

# Safe Subsea Lithium Ion Batteries for Oil & Gas Subsea and ROVs

## DNVGL Offshore Power Workshop

Leon Adams

Southwest Electronic Energy Group

- **Oil and Gas Subsea Battery Requirements**
- **Li Ion Modular Subsea Ready Battery Solutions**
  - **Battery Module with BMS, Case, PII, Observer**
  - **COTS Battery Configuration Scenarios**
  - **Testing and Certifications**
- **ROV Application Example**

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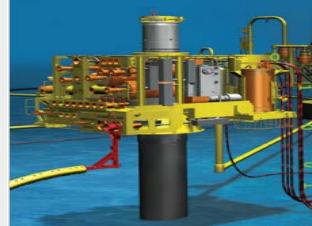
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# Pressure Tolerant Li Ion Superior for Subsea Batteries

## App

## Need

**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**
- **Smaller size**
- **Less Weight**
- **Longer life**

# Oil and Gas Subsea Completions and Work-over Control Systems

## BATTERY REQUIREMENTS

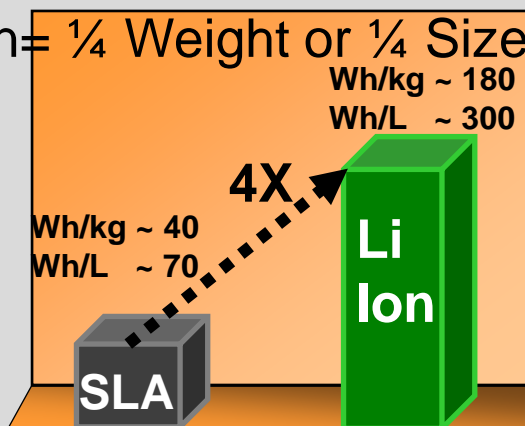
- ✓ **Safe, Reliable Operation**
- ✓ **Pressure tolerant to 3000 m sea depth**
- ✓ **Voltage range From 24 Volts to 360+ Volts, 600V**
- ✓ **High Current (power)...200 Amp, 600Amp**
- ✓ **100+ recharge cycles (1000s)**
- ✓ **Discharge Temperature: -20°C to +50°C**
- ✓ **Charge Temperature: 0°C to 45°C**
- ✓ **Subsea chargeable**
- ✓ **Protection and balancing internal**
- ✓ **Diagnostic information logged externally**
- ✓ **Battery Status software with GUI preferred**
- ✓ **International Shipping Safety certified  
(UN DOT 49CFR 173.185)**
- ✓ **Design of Subsea Equipment standard compliant  
(ISO 13628-6:2006)**
- ✓ **High Quality Manufactured (ISO9001-2008)**
- ✓ **Rugged Case such as 316 Stainless Steel**



# Pressure Tolerant Lithium Ion Polymer Ideal for Subsea (vs SLA)

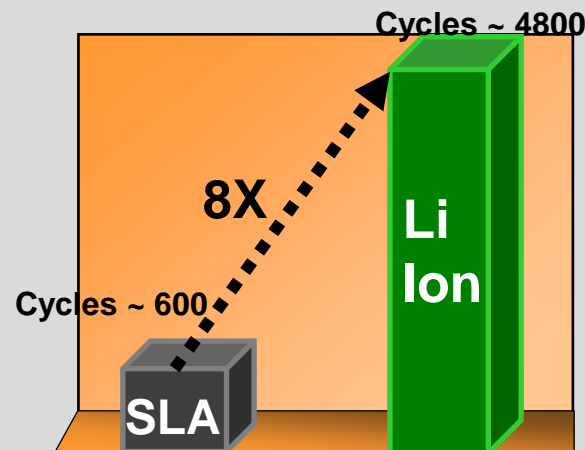
## 4X More Energy Density

Lilon = 1/4 Weight or 1/4 Size SLA

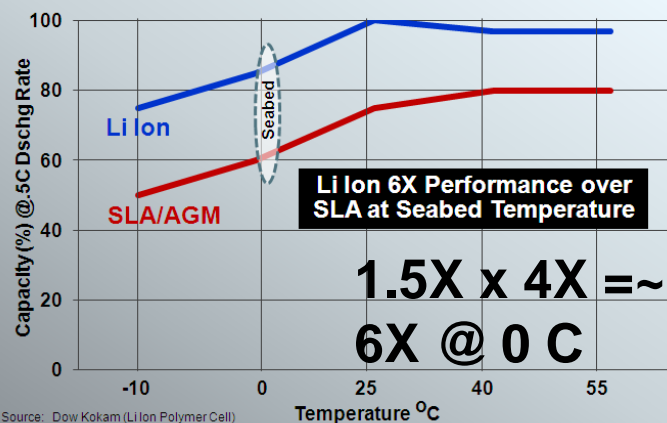


## SWE Li ION

## 8X Longer Cycle Life



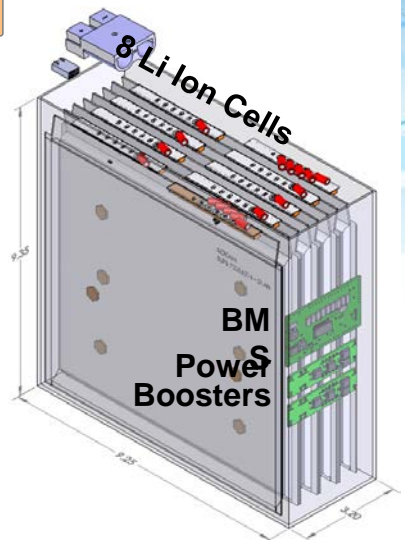
## 6X Superior Low Temp Operation



## Breakthrough Safety/Intelligence

	SLA	SWE BMS
Outgas During Charge	Yes	✓ No
Smart/Auto Battery Management	No	✓ Yes
Health/Status Reporting	No	✓ Yes
Durability	No	✓ Yes



