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Advanced Battery Solutions

AN ULTRALIFE COMPANY

Oceans 21
Subsea Endurance:

Technical Review of Subsea Battery Power at Different Temperatures and Rates

Leon Adams
VP

Brett Levins
Sr. Design Lead, Lithium Ion

Service **Quality** **Reliability**

bsi. ISO 9001 Quality Management

Energy Densities
Subsea Battery Cell Technology

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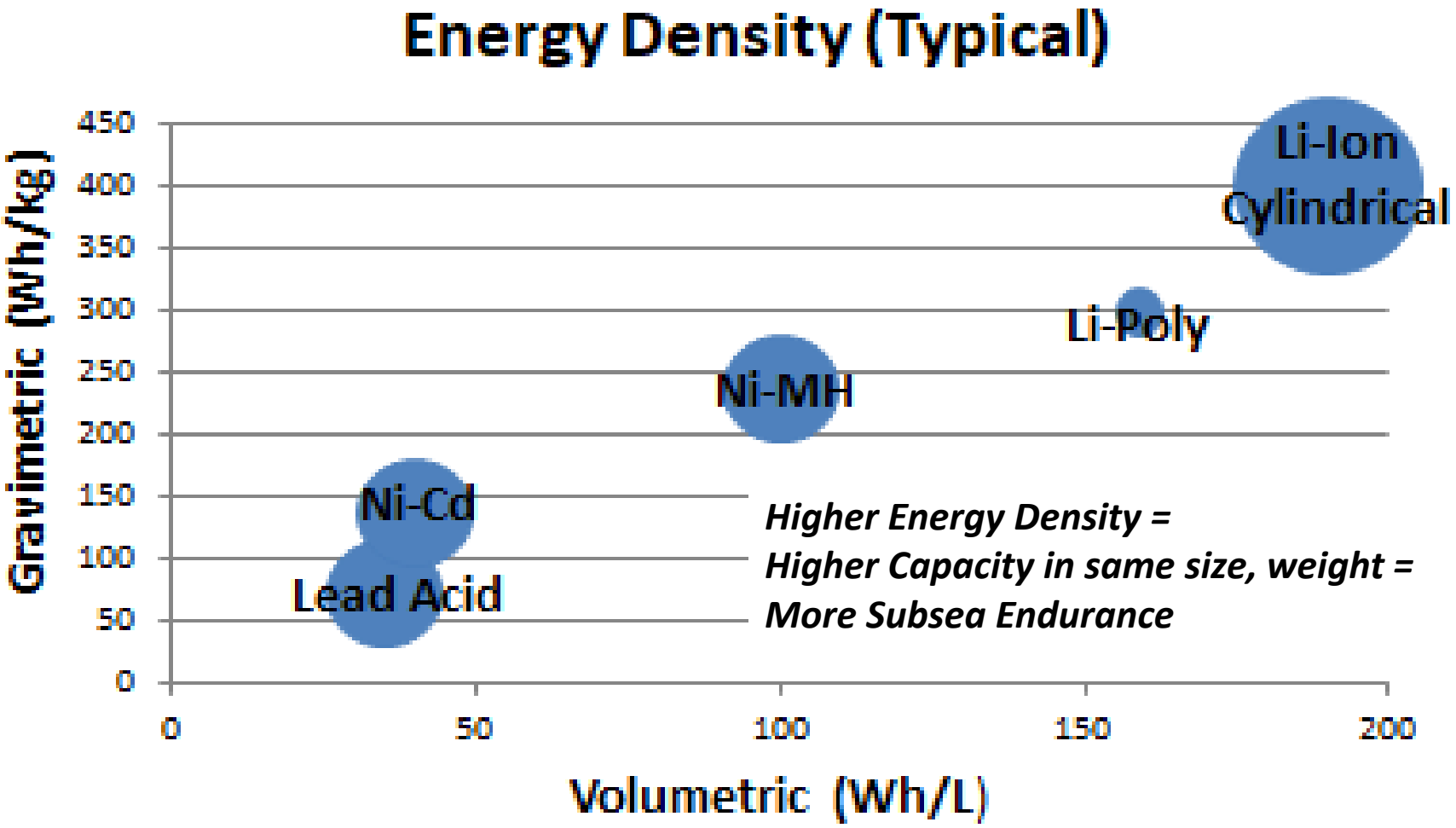

