Space Batteries Market Review 2017

NASA Battery Workshop
November 2017

Shmuel De-Leon
Shmuel De-Leon Energy, Ltd.
www.sdle.co.il
shmuel@sdle.co.il

Space Battery Requirements

- High energy and power density
- Hard vacuum operation
- Withstand severe launch environments (vibration, shock, and acceleration).
- Long cycle life (> 30,000 cycles) for orbiting spacecraft
- Long active service life (> 10-15 years)
- Radiation resistance
- Operation at temperatures as low as -80°C (planetary missions)
- Safety
- Quality

Space Batteries Applications

- GEO telecommunication satellites
- MEO global positioning satellites
- LEO Defense satellites
- Launchers
- Space vehicles
- Space experiments
- Rovers
- Planetary landers
- Astronaut tools
- Space object study
- Planetary/deep space probes

Is there any Electrochemistry System that can meet all requirements?

No!!!

Systems in use:

- **Silver-zinc rechargeable (Launchers)**
- **Nickel-cadmium rechargeable (past)**
- **Nickel hydrogen rechargeable (???)**
- **Lithium Primary**
- **Lithium Ion rechargeable**

Silver-zinc battery, made by General Electric, was the only power source for the Corona satellite's film return capsule

Lithium Primary Space Cells

CR123A Li-Mno2 cells used by the Astronaut Jetpack (Safer)

Lithium Ion Rechargeable Space Cells

Li-Ion batteries become the preferred choice because of their high energy & power density, reliability, robustness and long cycle life

Space Cells/Batteries Manufacturers/ Developers

ABSL - Enersys

ABSL Space Batteries

ABSL is a global leading supplier of Lithium-ion batteries for space applications where space heritage, innovation, and a proven delivery track record come together to produce market-leading batteries.

ABSL supplied the first rechargeable Lithium-ion battery flown in space, has the longest serving Lithium-ion spacecraft battery, and is the most demonstrated Lithium-ion space battery supplier with more Lithium-ion flight heritage than any other vendor.

ABSL is the space battery supplier of choice for the toughest space battery programs, including man-rated, high voltage, and long life missions. Driven by a passion for the space industry, ABSL is unmatched and solely committed to serving this market.

- Pioneer of space lithium-ion technology with the first lithium-ion batteries around Earth, Mars & Venus
- Battery supplier of choice for the toughest lithium-ion space battery programs
- Recipient of numerous awards from customers worldwide
- Abundant supply of cells in stock to meet the needs of future programs
- Quallion's Zero Volt ™technology available in ABSL space products
- Contracts for over one hundred spacecraft and launch vehicles

http://www.enersys.com/ABSL_Space_Batteries.aspx

BST Systems

BST Systems, Inc. designs, develops, manufactures and tests high-energy silver-zinc cells, specialty cells, underwater cables and connectors, complete battery systems, as well as Battery Chargers and Data Acquisition Systems Equipment.

BST's Quality Assurance program is in compliance with the requirements of ISO9001-2000, NASA NHB5300.4 (1C), AS9100 and is BMAR (Boeing) certified. These high quality standards are applied to the design, production and inspection of all BST's products.

BST's line of silver zinc rechargeable cells and batteries have many advantages, including excellent gravimetric energy density (ranging from 140-200 Wh/kg) and volumetric energy density (400-510 Wh/l), exceptional power density (up to 900W/kg), excellent charge retention and electrochemical efficiency. In addition, the silver zinc chemistry experiences little or no performance degradation at low temperatures (-23°C), and is capable of supporting a wide range of discharge rates, from less than C/6 to greater than 4C. Silver zinc batteries produced by BST range in size from 1.5 Wh to 1.2 MWh. Silver zinc cells range between 1.0 and 2400 ampere-hours. These products are lightweight, compact, rugged, rechargeable, reliable and safe. Depending on the specific application and cell type, they are ideal for both low rate and high rate applications.

BST SYSTEMS, Inc.

http://bstsys.com/

BST Systems

The silver zinc technology is used in a variety of applications where battery weight, volume and safety are critical. Silver zinc batteries truly serve a variety of markets - from underwater submersibles (manned and unmanned) to space, where they provide the main portable power source for Astronaut life support during Extravehicular Activities (EVA's, or "spacewalks") to interplanetary missions (the Mars Pathfinder Program). In addition, our batteries provide safe, reliable compact power in numerous launch vehicle applications.

The combination of their high gravimetric energy density, high volumetric energy density, superior power density, along with its long and storied success in multiples of vehicles and applications, make this couple extremely attractive. BST Systems also specializes in the packaging of lithium-based cells into batteries for various applications.

Our unique history in supplying batteries in support of the launch vehicle business has given BST a unique edge in designing robust products for demanding environments (high shock, random vibration, etc) regardless of the chemistry.

Finally, in order to better support our customers, a line of custom battery chargers, cyclers and data acquisition systems have been developed. Currently, they are in use in support of both military and aerospace applications.

http://bstsys.com/

China Aerospace Science & Industry Corp

Silver Zinc

China Aerospace Science & Industry Corp.

http://www.casic.com.cn/ http://chinacasic.en.china.cn/

Eagle Picher

Introduction to EaglePicher Technologies

EaglePicher Technologies, LLC
An OM Group Company

Leader in Batteries, Battery Management Systems, Battery Chargers & Energetic Devices for Defense, Space, Commercial, Alternative Energy, and Medical Applications

- *A wholly owned subsidiary of OM Group (NYSE: OMG) of Cleveland, OH.*
- *HQ in Joplin, MO*
- *10 Plants*
  - *Joplin, MO*
  - *Seneca, MO*
  - *Pittsburg, KS*
  - *Vancouver B.C.*
  - *Rothenbach, Germany (JV with Diehl)*
- *Expertise in >25 Chemistries*
- *Millions of Specialty Batteries Delivered From Thousands of Designs*

Headquarters - Joplin, Missouri

Trusted Power Reliable Power ♦ Innovative Power

EPT Market Segments

EaglePicher Technologies, LLC
An OMG Company

Missiles:
- Batteries
  - Thermal
  - Silver Zinc
  - Lithium Oxyhalide
  - Custom Packaging
- Energetic Devices

Launchers:
- Batteries
  - Silver Zinc
  - Lithium Ion

Portable Power:
- Batteries
  - Lithium Sulfur Dioxide
  - Lithium Carbon Monofluoride
  - Lithium Manganese Dioxide
  - Lithium Thionyl Chloride

Unmanned Vehicles:
- Batteries
  - Lithium Ion
  - Lead Acid
  - Nickel Cadmium
- Battery Assemblies
- BMS

Aircraft:
- Batteries
  - Lithium Ion
  - Nickel Cadmium
  - Nickel Metal Hydride
  - Primary Lithium
- Electronics
- BMS

Special Applications:
- Chargers & Charger/Analyzers
- Battery Systems
- Custom Cells & Batteries

Satellites:
- Batteries
  - Nickel Hydrogen
  - Lithium Ion
- Electronics & BMS

Distributed/ Commercial Power:
- Batteries
  - Sealed Lead Acid
  - Lithium Thionyl Chloride

Medical Power:
- Batteries
  - Lithium Ion
  - Lithium Manganese Dioxide
  - Lithium Carbon Monofluoride
  - Lithium Thionyl Chloride
  - Microcell
  - Nickel Cadmium

Alternative Energy:
- Hybrid Power Storage Systems
- HEV Systems

EaglePicher has over 600 batteries
in space; more than any other company!

