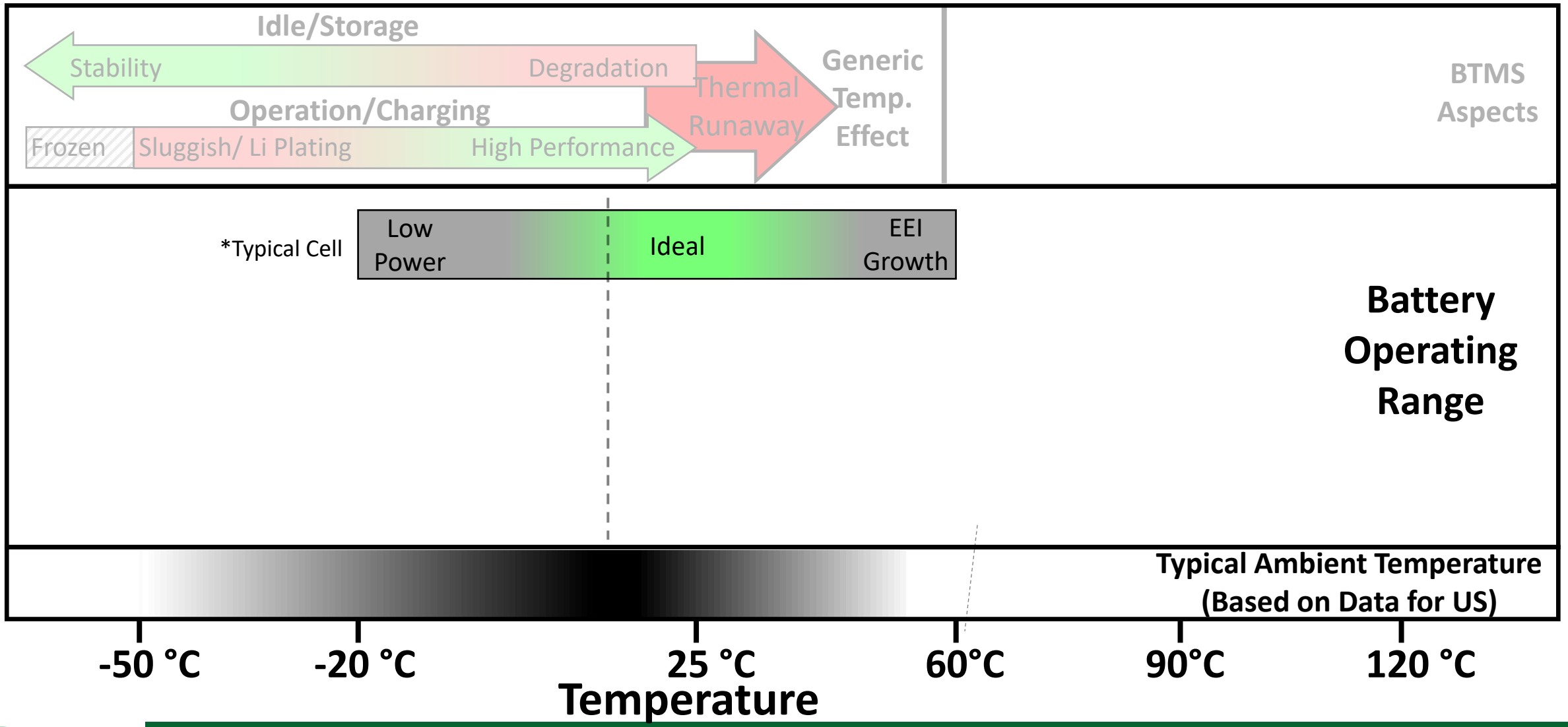

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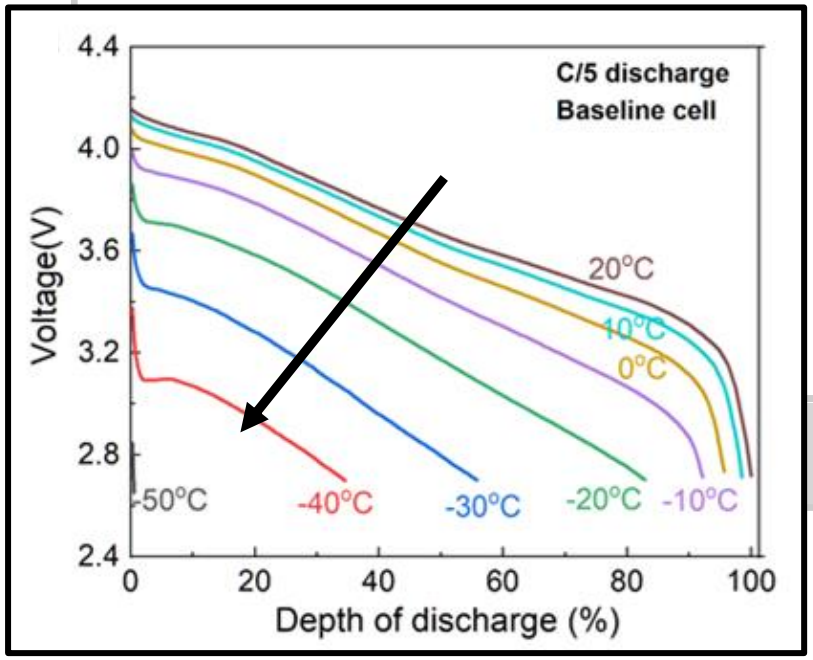
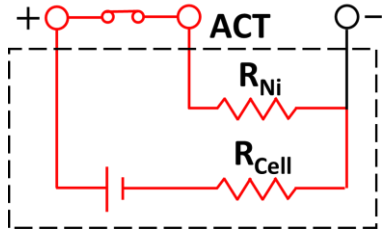
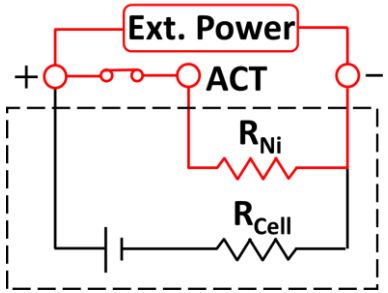


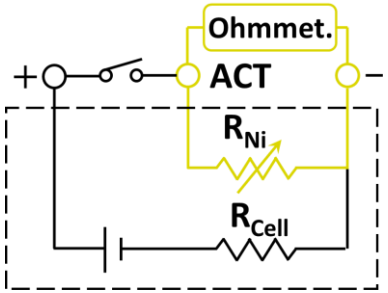
Self-Heating Battery Architecture



Self-Heating

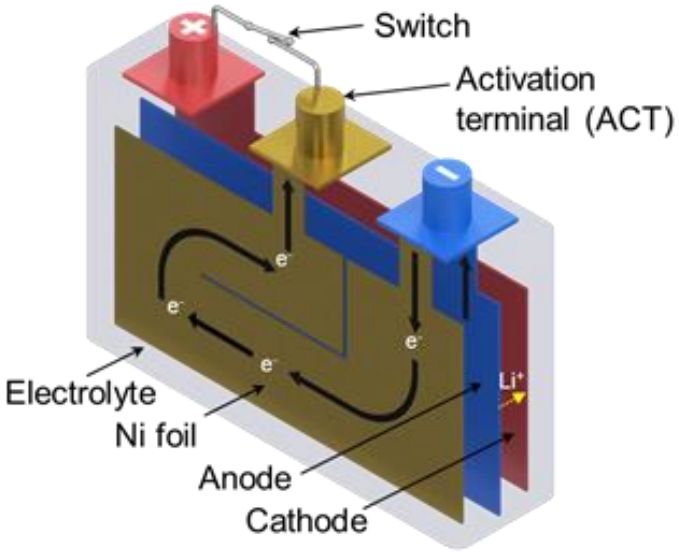


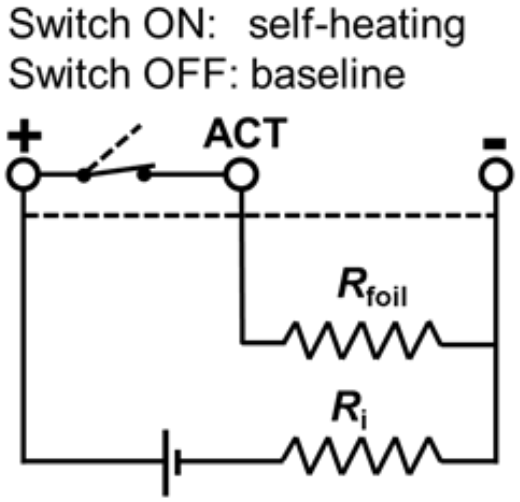
Charger Heating



Temp. Sensing

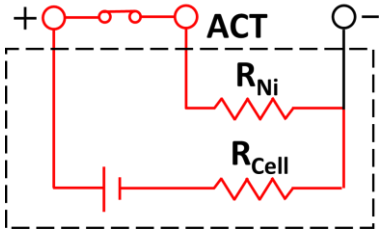
- **New cell structure**: Anode + Cathode + Electrolyte + 4th Component: a μm-thin Ni foil for rapid internal heating; 1-5°C/sec or 60-300°C/min & uniform
- Reduction of specific energy by <1.5%. Negligible increase in production costs.





Wang et al., Nature, 529 (2016) 515-518.