SeaSafe II and SeaSafe Direct Subsea Battery Modules – Internal View

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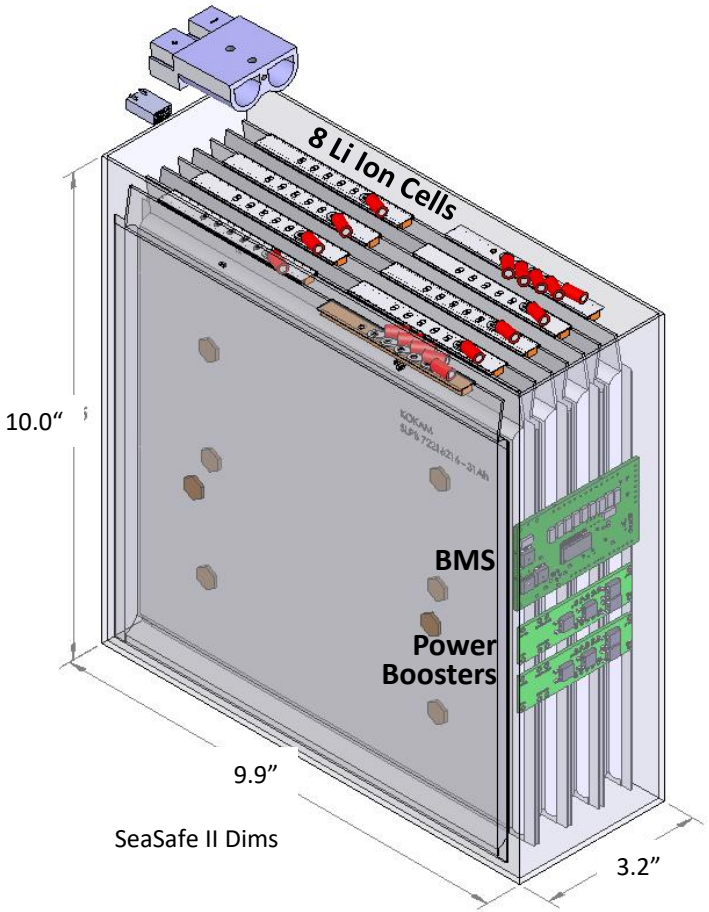
Used for these Discharge Tests



SeaSafe II Dims

Safety built into the electrical and physical construction of the module:

- **7 or 8 ea, 3.6v Lithium Ion 31 Ah Lithium Polymer Cells connected in series**
- **Safe, Autonomous Battery Management System (BMS)**
- **Power Booster Boards (Current paths)**
- **Potting Material: Thermally conductive, flame retardant, Shock & Vibration resistant polyurethane**
- **Polyurethane box**
- **Integrated Internal Safety Fuses as backup to BMS**

- **Connectors: SeaSafe II**
  - **DisCharge/Charge Connector: 2 pin Anderson SB50**
  - **Comm Connector: 8 pin Molex**
- **Connector: SeaSafe Direct**
  - **Discharge/Charge/Comm: IL10F type**

Battery Endurance Test Procedure

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- Charge battery module (normal charge)
  - 10A @ 25℃ to 90% SOC
    - 30V module 32.4V OCV
    - 24V module 28.3V OCV
- Discharge battery module
  - @specified temperature
  - @specified discharge rate (continuous)
  - Until 3V per cell cut-off voltage
    - 30V module 24V cut-off
    - 24V module 21V cut-off
- Log data
  - Voltages @ Temperature @ Discharge rate
  - Ah Capacities @ Temperatures @ Discharge rates

25°C Discharge

- Discharge Profiles @ Topside/Room Temperature: 25°C @Discharge Rate
  - SeaSafe II 30V 5A, 10A, 30A, 40A
  - SeaSafe Direct 30V 5A, 10A
  - SeaSafe II 24V 5A, 10A, 30A, 40A
  - SeaSafe Direct 24V 5A, 10A

