

# **Safe, Configurable, Pressure Tolerant Subsea Lithium Ion Battery System for Oil & Gas Deep Water Fields and ROVs**

## **Underwater Intervention 2014**

**Leon Adams and David White**

**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
- Deep Sea Application Example
- Summary and Beyond SeaSafe

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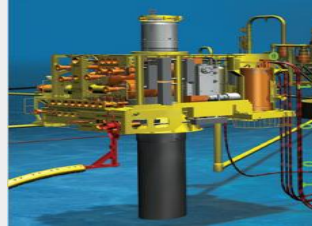
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# Pressure Tolerant Li Ion Superior for Subsea Batteries

## 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

**Li Ion  
vs Sealed Lead Acid**

- **4X more capacity**
- **8X longer cycle life**
- **6X more usable capacity @ 0°C**

# 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**
- ✓ **High Current (power)**
- ✓ **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**



✓ **Meets  
Requirements**

## 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

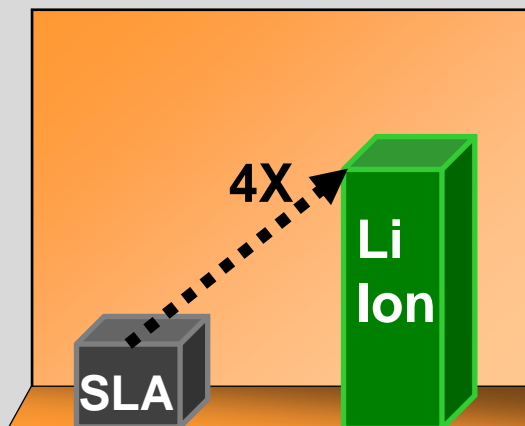
- BMS for Safety, Reliability
- $\leq 6000$  m depth
- 29V X 3S = 87V nom<sup>96V<sub>max</sub></sup>
- 1000+ recharge cycles
- -40 to + 85C discharge temperature range
- > 22 kWh in  $\leq 36$  x 24 x 12" ....  
3S x 9P @ 90% SOC
- < 12 hours recharge
- SWE BMS: Internal protection and balancing
- SWE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