The Next Generation: Lithium-ion

EaglePicher now designs and assembles batteries using large Li-ion cells, which provide higher energy levels and longer cycle life at a lower weight and in smaller volumes than Ni-Cd or Ni-H_2 batteries.

- State-of-the-art Li-ion research and manufacturing facilities
- First to launch prismatic Li-ion battery into orbit
- Multiple research grants and contracts for advanced Li-ion development

EP/ Yardney Technical Products

EaglePicher™
Technologies, LLC
An OM Group Company

YARDNEY TECHNICAL PRODUCTS, a division of EaglePicher, an OM Group Company, is a technology driven corporation that focuses on specialty battery technology for research and product development in high performance niche markets. Current chemistries include Lithium-ion, Silver-Zinc and Metal-Air.

Yardney Lithion

advanced technology
for your most demanding applications...

The world's leading supplier of High Energy Density Batteries for Air, Land, Sea, and Space...

AS9100C
+ISO9000:2008
CERTIFIED MANAGEMENT SYSTEM

http://yardney.com/

Yardney Lithion

Silver-Zinc Applications

- Strategic Missiles
- Tactical Missiles
- Target Torpedoes
- Unmanned Vehicles
- Space Power Satellites, Life Support
- DSRV, DSV, NR-1
- Sonobuoys
- Broadcast Industry (ENG)
- Pipeline Inspection

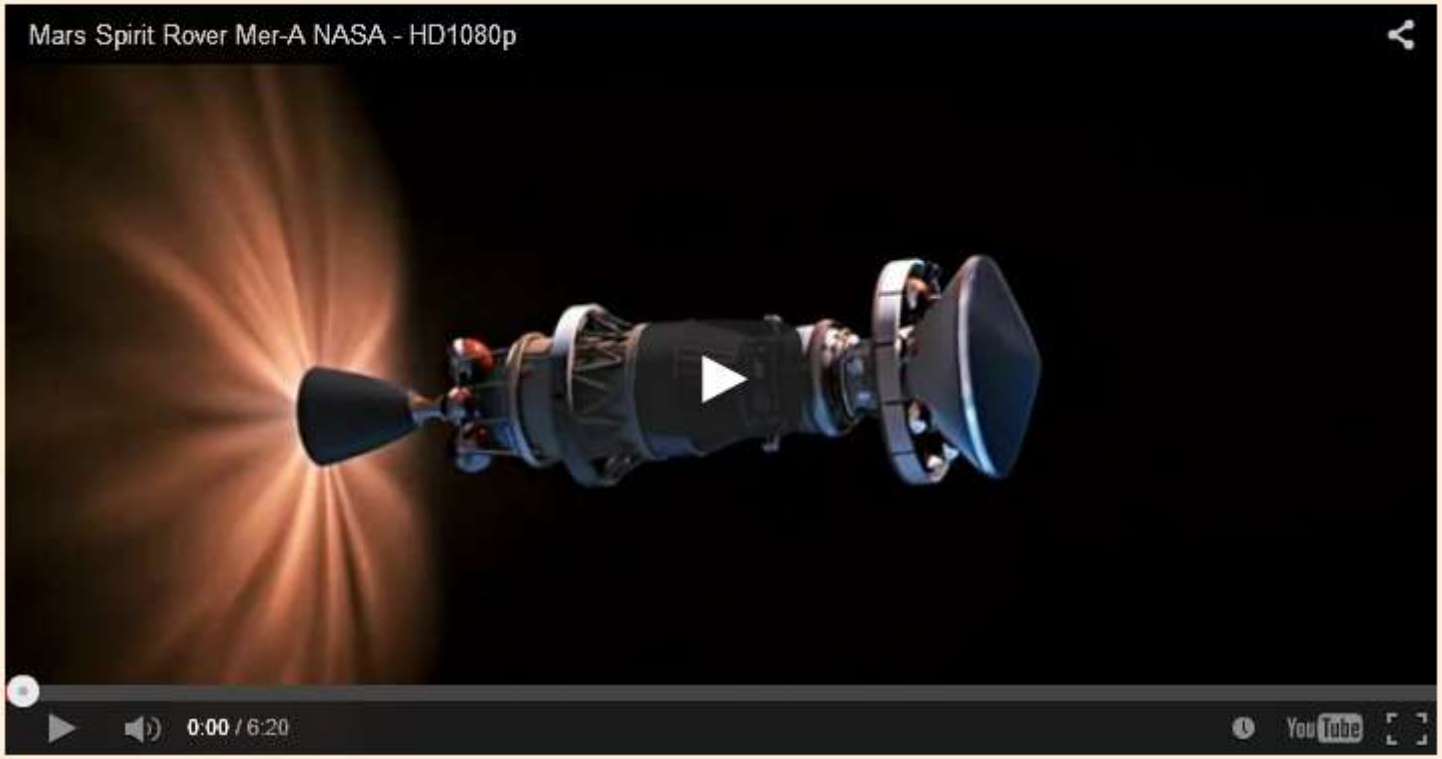
20 Jan 11 VAFB
2 each FTS on board
(20 x HR2.5DC-3)

Yardney Li-Ion

Lithion Batteries Started Working on Mars

11 years, 217 days, 20 hours, 45 minutes, 28 seconds ago

The Launch and Landing of "Spirit"



GS-Yuasa

GS Yuasa has manufactured space qualified Li-ion cells for use on satellites and other spacecraft since the early 1990's. During this time our expertise has been focused on developing the best and most reliable cell technology. GS Yuasa's technology is trusted by leaders in the satellite manufacturing and operating industries to provide uncommon reliability and the highest performance energy storage solutions for critical space applications.

To date, GS Yuasa has manufactured thousands of large format Li-ion cells for space and has built strong working relationships with many battery and spacecraft manufacturers including: JHU/APL, EaglePicher, ISRO, JAXA, MELCO, Orbital Sciences Corporation, Space Systems / Loral and Thales Alenia Space. The power systems of more than 50 satellites have relied on GS Yuasa's Li-ion cell technology for a total of more than 1,100,000Wh on orbit (over 37 million working cell hours) without anomaly or failure. On a total energy storage capacity basis (Wh), GS Yuasa is a world leader in Li-ion for space.

Our lithium ion cells for aerospace applications are exclusively manufactured by GS Yuasa Technology, LTD (GYT) in Kyoto, Japan. GYT is certified ISO9001, JIS Q9100 (technically equivalent to AS9100), and ISO14001. GYT is fully capable of performing in-house cell level qualification testing, including electrical, environmental and safety testing. Our lithium ion cells have successfully completed several unique space qualification programs.

Among the space programs that GYLP has supported is the Orbital Sciences Corporation's (OSC) Commercial Orbital Transportation Services (COTS) program. OSC's Cygnus vehicle is a commercial resupply vehicle for the International Space Station.

http://www.gsyuasa-lp.com/satellites-rockets-lithium-battery-markets

The GEN II LSE lithium ion prismatic cell design has been in production since 1999. Multiple cell designs have successfully completed space qualification programs and thousands of LSE Heritage cells have been on orbit for as long as 6 years without incident.