Self-Heating



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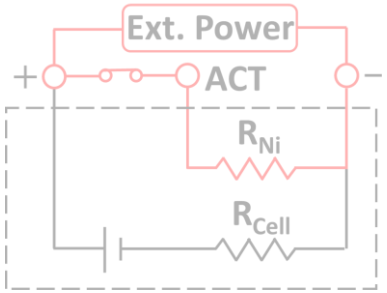

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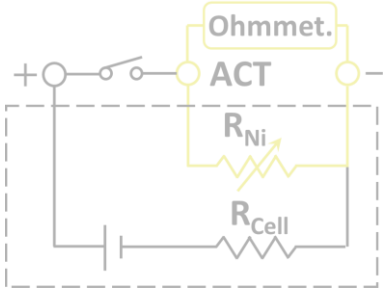

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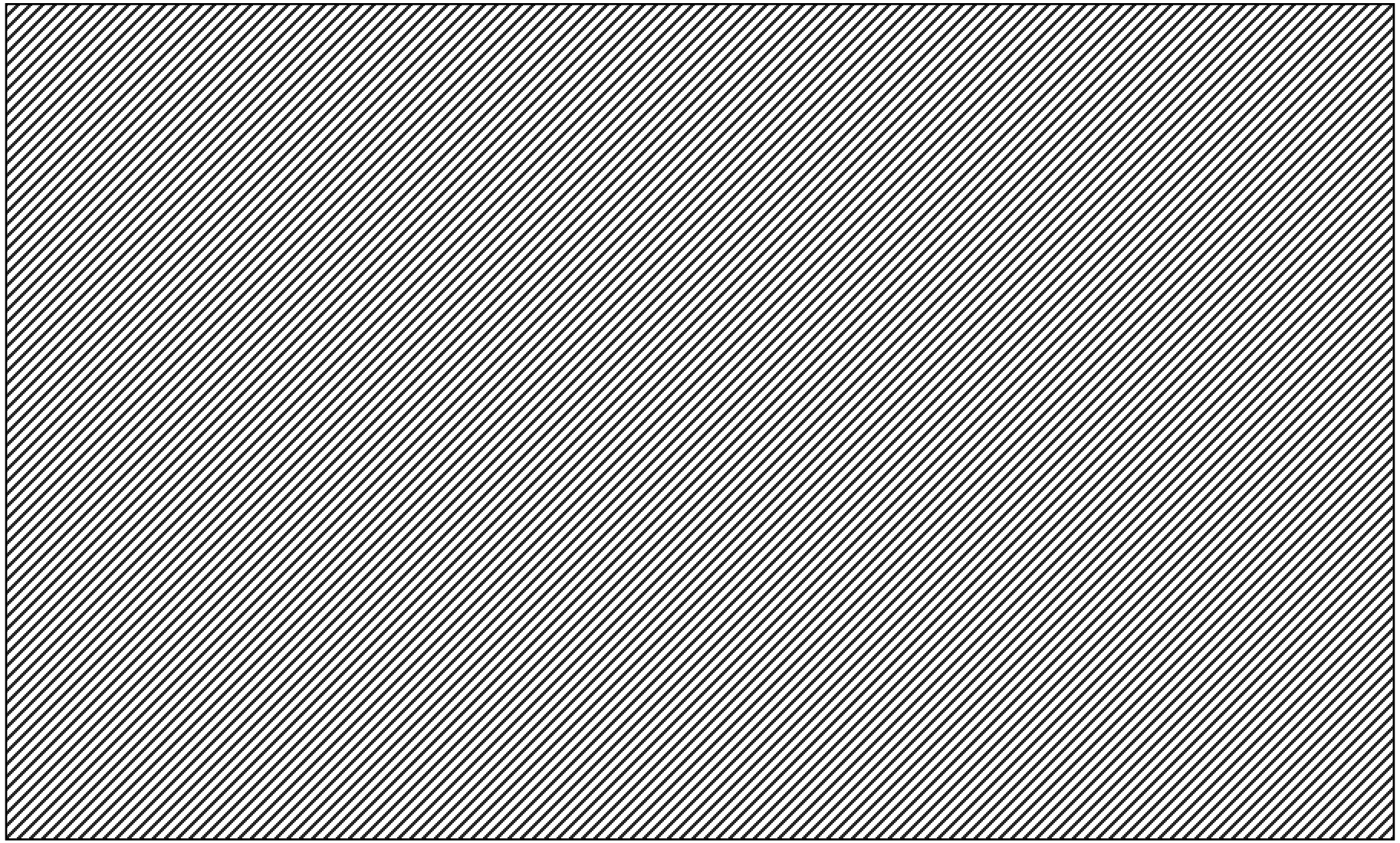

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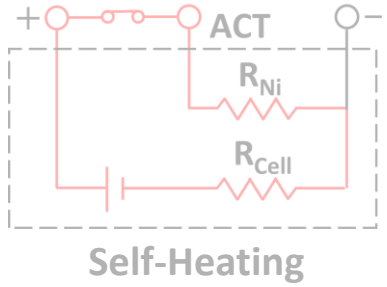

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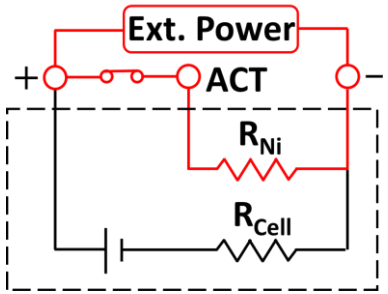

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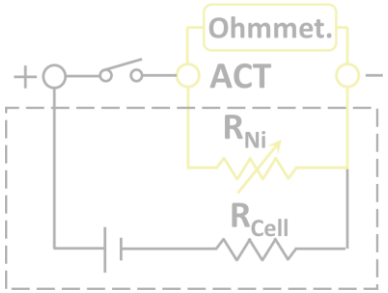
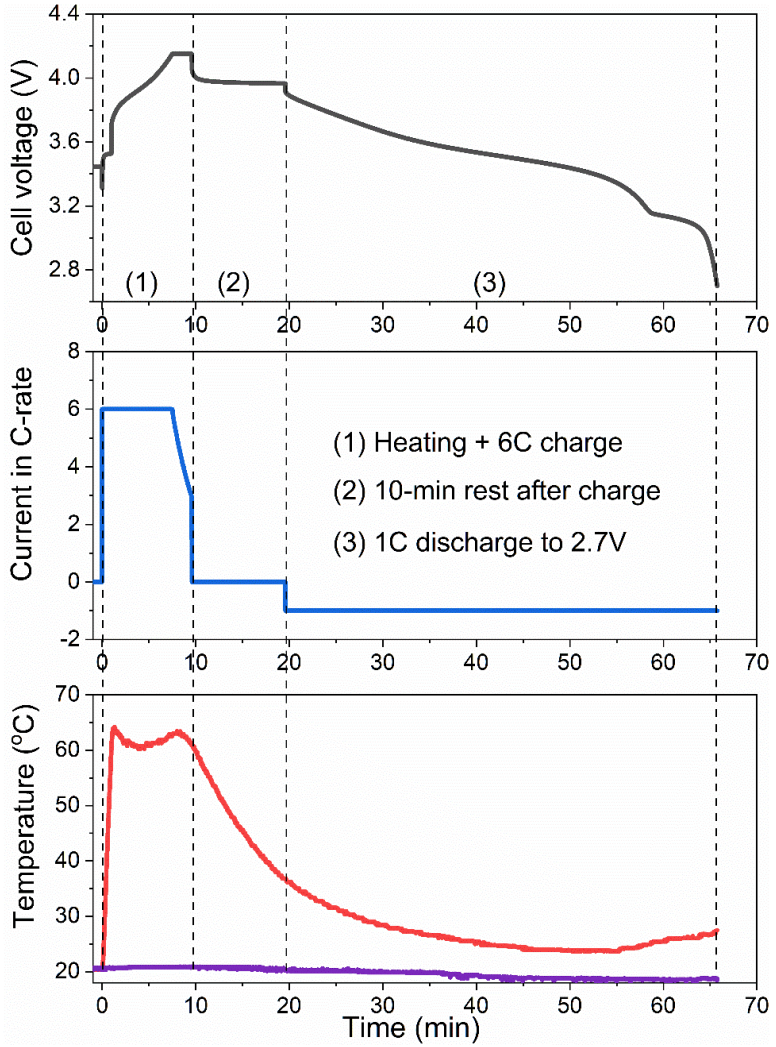
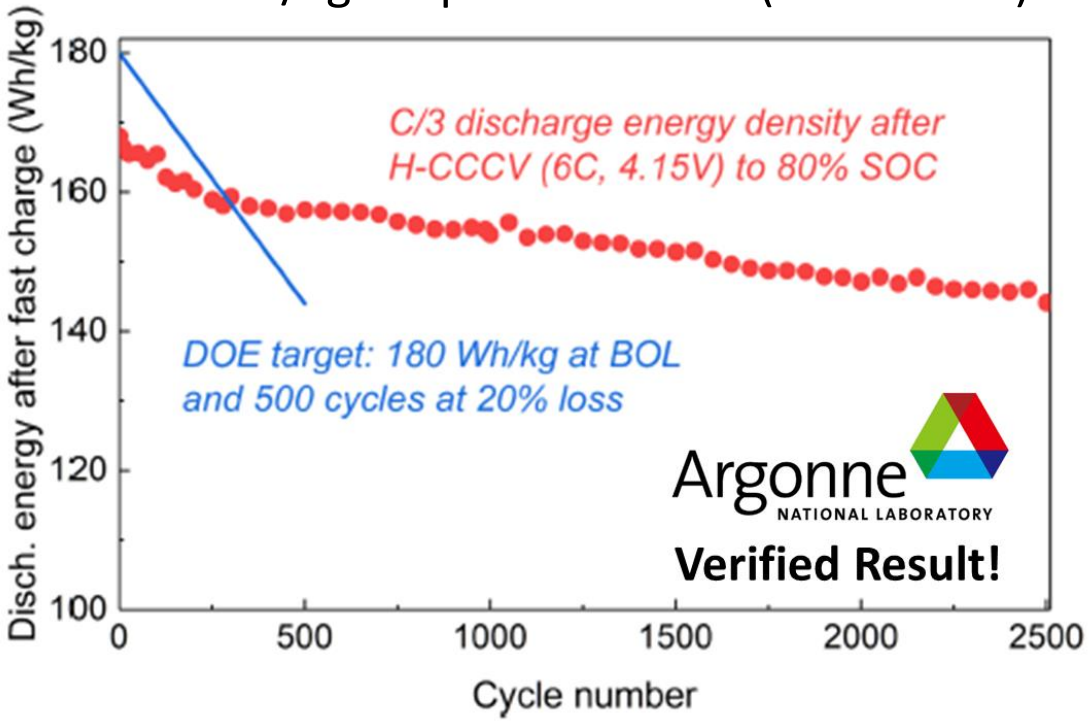