# SeaSafe Lithium Ion Ideal for Subsea vs SLA

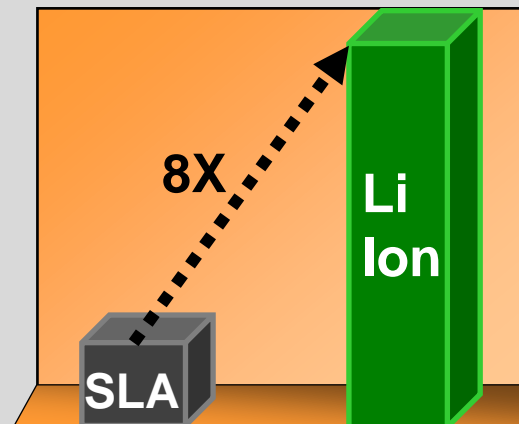
## SWE Li ION

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### More Energy Density



### Longer Cycle Life



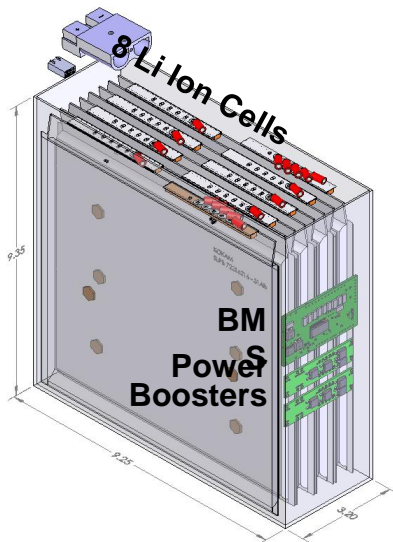
### Superior Low Temp Operation



### 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

5



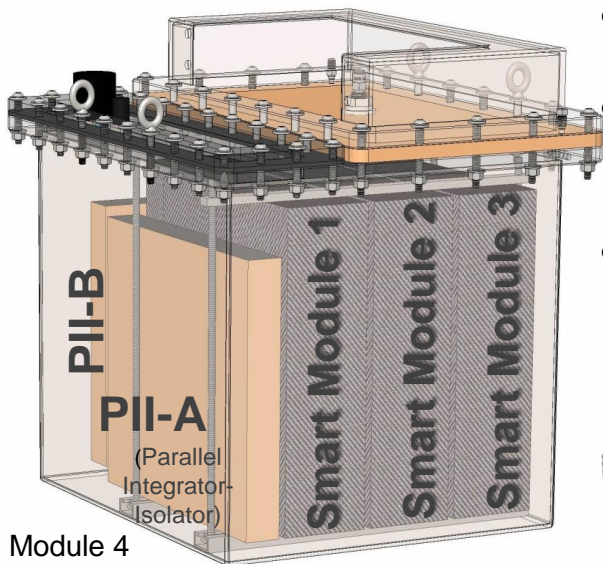
29V Smart Module  
Internal View



## About SWE SeaSafe

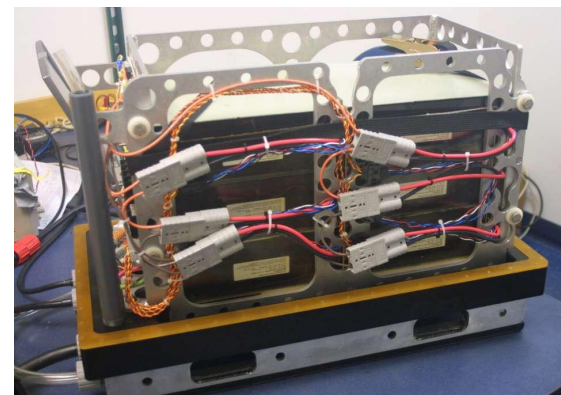
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- Pressure Tolerant Autonomous Smart Module Building Block w/RS-485 Modbus Com Port.
- Std 29V Module w/8 Series, 31Ah Li-Polymer Cells.
- Smart Module w/All Best Practice BMS Functions.
- 4-Module Pressure Tolerant 316 Stainless Steel Battery System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



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

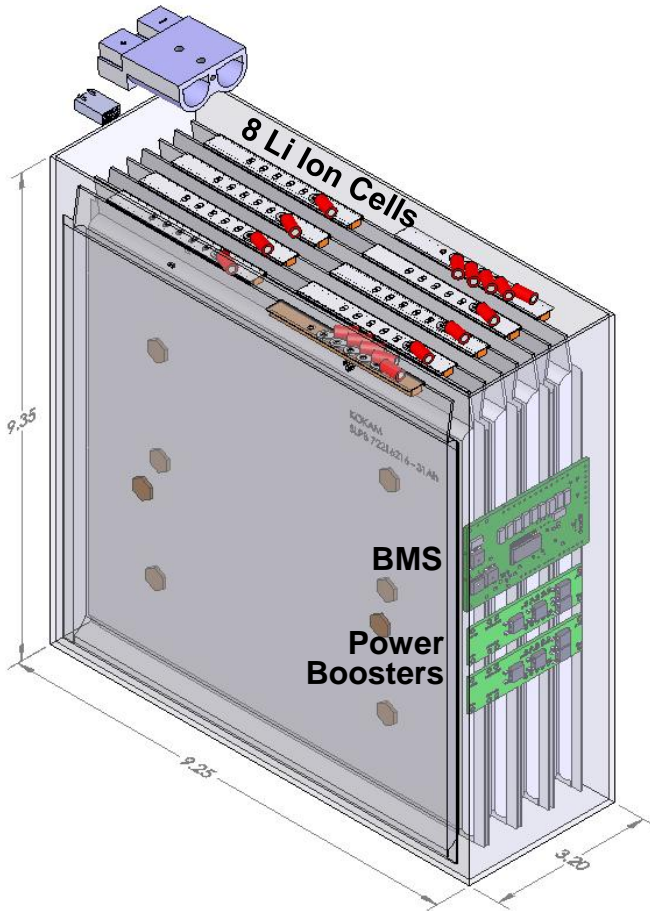


# Smart Battery Module BOM - Internal

## 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



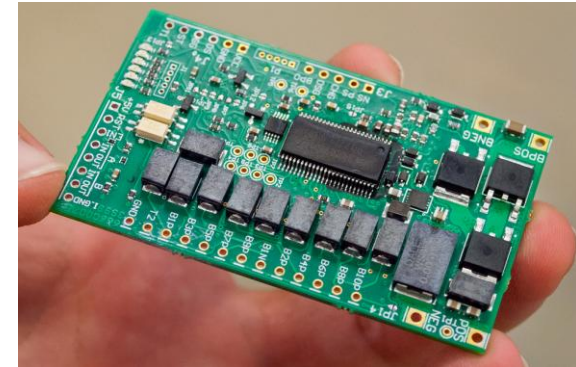
- Charge/Discharge Connector: 2 pin Anderson SB50
- Comm Connector: 8 pin Molex

