

Safe Subsea Lithium Ion Batteries for Subsea ROVs

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Southwest Electronic Energy Group

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

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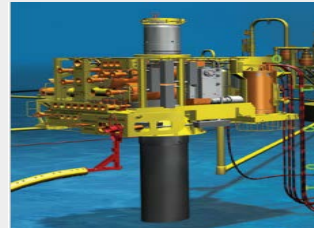
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Subsea Battery Requirements

App

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



Need

- 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

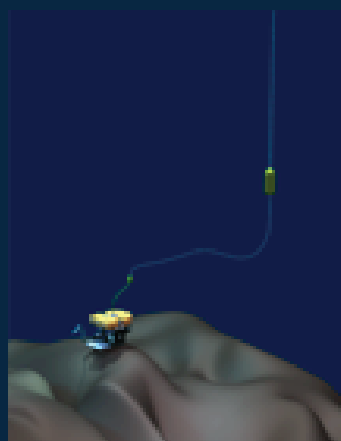
Subsea needs batteries with:

- **Safety first**
- **More capacity**
- **Higher Power**
- **Smaller size**
- **Less Weight**
- **Longer life**
- **High Reliability**

Hybrid Tethering

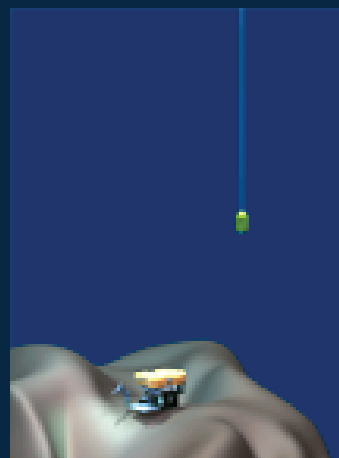
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New Insights



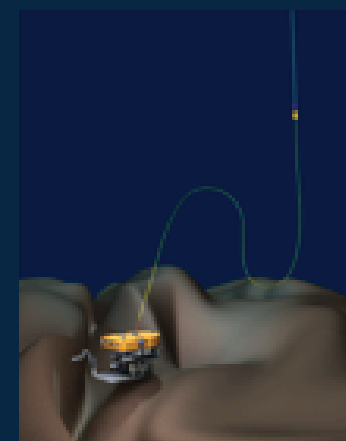
Light-Fiber Tether

Practically unlimited bandwidth with 30 km horizontal standoff.



Free-Space Optical

Through-water optical communications at ranges up to 100+ meters for complete freedom from a tether



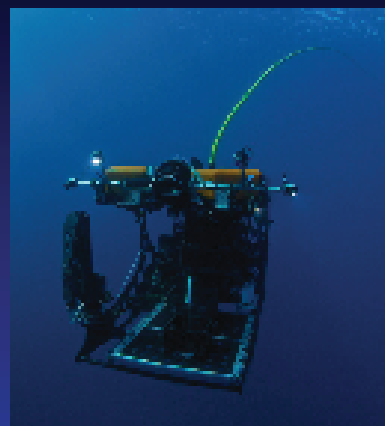
Small Footprint Tether

Light conventional tether (CTD wire) capable of trickle-charging with minimal on-board infrastructure