Temp. Sensing



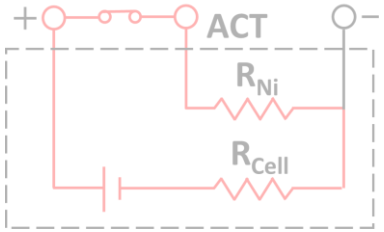
Rapid temperature modulation enhances charging kinetics while minimizing exposure time.

210 Wh/kg Graphite-NMC532(LFP Coated)



Yang et al., Joule, Vol. 3, pp. 1-18, 2019

Internal Temperature Sensing



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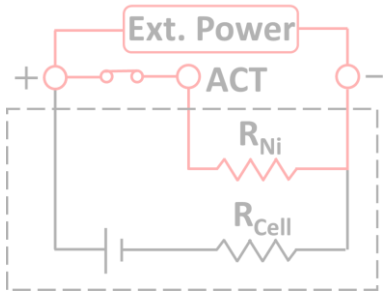

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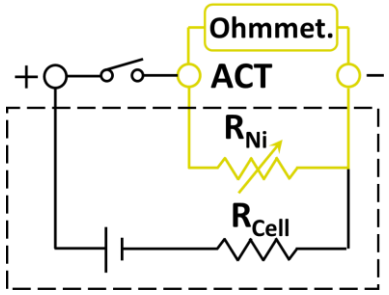
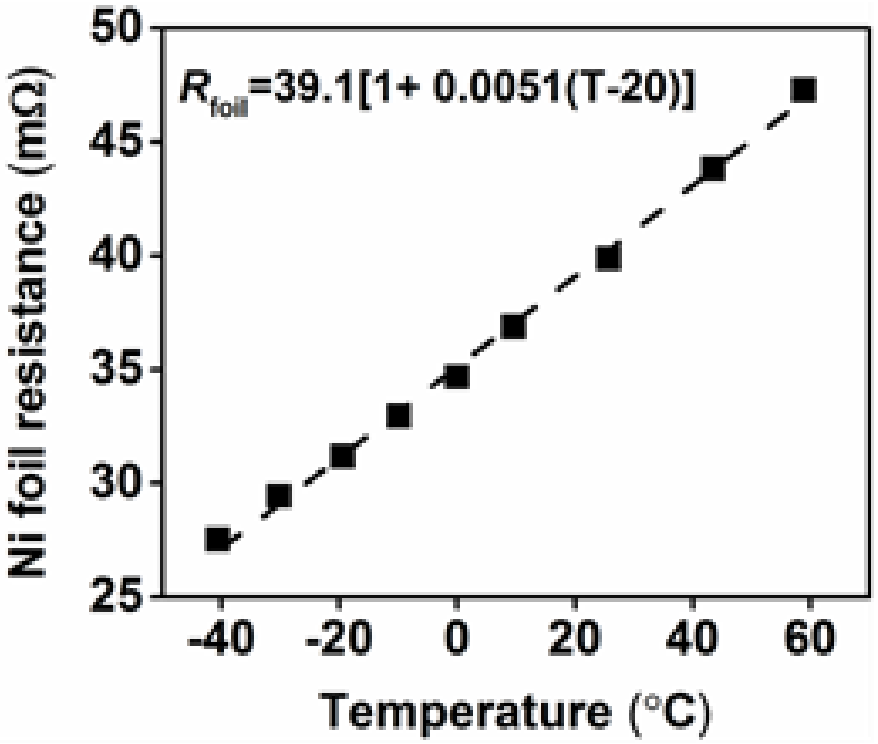
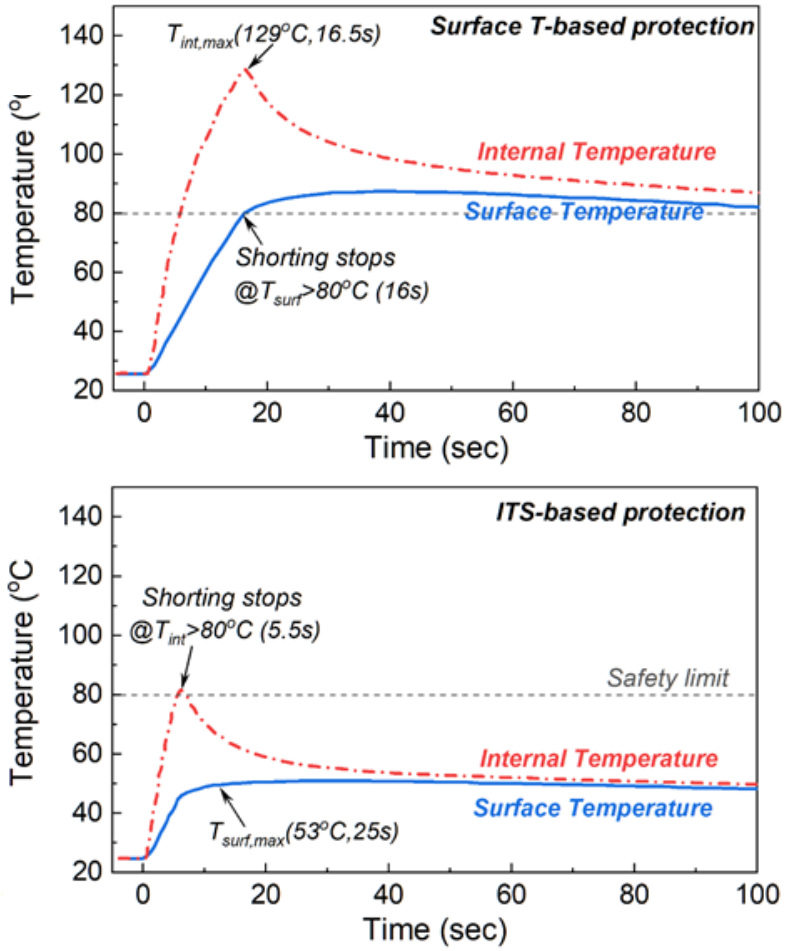


Temp. Sensing

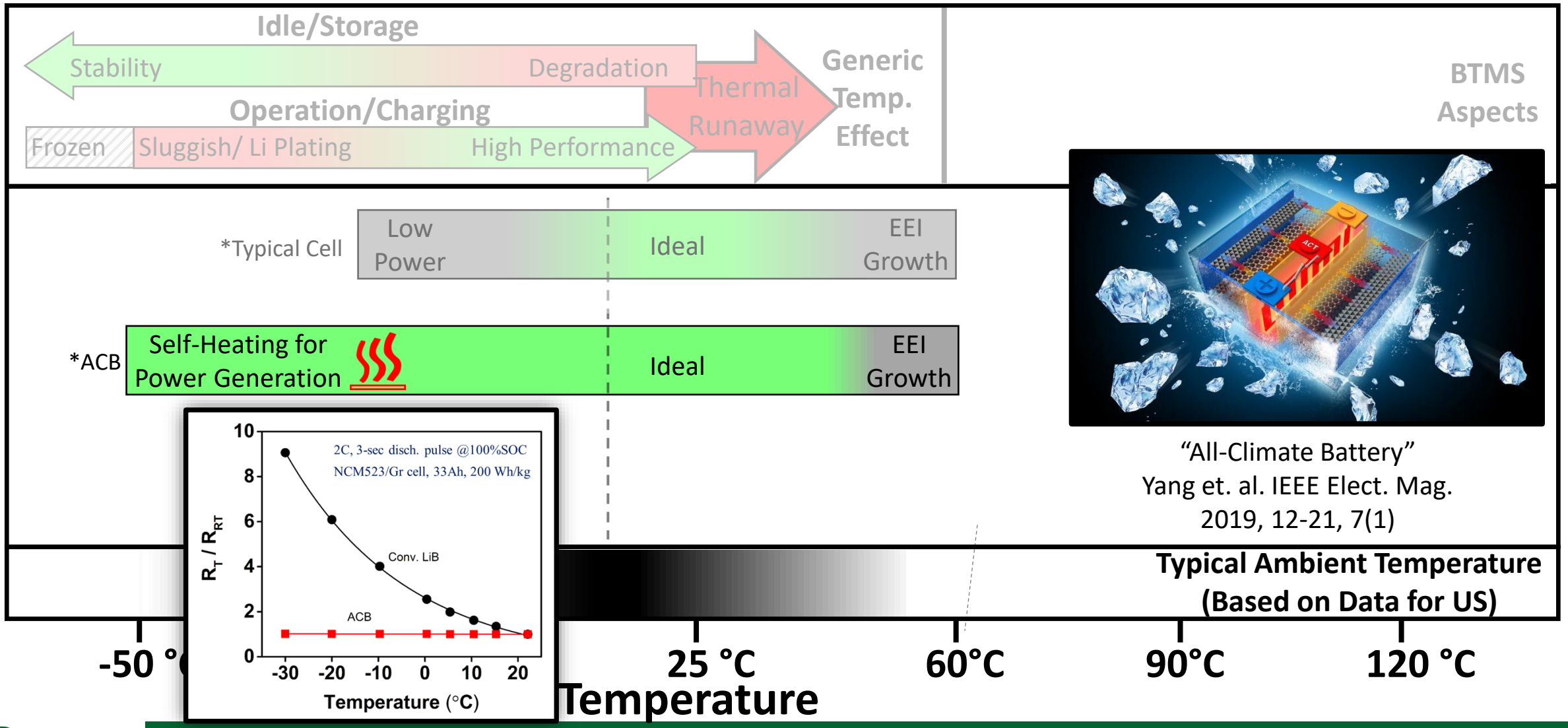
Linear correlation of temperature and resistances provides accurate internal temperature sensing.