Discharge Profile at Room Temperature
25°C (Capacity vs. Voltage) Plots
30V- SeaSafe II, SeaSafe Direct
24V- SeaSafe II, SeaSafe Direct

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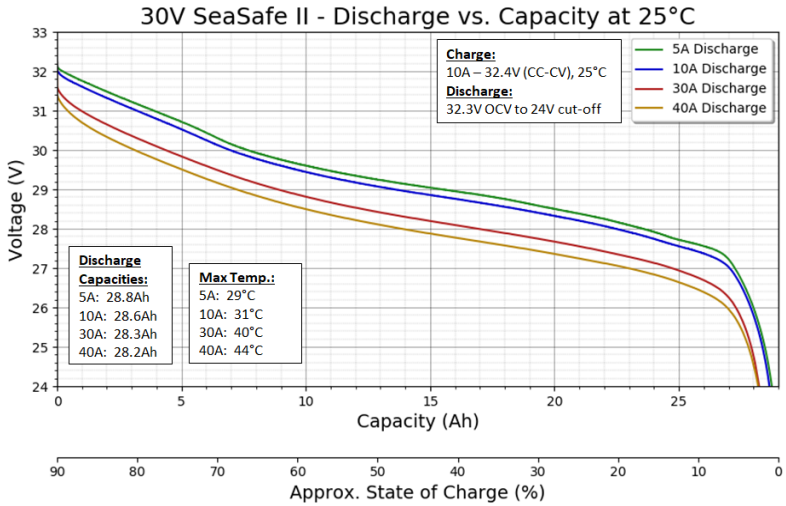
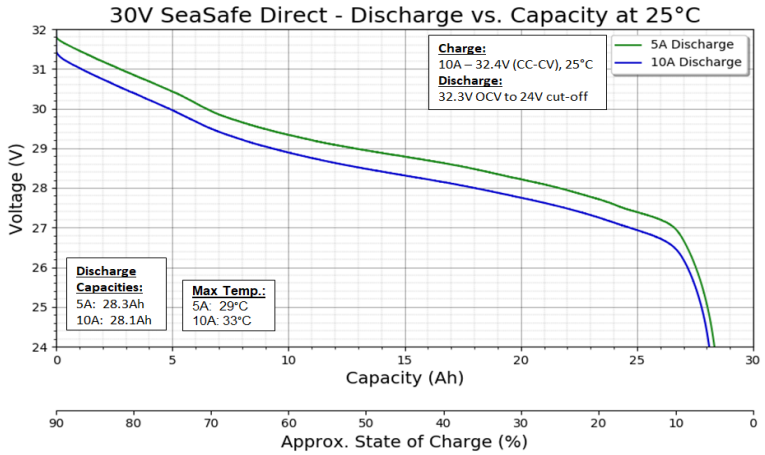
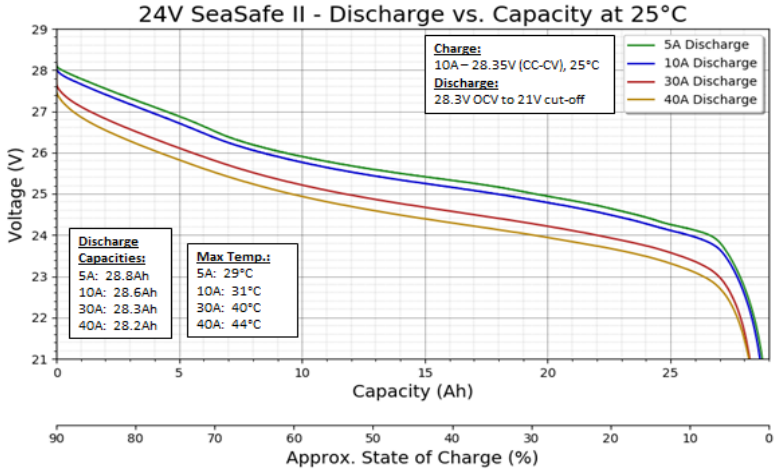
SeaSafe II **25°C** SeaSafe Direct