Nereid HT

What

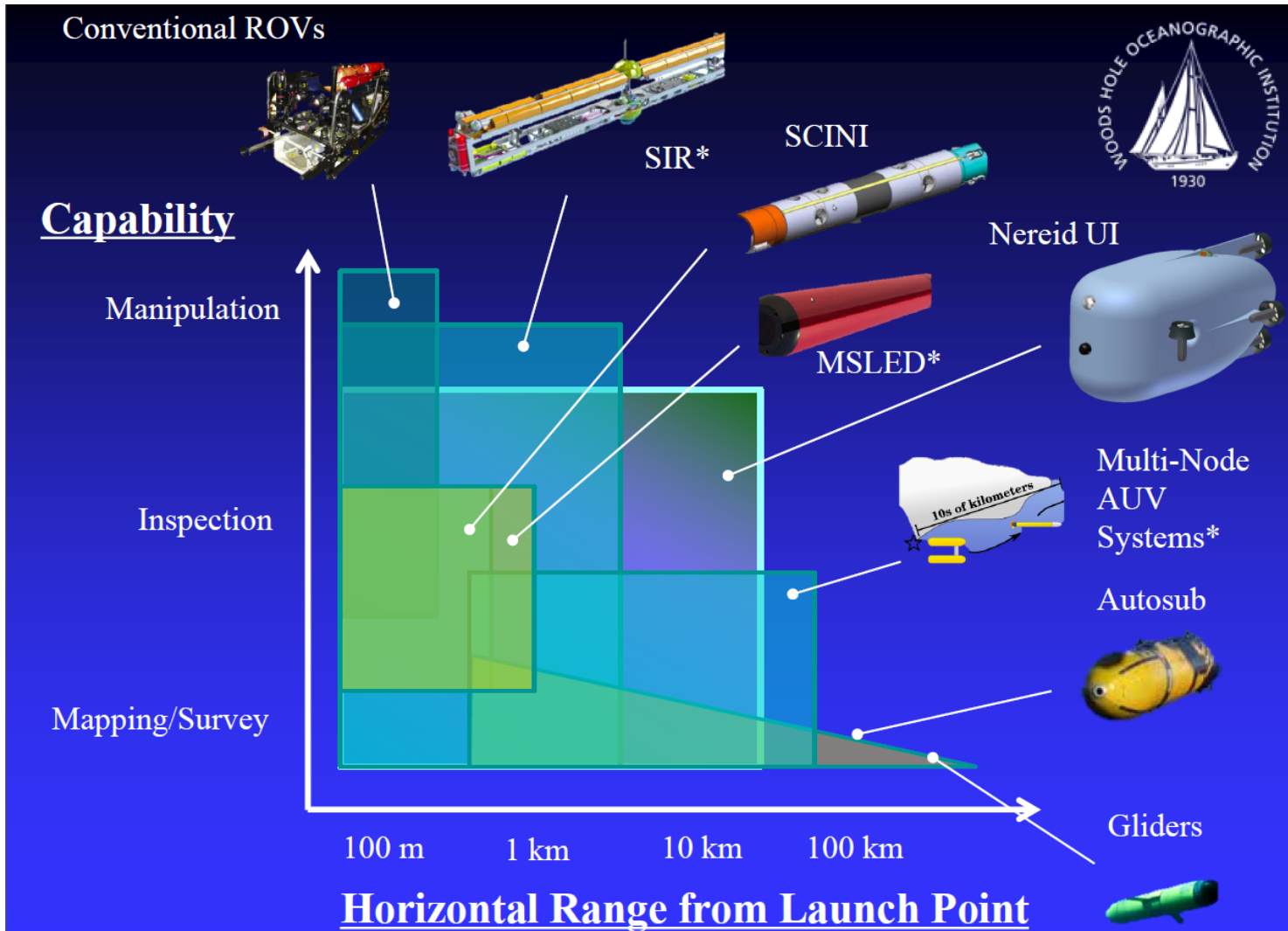
- Hybrid Light Work class ROV
- 3 modes of operation (tether)
- Re-Usable tether - .322 inch dia with lift-tether
- Immersive imaging
- Re-chargeable Lithium Ion
- Manipulation and Sampling (7 DOF master/slave)
- 2500 meters depth (extends to 5,000m)



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



WHOI Nereid Under Ice

Light-Tethered ROV : Innovation

Conventionally Tethered ROV Operations from Icebreaker in Permanent Moving Ice

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 sea-floor locations with vehicles
- Through-ice deployment concepts immature