Zhang, et. al. Scientific Reports, 5, (2015) 18237

Battery Thermal Management



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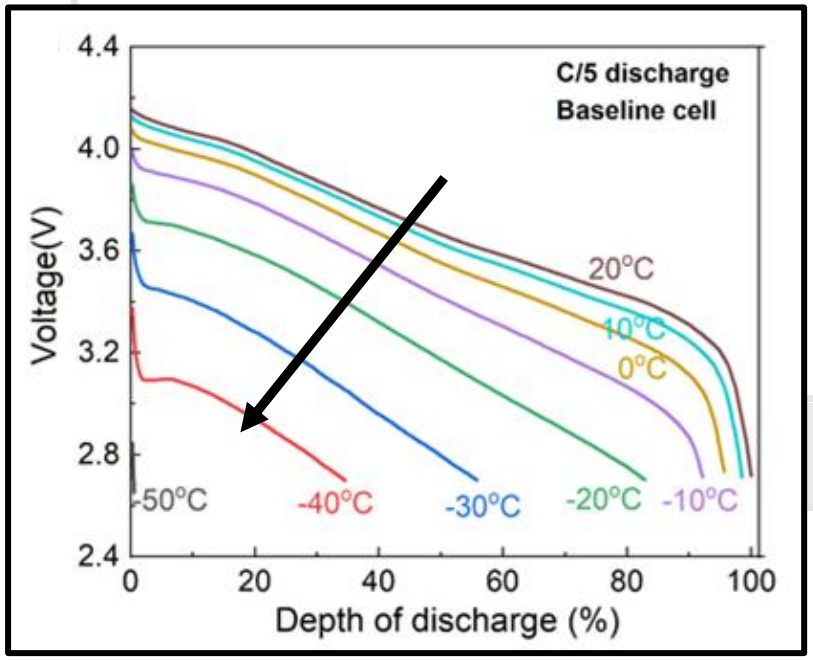

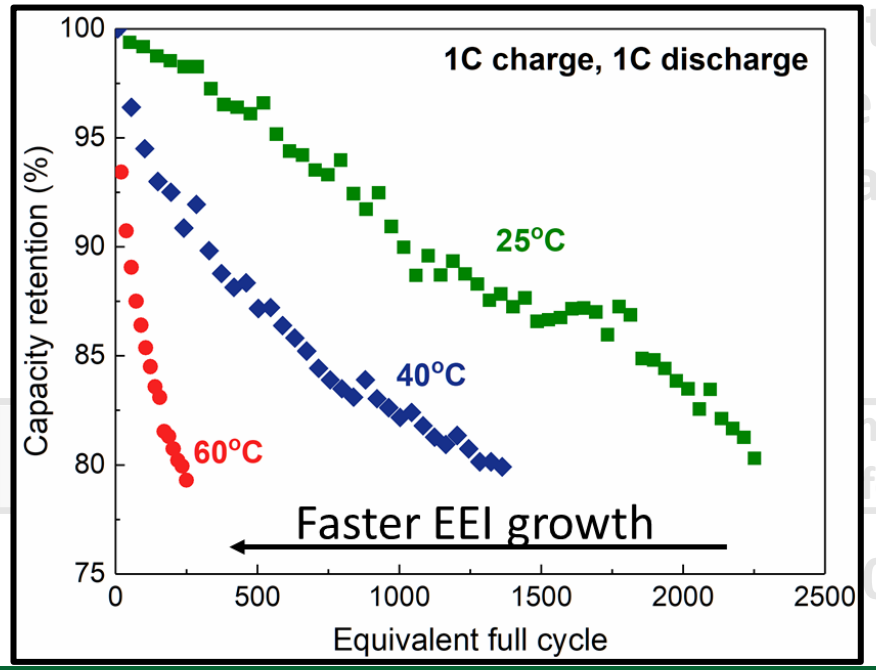

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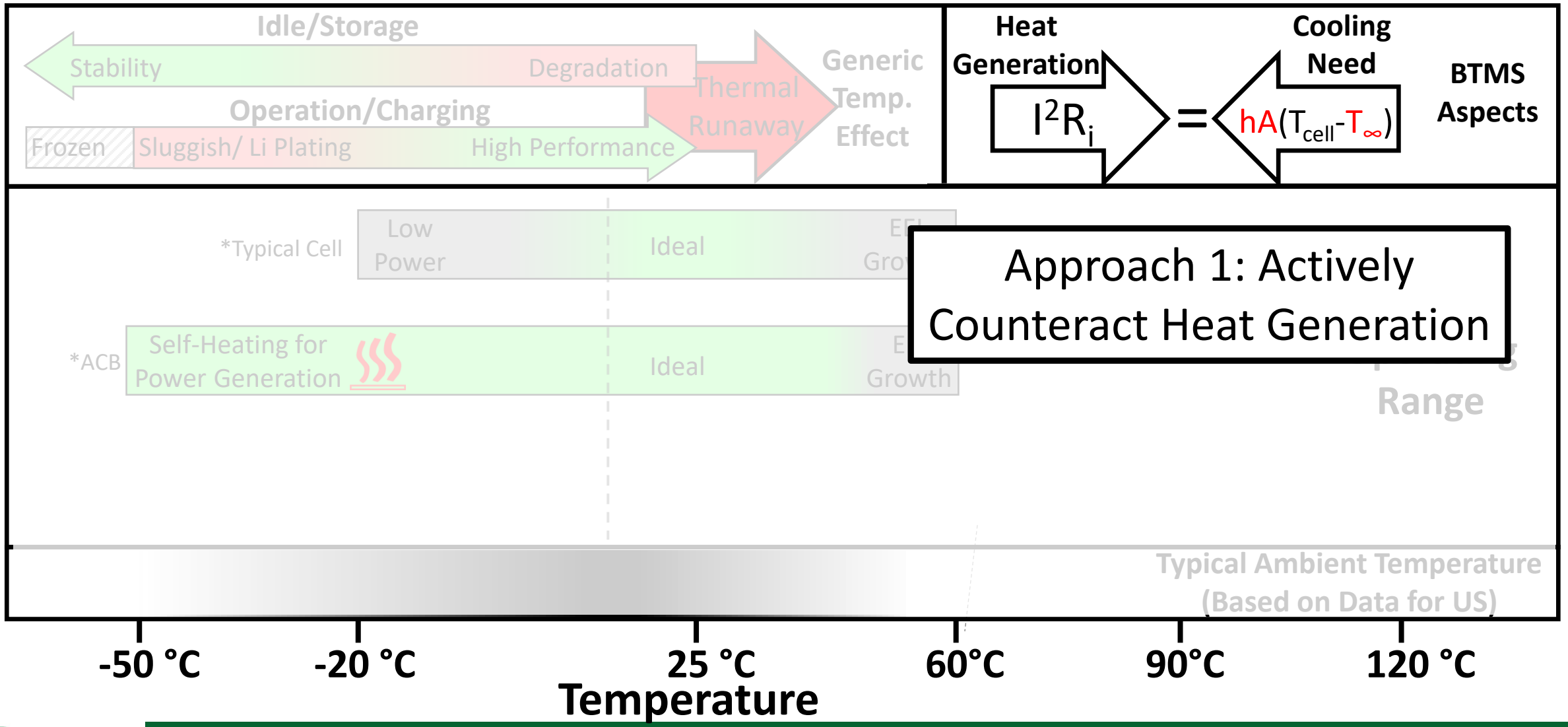