29V Smart Module Internal View

# 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. Three types of balancing (including module inter-cell and inter-module)
2. Patented algorithms to detect internal cell shorts
3. Method to prevent formation of metal dendrites at the separator
4. Autonomous control of charge level within each battery module
5. Thermal control of all cells and safety shut-off
6. Redundant short circuit fuse protection
7. 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



# Sub-Sea Ready Pressure Equalizing Battery Case

## PRESSURE EQUALIZED CASE

- Oil Fill Port
- Compartment Lid for stowing cables
- Translucent Urethane Pressure Compensating Bladder



- 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

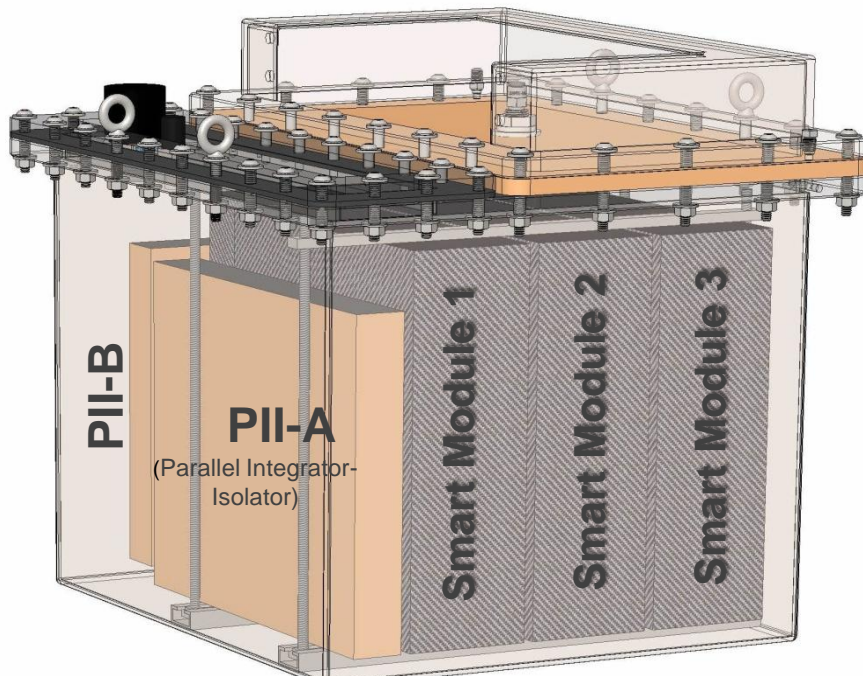
H=14.8", W=15.6", L=17.8"

# Sub-Sea Ready Pressure Equalizing Battery Case

## SEASAFE CASE

11

### Case Internal Layout

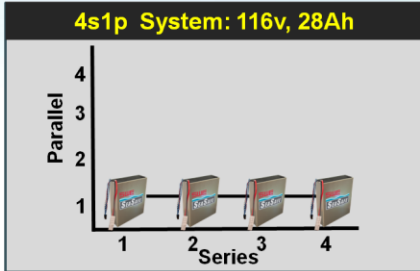


- 1,2,3 or 4 Modules
- PIIs (Parallel Integrator-Isolator)
  - For multiple string battery system configurations. (such as 2s2p)
  - Ensures reliable discharge and faster charge
- System filled with mineral oil
- Not shown:
  - Blanking Modules if system not fully populated (maintains pressure equalization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

Module 4 hidden from view

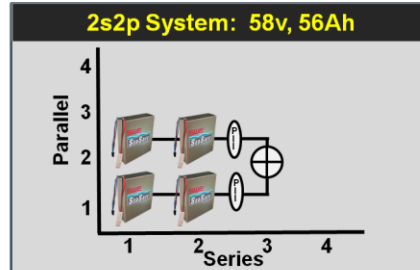
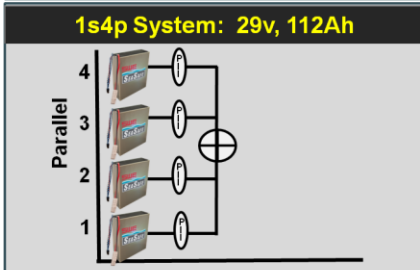
# Scalable Battery System Modular Configuration