Icebreaker Constrained to Move with Moving Ice Pack



Steel Armored Cable

Depressor/Garage

Conventional ROV

ROV Footprint of Operations: Small (~500 m) Under Ship, Moving with Ice

Light-Tethered Nereid UI Operations from Icebreaker In Permanent Moving Ice

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

Nereid UI

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

WHOI Nereid Under Ice Light Tethered ROV

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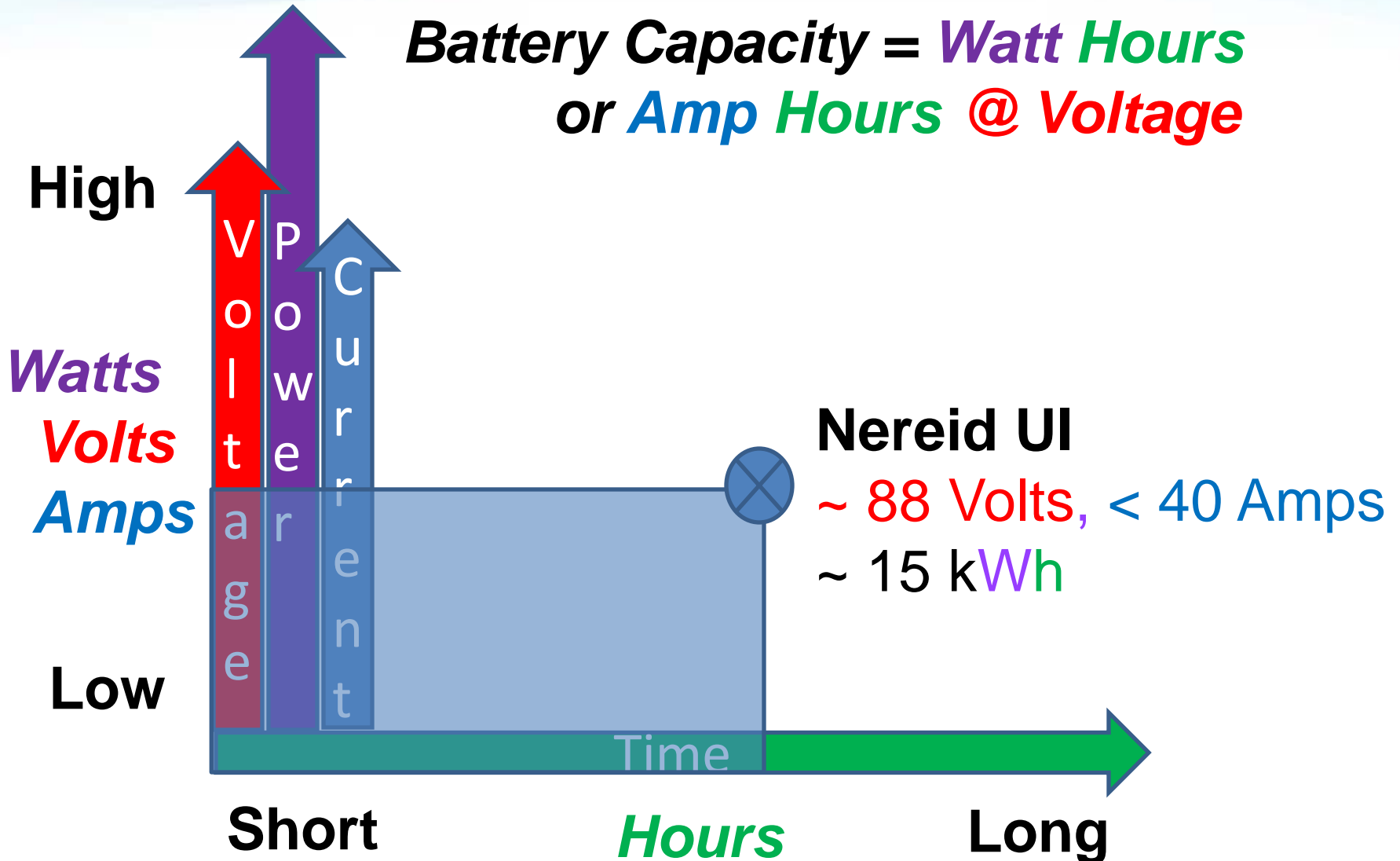
WHOI Battery Requirement

- Safe, Reliable Operation
- 2000 m depth
- ~ 88 volts
- << 40 Amps Continuous
- 100 recharge cycles
- -20C to +50C 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, 96V_{max}
- 40 Amps Continuous
- 1000+ recharge cycles
- -40C to + 85C 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

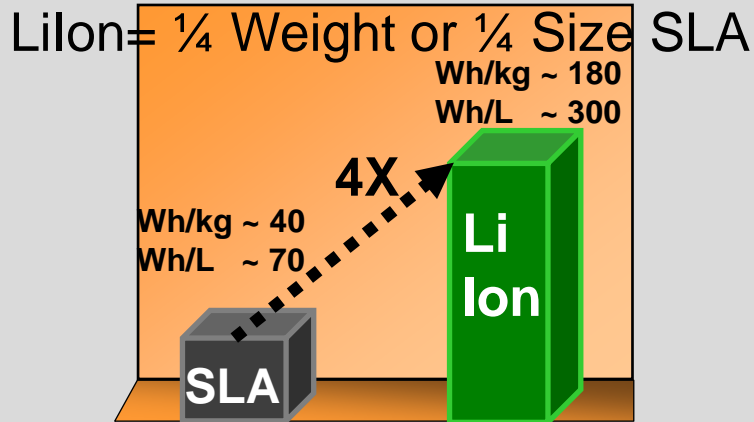
**Battery Capacity = Watt Hours
or Amp Hours @ Voltage**



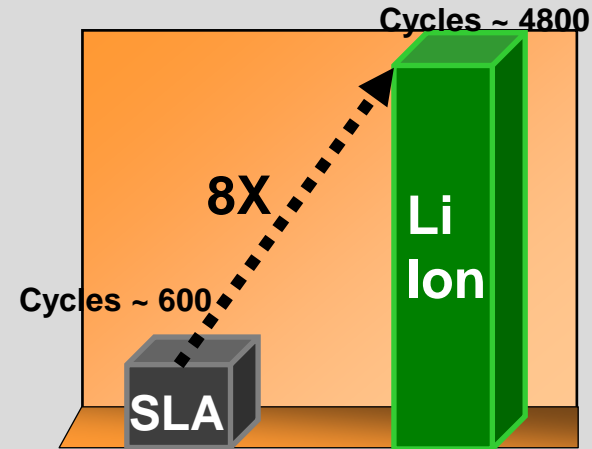
Pressure Tolerant Lithium Ion Polymer Ideal for Subsea (vs Lead Acid)