GYLP's advanced modeling capability allows us to work with your vehicle's duty cycle data to determine the optimal cell and battery configuration to best match your mission requirements.

Features:

- High energy density
- Excellent discharge characteristics
- Excellent cycle life
- Sealed structure
- Elliptic cylindrical shape for efficient packing and battery design.

OJSC/ Russia

OJSC "Research Design and Technological Institute of Battery "Istochnik"(JSC" NIAI "Istochnik") dates back to 1924 when, at the base of the first battery factory in Russia "Tudor" was established Central Laboratory Battery (TSAL). TSAL task was to ensure that the rapid scientific development of battery industry in the USSR.

Today JSC «NIAI« SOURCE »produces a range of products, nomenclature of which is continuously being expanded:

- batteries in cadmium and nickel (Ni-Cd),
- batteries in nickel metal (Ni-MH),
- batteries in nickel-hydrogen (Ni-H),
- batteries in lithium-ion (Li-Ion),
- batteries of these battery types.

Increasing production, expanding the spectrum of research and development activities. Through multistage quality control system, the products of JSC «NIAI» «Source» failproof able to work in severe operating conditions. Fruitful cooperation with the defense industry and the Federal Space Agency confirms in practice, the high performance of our products.

http://www.niai.ru/catalog.php?id=4&lang=eng

OJSC/ Russia

NICKEL-HYDROGEN RECHARGEABLE CELLS

Fields of application:

Space and rocket equipment

Deep-water immersing apparatus

Design

Nickel-hydrogen rechargeable cells were developed and produced firstly in the world in NIAI "Istochnik". Nickel-hydrogen rechargeable cell represents the sealed alkaline rechargeable cell combining in itself the traditional nickel-oxide electrode and gas hydrogen electrode.

The main current-forming process is described by the equation:

$$Ni(OH)_2 \underset{Р\text{-}з}{\overset{Э\text{-}р}{\rightleftarrows}} NiOOH + 1/2\ H_2$$

Potassium hydroxide (KOH) is the electrolyte in nickel-hydrogen rechargeable cell. When charging at hydrogen plate hydrogen which is accumulated in the free cell volume, is evolved rising its internal pressure. Thereat, this pressure is directly proportional to the given charge capacity. When discharging hydrogen is electrocatalytically ionized at hydrogen plate and the pressure is decreased.

HB-40, HB-60, HB-100

Technical Advantages

- Sealingness
- Serviceability at any space position
- Automatic control of charge state degree
- Stability to mechanical loads

In NIAI "Istochnik" the rechargeable cells and batteries of any intention, with any voltages and capacities under customer's demands can be developed and manufactured.

Type	HB-40	HB-50	HB-100
Nominal capacity, Ah	40	50	100
Factual capacity, Ah	45	54	110
Power consumption, Wh	58,5	70,2	125
Max pressure of hydrogen, MPa	9	11	11
Safety factor	2,5	2,5	2,5
Overall dimensions (diameter x height), mm	70x170	70x185	90x274
Weight, kg, not more	1,1	1,2	3,2
Specific energy, Wh/kg	50,8	58,5	40
Working temperature, °C	0... + 30	-20 ... + 30	0... + 30
Self-discharge at 20°C (24 h/72 h), %	30/40	30/40	30/40
Charging current (mean/max), A	10/2	12/30	25/50
Discharging current (mean/max), A	10/30	12/50	25/100
Current of discharge (in pulse of up to 1 min), A	80	120	250
Service life, years/cycles a) discharge depth up to 80 % б) discharge depth up to 25%	5—7/3000 5/500 3/17000	8-10/3000 10/1000 5/28000	5/3000 5/500 3/17000

Nickel-Hydrogen Batteries

	24HB-40	28HB-40
Nominal capacity, Ah	40	40
Nominal voltage, V	30	35
Weight, kg	34	40
Charge/Discharge current, A	8/23	10/25
Charging Control	Pressure sensors and thermal relay	
Service life, years	5	5

Battery 24 HB-40

http://www.niai.ru/catalog.php?id=4&lang=eng

QinetiQ

High-g tolerant lithium primary cells for space applications

NASA Battery Workshop

Huntsville, AL, USA

Kevin Green, **Gary Mepsted, Mark Fyrth, Robert Churton, Philip Church and Philip Holland**

18th November 2015

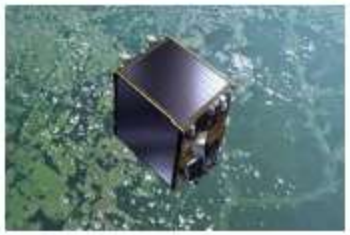
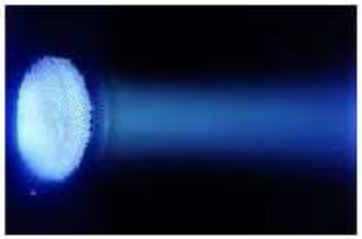
QINETIQ/15/04048

www.QinetiQ.com

QinetiQ Proprietary

QinetiQ – Space Operations

QinetiQ

Satellites & Platforms	Scientific Payloads	Subsystems	Downstream services
			
Small satellite bus End-to-end mission solutions	Microgravity research Planetary exploration Earth observation	On-board computers Docking & Berthing Space Mechanisms	Satellite Operations Integrated Applications Technical consultancy
	(FMP) Frequency Monitoring Payload **Metrology**	**Electric Propulsion** **UHF transponders** **GNSS Applications**	**GIS applications & services** **Test Facilities** **Space tourist training**

Enersys/ Quallion

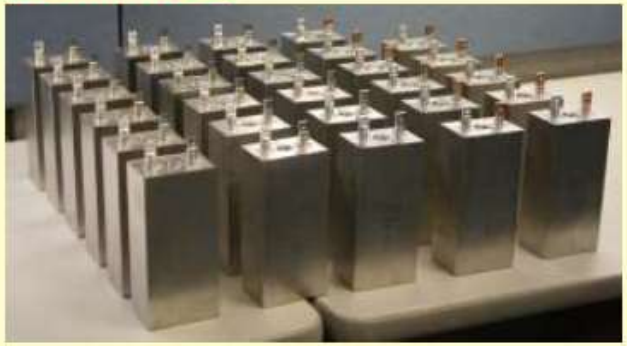
The U.S. based company designs, fabricates and manufactures state-of-the-art lithium ion cells and battery packs, and develops new battery chemistries for the military, aerospace, medical and automotive industries. Building on its legacy leadership position in the medical device industry, the company has developed a range of novel enabling technologies that include the world's smallest implantable secondary battery and the proprietary Zero-Volt™ and SaFE-LYTE™ technologies. Leveraging its core engineering capabilities, Quallion has established itself as a leader in applications where advanced battery technology, safety, reliability and custom engineering are most valued. For more information about Quallion, visit www.quallion.com

http://www.quallion.com

Battery Design Support (Hardware, Electronics)