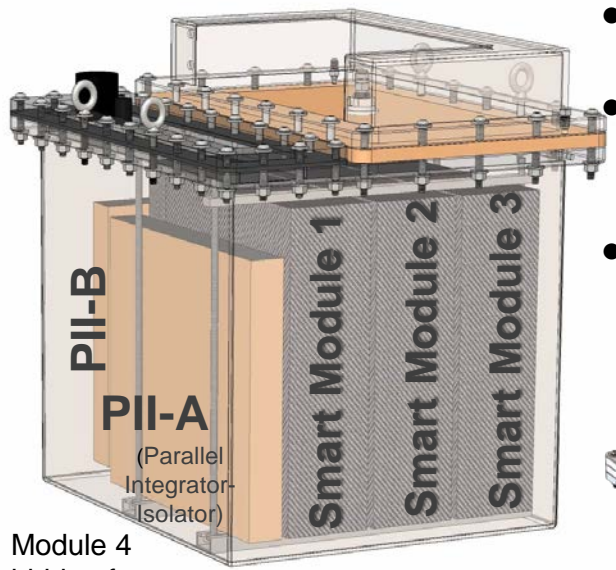


29V Smart Module  
Internal View



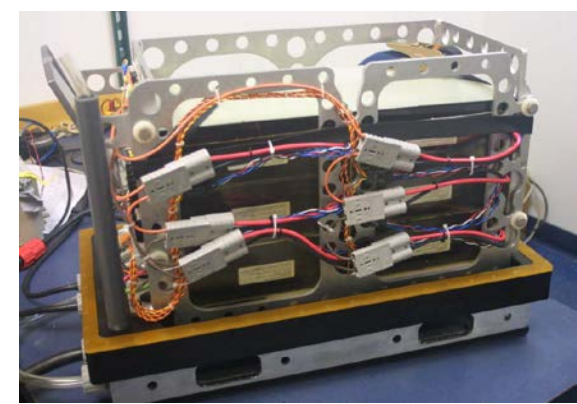
## Lithium Ion Subsea Solution

- Pressure Tolerant Autonomous Smart Module Building Block w/RS-485 Modbus Com Port.
- Std 29V Module w/8 Series, 31Ah Li-Polymer Cells.
- Smart Module w/All Best Practice BMS Functions.
- 4-Module Pressure Tolerant 316 Stainless Steel Battery System Building Block is Standard.
- Custom Battery Systems for WOCS, AUVs, ROVs



Module 4  
hidden from  
view

SeaSafe 4-Module System  
Internal View



# Easy to Integrate Smart Lilon Battery Modules

## SMART MODULE SPECS

Pressure Tolerant  
6000 Meters Depth



Smart Module

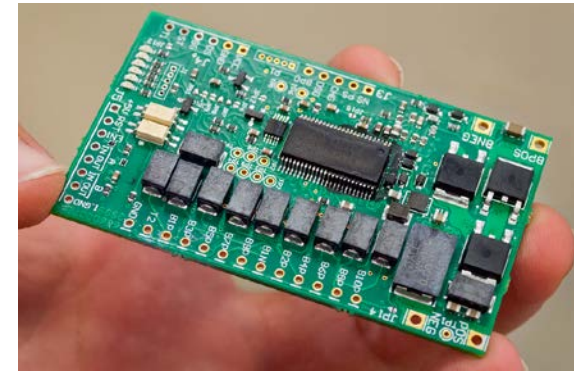
		Smart Modules	
		29V	24V
Cells in series		8	7
Dimensions (in)	H	9.4	9.4
	W	3.2	3.2
	L	9.3	9.3
Weight (lbs)	Total Module (air)	20.0	20.0
	Total Module (sea)	9.7	9.7
Voltage (V)	min	24	21
	nom	29	25
	max	32	28
Current (A)	Max Dschg (continuous)	40	40
	Max Dschg (30s pulse)	75	75
	Max Dschg (1s pulse)	90	90
Power (W)	Dschg (nom)	1160	1015
Capacity	Ah	28	28

# 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. Patented algorithms to detect internal cell shorts

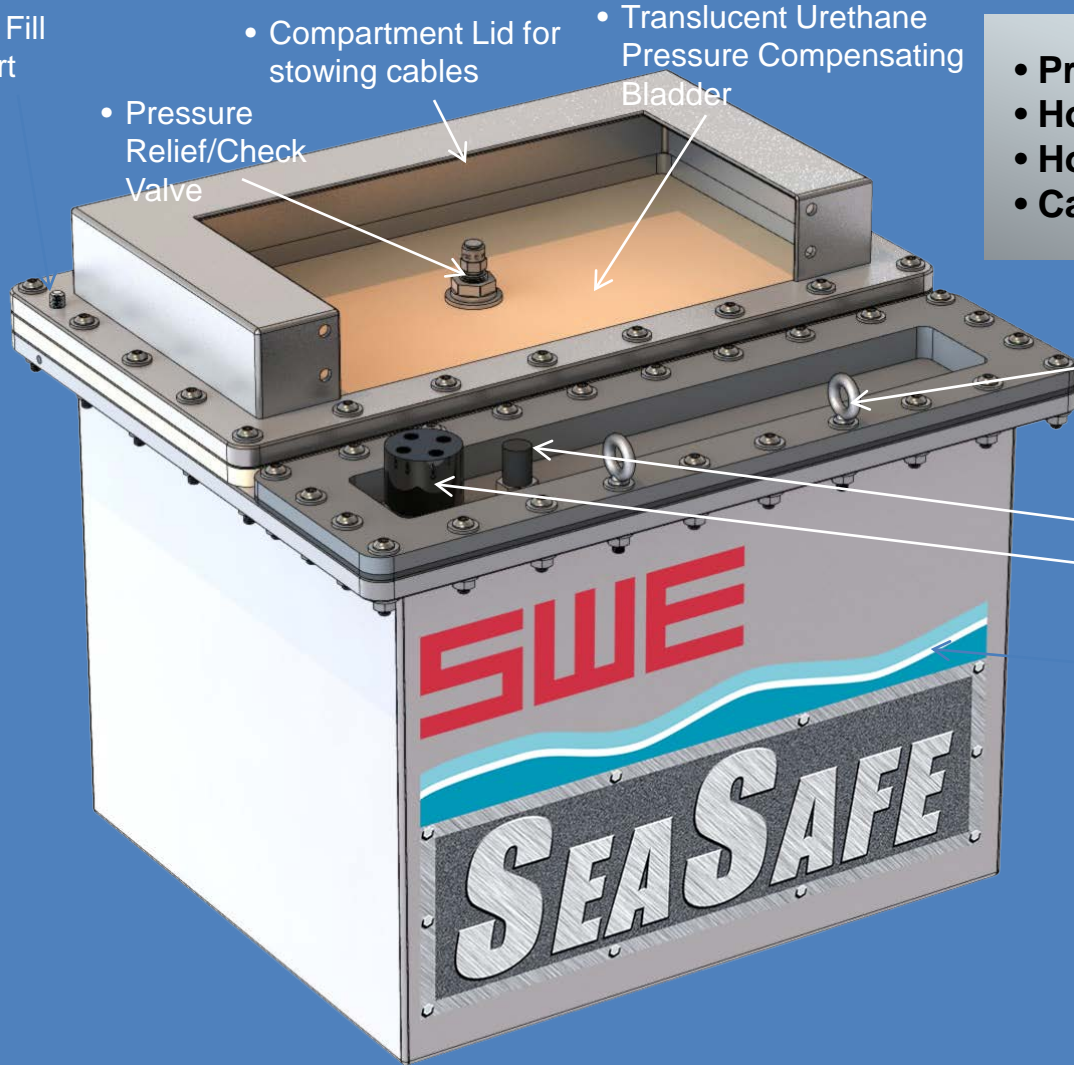
7. Method to prevent formation of metal dendrites at the separator