SWE Li ION

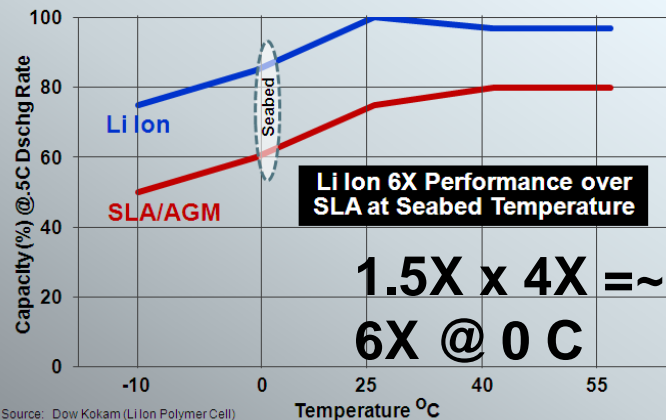
4X More Energy Density



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

Easy to Integrate Smart Lilon Battery Modules

SMART MODULE SPECS

Pressure Tolerant
6000 Meters Depth



Smart Module

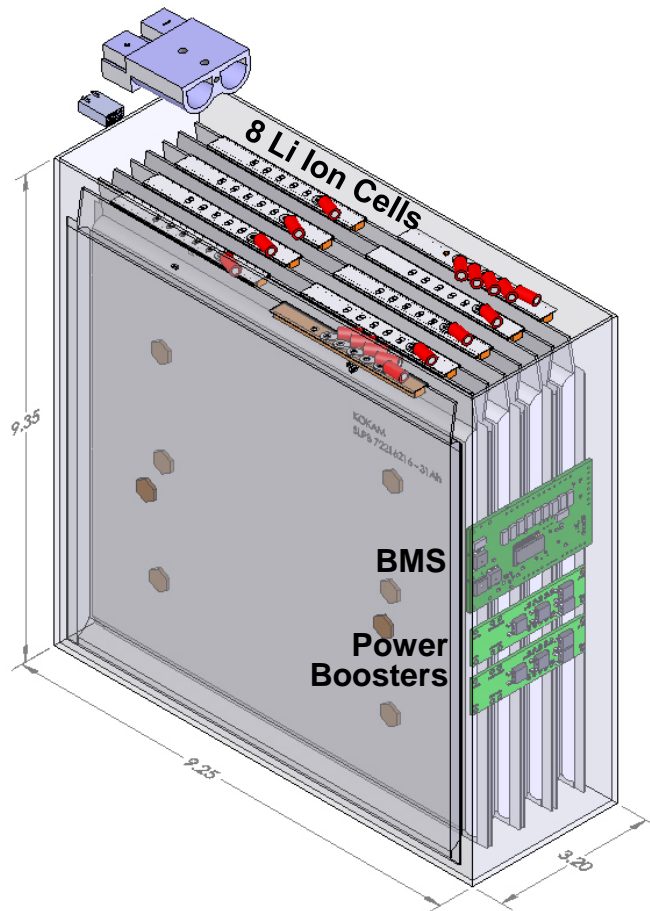
		Smart Modules	
		29V	24V
Cells in series		8	7
Dimensions (in)	H	9.4	9.4
	W	3.2	3.2
	L	9.3	9.3
Weight (lbs)	Total Module (air)	20.0	20.0
	Total Module (sea)	9.7	9.7
Voltage (V)	min	24	21
	nom	29	25
	max	32	28
Current (A)	Max Dschg (continuous)	40	40
	Max Dschg (30s pulse)	75	75
	Max Dschg (1s pulse)	90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



29V Smart Module Internal View



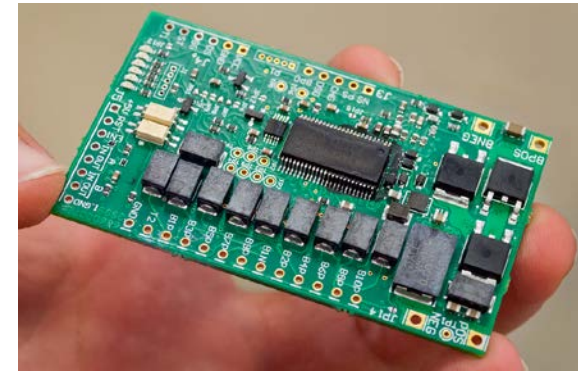
- Charge/Discharge Connector: 2 pin Anderson SB50
- Comm Connector: 8 pin Molex

Modular, Distributed BMS Suite of SAFETY and Reliability Features

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

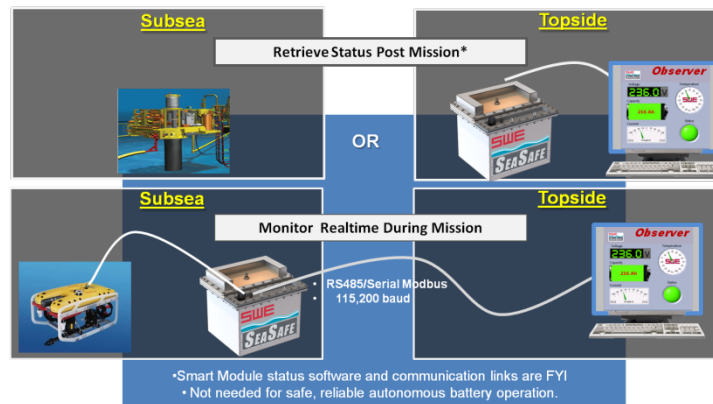
1. Safety features configurable to your mission/application
 - Over and under voltage detection/prevention
 - Excessive charge & discharge detection/prevention
 - Charge temperature protection
 - Discharge temperature protection
 - Short circuit detection and prevention
 - High current pulse discharge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