## V, Ah Module Increments: Module or Case

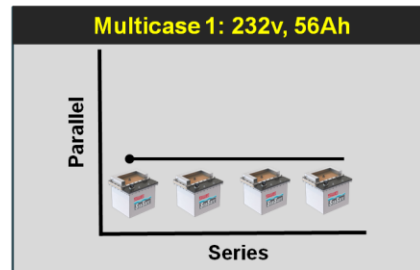


### Module Increments Battery System

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



11

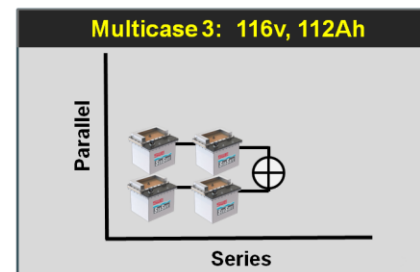
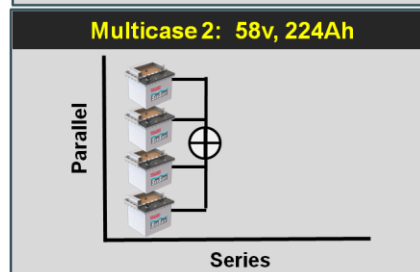


### COTS-CTO FLEXIBILITY

#### Case Increments Battery System

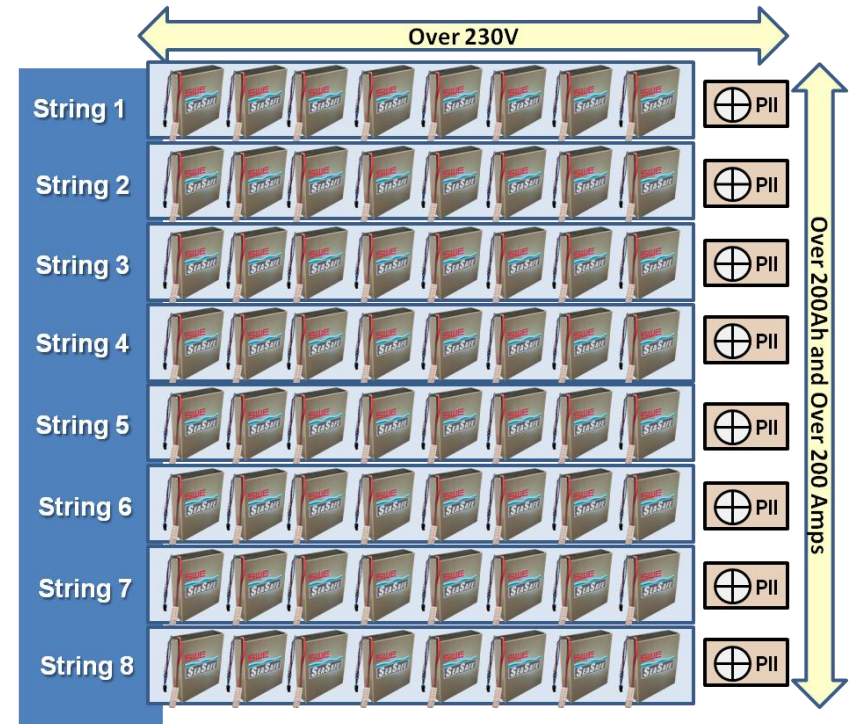
- Voltage: Modules connected in series for V increments
- Ah Capacity: Modules connected in parallel for A, Ah increments