# Sub-Sea Ready Pressure Equalizing Battery Case

## PRESSURE EQUALIZED CASE



- Pressure validated to 6000m sea depth
- Holds four 29v or 24v Smart Modules
- Holds 1 or 2 PIs and Wiring Harness
- Cases are stackable

- Eyebolts for handles or lockdown
- Configurable Connector Plate (Seacon Wet-Con – Standard)
  - Communications
  - Charge/Discharge
- 316 stainless steel body filled with pressure compensating oil

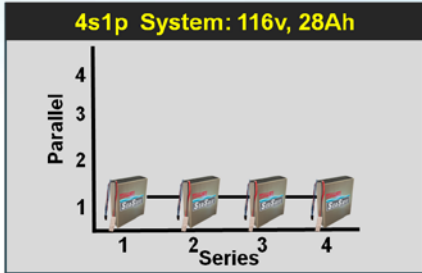
**Weight in Air (Water)**

- Case Only: 70lbs
- 4 Module System: 206lbs (105)

**Dimensions**  
H=14.8", W=15.6", L=17.8"

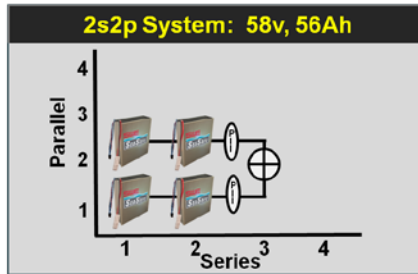
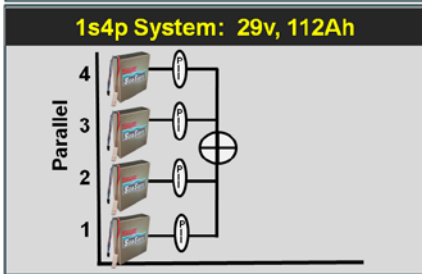
# Scalable Battery System Modular Configuration

## V, Ah Module Increments: Module or Case



### Module Increments Battery System

- Voltage: Modules connected in series for V increments
- Ah Capacity: Modules connected in parallel for A, Ah increments

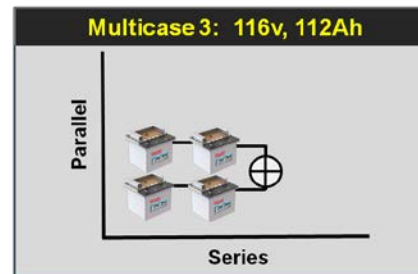
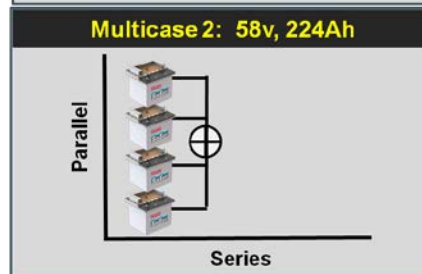


### COTS-CTO FLEXIBILITY

#### Case Increments Battery System

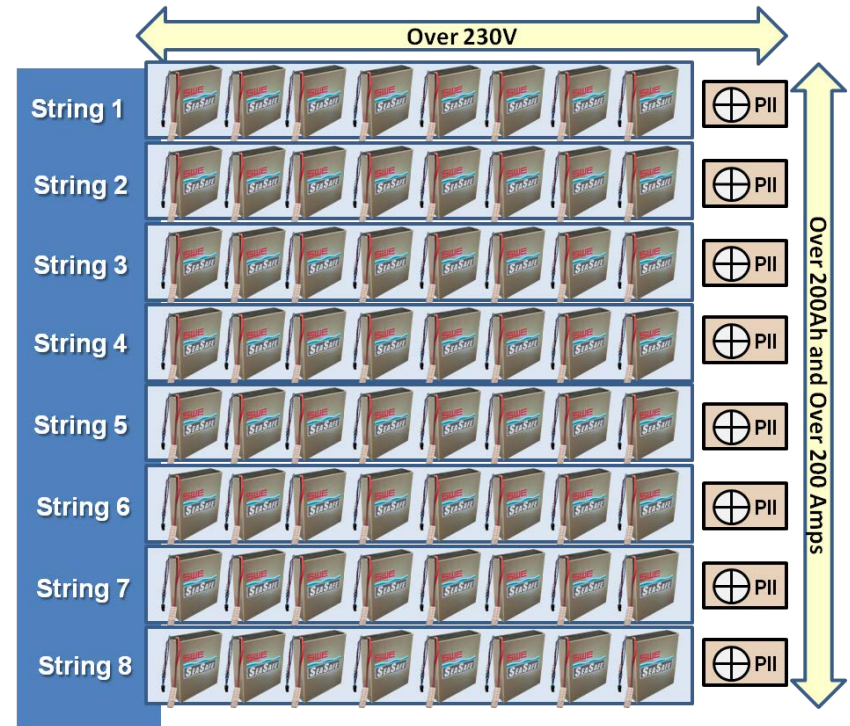
- Voltage: Modules connected in series for V increments
- Ah Capacity: Modules connected in parallel for A, Ah increments