MODULE ID: 10 **Current Time:** 9/17/2013 8:40:48 AM Polling Data... **Module Info**

Last Updated: 9/17/2013 8:40:48 AM COMM Poll/5 seconds

Messages

8S1P 10

+10 +11 +12 +13 +14 +15 +16 +17

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
-50 0 50
DSG CHG
-0 Amps

TEMP
-20 0 20
-40 40
-60 60
100 80
C

STATUS
Green sphere indicator

REMAINING CAPACITY
69% 21.9 Ah

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



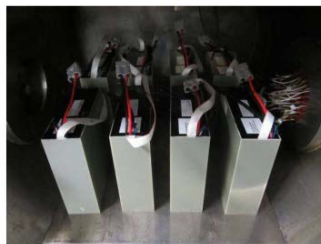
SeaSafe UN DOT Certification

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.

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



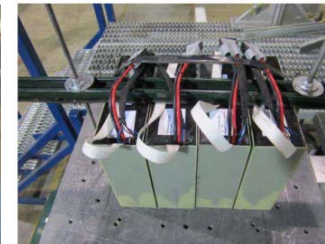
T2 – Thermal Test



T3 – Vibration Test



T4 – Shock Test



T5 – External Short Circuit



T7 – Overcharge



T1

T2

T5

T3

T4

T7

4800 Hein Street
Suite 100
Plymouth Twp, MI 48170
Telephone: 734-462-2000
Facsimile: 734-462-2001
www.intertek.com

TEST VERIFICATION OF CONFORMITY

TEST METHOD: UN-DOT Manual of Tests and Criteria "Recommendations on the Transport of Dangerous Goods," section 38.3
"Lithium Batteries"
Document number: STS00AC.1011 (Rev. 1, Amend 1)
Revision #: 2, Scope Amendment 1
Effective Date: April 2012

SAMPLE DESCRIPTION: Eight (8) 801PCW/918WH Battery Packs
MANUFACTURER: Southwest Electronic Energy Corp.
SPECIFICATION SECTIONS T1 through T6 and T7: Eight (8) 801PCW/918WH Battery Packs, sample numbers:
BATTERY PACKS: 1 – Cycle
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

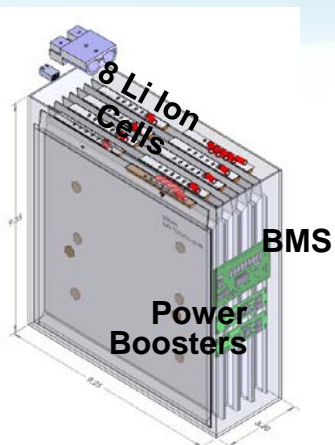
Michael Wells
 Department Manager

February 12, 2013
Report No.: 10289123DE1-001

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Lithium Ion Subsea Battery Deployed in WHOI Hybrid ROVs



29.6 V Smart Battery Module Internal View

- 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

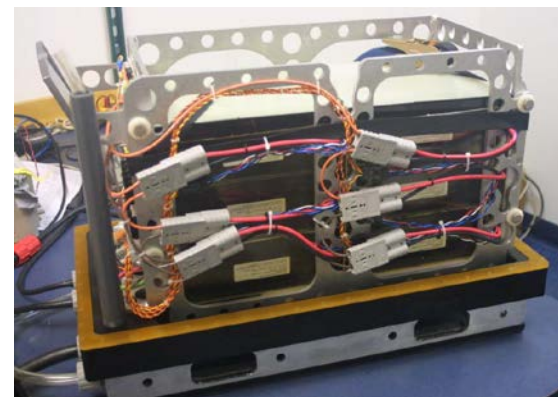


29.6 V Smart Battery Module External View

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

Per Battery Case with room for more

WHOI Pressure Equalizing Battery Case



SeaSafe Batteries in Nereid-UI

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Battery System



Battery chassis during assembly



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)