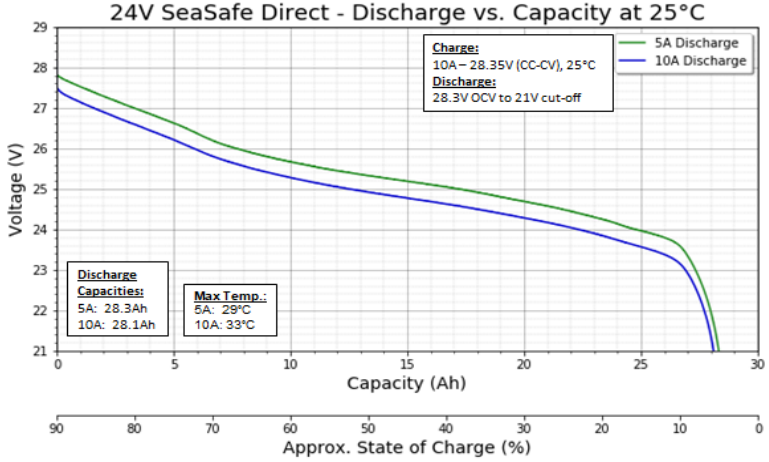
30V





24V





Observations at 25℃ Discharge

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- Higher Discharge rate = Lower Discharge Volts
  - Voltage Droop vs. 5A baseline (Continuous)
    - 10A ~ -0.2V Droop
    - 30A ~ -0.8V Droop
    - 40A ~ -1.1V Droop
- Discharge Capacities (Endurance) decline as discharge rate increases
    - 5A ~ 28.8 Ah / 28.3Ah
    - 10A ~ 28.6 Ah / 28.1 Ah
    - 30A ~ 28.3 Ah
    - 40A ~ 28.2 Ah
    - However, all rates EXCEED 28 Ah Nom Capacity rating

0°C Discharge

- Discharge Profiles @ Deep Subsea Temperature: 0°C @Discharge Rate
  - SeaSafe II 30V 5A, 10A, 30A, 40A
  - SeaSafe Direct 30V 5A, 10A
  - SeaSafe II 24V 5A, 10A, 30A, 40A
  - SeaSafe Direct 24V 5A, 10A

Discharge Profile at Room Temperature
0°C (Capacity vs. Voltage) Plots
30V SeaSafe II