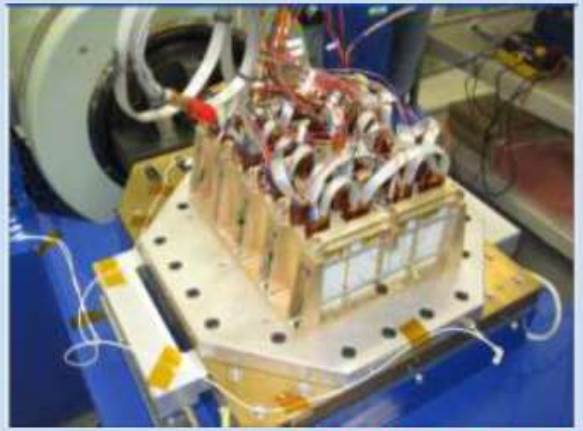
Cell Design Support (Hardware, Chemistry)

QL075KA-SS



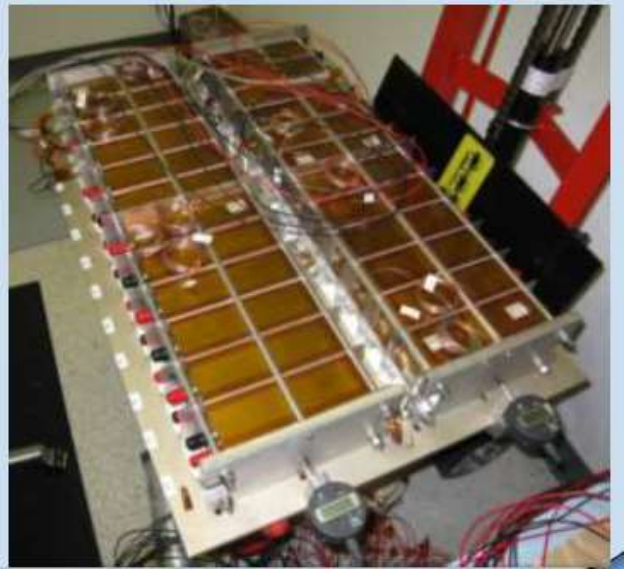
QL015KA-SS

QL015KA-SS, 8S-2P Battery



QL015KA-SS, 8S-1P Battery

QL075KA-SS, 12S-2P Battery



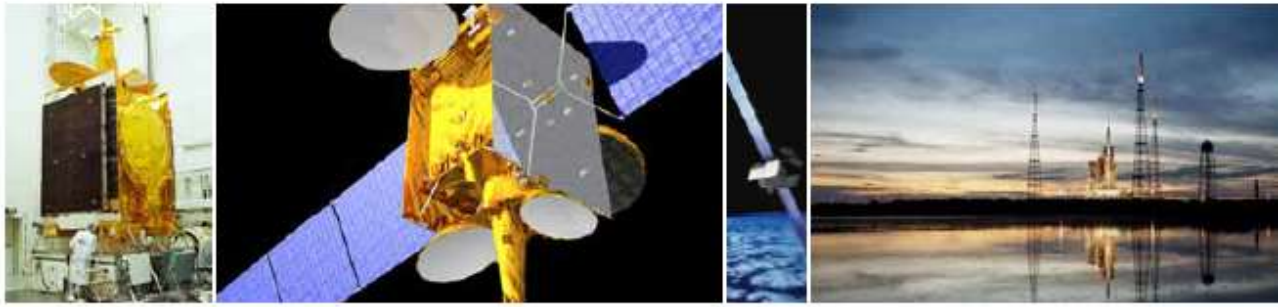
Saft Batteries

With over 45 years of experience and several 'firsts' in space, Saft knows how to ensure the quality of a battery system's life including extensive mission duration, vibration and shocks, vacuum and extreme temperature resistance and proper functioning, while respecting stringent size and weight constraints.

Employing the most rigorous of standards in terms of quality, testing and documentation, Saft's record designing and building lithium-ion batteries for space applications speaks for itself. With an extreme space environment, batteries cannot jeopardize a mission and our solutions withstand extremely demanding missions such as GEO telecommunication satellites (power needs), and MEO global positioning satellites, and support specific applications from high power telecommunications to observation and defense LEO satellites.

While we are a pioneer in lithium-ion batteries in space applications, we offer advanced battery solutions providing very long shelf-life (up to 20 years). As no space mission is the same, no space application battery is the same and Saft will work with you to custom design a solution for your space needs.

http://www.saftbatteries.com/market-solutions/space



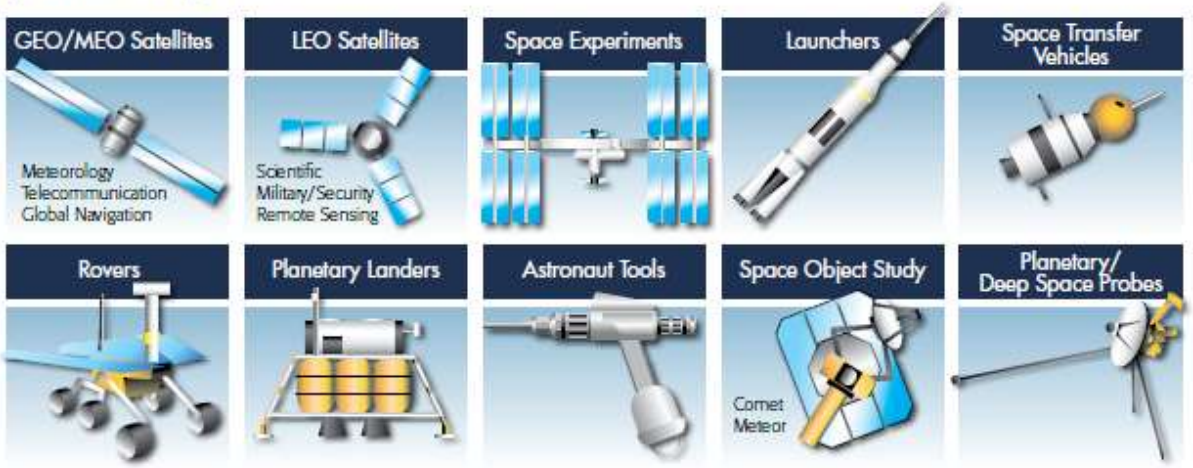
Saft is the world leader in developing and manufacturing batteries for the space market. With more than 46 years of experience, Saft has become a pioneer in space through innovative thinking and development of advanced technology. Since the launch of our first battery in 1966 on board the D1A "Diapason", Saft has gained significant experience to become the top supplier worldwide of batteries for satellites and a multitude of space applications.

Superior technology

Saft's global customers include prime contractors, telecoms operators and space agencies. These organizations value our complete mastery of all battery chemistries, whether primary or rechargeable. They also value our proven ability to develop new products and offer breakthrough technology. Saft is the only battery manufacturer offering all technologies used in space: primary lithium ($Li-SO_2$, $Li-SOCl_2$, $Li-MnO_2$), Li-ion, Ni-Cd, and $Ni-H_2$.