Examples shown: Case has four 29v Modules in a 2s2p configuration



# 8s8p Battery System

## 8 parallel strings of 8 Smart Modules in series



# SeaSafe Observer

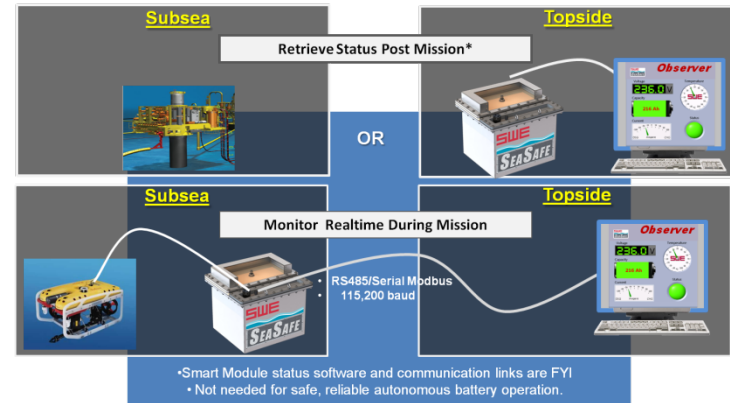
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Advanced Battery Solutions

## 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.



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**SEA SAFE OBSERVER** **MODULE ID: 10** **Current Time:** 9/17/2013 8:40:48 AM **Last Updated:** 9/17/2013 8:40:48 AM **Module Info**

Messages

8S1P 10

Module S/N: W25629-48-0002

Store Data Dump/5 seconds

Go to BATTERY SYSTEM OBSERVER

File path

**Module Dashboard**

VOLTMETER 30.5 V

CURRENT 0 Amps

TEMP 20 C

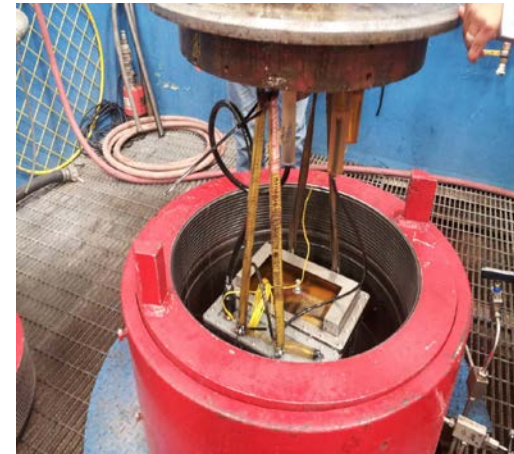
STATUS

REMAINING CAPACITY 69% 21.9 Ah



# Extensive SeaSafe Testing and Certification

- Exhaustive functional testing over years
- External direct shorts tests: module automatically shuts off safely for currents in excess of 90 amps
- 8 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





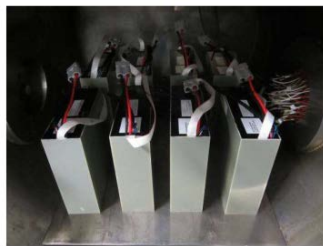
# Extensive SeaSafe Testing and Certification

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

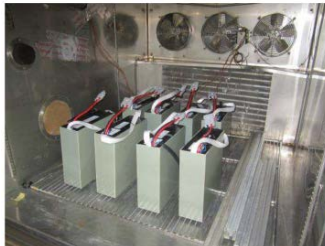
**RESULT SUMMARY:** The tested samples met the test requirements. See below breakout for tests performed.

Specification Section	Test Description	Results
T1	Altitude Simulation	Conforms
T2	Thermal Test	Conforms
T3	Vibration	Conforms
T4	Shock	Conforms
T5	External Short Circuit	Conforms
T7	Overcharge	Conforms

T1 – Altitude Simulation Test



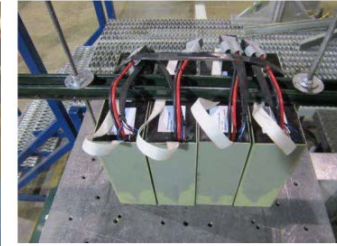
T2 – Thermal Test



T3 – Vibration Test



T4 – Shock Test



T5 – External Short Circuit



T7 – Overcharge



**Intertek**

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Suite 100  
Plymouth Twp, MI 48170  
Telephone: 734-462-2000  
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**TEST VERIFICATION OF CONFORMITY**

**TEST METHOD:** UN38.3 Manual of Tests and Criteria "Recommendations on the Transport of Dangerous Goods," section 38.3  
"Lithium Batteries"  
Document number: 8780-AC-1011 (Rev. E, Amend 1)  
Revision #: 2, Safety, Amendment 1  
Effective Date: April 2012

**SAMPLE DESCRIPTION:** Eight (8) 801PC91918AH Battery Packs  
Battery Packs – 10 Cycles

**MANUFACTURER:** Southwest Electronic Energy Corp.

**SPECIFICATION SECTIONS T1 through T6 and T7:**  
Eight (8) 801PC91918AH Battery Packs, sample numbers:  
Battery Packs – 10 Cycles