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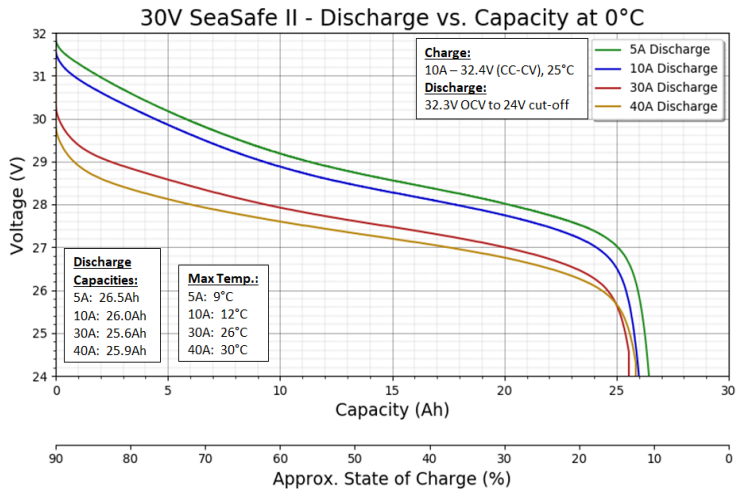
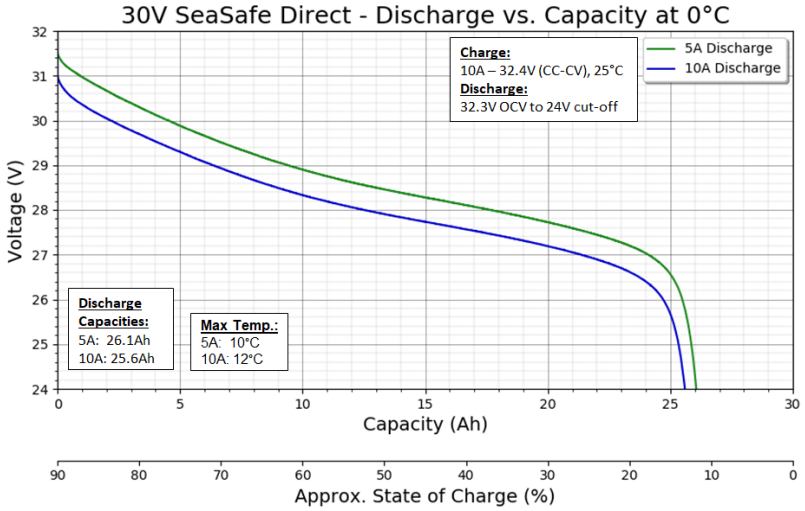
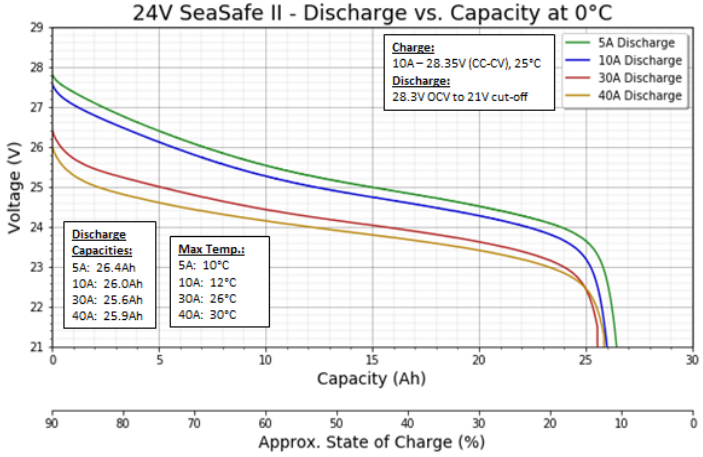
SeaSafe II **0°C** SeaSafe Direct

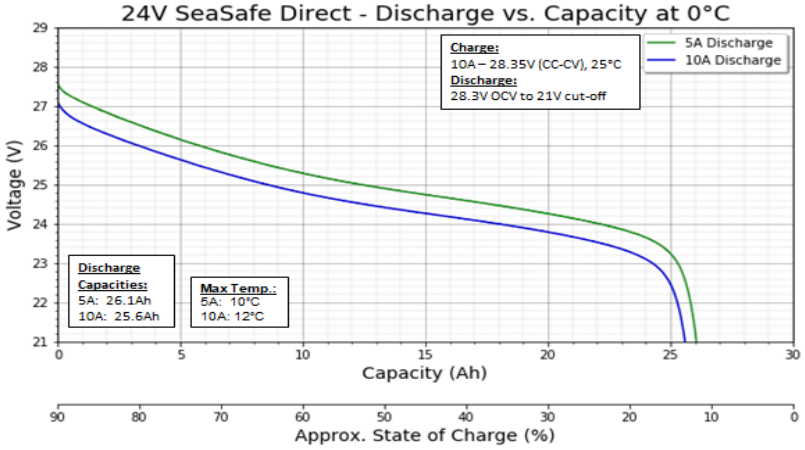
30V





24V





Observations at 0℃ Discharge

- Higher Discharge rate = Lower Discharge Volts
  - More Voltage Droop at 0℃ Discharge vs. 25℃
  - Higher Discharge rate = more significant 0℃ voltage droop
  - Voltage Droop vs. 5A baseline (Continuous)

	@ 25℃	@ 0℃	Delta @ 0℃
•	10A ~ -0.2V Droop	~ -0.3V Droop	~ -0.1V Droop
•	30A ~ -0.8V Droop	~ -1.0V Droop	~ -0.2V Droop
•	40A ~ -1.1V Droop	~ -1.4V Droop	~ -0.3V Droop

- Discharge Capacities (Endurance) decline more at 0℃ as discharge rate increases
  - 5A ~ 26.5 Ah / 26.1 Ah 10A ~ 26.5 Ah / 25.6 Ah
  - 30A ~ 25.6 Ah 40A ~ 25.9 Ah
  - However, all rates DO NOT MEET 28 Ah Nom Capacity rating

