Safe Subsea Lithium Ion Batteries
for Subsea ROVs

Leon Adams, David White
Southwest Electronic Energy Group

• Subsea Battery Requirements
• WHOI Nereid HT and Under Ice Light-Tethered ROV
  • Battery Requirements
  • Pressure Tolerant Subsea Battery Solution
    • Battery Module with BMS
    • Testing and Certifications
  • WHOI Nereid UI Application Example
• Work Class ROV Support Battery Scenarios
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# Subsea Battery Requirements

<table>
<thead>
<tr>
<th>App</th>
<th>Need</th>
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</thead>
</table>
| Deep-Sea Oil & Gas Work Over Controls, Chokes, MWCS | • Electronic control  
• Electrical drives  
• Primary and/or back-up  
• More precision, feedback  
• Long life sensors/monitors |
| MUVs (Manned Underwater Vehicles)         | • Safe operation  
• Deeper dives  
• Longer observation times  
• Lighter weight |
| ROVs (Remotely Operated Underwater Vehicles - Hybrid & Data-tethered) | • Electric powered motors, manipulators  
• High Voltage, High Power  
• Light weight, Pressure |
| AUVs (Autonomous Underwater Vehicles)     | • Longer survey runs  
• Deeper dives  
• Lighter weight |

Subsea needs batteries with:

• Safety first  
• More capacity  
• Higher Power  
• Smaller size  
• Less Weight  
• Longer life  
• High Reliability
Hybrid Tethering

New Insights

**Light-Fiber Tether**
Practically unlimited bandwidth with 20 km horizontal standoff.

**Free-Space Optical**
Through-water optical communications at ranges up to 100+ meters for complete freedom from a tether.

**Small Footprint Tether**
Light conventional tether (CTD wire) capable of trickle-charging with minimal on-board infrastructure.

Woods Hole Oceanographic Institution
Nereid HT

What

- Hybrid Light Work class ROV
- 3 modes of operation (tether)
- Re-Usable tether - .322 inch dia with lift-tether
- Immersive imaging
- Re-chargeable Lithium Ion
- Manipulation and Sampling (7 DOF master/slave)
- 2500 meters depth (extends to 5,000m)

When

- At Sea test March '14 (New Zealand)
  - Successful demo of ROV ops from non-DP platform with small winch
  - Uncovered issues with lifting tether requiring a revision, presently in work
  - Second trial awaiting approval and schedule
  - Commercial partnering/licensing with WHOI of interest?
WHOI Nereid Under Ice
Light-Tethered ROV : Innovation

Capability
- Manipulation
- Inspection
- Mapping/Survey

Horizontal Range from Launch Point
- 100 m
- 1 km
- 10 km
- 100 km

Conventional ROVs
- SIR*
- SCINI
- MSLED*
- Nereid UI
- Multi-Node AUV Systems*
- Autosub
- Gliders
**WHOI Nereid Under Ice**

**Light-Tethered ROV: Innovation**

**Conventional Arctic ROV**
- **ROV Footprint of Operations**
  - Small (~500 m)
  - Under Ship moving with ice
- **Power Source**
  - Tether Umbilical

**Light-Tethered Arctic ROV**
- **ROV Footprint of Operations**
  - Large (~20,000 m)
  - 40X Range
  - Decoupled from Ship moving with ice
- **Power Source**
  - Onboard SWE SeaSafe Batteries

**Challenge:**
- Present vehicles ROVs are constrained by their tethers during ice-bound operations
  - Tethers vulnerable to ice damage
  - Vehicle systems not resistant to tether connection damage or loss (e.g., no “come home” function)
  - Surface ships cannot hold position thus limiting ability to work predictably in specific seabed locations with vehicles
  - Through-ice deployment concepts immature

**Solution:**
- Recent advances in ROV tethering technologies now enable real-time control over extended distances thus freeing the vehicle from restrictions imposed by surface ice cover
- **Steel Armored Cable**
- **Depressor/Garage**
- Light Fiber-Optic Tether
- **Nereid UI Footprint of Operations**: Large (~20 km) and Decoupled From Ship
WHOI Nereid Under Ice Light Tethered ROV

WHOI Battery Requirement

• Safe, Reliable Operation
• 2000 m depth
• ~ 88 volts
• <= 40 Amps Continuous
• 100 recharge cycles
• -20°C to +50°C temperature range
• > 15 kWh in 36” x 24” x 12”
• 12 hours recharge time
• Protection and balancing internal
• Diagnostic information logged externally