- SN 1
- SN 2
- SN 3
- SN 4
- SN 5
- SN 6
- SN 7
- SN 8

**Condition of Test Sample:** Production

**DATE RECEIVED:** 12/10/2012  
**DATES TESTED:** 12/14/2012 through 02/12/2013

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

Specification Section	Test Description	Results
T1	Altitude Simulation	Conforms
T2	Thermal Test	Conforms
T3	Vibration	Conforms
T4	Shock	Conforms
T5	External Short Circuit	Conforms
T7	Overcharge	Conforms

February 12, 2013  
Report No.: 102891242DE1-001

Nick Diamond  
Engineering Supervisor

Michael Wells  
Department Manager

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T1

T2

T5

T3

T4

T7



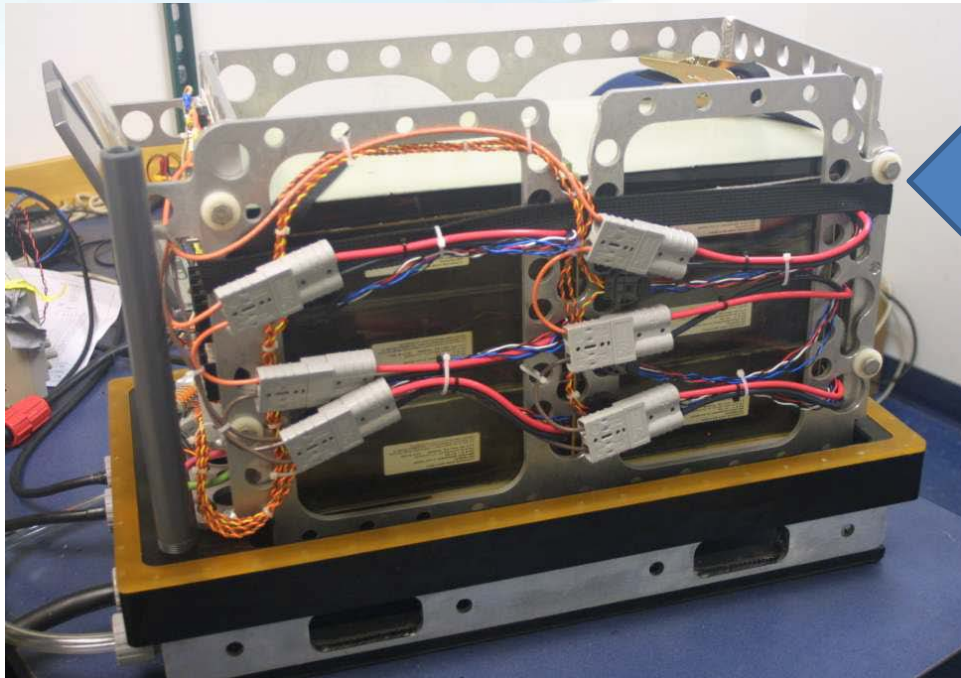
# New WHOI ROV Designed for High Definition 3D Cinematography

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*Advanced Battery Solutions*

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**6 SeaSafe Smart Battery Modules**

**... into a 3 Series  
x 2 Parallel  
configuration In a  
WHOI designed  
Pressure  
Equalization  
Case...**



**...into a WHOI  
ROV Mission.**

**Powered by SWE SeaSafe Smart Battery Modules**





# SeaSafe Subsea Applications

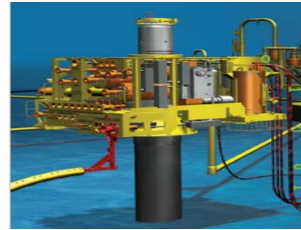
## COTS Modularity Flexibility or Custom



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Advanced Battery Solutions

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**Deep-Sea Oil & Gas  
Work Over Controls,  
Chokes, MWCS**



### Battery Case/System



Or Custom

or Customer Designed



### Battery Modules



Or Custom

**ROVs**

(Remotely Operated Underwater  
Vehicles - Hybrid & Untethered)



Or Custom

**MUVs**

(Manned Underwater  
Vehicles)



Customer Designed



Or Custom

**AUVs**

(Autonomous  
Underwater Vehicles)



Customer Designed



Or Custom



The logo for Southwest Electronic Energy Group (SWE) features the letters 'SWE' in a bold, red, sans-serif font. The background of the slide includes abstract blue and white wavy lines at the top and a solid red circle on the right side.

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*Advanced Battery Solutions*

# Backup





## Who is SWE?

# Advanced Battery Solutions Industrial, O&G



SWE named in top 100 of emerging technology companies by *Marine Technology Reporter*



### ABOUT SWE

- Since 1964 - Quality supplier to Oil and Gas
- 20 years - Ruggedized Lithium battery experience
- 13 years - Lithium Ion experience
- 10 patents - Li Ion Battery Management System
- Over 55,000 sq ft - Battery systems R&D and ISO 9001/2008 certified manufacturing
- 300+ customers including many top Oil & Gas Service, Drilling, and Production Companies
- Focus on Service, Quality, and Reliability