Capacity (Endurance) vs Temperature

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- Capacity vs. Temperature @Discharge Rate
  - SeaSafe II 30V 5A, 10A, 30A, 40A
  - SeaSafe Direct 30V 5A, 10A
  - SeaSafe II 24V 5A, 10A, 30A, 40A
  - SeaSafe Direct 24V 5A, 10A

Capacity vs. Temperature

30V- SeaSafe II, SeaSafe Direct

24V- SeaSafe II, SeaSafe Direct

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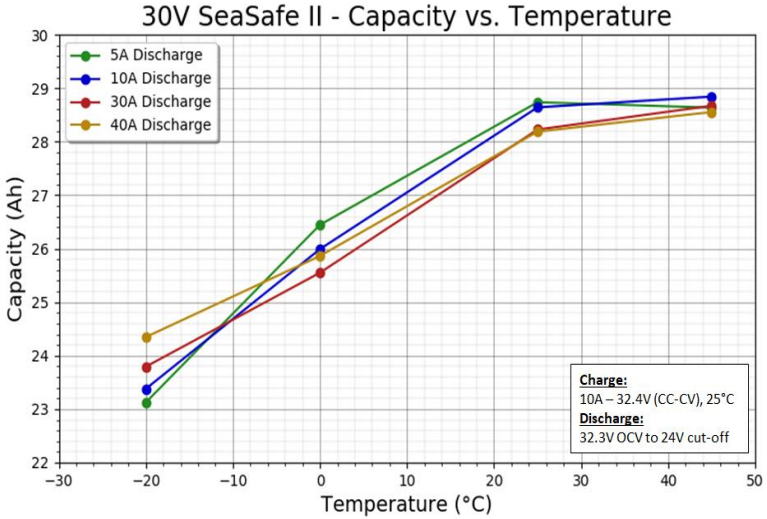
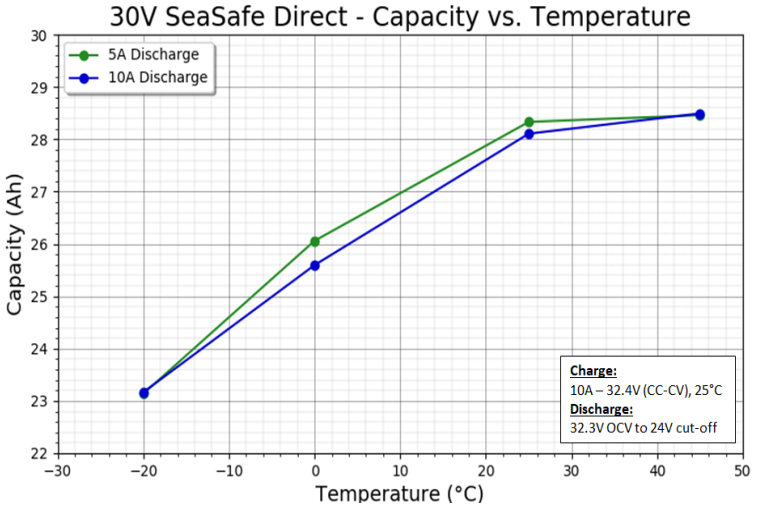
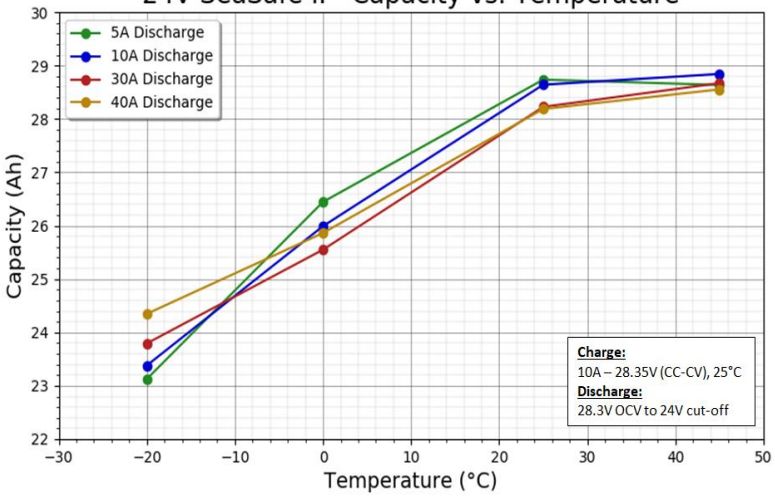
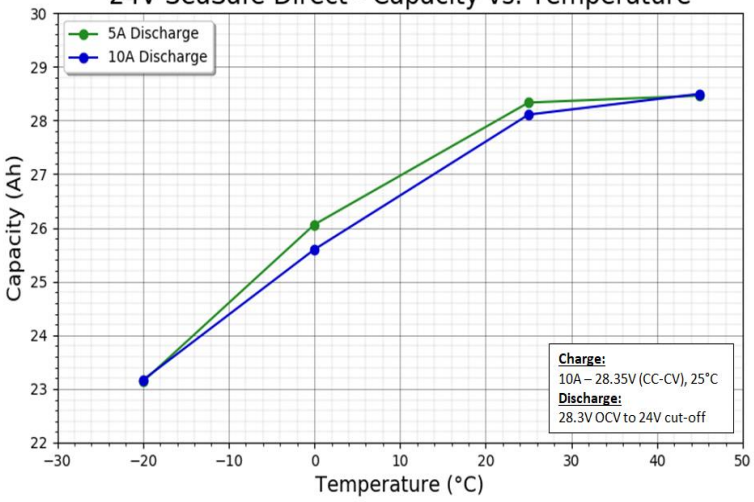
	SeaSafe II	SeaSafe Direct
30V		
24V		