Space applications served by Saft batteries

Low mass and volume coupled with long life and simplified electronics make Saft's highly customizable battery solutions perfect for these applications:



Saft's space-qualified Li-ion cell offering

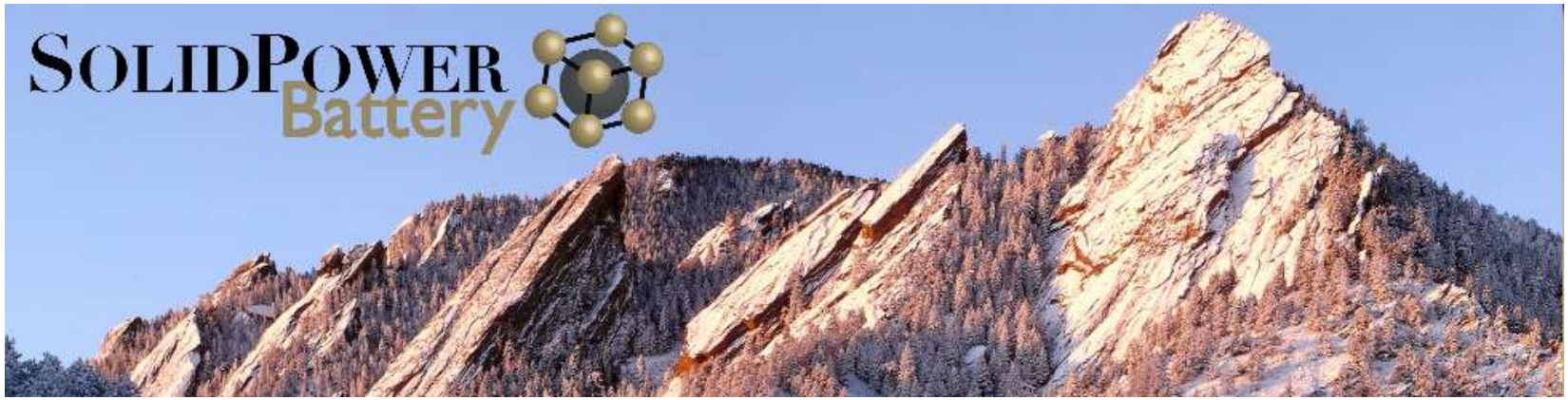
	VES 140	VES 180	VES 16	VL 48E	VL 8P	VL 9E
Nominal capacity (Ah)	39	50	4.5	48	7.5	11
Mean voltage at C/1.5	3.6	3.6	3.6	3.6	3.6	3.6
End of charge voltage (V)	4.1	4.1	4.1	4.1	4.1	4.1
Energy (Wh)	140	180	16	170	100	40
Specific energy (Wh/kg)	126	165	155	150	118	165
Height (mm)	250	250	60	250	104	130
Diameter (mm)	53	53	33	54	47	34
Weight (kg)	1.13	1.11	0.155	1.13	0.38	.24
Main application	GEO, MEO	GEO, MEO	LEO, GEO	GEO, LEO	Launcher	Launcher

Our customers in the space industry include:

- ARSAT
- Boeing
- CNES
- EADS Astrium
- ELV
- ESA
- IAI
- INTA
- INVAP
- ISRO
- KARI
- Lockheed Martin
- NASA
- Northrop Grumman
- OAO ISS Reshetnev
- OHB CGS
- Orbital Sciences Corporation
- Thales Alenia Space
- United Launch Alliance
- Energya
- SABCA
- Satrecl
- SSTL
- Tübitak Uzay
- VNIIEM
- Yuzhnoe Design Office

Solid Power Battery

- **Founded:** 2012
- **Manufacturing sites:** USA
- **Product Status:** Development
- **Corporate manager:** Mr. Douglas Campbell
- **Web-site:** http://www.solidpowerbattery.com/
- **Comments:**



High-Energy Bulk Solid-State Batteries

SolidPower Battery

- Historically, commercial solid-state batteries were thin-film form
  - Low capacity, low energy batteries
  - Largely attributed to low ionic conductivity of materials (e.g., LIPON)
- Key requirements for high energy "bulk" solid-state batteries:
  - High capacity electrodes (incl. cathode)
  - High ionic conductivity (>10^{-3} S/cm)
- Solid Power's Solution:
  - Ultra high capacity cathodes
  - Scalable, high ionic conductivity electrolytes

EP/ Yardney Technical Products

EaglePicher™
Technologies, LLC
An OM Group Company

YARDNEY TECHNICAL PRODUCTS, a division of EaglePicher, an OM Group Company, is a technology driven corporation that focuses on specialty battery technology for research and product development in high performance niche markets. Current chemistries include Lithium-ion, Silver-Zinc and Metal-Air.

Yardney Lithion

advanced technology
for your most demanding applications...

The world's leading supplier of High Energy Density Batteries for Air, Land, Sea, and Space...

AS9100C
+ISO9000:2008
CERTIFIED MANAGEMENT SYSTEM

http://yardney.com/

Yardney Lithion

Silver-Zinc Applications

- Strategic Missiles
- Tactical Missiles
- Target Torpedoes
- Unmanned Vehicles
- Space Power Satellites, Life Support
- DSRV, DSV, NR-1
- Sonobuoys
- Broadcast Industry (ENG)
- Pipeline Inspection

20 Jan 11 VAFB
2 each FTS on board
(20 x HR2.5DC-3)

Space Battery Assemblers

Acme Aerospace

Acme Aerospace

Trust Acme for Your Emergency Back-up Power Needs

Acme Aerospace has over 30 years experience in the custom design and manufacturing of aviation and aerospace battery systems and similar support products. Our reputation has been built through the thousands of Fiber Nickel Cadmium (FNC) "Zero Maintenance" batteries, charge control units and converters flying around the world. Our sytems are utilized by a wide range of commercial and military aerospace customers, as well as many ground based and industrial clients because we offer true "one-stop".

Acme Aerospace is the Only True "One-Stop" Battery and Electronics Company.

We offer both development engineering and manufacturing all under one roof. We are committed to dedicated and genuine partnerships with both our customers and suppliers. This philosophy has proven to be highly effective when providing power solutions for the latest technologies.

Acme Aerospace Inc.

http://acme-aero.com/

Lithium Batteries

Acme Aerospace Inc. is on the forefront of advanced battery, chargers and battery management system design. Our unique in -house capabilities and experience allows us a distinct approach to Li-Ion batteries with a focus on safety, performance, reliability and system integration. Acme is currently the battery supplier of choice of the Sikorsky S-97 RAIDER platform and is a team sponsor under Avionic Instruments LLC.

It is extremely important when considering the use of Li-Ion battery systems for airborne applications to consider its performance parameters, environment and how the battery is expected to integrate with the rest of the electrical system architecture, especially the charger and battery management system. These issues must be addressed and overcome on any platform in order to satisfy the current FAA Special Conditions Safety Criteria established by the authorities.