SWE modules ready for installation

SeaSafe Batteries in Nereid-UI

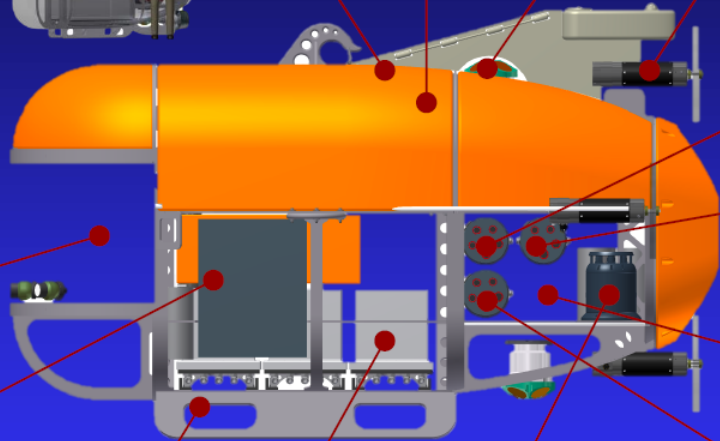
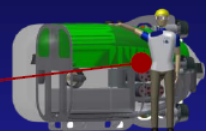


Acoustic Telemetry:
WHOI
Micromodem

Flotation:
CMT 2500 meter

Doppler Velocity Logs Two TRDI
300 kHz

Thrusters:
WHOI design
1200 Watts x 8



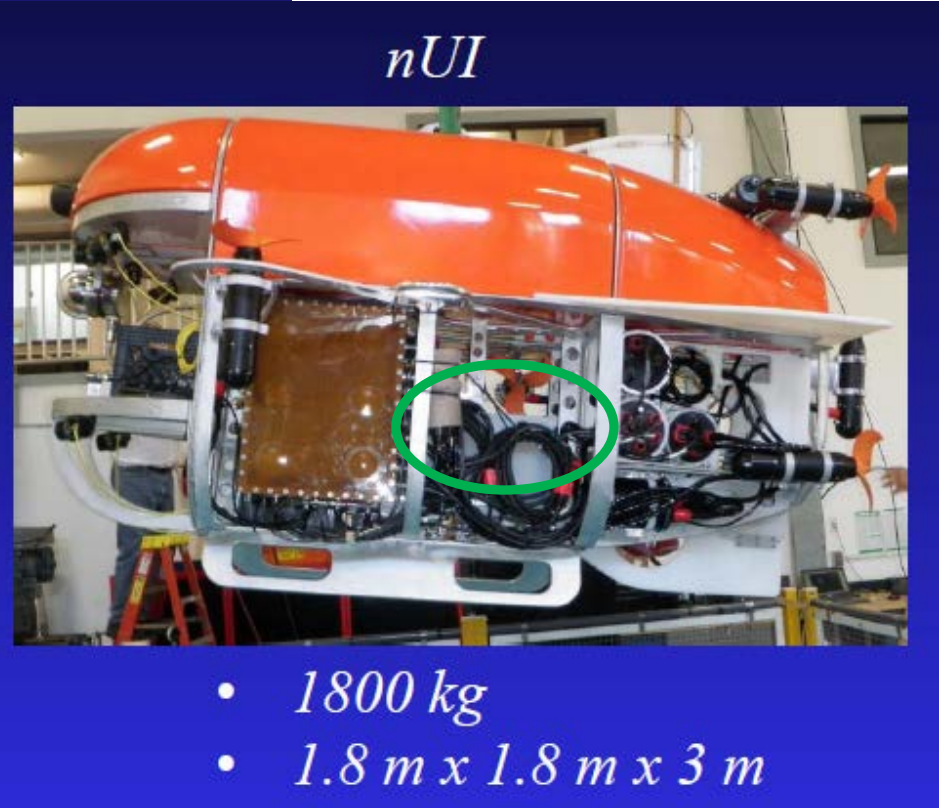
Phins 6k

DSL
In ho

Vehicle Frame:
Welded Aluminum

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

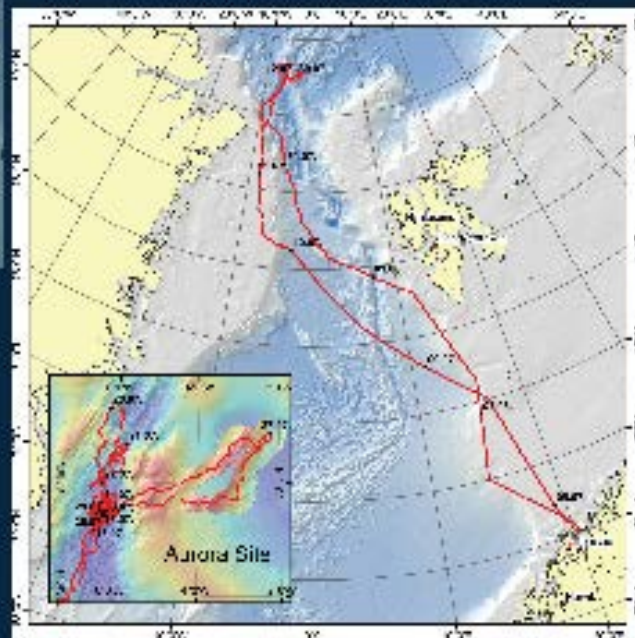
Science Sensing:
Kongsberg PTZ with DSPL aux. DSPL lighting. Sonars: Blueview, Reson. Chemical sensing suite notional.