SWE SeaSafe Li Ion Delivers

• BMS for Safety, Reliability
• <= 6000 m depth
• 29V X 3S = 87V nom, 96Vmax
• 40 Amps Continuous
• 1000+ recharge cycles
• -40°C to +85°C discharge temperature range
• 22 kWh in <= 36” x 24” x 12”
• 3S x 9P @ 90% SOC
• < 12 hours recharge time
• SWE BMS: Internal protection and balancing
• SWE BMS: RS485 Modbus access to battery status on demand, log external
Battery Capacity = \textit{Watt Hours} or \textit{Amp Hours} @ Voltage

- **High**
  - Volts
  - Watts
  - Current

- **Low**
  - Volts
  - Watts
  - Current

- **Nereid UI**
  - ~ 88 Volts, < 40 Amps
  - ~ 15 kWh
### Pressure Tolerant Lithium Ion Polymer Ideal for Subsea (vs Lead Acid)

#### 4X More Energy Density

<table>
<thead>
<tr>
<th></th>
<th>SLA</th>
<th>Li Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>¼</td>
<td>¼</td>
</tr>
<tr>
<td>Size</td>
<td>¼</td>
<td></td>
</tr>
<tr>
<td>Wh/kg</td>
<td>~ 40</td>
<td>~ 180</td>
</tr>
<tr>
<td>Wh/L</td>
<td>~ 70</td>
<td>~ 300</td>
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</table>

#### 6X Superior Low Temp Operation

1.5X x 4X = 6X @ 0 C

#### 8X Longer Cycle Life

<table>
<thead>
<tr>
<th></th>
<th>SLA</th>
<th>Li Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycles</td>
<td>~ 600</td>
<td>~ 4800</td>
</tr>
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</table>

#### Breakthrough Safety/Intelligence

<table>
<thead>
<tr>
<th></th>
<th>SLA</th>
<th>SWE BMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outgas During Charge</td>
<td>Yes</td>
<td>✓ No</td>
</tr>
<tr>
<td>Smart/Auto Battery Management</td>
<td>No</td>
<td>✓ Yes</td>
</tr>
<tr>
<td>Health/Status Reporting</td>
<td>No</td>
<td>✓ Yes</td>
</tr>
<tr>
<td>Durability</td>
<td>No</td>
<td>✓ Yes</td>
</tr>
</tbody>
</table>

Source: Dow-Kelco (Lithium Polymer Cells) PowerSpin (SLA/AGM)
**Easy to Integrate Smart LiIon Battery Modules**

**SMART MODULE SPECS**

<table>
<thead>
<tr>
<th></th>
<th>29V</th>
<th>24V</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cells in series</strong></td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td><strong>Dimensions (in)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>9.4</td>
<td>9.4</td>
</tr>
<tr>
<td>W</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>L</td>
<td>9.3</td>
<td>9.3</td>
</tr>
<tr>
<td><strong>Weight (lbs)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Module (air)</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Total Module (sea)</td>
<td>9.7</td>
<td>9.7</td>
</tr>
<tr>
<td><strong>Voltage (V)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>min</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>nom</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>max</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td><strong>Current (A)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Dschg (continuous)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Max Dschg (30s pulse)</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Max Dschg (1s pulse)</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td><strong>Power (W)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dschg (nom)</td>
<td>1160</td>
<td>1015</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ah</td>
<td>28</td>
<td>28</td>
</tr>
</tbody>
</table>
• 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
• Potting Material: Thermally conductive, flame retardant, Shock & Vibration resistant polyurethane
• Fiberglass box
• Integrated Internal Safety Fuses as backup to BMS

Charge/Discharge Connector: 2 pin Anderson SB50
Comm Connector: 8 pin Molex
Modular, Distributed BMS Suite of SAFETY and Reliability Features

SWE distributed Battery Management System (BMS) builds advanced SAFETY and reliability features into each autonomous smart module battery

1. Safety features configurable to your mission/application
   • Over and under voltage detection/prevention
   • Excessive charge & discharge detection/prevention
   • Charge temperature protection
   • Discharge temperature protection
   • Short circuit detection and prevention
   • High current pulse discharge allowance yet short circuit cut-off

2. Autonomous control of charge level within each battery module

3. Three types of balancing (including module inter-cell and inter-module)

4. Thermal control of all cells and safety shut-off

5. Redundant short circuit fuse protection

6. Load voltage, rate of current, and remaining battery capacity gauging

7. Patented Algorithm to assess State of Health and preventative maintenance
SeaSafe Observer

Battery State of Health & State of Charge Status

- Read Post Mission or Run Time
  - RS485 Modbus
- Easy to use PC Graphical User Interface
  - Or command driven comm
- For Information only.
  - Not needed for battery operation.
Extensive SeaSafe Testing