Acme's smart Lithium-Ion battery system contains a balance between power density (reduced weight) and the necessary levels of redundant safety features to ensure fault isolation and avoid propagation failure. The engineers at Acme have evaluated all available chemistry options for Lithium-Ion cells and have identified multiple reliable sources for the different chemistries. Lithium Iron Phosphate has been chosen due to its thermal stability characteristics and overall safety. The battery system design includes the cells, charger, battery management system (BMS) and associated electronics to maintain the battery in a charged condtion and provide power when required for engine starting. The function of the BMS is to monitor, evaluate and protect the lithium chemistry cells

Acme Aerospace's Li-Ion Battery System consists of the following components:

1. Lithium Ion Battery – The arrangement of cells is dependent on the technical parameters of the specified battery, but all cells are arranged in a physical configuration utilizing specific thermal materials to prevent cell failure propagation.

2. Battery Charger: The charger converts the unregulated 28 VDC input into a constant current -constant voltage (CC/CV) output to charge the battery.

3. Battery Management System (BMS): The BMS provides full protection for the battery in the case of over-voltage, under-voltage and over-temperature conditions. The BMS also controls the series cell balancing is achieved using a microcontroller.

ASP – Equipment GmbH

Infinite possibilites for your power supply solutions

ASP, Advanced Space Power Equipment GmbH, is your primary address for power supplies for space, aviation, defence and demanding industrial applications. The company is located in Salem, close to the Lake of Constance and was founded in 2003. ASP now ranks among the leading experts worldwide both in the development of customised solutions and the manufacturing of high-end products.

A flexible response to their requirements is always in the core of our activities. By virtue of our expertise and high technologcial standards, we are in the position to meet stringent and manifold requirements with particular emphasis on high electrical efficiency and high-reliability power supply combined with minimum mass and volume. Throughout all project phases, we are committed to keep up a continuous and extensive communication with our customers.

In space, in the skies and on the ground – right beside the customer

As a medium-sized enterprise, it goes without saying that our natural strengths are the dedicated focus on customer requests, rapid and flexible response to specificiation changes, full compliance with the technical requirements and on-time delivery. We are indepdendent from large groups and focus on short decision-making channels. The manufacturing process of all of our products and small series requires a huge amount of manual work done by specialised staff and in compliance with high-quality standards. In order to provide this, we carry out almost 100 % of our value chain in-house and stick to a consistent Quality Management System (QMS) – for highest quality "Made in Germany".

We focus on our core capabilites in the design, analysis, manufacturing and testing of our power supply equipment. The ASP quality management system is certified according to EN9100:2009. The challenge we give ourselves is to meet the high technical requirements whilst ensuring a competitive "value for money".

Our origins lie in the space industry but, in the meantime, our know-how and expertise are also highly appreciated in the aviation sector, with commercial and civil applications as well as other technically demanding industries.

Our services for your success – facilities at ASP

- Laboratory for electronic design, assembly and electronics integration area
- Manufacturing of high voltage/low voltage transformers and inductors
- Encapsulation facility: Potting under vacuum conditions and curing under pressure
- Thermal vacuum chamber
- Clean room ISO class 8 for manufacturing, assembly, integration and test (MAIT)
- Process laboratory
- Microsectioning laboratory

http://www.asp-equipment.de

Li/Ion Battery and Battery-Management System (60Ah)

Space Products

Born out of the long experience with Primary Power Systems the idea emerged to create and test a Li/Ion battery system for space. After developing an innovative Battery Management System COTS Li-Ion batteries were upgraded to perform in space environmental conditions. Qualification on ground finalised this successful study.

Details:

60Ah Li-Ion Battery, in Total 4 Cells
14,4V Rated Voltage
Battery Management System Included
330 x 257 x 112 mm

Back

http://www.asp-equipment.de

Bren-Tronic

A History of Innovation
When Leo Brenna founded Bren-Tronics in 1973, he set out to produce batteries that would deliver reliable power in both military and industrial applications where failure was not an option. From our start in primary batteries, we shifted our focus to secondary or rechargeable batteries in the 1980s. When Operation Desert Storm demonstrated that rechargeables were the answer to meeting the power needs of troops on the ground while reducing their logistics load, we helped lead the way in nickel-cadmium rechargeables.

From those early secondary batteries to today's lithium-ion systems, we've succeeded in engineering solutions that deliver the staying power of primary cell batteries with the extreme reusability demanded by today's military. We continue to innovate with lithium polymer chemistries and solutions tailored for use with solar cells and fuel cells.

More Reliable and Lower Cost
One of the main benefits of rechargeable batteries is lower cost compared with batteries that must be replaced frequently. We know that cost is key to the success of our products. Yet we also know that our customers cannot afford that lower cost if it comes at the expense of reduced reliability.

Rather than designing our systems from the ground up to military specifications, we keep costs low by combining proven off-the-shelf technologies with our innovative solutions, and then ruggedizing our systems to meet mission requirements. The result is systems that out-perform at a lower cost, every time.

One-Stop Power Shop
Our staff of engineers works with our military and industrial customers to engineer solutions for every conceivable application.

From research and development to comprehensive testing - including certification, first article, and UN Transportation Safety testing - all the way through manufacturing, we are your partners every step of the way in fielding your application quickly and cost-effectively.

Bren-Tronics, Inc.
Intelligent Military Batteries & Charging Systems™

http://www.bren-tronics.com

Clyde Space - UK

Clyde Space Overview

Clyde Space is an award winning supplier of small and micro spacecraft systems. We are mostly kept busy with work on our high performance power subsystems, DC-DC Converters, lithium polymer batteries and high efficiency solar panels, typically for small satellite missions. Not content with being the small satellite power guys, we also design and build very reasonable Attitude Control and Determination Systems. We are a World leading CubeSat vendor, and pioneered the CubeSat Shop which you can peruse at your leisure once you are done reading this; maybe also buy a satellite or two with your credit card. Finally, we have recently completed development of an advanced nanosatellite platform, Scotland's first satellite, in conjunction with leading academic and commercial organisations in the UK and the rest of World.

What sets us apart from the rest is our team's extensive experience in small satellite missions and our ability to innovate. We consider our business to have two halves; our off-the-shelf products from our online shop and tailored/bespoke products either designed from scratch or modified from our range of heritage products. We have a combined experience in over 50 space programmes and this means that we have the knowledge to enable us to support space missions at all levels, from conceptual design, development, integration, through to analysis of data from on orbit operations.

Everything we do at Clyde Space is governed by our values; Excellence, People, Innovation, Relationships and Integrity. Continuous improvement in all our disciplines underpins our long term reputation. We love what we do and we have fun doing it.

Clyde Space customers include international universities, commercial companies and government organisations. Approximately 80% of Clyde Space sales are outside of the European Union and over 95% outside of the UK.

Founded in 2005 by Craig Clark, Clyde Space is a privately owned company. In December 2010, Clyde Space received significant investment from two major Scottish private equity investors, Nevis Captial and Coralinn, who are committed to supporting the growth ambitions of Clyde Space.