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



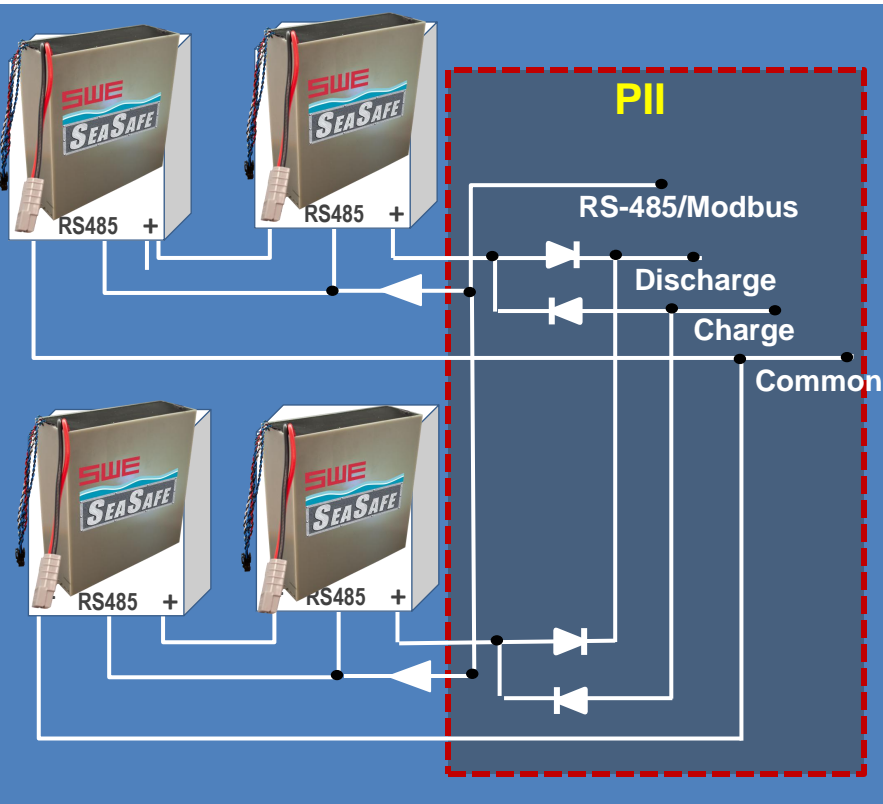
## 8s8p Battery System

### 8 parallel strings of 8 Smart Modules in series



# PIIs for Safer, Reliable Parallel Configuration

## SMART MODULE TECHNICAL DETAILS



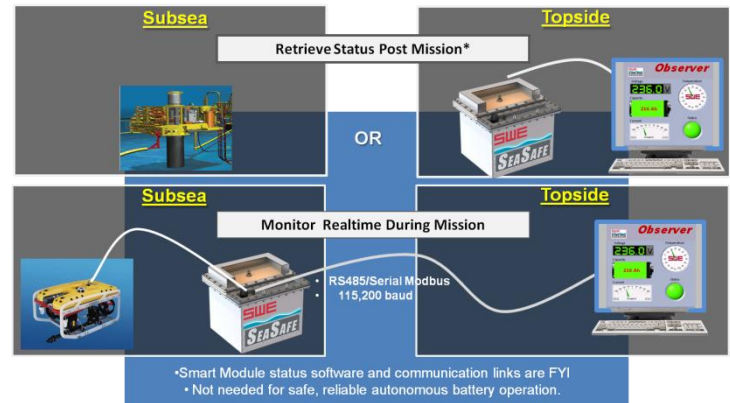
## Parallel Integrator Isolator (PII)

- **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.

# 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.



**MODULE ID: 10** Current Time: 9/17/2013 8:40:48 AM Polling Data...  
Last Updated: 9/17/2013 8:40:48 AM COMM Poll/5 seconds

**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

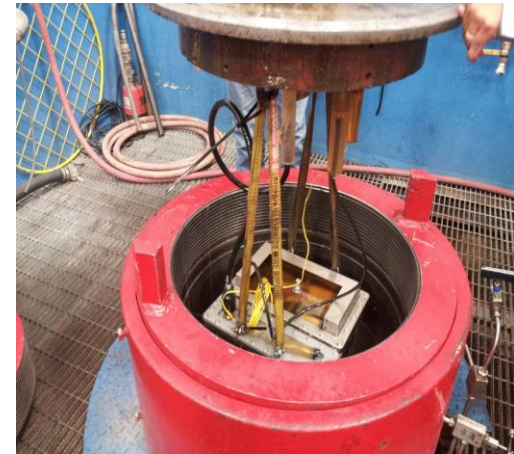
TEMP 0 C

STATUS

REMAINING CAPACITY 69% 21.9 Ah

# Extensive SeaSafe Testing and Certification

- Exhaustive functional testing for over a year
- External direct shorts test validating the 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)
- ISO9000-2008 Quality Compliant Manufacturing





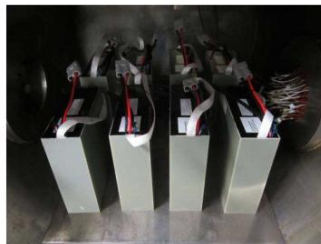
# Extensive SeaSafe Testing and Certification

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

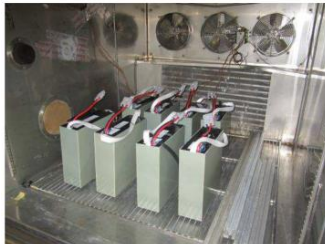
**RESULT SUMMARY:** The tested samples met the test requirements. See below breakout for tests performed.