- 1800 kg
- 1.8 m x 1.8 m x 3 m

NUI Summer 2014 Deployments at 83 N 6 W F/V Polarstern PS86-3

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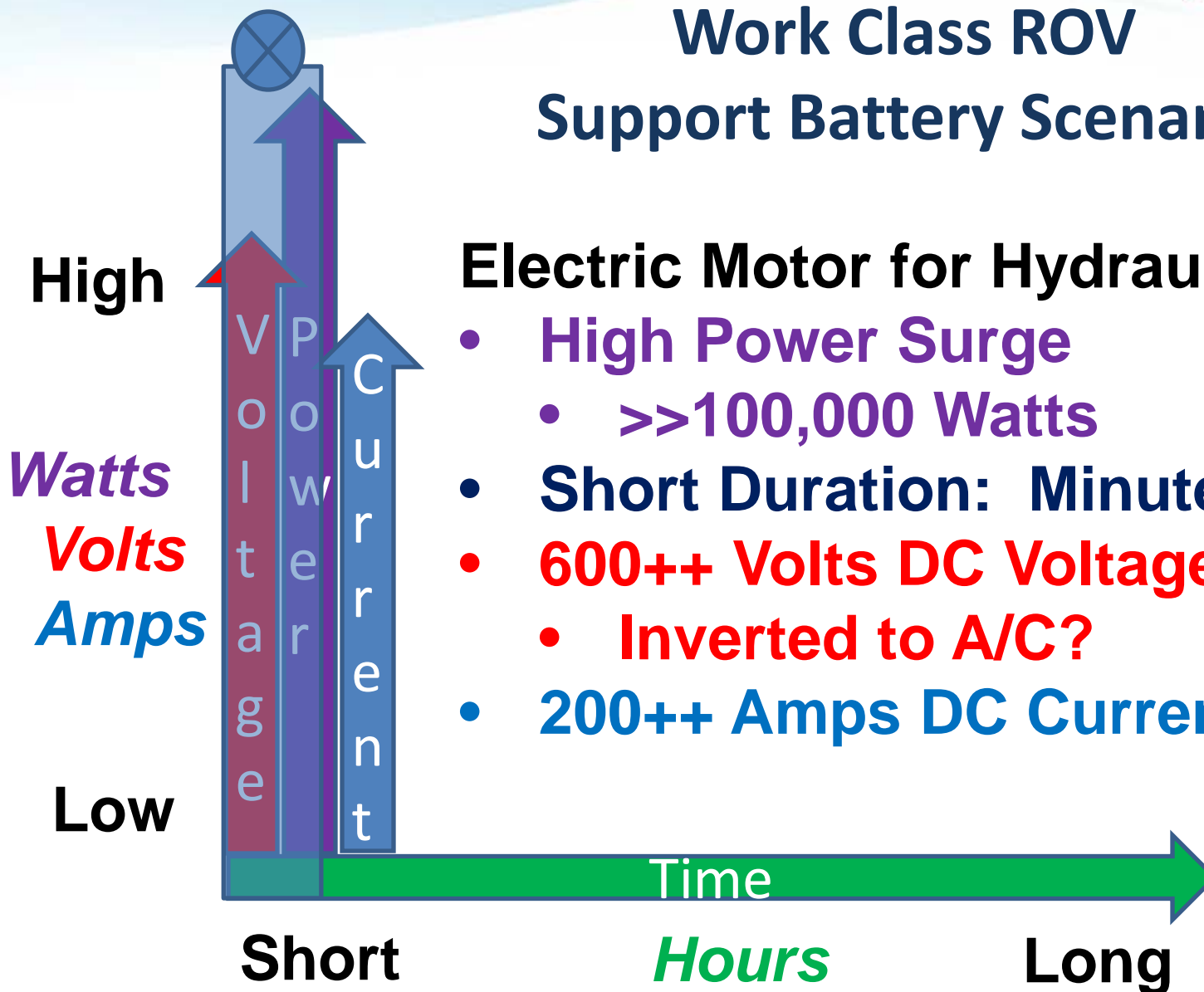
Dive Statistics

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Station	Date	Launch Time (UTC)	Recovery Time (UTC)	Dive Duration
PS86/0053-1	7/21/2014	11:44	16:52	5:08
PS86/0060-1	7/23/2014	11:03	16:08	5:05
PS86/0070-1	7/26/2014	6:43	11:44	5:01
PS86/0080-1	7/28/2014	12:29	17:49	5:20