SWE Corporate Headquarters  
Houston, Texas

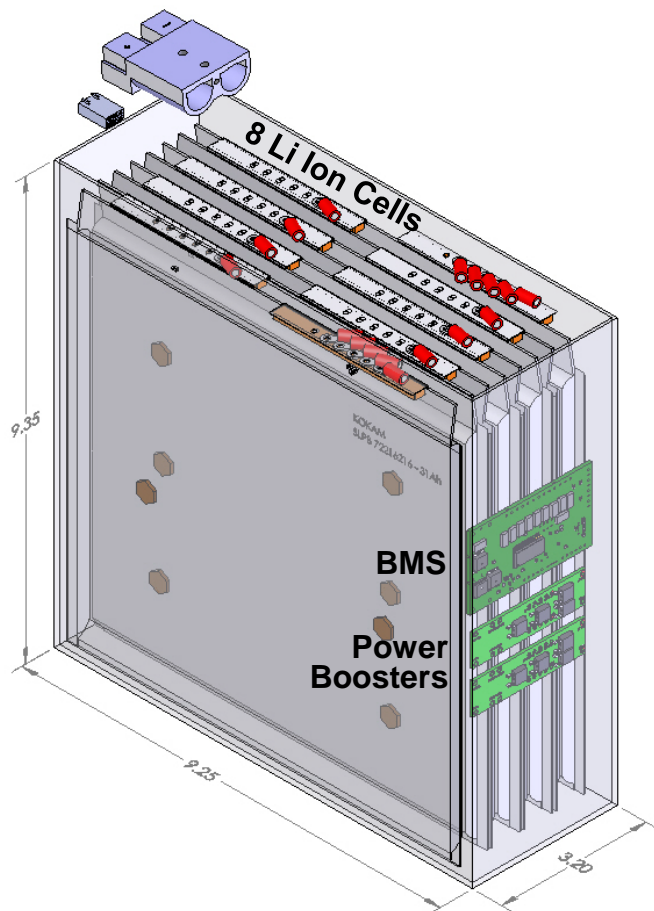
# Smart Battery Module BOM - Internal

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## SMART MODULE TECHNICAL DETAILS

### 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
- Potting Material: Thermally conductive, flame retardant, Shock & Vibration resistant polyurethane
- Fiberglass box
- Integrated Internal Safety Fuses as backup to BMS



29V Smart Module Internal View

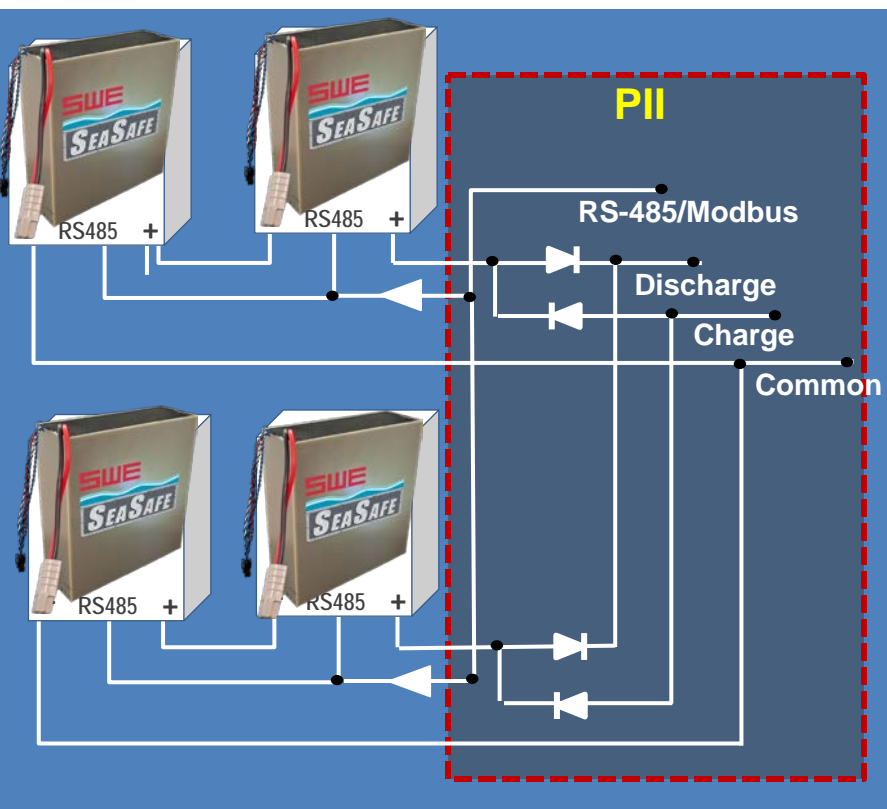


- Charge/Discharge Connector: 2 pin Anderson SB50
- Comm Connector: 8 pin Molex

# PIIs for Safer, Reliable Parallel Configuration

## SMART MODULE TECHNICAL DETAILS

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## Parallel Integrator Isolator (PII)

- **Ideal diode ORing circuit:**
- **Parallel connects Battery module strings into System**
- **Integrates** string outputs: single discharge bus
  - Increased capacity and max current
- **Isolates** string inputs: Isolated charge busses
  - Battery safety, reliability, and faster charge time
- Provides one RS485 load per string (HV PII only)
- Pressure tolerant; fits in SeaSafe Case with Modules
- High Voltage (Up to 460 V) or low Voltage (36 V)
- One PII for each string or Case connected in parallel.

# Backup- UN DOT 38.3 Tests

**Table 3. UN transportation tests**

UN 38.3.4.1	Test T.1 – Altitude Simulation		Cells and batteries stored at a pressure of 11.6 kPa or less for at least six hours at ambient temperature
UN 38.3.4.2	Test T.2 – Thermal Cycling		Rapid thermal cycling between high- (75°C / 167°F) and low- (-40°C / -40°F) storage temperatures
UN 38.3.4.3	Test T.3 – Vibration		Vibration exposure: sinusoidal waveform with a logarithmic sweep from 7 Hz (1 g peak acceleration) to 200 Hz ( 8 g peak acceleration) and back to 7 Hz; 12 cycles, 3 perpendicular mounting positions
UN 38.3.4.4	Test T.4 – Shock		Shock exposure: half-sine shock, 150 g peak acceleration, 6 msec pulse duration, three shocks in positive and negative directions for each of three perpendicular mounting positions (total of 18 shocks)
UN 38.3.4.5	Test T.5 – External Short Circuit		Short circuit of less than 0.1 ohm at 55°C (131°F), 1 hour duration
UN 38.3.4.6	Test T.6 – Impact	N/A	15.8 mm diameter bar placed across cell center, and a 9.1 kg mass is dropped onto the bar from 61 cm height
UN 38.3.4.7	Test T.7 – Overcharge		Over current (2X manufacturer's recommended maximum) and over voltage (for 18 V packs or less, charge to the lesser of 22 V or 2X recommended charge voltage. For > 18 V packs, charge to 1.2X recommended charge voltage) charge (applied to battery packs only)
UN 38.3.4.8	Test T.8 – Forced Discharge	N/A	Over-discharge cells a single time



