REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. <b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b>					
1. REPORT DATE (DD-MM-YYYY)	REPORT DATE (DD-MM-YYYY)     2. REPORT TYPE			3. DATES COVERED (From - To)	
02/16/2010	Technical Report - Briefing C	Charts			
4. TITLE AND SUBTITLE		5a. CONTRACT NUMBER			
Pure Form of LiBOB Salt and the Purification Process Producing Such					
Form			5b. GRANT NUMBER		
			5c. PR	5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) 5d.			5d. PR	OJECT NUMBER	
				TASK NUMBER	
			5e. IA	TASK NUMBER	
5f. V			5f. WO	RK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION	
Army Research Laboratory Adelphi MD United States				REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
Army Research Laboratory Adelphi MD United States					
			_	11. SPONSOR/MONITOR'S REPORT	
				NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT					
A = Approved For Public Release 12/3/2015 No					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
		40 1000000			
16. SECURITY CLASSIFICATION O	ABSTRACT	18. NUMBER OF	19a. NAME	OF RESPONSIBLE PERSON	
	. THIS PAGE	PAGES			
	5		19b. TELEP	HONE NUMBER (Include area code)	



U.S. Army Research, Development and Engineering Command

# Pure Form of LiBOB Salt and the Purification Process Producing Such Form



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Inventor: Dr. Kang Xu ARL 09-33

APPROVED FOR PUBLIC RELEASE

February 16, 2011

**Technology Overview** 



The invention describes the synthesis and purification of a new lithium salt, bis(oxalato) borate (LiBOB).

Due to inherent limitations, there is interest in replacing LiPF6 salt. LiBOB is viewed as a good option because:

No P-F bond, does not attack organic components
Does not decompose thermally into HF (as LiPF6 does); CO2 as benign products

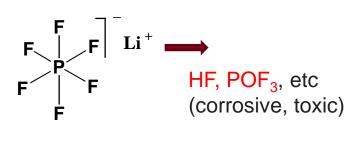
However, "purified" LiBOB is required to maximize performance benefits. This is currently difficult and expensive to achieve.

The core technology provided by this invention is the purification procedure, the quality-control standard and the resulting pure form of LiBOB obtained from this process.

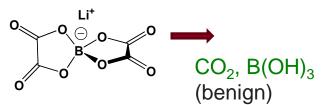
This pure form of LiBOB is a distinct compound as compared with other available commercial products.

## APPROVED FOR PUBLIC RELEASE

RDEGON



SOA Electrolyte contains LiPF<sub>6</sub>



Thermally Stable Electrolyte contains LiBOB

**Technology Overview** 

The innovation of preparing pure form of LiBOB and the QC

- Impure LiBOB from commercial source cannot support high temperature operation
- The pure form of LiBOB can support Li ion batteries operating at elevated temperatures up to 80 °C
- It also improves safety under abusive over-charge and high-temperature storage

Impure LiBOB does not support HT operation

1.1 Cell Vent Capacity Retention 0.8 0.7 LIBOB/EC/DMC ( 0.6 Baselin 0.5 50 100 150 35 % 30 Dc Impedance 25 20 15 100 Cycle Number

APPROVED FOR PUBLIC RELEASE

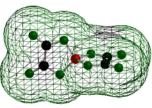
US ARMY

RDECOM

## TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

1.2 75 ° C (NCA) or 60 °C (LFP) cycling at 1C Capacity Retention **Capacity Retention** 0.8 0.8 0B-1 NCA 0.6 0.6 OB -2 NCA 0.4 0.4 ICA LIBOB-0.2 LEP LIBOR-2 0.2 BOB-2 LFP LEP LIBOB--iBOB-3 LFF 0 200 400 200 400 600 800 1000 Cycle Number Cycle Number

Pure Form of LiBOB supports HT operation of Industry Li Ion Cells for > 1000 cycles Libob





High temperature stability is critical for battery packs in electrified vehicles

• SOA electrolyte fail to do so

RDECOM

• Become dangerous over 60 °C due to HF production

The pure form LiBOB can widen service temperature range of Li ion batteries

•Dramatically improves capacity retention at both room and high temperature up to 80 °C

•Significantly reduces cell impedance

The invention of the process provides easy production of high purity of LiBOB and its effective Quality Control

Safety advantage over SOA electrolytes •LiBOB allows large format Li ion cells with higher safety than SOA electrolyte salt LiPF<sub>6</sub>

•Higher stability for both over-charge and HT abuses

INOLOGY DRIVEN. WARFIGHTER FOCUSED.