Observations
Capacity (Endurance) vs. Temperature

- Capacity EXCEEDs nominal rating for all Ambient temperatures 25℃ or higher at all discharge rates
- Capacity at temperatures below ~ 15℃ do not meet rated Nom Capacity for any discharge rate
- Cold Temperatures cause significant degradation in Capacity at all discharge rates
  - Capacity decreases more as the ambient temperature decreases
  - Capacity loss @ temp vs baseline @ 25℃ ambient
    - @ 0℃ ~ - 9 to -10 % Capacity loss (discharge rate dependent)
    - @ -20℃ ~ -14 to -19 % Capacity loss (discharge rate dependent)

Endurance Technical Take-Aways
Subsea Batteries

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- Discharge rate effects battery capacity (endurance):
  - Higher discharge rates typically deliver relatively lower battery capacity.
  - Higher discharge rates typically cause voltage droop that may affect the application based on power delivered or minimum voltage requirements.
  - One should plan application use-case capacity to be delivered using Capacity at discharge test charts to interpolate expected value based on use-case discharge rates.
- Ambient operating temperature affects battery capacity (endurance):
  - Higher temperatures (25°C and above) deliver nominal or higher than rated capacity.
    - This is relevant to lab tests and topside tests.
  - Lower temperatures, especially “freezing” 0°C or lower temperatures, have the most negative impact on endurance by delivering lower than nominal rated capacity.
    - The lower the temperature, the lower the expected capacity expected to be delivered.
  - One should plan application use-case capacity to be delivered using Capacity at specific subsea temperature discharge test charts where that temperature will reflect likely worst case (coldest) subsea operating temperature.

Endurance Technical Take-Aways
Subsea Batteries

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- Despite discharge rate and cold temperature capacity degradation, Lithium Ion batteries, including Lithium Ion Polymer test data reviewed in this paper, are among the highest endurance subsea battery technologies available in production today.
- Be sure to adjust battery system voltage, peak current, power, and capacity plans for battery utilization and endurance based on discharge rate and ambient operating temperature based effects of the use-case application.
  - Plan for more batteries in series to maintain adequate application battery system voltage if necessary at high discharge rates and/or sub-freezing ambient operating temperatures.
  - Plan for more parallel battery strings to share the application power load to ensure sufficient application peak current is available if high peak or pulse currents are required without commensurate voltage droop to maintain sufficient battery system voltage.

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