Clyde Space is named after the River Clyde, the main river running through Glasgow. At one point in the past, 25% of all of the World's ships were made on the River Clyde; in the future, perhaps the Clyde will be equally successful building spaceships ...

http://www.clyde-space.com/products/spacecraft_batteries

SPACE QUALIFIED BATTERIES_

High Energy Density, Flight Proven Batteries for Advanced Small Satellites and CubeSats

MAIN FEATURES

- High Energy Density; up to 150Wh/kg
- Suitable for hard vacuum conditions
- Integrated battery heater with thermostat to maintain battery temperature above 0°C
- Battery over-current protection
- Battery temperature, voltage, and current telemetry via integrated digital interface
- Available in 8.2V and 32.8V versions as standard; custom voltages also available
- Scalable battery capacity through use of parallel connected strings
- Inherently redundant for multi-string configurations
- Lithium Polymer for increased performance:
  - Low magnetic signature due to aluminium foil casing
  - Verified cycle life 5000 cycles (accelerated life test). 35000 cycle life expected (usage conditions dependent)
  - Batch LOT acceptance cells
- Other cell types available on request

CELL ACCEPTANCE TESTING

Lot Acceptance tests are performed on flight cells to verify integrity for space use.

Once the batch has passed this test, the cells are matched for capacity and voltage characteristics over temperature. This helps verify the individual cell integrity and also enables selection of cells with matched characteristics for flight batteries.

We are continuing to characterise our cells and are conducting further life tests in order to build up data for battery sizing for different mission scenarios.

LITHIUM POLYMER BATTERY OVERVIEW

A commercial Lithium Polymer cell has been selected by Clyde Space for use on small satellites. Prior to selecting this cell it has undergone a number of tests to verify its performance in a space environment. These tests were as follows:

- Capacity at C/10 under vacuum
- Radiation up to 500krad
- DPA
- Capacity at -10°C, 0°C, 20°C and 40°C
- Resistance
- Self-Discharge
- Missions Scenario Tests
- EMF vs SOC
- Cycling Tests at reduced pressure (15-20mbars) - 30% DoD, C/2 Charge/Discharge >5000 cycles

Clyde Space has performed further analysis and qualification of our cell under an ESA contract. In addition, NASA Goddard have tested and passed our battery for manned space flight on the shuttle.

SPACE QUALIFIED BATTERIES_

High Performance Small Satellite Batteries Designed for Small Satellite Budgets

Figure:10Whr battery integrated with 1U EPS (left) and 10Whr Remote Battery Board (middle & right)

CUBESAT BATTERIES

We have developed our CubeSat battery product to be as configurable and adaptable to different mission requirements. The flat-packed nature of our cells makes them very mass and volume efficient, enabling us to offer excellent energy densities. Our batteries are used on more CubeSat missions than any other provider.

The Clyde Space 1U – 2U EPS range comes with the option for either a 10Whr or 20Whr integrated battery. For missions needing more battery capacity, our stand-alone CubeSat battery is available in 10, 20 and 30Whr versions. We also have a Remote Battery Board (RBB) to make use of unused volume in your CubeSat. Each 10Whr string has a voltage of 8.2V and 1.25Ah capacity.

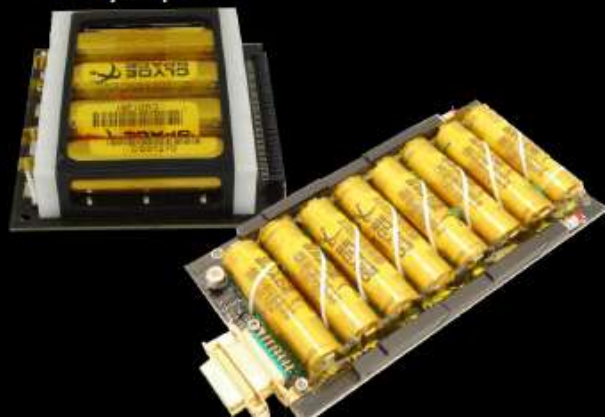
All batteries have an integrated, thermostatically controlled battery heater and built in over-current protection. The stand-alone battery and RBB each have dedicated I2C nodes for telemetry and command.

ENVIRONMENTAL TEST

- All Clyde Space products are subject to a strict qualification process before being released as a product. These tests include:
  - Component TID radiation testing to 15krads following ECSS guidelines.
  - Qualification thermal cycling.
  - Vibration and shock to NASA GEVS.
- Test data can be found in the product User Manuals

OTHER BATTERY PRODUCTS

The battery experts at Clyde Space have been known to apply their skills to other battery types. We have experience in using 18650 Lithium Ion cells for both CubeSats and Small Satellites. We have also produced batteries using the SAFT MPS176065 cell. These battery designs have been qualified to levels comparable to NASA GEVS and in some cases we have integrated our battery balancing circuit into the design. Below are some pictures of other batteries from Clyde Space:



Diehl & Eagle-Picher

DIEHL & EAGLE PICHER
Batterie-Systeme

Thermal Batteries

Read more

Main operation areas of the thermal batteries developed and produced by Diehl & Eagle Picher are military programs (missiles and ammunition) and aerospace applications as well as acoustic and electronic Torpedo countermeasures. Aircraft ejection seats and guided artillery ammunition, all of them presuming a long, maintenance-free shelf life in a broad temperature range, climate and dynamic environment. Our thermal batteries are designed according to customers' requirements and remain absolutely inert during storage. After activation those systems supply power within very short time.

Publications

Miniaturized Reserve Battery

Diehl & Eagle Picher (D&EP), a German-American joint venture, develop and produce activatable thermal batteries for defence applications and customized battery packs for both the defence and civil market...

NDIA Fuze Conference 2014

Every year international defense companies as well as US government officials and military personnel take advantage of the NDIA Fuze Conference exchanging information and important innovations in the fuze sector for military applications ...

Power Sources Conference 2014

Taking place in a biannual rhythm the Power Sources Conference is one of the most important exhibitions and information sources in the sector of military energy supply for both defense industry and many international government representatives ...

Mode of Operation of a Thermal Battery

Shematic structure and typical application of a thermal battery.

http://www.diehl.com/de/diehl-eagle-picher.html

Electric-Fuel/Epsilor

Company Profile

Epsilor is a world leader in the development and production of custom and moblie portable power systems for the military, medical, aerospace, industrial and EV markets. Epsilor's expertise lies in battery cell selection, primary and rechargeable battery pack design, assembly and electronic circuitry; battery charging systems and smart charging electronics. Customers include government agencies, the military and large corporations.

Epsilor works with its customers to provide high quality and unique power solutions for a vast array of applications. With over a decade of experience in providing cutting edge solutions with a wide range of electrochemistries, including Lithium Ion, Lithium Polymer, Nickel Metal Hydride, and Zinc Air, Epsilor has the experience and expertise to create the optimal portable power solution for the most challenging applications.

Epsilor's personnel numbers more than 140 employees, including an extensive engineering department made up of more than 30 engineers, electronics, software, mechanical and chemical. Epsilor's technical team combined with its on-site testing facilities is a one-stop-shop starting from the conceptual design stages through first article testing and qualification on to serial manufacturing.

Epsilor has two R&D and manufacturing facilities in Israel, located in Dimona and Beit Shemesh.

Epsilor is part of Arotech Corporation's (Nasdaq: ARTX) power sources division which is made up of the Epsilor-Electric Fuel Ltd. facilities in Israel and Electric Fuel Battery Corporation in Alabama, USA.

http://www.efbpower.com/ http://www.epsilor.com/

Electric-Fuel/Epsilor

Epsilor designs and manufactures custom-designed battery packs for a variety of aerospace applications. Whether for aircraft, UAVs, satellites or rockets, Epsilor's solutions are designed to operate in the extreme environmental conditions that these airborne applications demand, and also meet the most stringent quality requirements.