8 Ah Li ion cell





**Battery Pack in Prius** 

Video - SOA Electrolyte (LiPF6) w/o LiBOB

Video - Electrolyte with pure LiBOB

Technology Advantages

This invention holds a number of advantages over the current state-of-art:

- Enables the high temperature application of Li ion battery
  - Demonstrates excellent stability at high temperature; up to 80°C
- Is well suited for harsh environments of Hybrid Electric Vehicles (HEV
- Provides superior performance vs. existing commercial LiBOB; maintains 95% energy density after 1,000 cycles
  - at 75 °C capacity retention ~90% at 1000<sup>th</sup> cycle while most SOA failed before 400<sup>th</sup> cycle
  - at 60 °C capacity improved by 15% vs. SOA at 2000<sup>th</sup> cycle
- •Establishes purification process and standard; nearly 100% pure
- Improves safety of Li ion battery under both over-charge and HT abuses
- Open system accommodates a variety of cathode chemistries

RDECOM

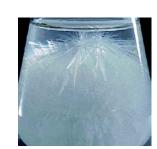
**Technology Proof of Concept** 

# Method of preparation of these novel additives

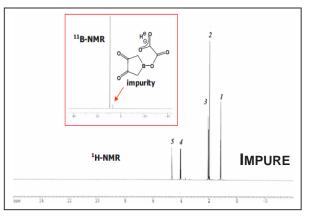


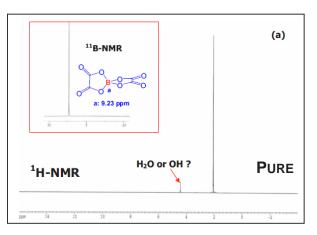
US ARMY

RDECOM



Evaporation/Precipitation Recrystallization





### Structural characterization/QC

Soxhlet Extraction



Coin Cells Industry Cells (8 Ah)



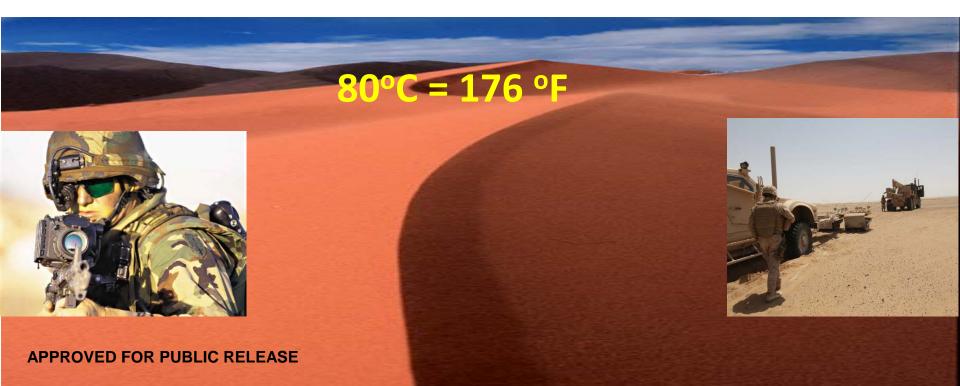
### TECHNOLOGY

# TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

APPROVED FOR PUBLIC RELEASE



- Military hybrid electric vehicle applications to reduce fuel consumption and reduce the need for dangerous logistical refueling operations
- Soldier Power in hot climate
  - Battery life significantly improved



**Commercial Applications** 

Two major markets

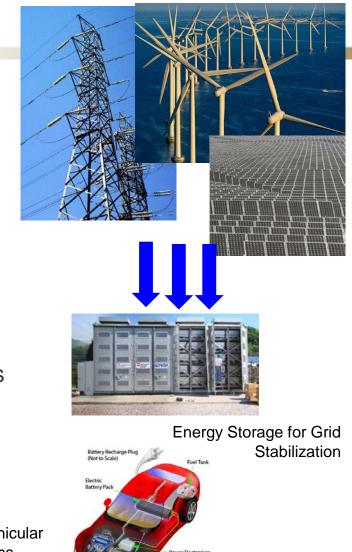
RDECOM )

- Electric Vehicle, Hybrid Electric Vehicle
- Large scale stationary energy storage

The invention provides high temperature stability of Li ion battery.

In particular, the invention benefits Li ion battery high temperature applications/environments such as those found in hybrid electric vehicles (HEV).

The purification method developed is also useful for producing other salts that have the BOB anion, such as NaBOB, Mg(BOB)<sub>2</sub> or other metal salts as additives, ionic liquid for double layer capacitors and batteries, etc.



ITER FOCUSED.

Electrified Vehicular Power Systems

**TECHNOLOGY** 

APPROVED FOR PUBLIC RELEASE



A patent license and CRADA is sought.

The current technology is TRL 6 and will benefit from a collaboration between the inventor team and the commercialization partner in order to speed the development to the market. This would most readily be done through a license agreement/CRADA.

A provisional patent application has been filed.