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



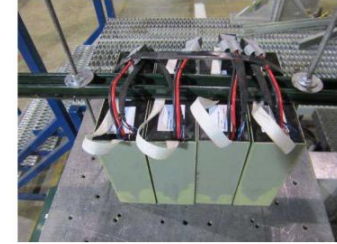
T2 – Thermal Test



T3 – Vibration Test



T4 – Shock Test



T5 – External Short Circuit



T7 – Overcharge



T1

T2

T5

T3

T4

T7

4800 Main Street  
Suite 101  
Plymouth Twp., MI 48170  
Telephone: 734-882-2800  
Facsimile: 734-882-2001  
www.intertek.com

**TEST VERIFICATION OF CONFORMITY**

TEST METHOD: UN-007 Manual of Tests and Criteria "Recommendations on the Transport of Dangerous Goods," section 38.3  
 Various Subtests  
 Document Number: 8762/UN-071 (Rev. E, Amend 1)  
 Section: 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 6.10, 6.11, 6.12  
 Effective Date: April 2012

SAMPLE DESCRIPTION: Eight (8) 85-1P20V-91850H Battery Packs  
 MANUFACTURER: Southwest Electronic Energy Corp.  
 SPECIFICATION SECTIONS T1 through T6 and T7:  
 Eight (8) 85-1P20V-91850H Battery Packs, sample numbers:  
 Battery Packs – 10 Cycles

• SN 1	• SN 5
• SN 2	• SN 6
• SN 3	• SN 7
• SN 4	• 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

Nick Diamond  
 Engineering Supervisor  
 February 13, 2013  
 Report No.: 10089152/DET-001

Michael Wells  
 Department Manager

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 Telephone: 734-882-2800 \*Fax: 734-882-2001 \* www.intertek.com

# 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

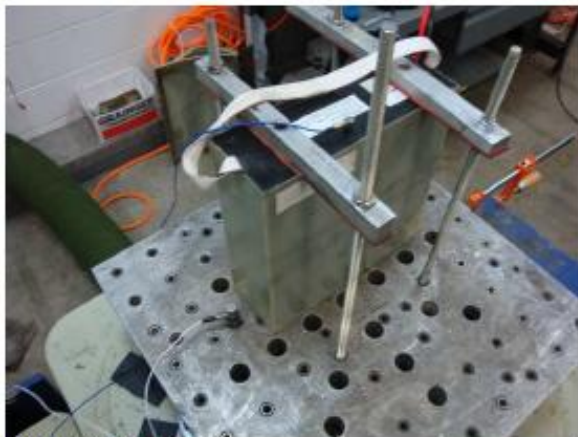


Figure 1: Vertical setup.

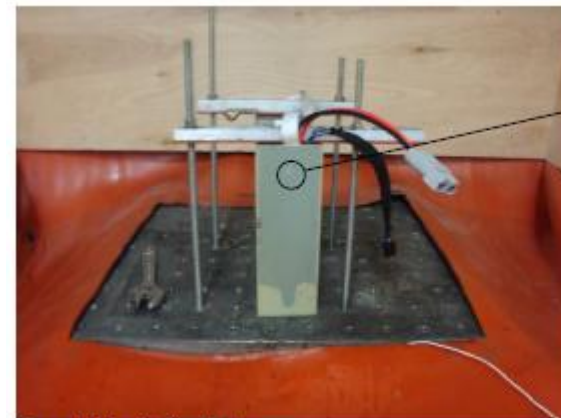
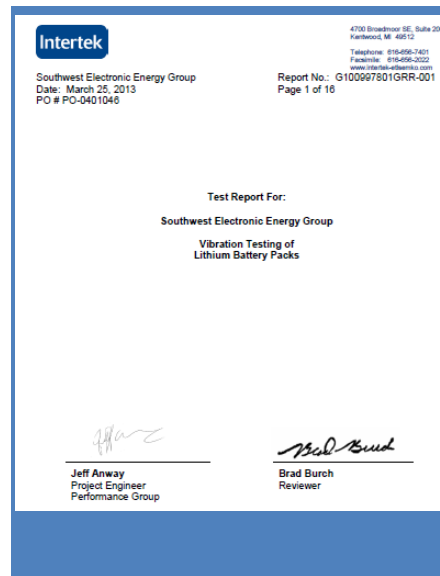
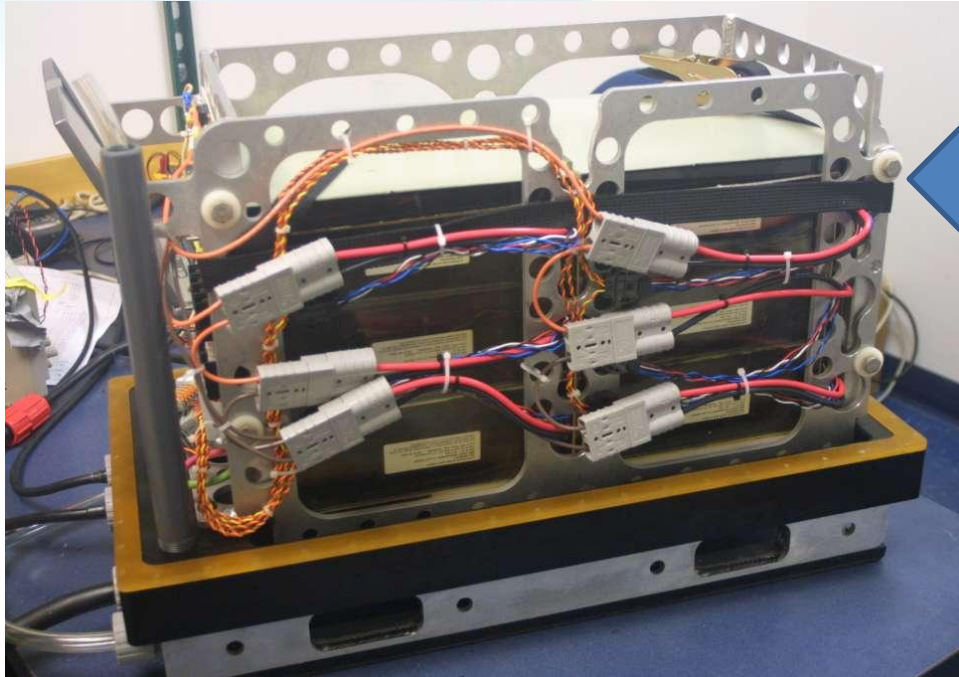