• Exhaustive functional testing over 6+ years
• External direct shorts tests: module automatically shuts off safely for currents in excess of 90 amps
• 10+ separate pressure tests over years of testing.
  – Shown: SeaSafe 316 stainless steel case with four SeaSafe battery modules and one PII being lowered into the 30 inch hyperbaric chamber at the Southwest Research Institute
  – 18 complete pressure cycles up to 10,000 psi and back down on a module while performing live charge and discharge cycles
    • 10,000 psi provides for 6000+ meter sea depth
• Design of Subsea Equipment standard compliant (ISO 13628-6:2006) to Battery relevant tests (shock & vibration)
• ISO9001-2008 Quality Compliant Manufacturing
SeaSafe UN DOT Certification

International Shipping Safety Certified - UN Manual of Test and Criteria Section 38.3

RESULT SUMMARY: The tested samples met the test requirements. See below breakout for tests performed.

<table>
<thead>
<tr>
<th>Specification Section</th>
<th>Test Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Altitude Simulation</td>
<td>Conforms</td>
</tr>
<tr>
<td>T2</td>
<td>Thermal Test</td>
<td>Conforms</td>
</tr>
<tr>
<td>T3</td>
<td>Vibration</td>
<td>Conforms</td>
</tr>
<tr>
<td>T4</td>
<td>Shock</td>
<td>Conforms</td>
</tr>
<tr>
<td>T5</td>
<td>External Short Circuit</td>
<td>Conforms</td>
</tr>
<tr>
<td>T7</td>
<td>Overcharge</td>
<td>Conforms</td>
</tr>
</tbody>
</table>
Lithium Ion Subsea Battery Deployed in WHOI Hybrid ROVs

- Pressure Tolerant, Autonomous Smart Module Batteries w/RS-485 Modbus Com Port
- Std 29V Module w/8 Series, 31Ah Li-Polymer Cells
- Best Practice Battery Management System Built-in

29.6 V Smart Battery Module Internal View

X 3 in Series = 89 V
X 2 in Parallel = 56 Ah
Total = ~ 5 KWh

WHOI Pressure Equalizing Battery Case

Per Battery Case with room for more
SeaSafe Batteries in Nereid-UI

Battery System

Completed modules #1, #2 installed in nUI.
- 10 kW max power with 3 modules
- Design tested to 6000 m
- Monitoring/interface s/w completed
- 18 kWhr total capacity (3 modules)
SeaSafe Batteries in Nereid-UI

<table>
<thead>
<tr>
<th>Flotation:</th>
<th>Doppler Velocity Logs Two TRDI 300 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic Telemetry:</td>
<td>WHOI CMT 2500 meter</td>
</tr>
<tr>
<td>Thrusters:</td>
<td>WHOI design</td>
</tr>
<tr>
<td></td>
<td>1200 Watts x 8</td>
</tr>
</tbody>
</table>

**Battery module (1/3):**
- SWE modules in WHOI enclosure

**Vehicle Frame:**
- Welded Aluminum

**nUI**
- 1800 kg
- 1.8 m x 1.8 m x 3 m

**Science Sensing:**
- Kongsberg PTZ with DSPL aux. DSPL lighting
- Sonars: Blueview, Reson
- Chemical sensing suite notional
Dive Statistics

- Four to six dives anticipated
- Attempted five, four resulted in successful separation
- Dives nui003, nui004
  - science-focused
  - ~4 km under-ice
Work Class ROV Support Battery Scenario

Electric Motor for Hydraulic Pump

- High Power Surge
  - \(>> 100,000\) Watts
- Short Duration: Minutes
- \(600++\) Volts DC Voltage
- Inverted to A/C?
- \(200++\) Amps DC Current
### Work Class ROV Support Battery Scenario

**Watts**
- **High**
- **Low**

**Volts**
- **Short**
- **Long**

**Amps**
- **Short**
- **Long**

**Power**
- **Time**
- **Hours**

**Sensors, Monitors, Meters, etc.**
- **Very Low Power**
- **Very Long Duration: Months+**
- **24 Volts DC Voltage**
- **< 0.1 Amps DC Current**

**Time**
- **Watts**
- **Volts**
- **Amps**
Thanks!

Acknowledgements

- Woods Hole Oceanographic Institution
  - Andrew D. Bowen  abowen@whoi.edu
  - Daniel Gomez-Ibanez  dgi@whoi.edu

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- 20+ years- Ruggedized Lithium battery experience
- 15+ years - Lithium Ion battery experience
  - 10+ patents - Li Ion Battery Management
- 300+ customers: Most top Oil & Gas Service, Drilling, and Production Companies
- 55,000 sq ft - Battery systems R&D and ISO 9001/2008 certified manufacturing in Houston