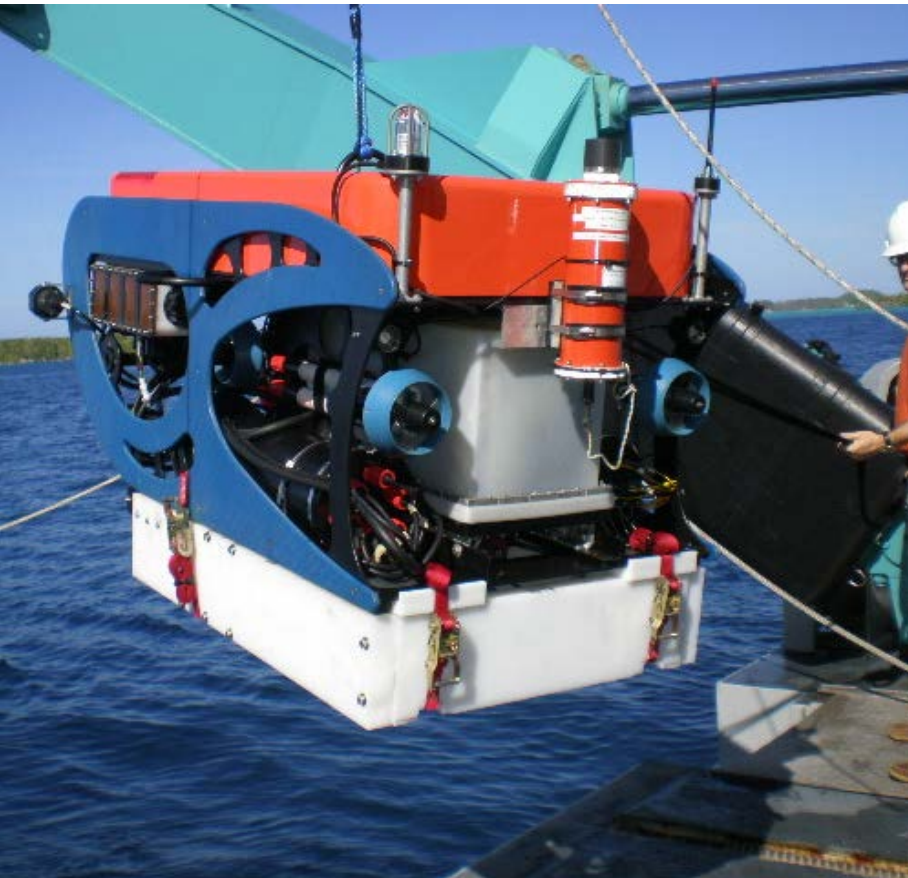
## WHOI Battery Requirement

- Safe, Reliable Operation
- 2000 m depth
- 88 volts ..... (3 series)
- 100 recharge cycles
- -20 to +50C temperature range
- > 15 kWh in 36 x 24 x 12" ....  
3S x 9P
- 12 hours recharge time
- Protection and balancing internal
- Diagnostic information logged externally

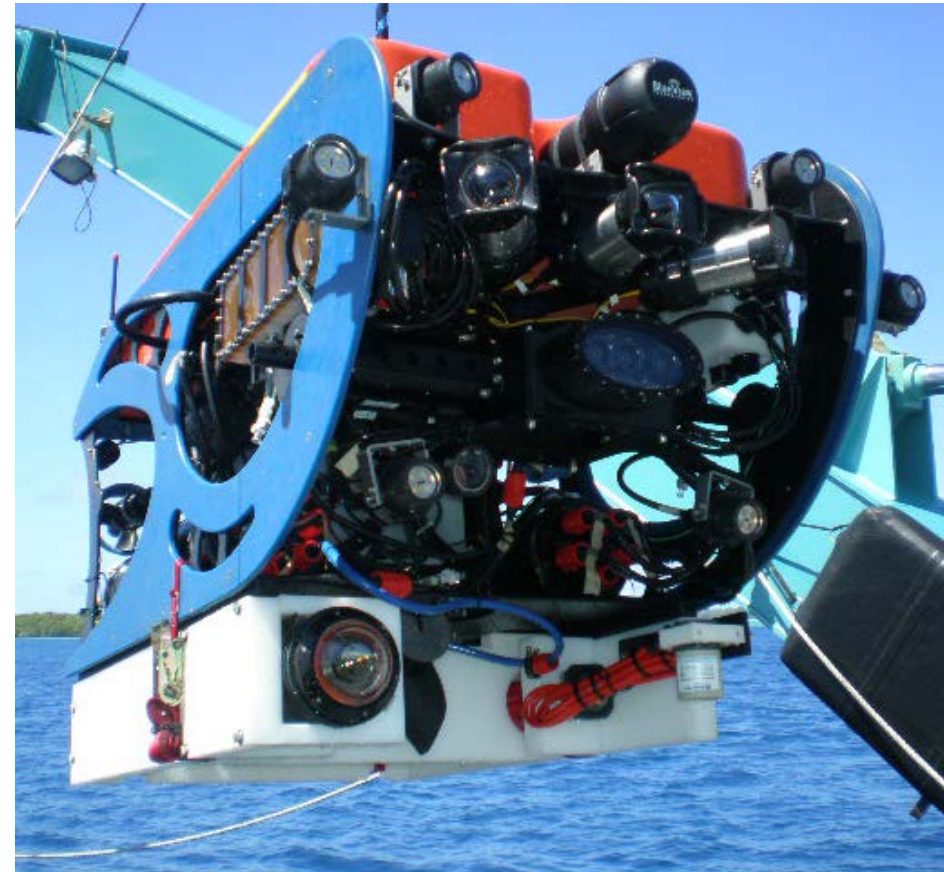
## SWE SeaSafe Li Ion Delivers

- BMS for Safety, Reliability
- $\leq 6000$  m depth
- 29V X 3S = 87V nom<sub>96Vmax</sub>
- 1000+ recharge cycles
- -40 to + 85C discharge temperature range
- > 22 kWh in  $\leq 36$  x 24 x 12"  
....3S x 9P @ 90% SOC
- < 12 hours recharge
- SWE BMS: Internal protection and balancing
- SWE BMS: Modbus access to battery status on demand, log external

# SeaSafe Battery System in WHOI 3D HD Video ROV



Rear of 3D Video ROV Shows Battery System in White Box at Center.