Figure 14: Longitudinal setup.

# New WHOI ROV Designed for High Definition 3D Cinematography



**6 SeaSafe Smart Battery Modules**

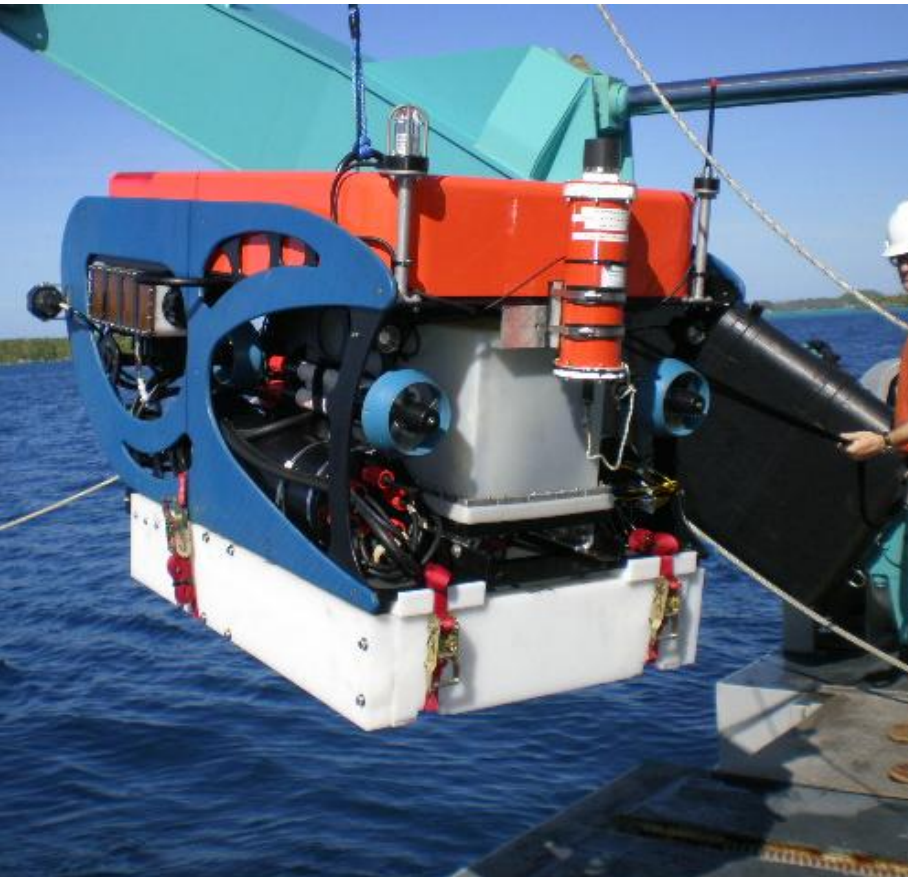
**... into a 3 Series  
x 2 Parallel  
configuration In a  
WHOI designed  
Pressure  
Equalization  
Case...**