Epsilor chooses the optimal battery chemistry and tailors the battery pack design to meet the mission critical requirements, such as: specific energy & power density, weight, volume, reliability, life cycle and cost.

UAV Battery

Please contact us in order to learn more about our capabilities in this challenging specialty.

UAV

- Rechargeable batteries: High energy density (up to 240Wh/Kg), operating temperature range -55°C to 60°C, lightweight and reliable.
- Chargers: Accurate battery balancing, storage mode and battery testing capability.

Rockets & Launchers

- Primary and Rechargeable Batteries which meet full Milspec for extreme environmental conditions (2000 G, altitude, temperature, high current load, high reliability, long storage life)
- Chargers: Record battery information, accurate battery balancing, battery testing capability

Satellites

- Rechargeable Battteries for use in space conditions: meet full milspec for extreme environmental conditions with a emphasis on high reliability and long life cycling

http://www.efbpower.com/ http://www.epsilor.com/

Electrochem Solutions

Founded in 1979 Electrochem is recognized as an industry leader in customized total power solutions for applications where failure is not an option. Our product solutions have been on space shuttle flights with NASA, in the desert with the U.S. military, in the oceans to warn of tsunamis and monitoring the operational performance of multi-million dollar production equipment – to name just a few. For over 30 years, our expert knowledge and unparalleled experience have allowed us to develop unique solutions that satisfy our customers' needs for today, along with envisioning and designing solutions for tomorrow's challenges.

With our recent acquisition of Micro Power Electronics, located in Beaverton, OR, we now provide an even greater range of customized power solutions that enable the success of our customers' critical market applications. The combination of Electrochem and Micro Power brings together two complementary organizations that possess stringent industry certifications, superior product and IP portfolios, engineering expertise, thought leadership, world-class processes, innovative mindsets and financial stability.

Born from the lithium battery, invented for the implantable pacemaker by our founder, Wilson Greatbatch, Electrochem embraces our heritage of quality, reliability and innovation. With one of the broadest portfolios on the market today, we offer customized rechargeable and non-rechargeable cells, battery packs, charging and docking stations and power supplies for the portable medical, energy, military and environmental markets.

Electrochem is much more than a manufacturer of batteries -- with our seasoned team of chemical, mechanical and electrical engineers, supply chain managers and regulatory experts, we are uniquely positioned to partner with you to create solutions that meet and exceed your expectations at a Total Cost of Ownership (TCO) that enables you to win market share in an increasing competitive global market. And, with our state-of-the-art manufacturing facility and expanded coast to coast footprint, we are equipped to rapidly develop your new and existing technology solutions even better than before.

ELECTROCHEM

http://electrochemsolutions.com

HBL - India

HBL Power Systems Ltd is a listed Indian company, in business since 1977, with a focus on engineered products and services.

Our initial business strategy was to identify technology gaps in India that the company could fill by 'indigenous efforts'.

The first products selected and successfully developed were Aircraft batteries - eventually leading to HBL offering the worlds widest range of specialized batteries.

Our expertise in batteries generated opportunities and ideas to diversify. The company moved into new businesses and markets that utilise our batteries, such as industrial electronics, defense electronics, and railway electronic signaling.

Recent diversification, leveraging the companies engineering strengths, has led to new businesses in precision manufacturing, spun reinforced concrete and 'green' technology products.

Our success has been built serving some of the world's most demanding customers and applications. We would value your opportunity to serve your business.

http://www.hbl.in/product-1-batteries

HBL - India

MISSILE BATTERIES

Silver Oxide Zinc Missile Batteries

HBL's Silver Oxide Zinc batteries are used in Missiles as a source of energy for control systems.

HBL-SZ-18 Batteries meets the specification requirements of Surface to Air Missiles P-15, P-20 and P-22 series.

http://www.hbl.in/product-1-batteries

Space Vector

Batteries

Space Vector currently fabricates a variety of rechargeable (secondary) batteries used in launch vehicle, spacecraft and Unmanned Aerial Vehicle (UAV) applications. These rugged 28 Vdc batteries power vehicle systems under severe boost and space conditions. Batteries can be mounted with or without isolators. The 2.2 AH battery is used on several range approved RCC-319 Flight Termination Systems (FTS) and often coupled with our FTS relay box to power the command/destruct receivers, S&A, and destruct ordnance as shown the block diagram below. The 10 AH battery is qualified to power range tracking systems and has cell heaters for operating in cold environments. Our batteries have successfully passed qualification level thermal cycling, vibration, shock, vacuum, humidity, fungus resistance, fine sand, salt fog, explosive atmosphere, and EMI/EMC testing and have flown on a variety of missions and vehicle configurations.

Space Vector also produces a line of aerospace grade lithium-ion and lithium-polymer batteries. The 1.5 Ah battery is designed as a drop in replacement for our existing 2.2 Ah battery and incorporates high-current cells capable of delivering over 30 Amps (30 ms pulse) at 28 Vdc under extreme temperature ranges. The 20 Ah battery is capable of delivery over 200 Amps continuously from a single, lightweight package. Each battery uses SVChargeTM Smart Battery Technology which provides Programmable Protection and Monitoring. The cells within the battery are balanced during charging with optional "Flight Mode" lockout of protection features during flight. Li-Ion and Li-Poly batteries can be purchased either with an internal or external Battery Management System (BMS) and are designed to be stackable.

7 Ah and 10 Ah System Batteries with Heaters

http://spacevector.com/

Space Vector

2.2 Ah Range Approved Flight Safety Battery

7 Ah System Battery

20 Ah Li-Poly System Battery

1.5 Ah Li-Ion Flight Safety Battery

http://spacevector.com/

Total Battery Solutions

TBS high quality batteries and chargers for various Aerospace sectors

Aerospace batteries

TBS battery packs and chargers are specifically designed and engineered to work in the aerospace market sector, ensuring safety and reliability.

The Aerospace sector covers a vast amount of areas and TBS can offer our customers the right solutions, whether the requirements are for basic Lithium Ion rechargeable battery packs to new technologies with a TBS fully designed battery management system and dedicated charger.

View our aerospace battery products

http://www.totalbatterysolutions.co.uk/aerospace-batteries/

Uralelement OAO / Russia

http://www.elems.ru/ourproduction.html

Thank You for Your Attention

Shmuel De-Leon
Shmuel De-Leon Energy Ltd
www.sdle.co.il
shmuel@sdle.co.il

Information for presentation obtained by:

1. **Public web sources.**
2. **Shmuel De-Leon Battery/Energy Sources DataBase ® (Includes 29000 cell PDF data sheets) http://www.sdle.co.il/Default.asp?sType=0&PageId=45580**

Shmuel De-Leon Energy Ltd

This presentation has been compiled for the exclusive, internal use by our client. Within the framework of the engagement, Shmuel De-Leon Consultants will act solely in the interest of the client. Property rights in favor of third parties will not be constituted and no protective effect shall arise for the benefit of third parties.

The presentation shall be treated as confidential and may not be passed on and/or may not be made available to third parties without prior written consent from Shmuel De-Leon Energy.