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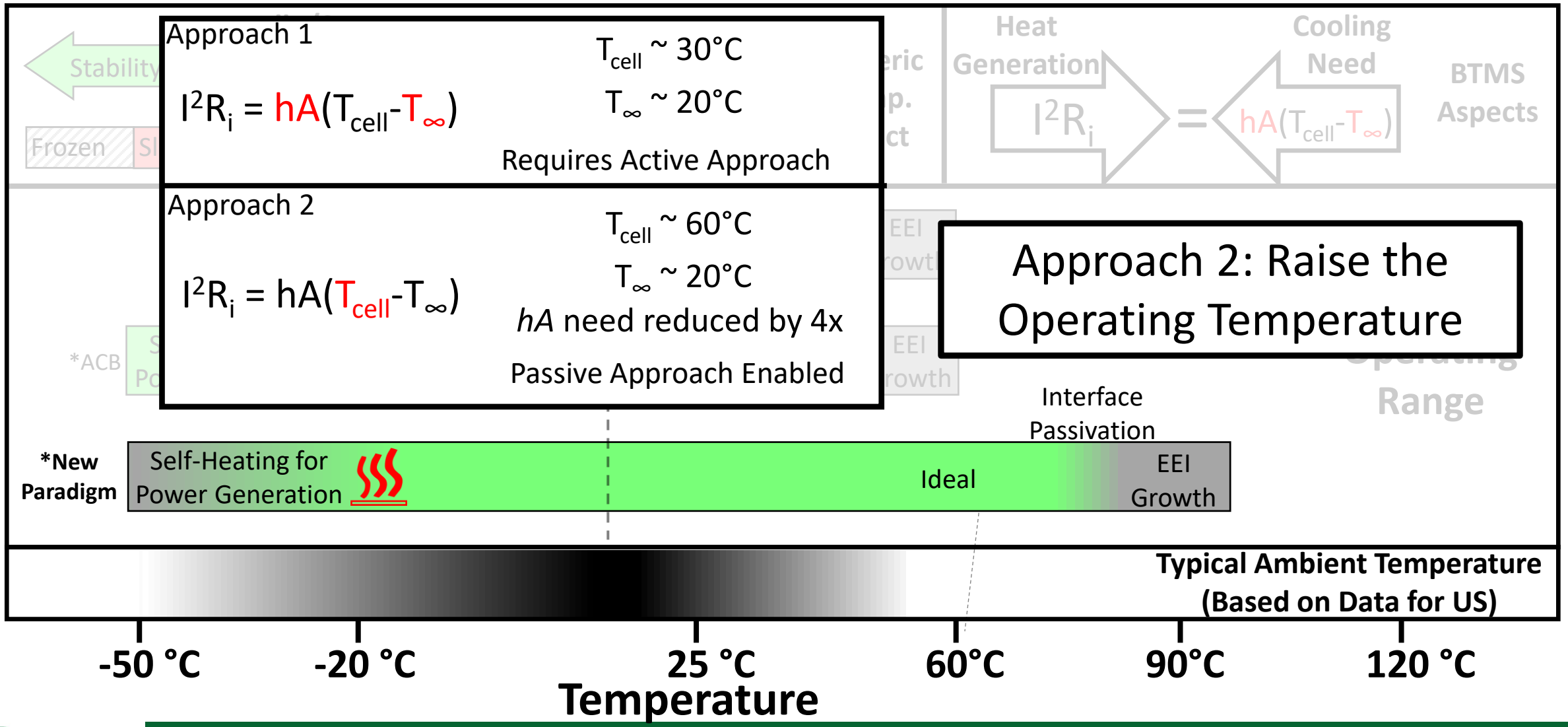
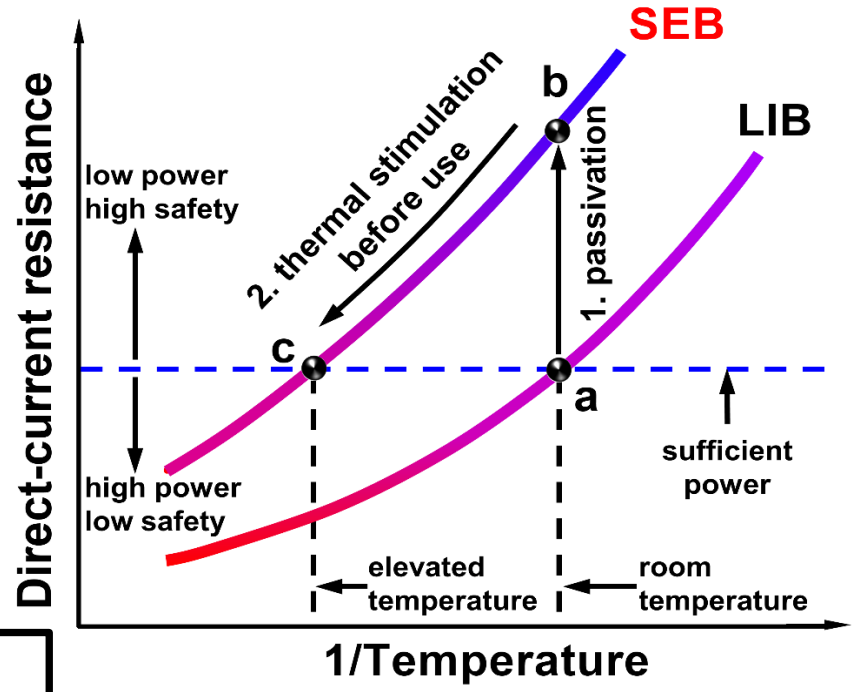
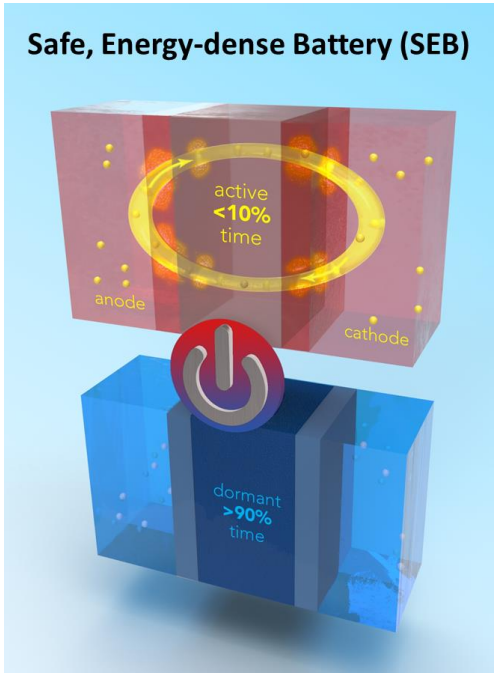


The “Safe, Energy-Dense Battery”

1. Passivating battery to have low reactivity of the electrolyte-electrode interface or a large charge-transfer resistance -> stability, safety & low degradation
2. Heating before use thru a “thermal switch” to have high power





Ge et al., Sci. Adv. 3, 2020

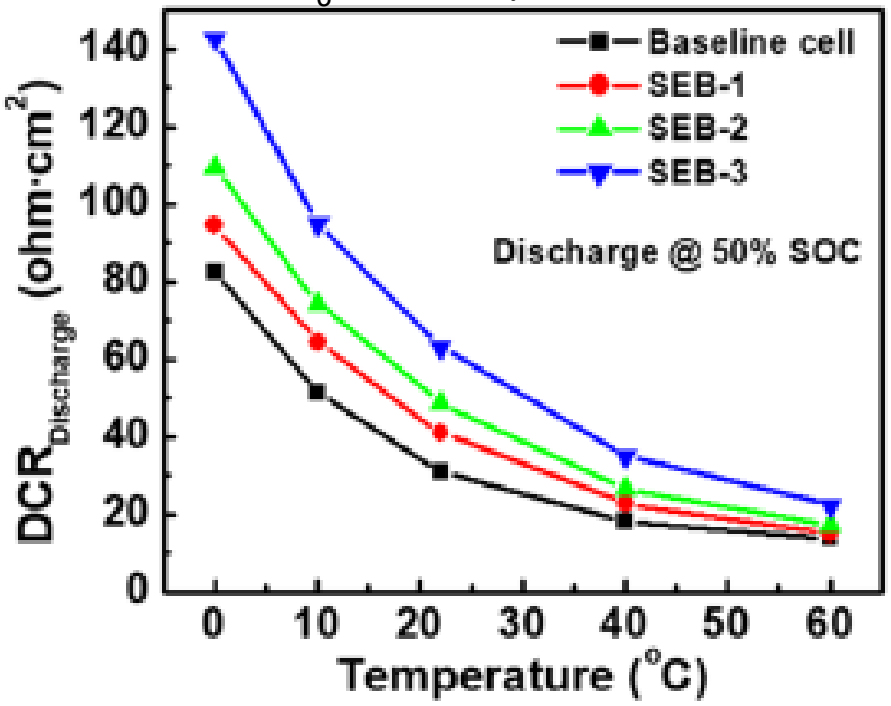
Passivation can be achieved by:

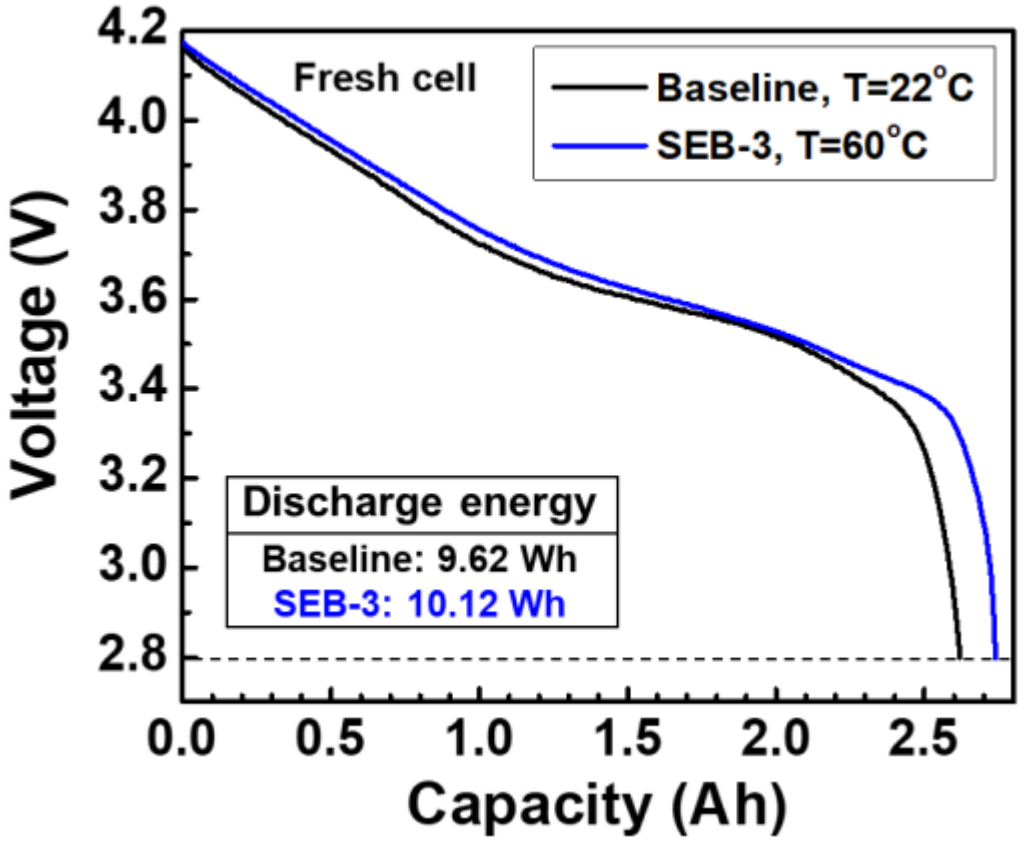
- Larger electrode particles (less surface area)
- Increasing initial EEI thickness
- Decrease the electrolyte conductivity
- Use solid-state electrolytes
- Use less reactive electrode materials

Passivation at the Electrode-Electrolyte Interface

Mix of 1-3% (w/w) Triallyl Phosphate (TAP) leads to robust EEI formation.
Xia *et. al.* J. Power Sources, 295, (2015), 203-211