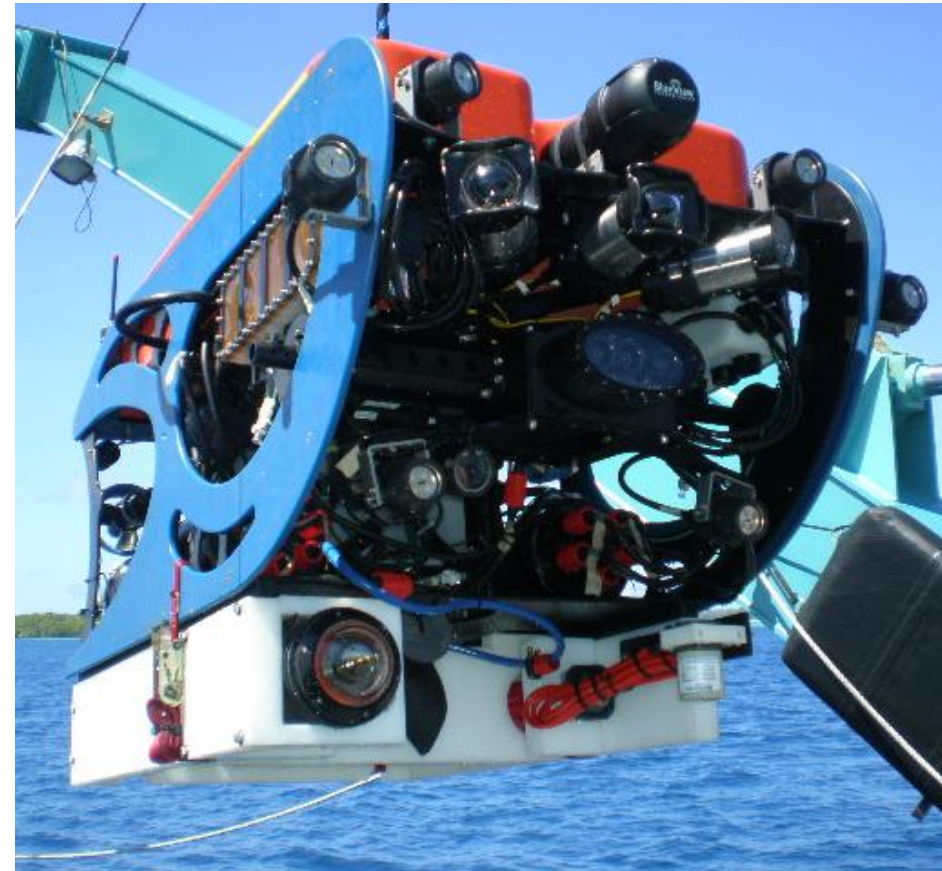
**...into a WHOI  
ROV Mission.**

**Powered by SWE SeaSafe Smart Battery Modules**

# SeaSafe Battery System in WHOI 3D HD Video ROV



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



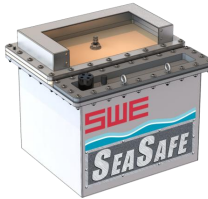
Front (Business End) of 3D Video ROV Shows Camera Lens and Light Sources. Battery Provides Local Power.

## Subsea-Ready Battery Solutions

SeaSafe Smart  
Battery Modules



SeaSafe Pressure  
Equalizing  
Battery Case



Parallel  
Integrator  
Isolator



SeaSafe  
Observer  
Software



Service,  
Quality,  
Reliability



### SUMMARY

20

✓ 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)

[www.swe.com/seasafe](http://www.swe.com/seasafe)

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

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

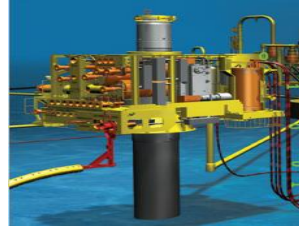
- Need More Voltage ?
  - Battery systems to 100s of Volts
- Need Higher Current ?
  - Battery systems to 100+ Amps
- Need Higher Power ?
  - Battery systems to 100s of KiloWatts

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

# SeaSafe Subsea Applications

## COTS Modularity Flexibility or Custom

**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)



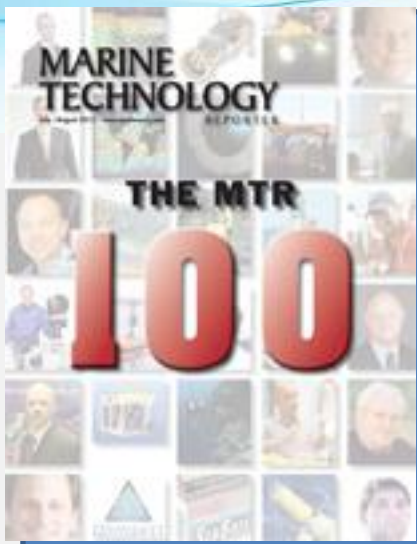
Customer Designed



Or Custom

## Who is SWE?

## Industrial, O&G Batteries



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



# 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