Front (Business End) of 3D Video ROV Shows Camera Lens and Light Sources. Battery Provides Local Power.

# Subsea-Ready Battery Solutions

SeaSafe Smart Battery Modules



SeaSafe Pressure Equalizing Battery Case



Parallel Integrator Isolator



SeaSafe Observer Software



Service, Quality, Reliability



## SUMMARY

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- ✓ Safe, Reliable
- ✓ Autonomous

- ✓ 4X More Energy
- ✓ 8X Longer Cycle Life

- ✓ Configure-to-Order (V, Ah)

- ✓ Sea Depth Tolerant-6000m

- ✓ Certified

# Thank You!

• Leon Adams [ladams@swe.com](mailto:ladams@swe.com)

\* David White [Dwhite@swe.com](mailto:Dwhite@swe.com)

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[seasafe@swe.com](mailto:seasafe@swe.com)





# Beyond SeaSafe: Need Even Higher Power for High Voltage, High Power Motors?

- Need More Voltage ?
  - Battery systems to 600 Volts
- Need Higher Current ?
  - Battery systems to 600 Amps
- Need Higher Power ?
  - Battery systems to 100s of KiloWatts

***Let us Engineer a Custom  
Advanced Battery Solution  
to meet your needs!***

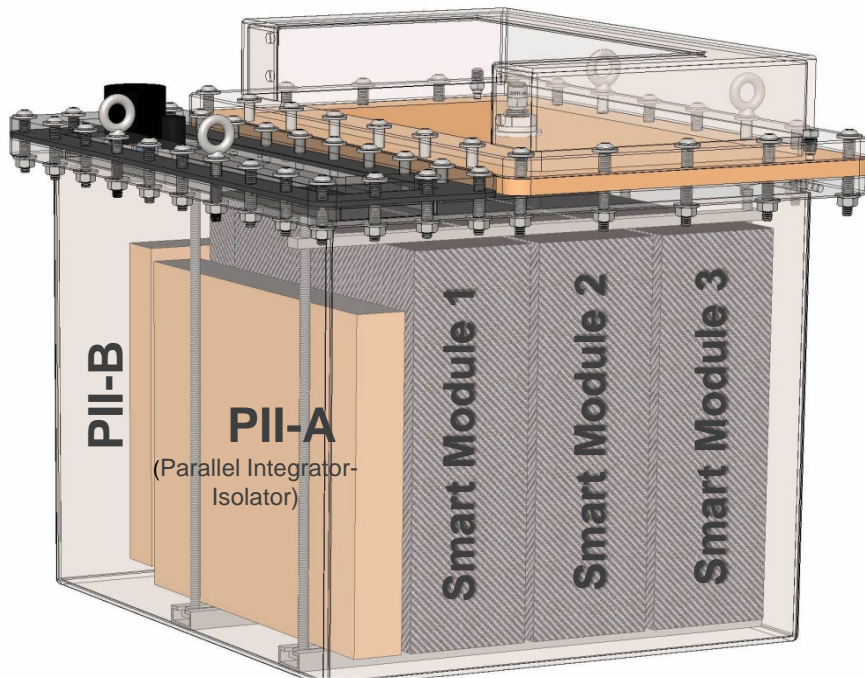


# Sub-Sea Ready Pressure Equalizing Battery Case

## SEASAFE CASE

24

### Case Internal Layout



- 1,2,3 or 4 Modules
- PIIs (Parallel Integrator-Isolator)
  - For multiple string battery system configurations. (such as 2s2p)
  - Ensures reliable discharge and faster charge
- System filled with mineral oil
- Not shown:
  - Blanking Modules if system not fully populated (maintains pressure equalization characteristics).
  - Inter-module harness

Module 4 hidden from view

# Extensive SeaSafe Testing and Certification

- **Design of Subsea Equipment standard (ISO 13628-6:2006) relevant to Batteries**
  - Testing per ISO 13628-6 2006
    - Shock per section 11.2.5.2.1 method Q2. Sinusoidal
    - Vibration per section 11.2.5.2.2 method Q2. Random

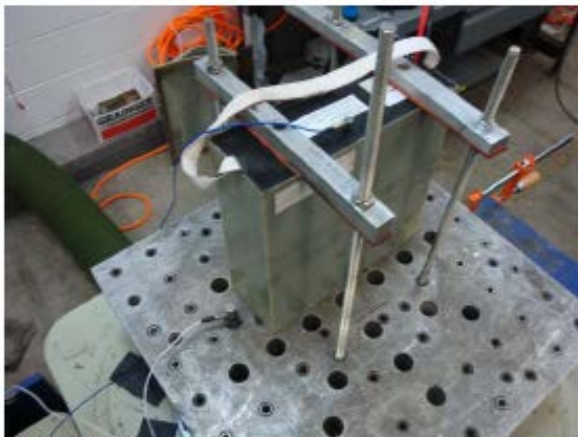


Figure 1: Vertical setup.

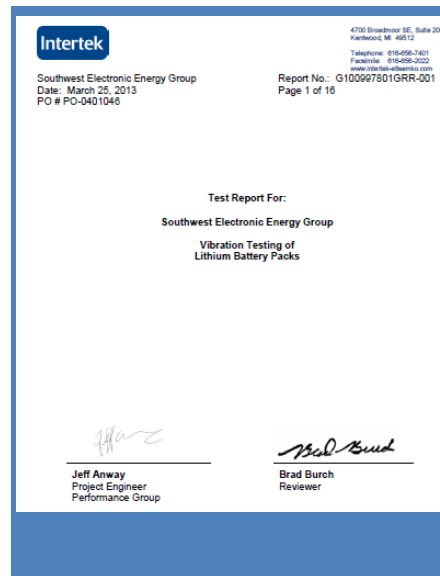


Figure 14: Longitudinal setup.