Graphite-NMC622
1M $LiPF_6$ in 3:7 EC/EMC with **0-1.5% TAP**



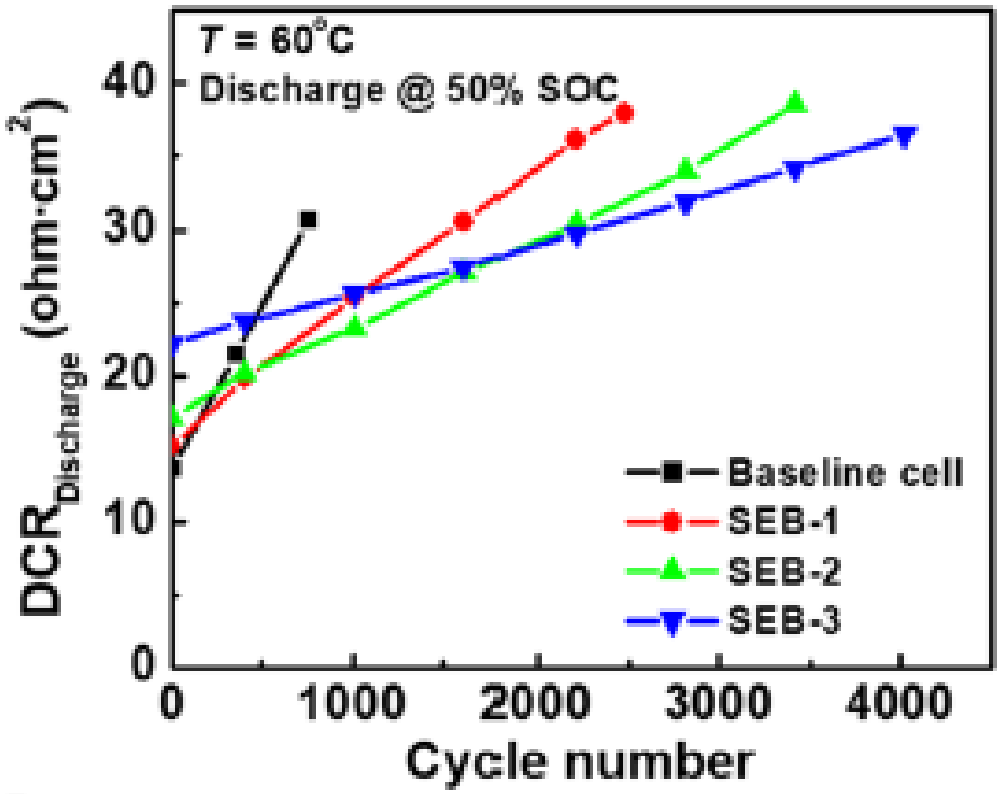


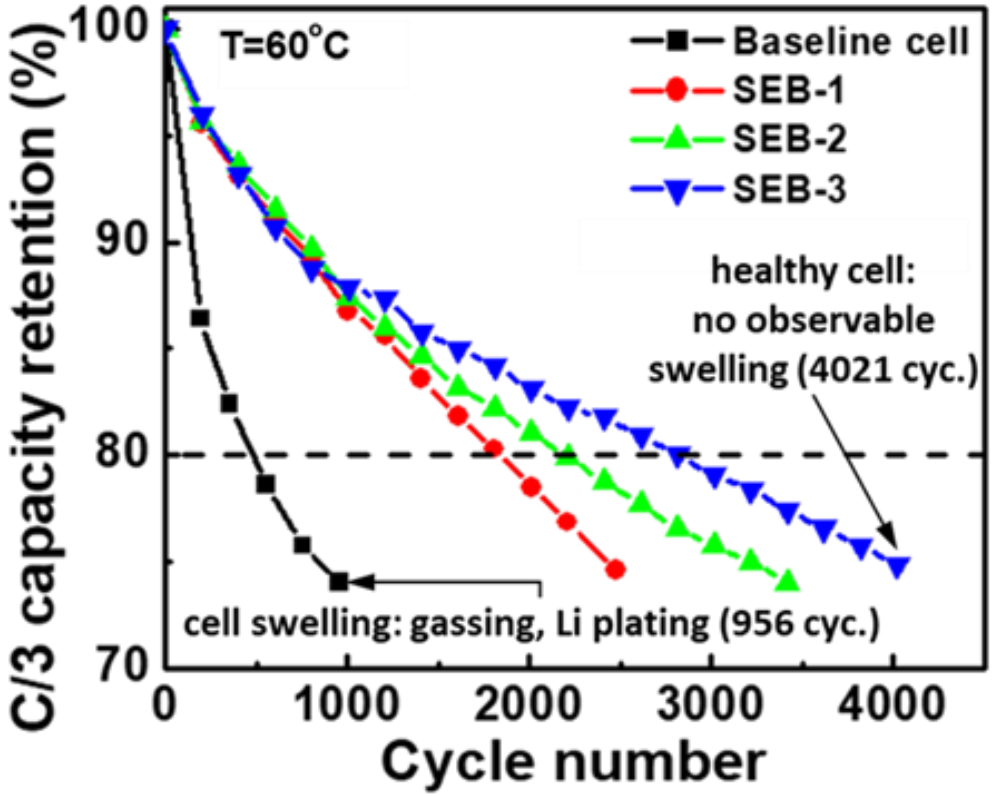
Ge et al., Sci. Adv. 3, 2020

Passivation at the Electrode-Electrolyte Interface

Long Cycle-Life at 60°C

1C, 4.2 V CCCV Charge; 1C Discharge



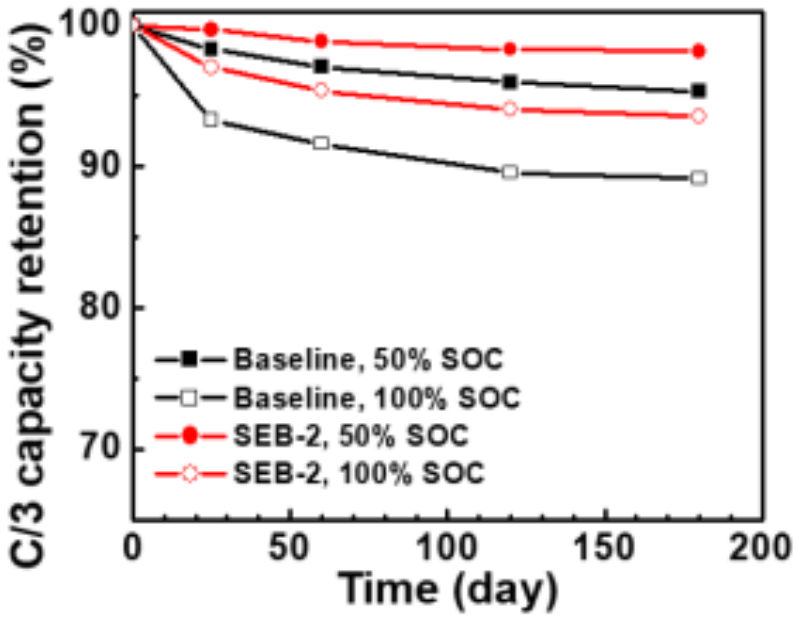


Ge et al., Sci. Adv. 3, 2020

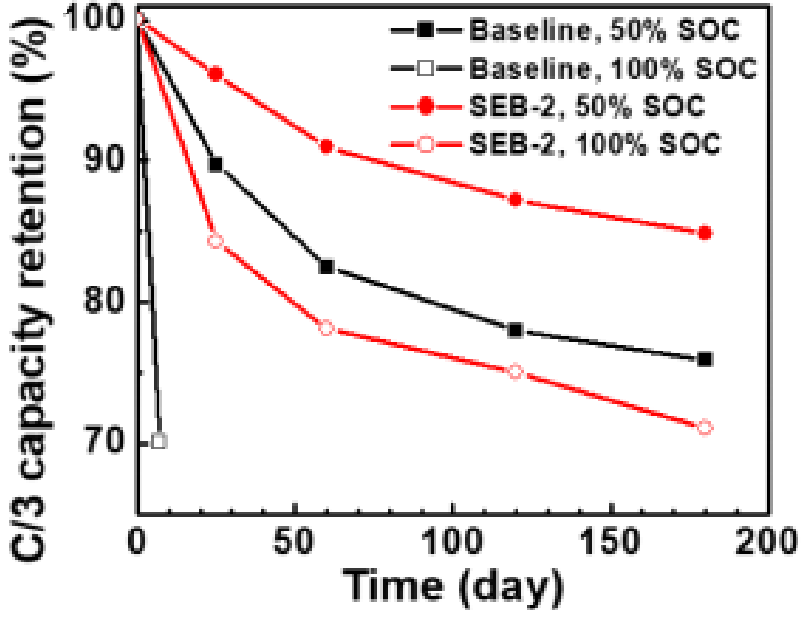
Passivation at the Electrode-Electrolyte Interface

Longer Calendar Life
Especially at Higher Temperatures

T = 22°C



T = 60°C



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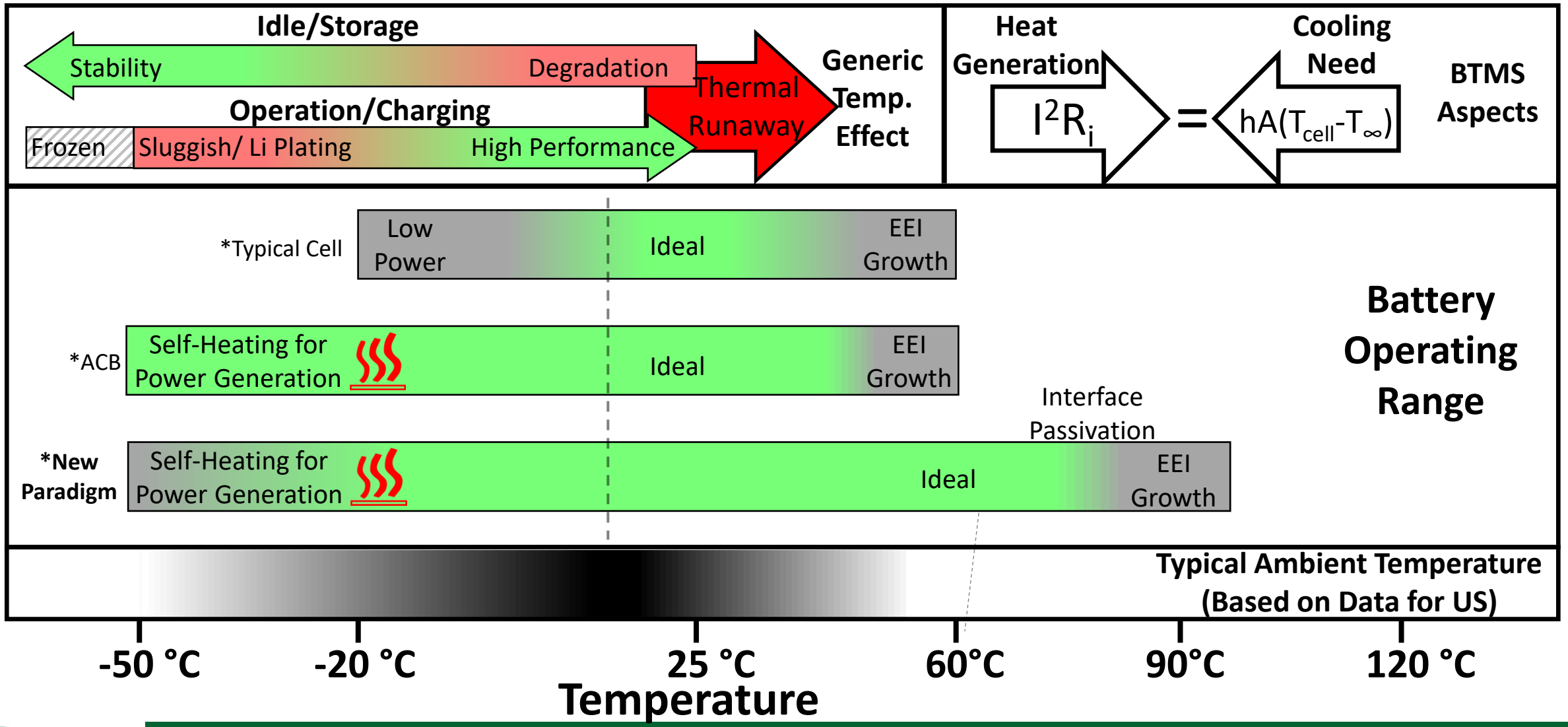

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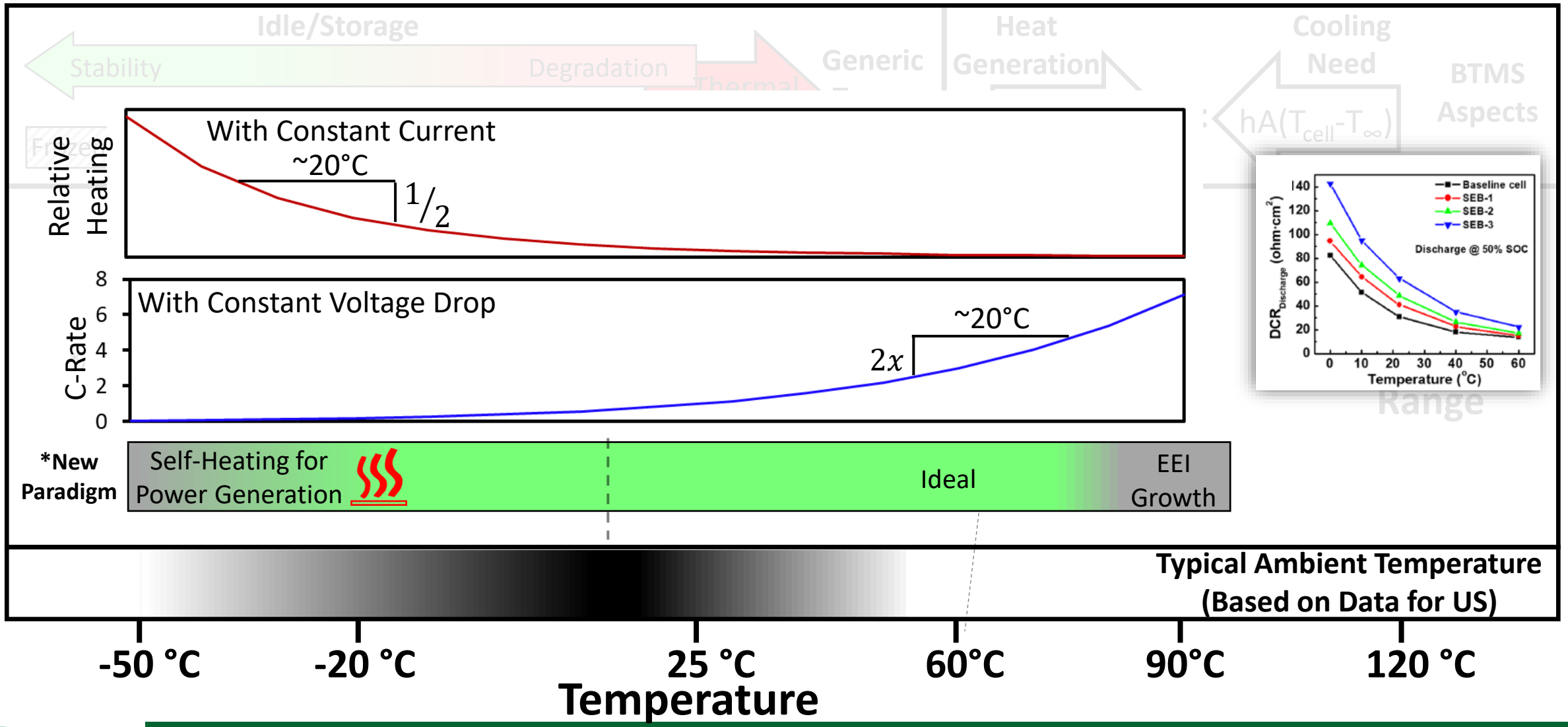