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

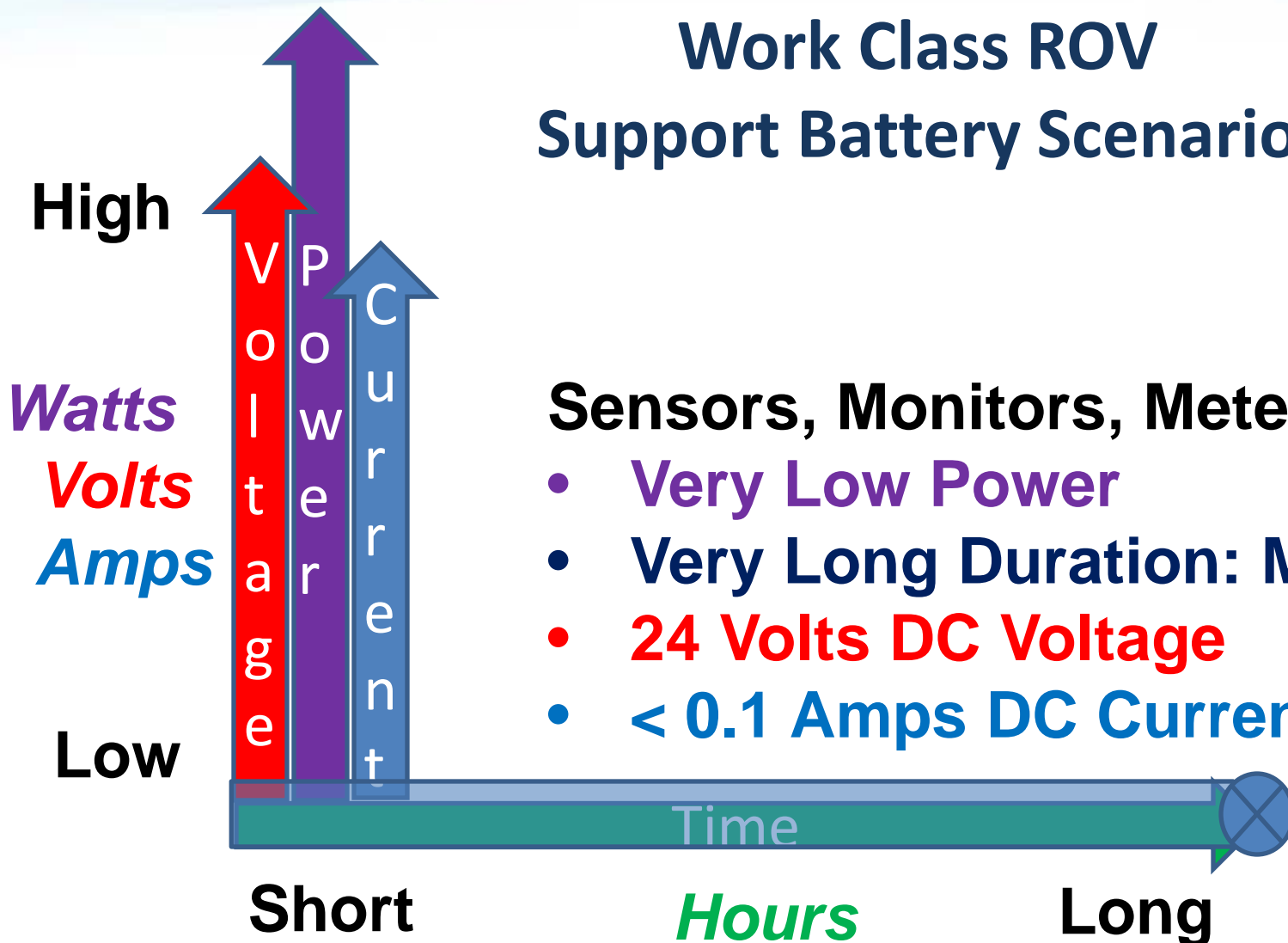
Work Class ROV Support Battery Scenario



Electric Motor for Hydraulic Pump

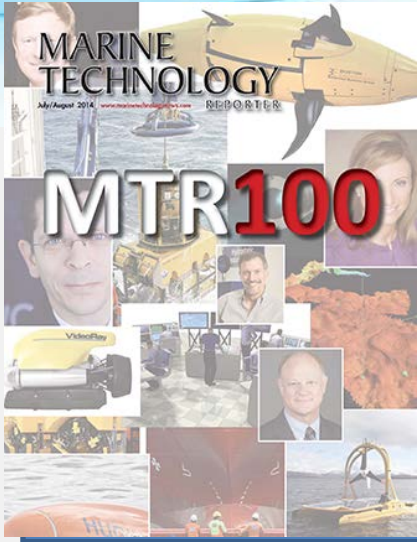
- High Power Surge
 - $\gg 100,000$ Watts
- Short Duration: Minutes
- 600++ Volts DC Voltage
 - Inverted to A/C?
- 200++ Amps DC Current

Work Class ROV Support Battery Scenario



Sensors, Monitors, Meters, etc.

- **Very Low Power**
- **Very Long Duration: Months+**
- **24 Volts DC Voltage**
- **< 0.1 Amps DC Current**



Thanks !

Acknowledgements

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

ABOUT SWE

www.swe.com

- Since 1964 - Quality supplier to Oil and Gas
- 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



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



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