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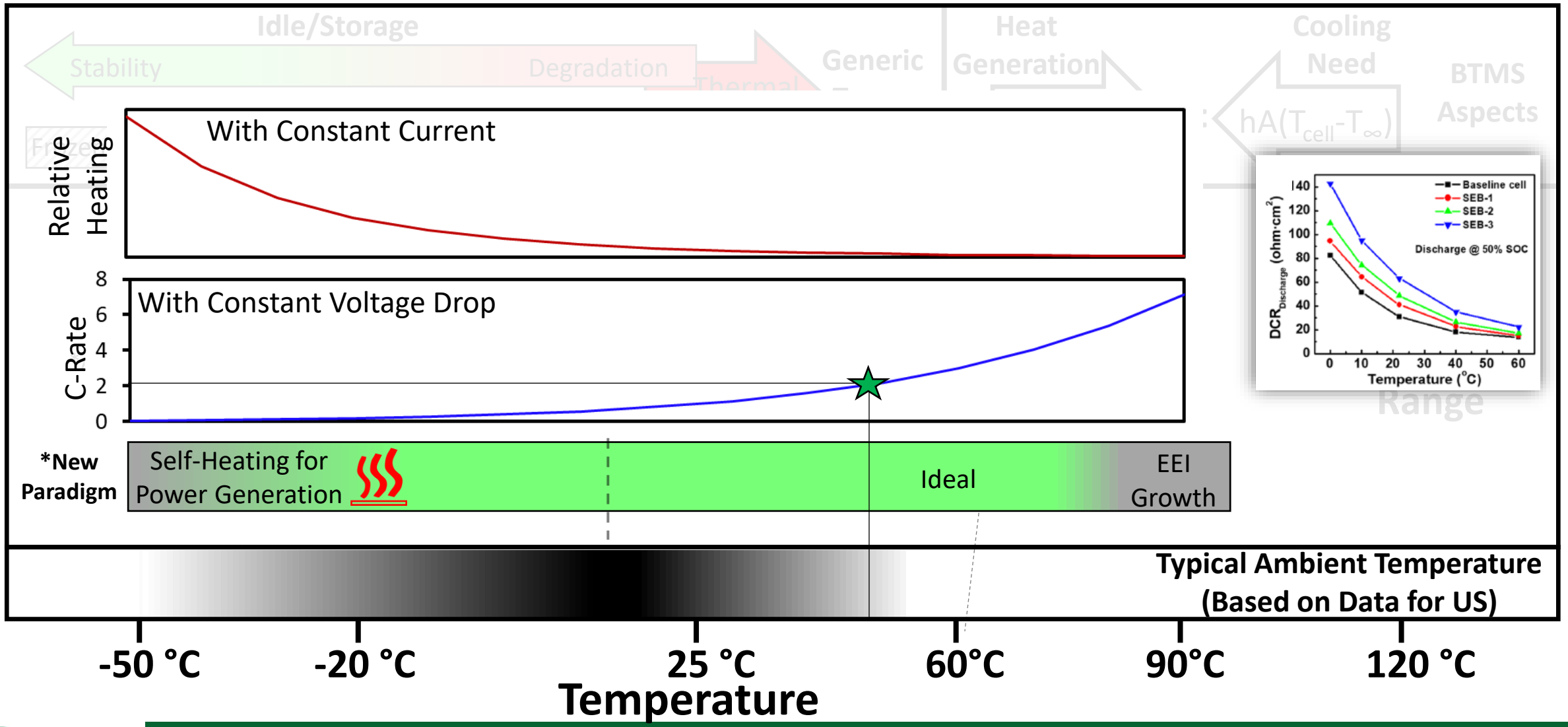
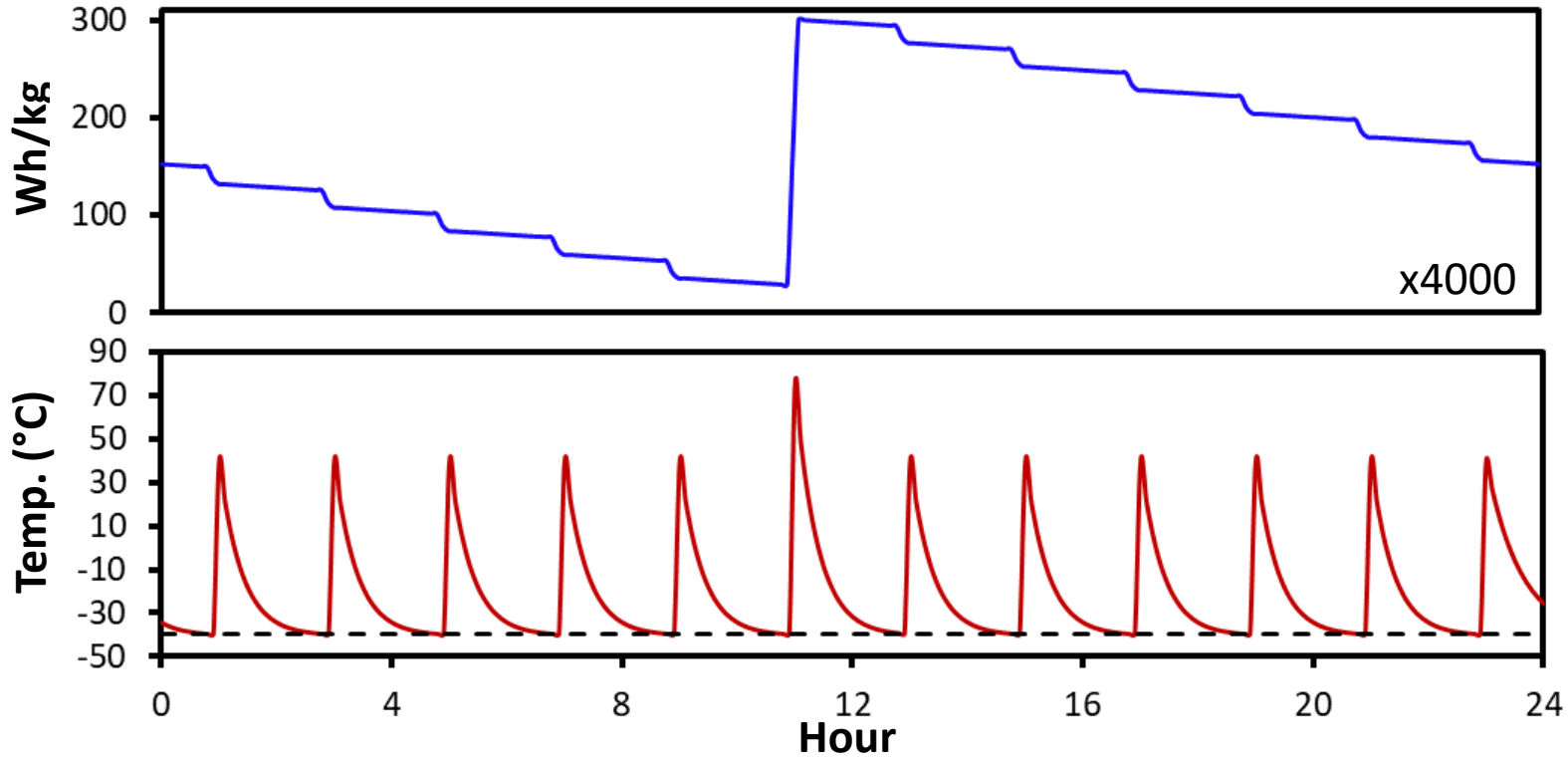
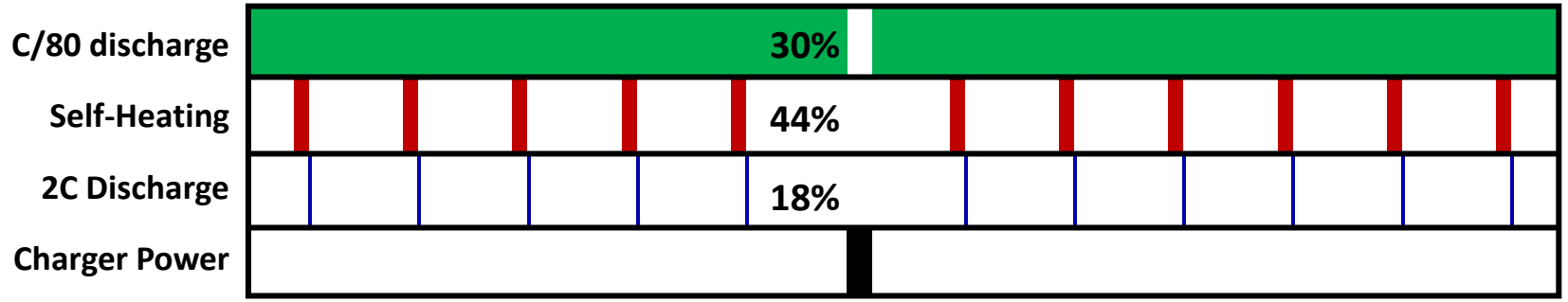


Simple Case Study





Conditions:

1. 300 Wh/kg Battery
2. Ambient -40°C
3. Constant C/80 discharge
4. 30 s 2C discharge every 2 hours
5. 3C charge every 24 hours

Unique Aspects:

1. Safety at high energy densities
2. High power at low temperature.
3. No added weight from external thermal management.
4. >10 years of continuous operation.
5. **Small-format compatible (i.e. <50 g, <50 cm^3)**

Summary

1. Self-heating battery architecture provides temperature independent power/charging speed.

2. Intentional EEI passivation leads to safer and longer lasting energy-dense batteries.

3. **Combining the two leads to batteries that require no external thermal management. Simplifying design, expanding the batteries operational space, and enabling effective thermal management strategies for small format batteries.**

Where do we go from here:

1. Increases in achievable energy-density will continue to reduce the impact of self-heating and increasing its relevance.
2. Development of high temperature electrolytes, separators, and cathode materials, or effective solid-state electrolytes will combine with self-heating to open the door to next generation space technologies.