SAFT-USABC 12V Start-Stop Phase II

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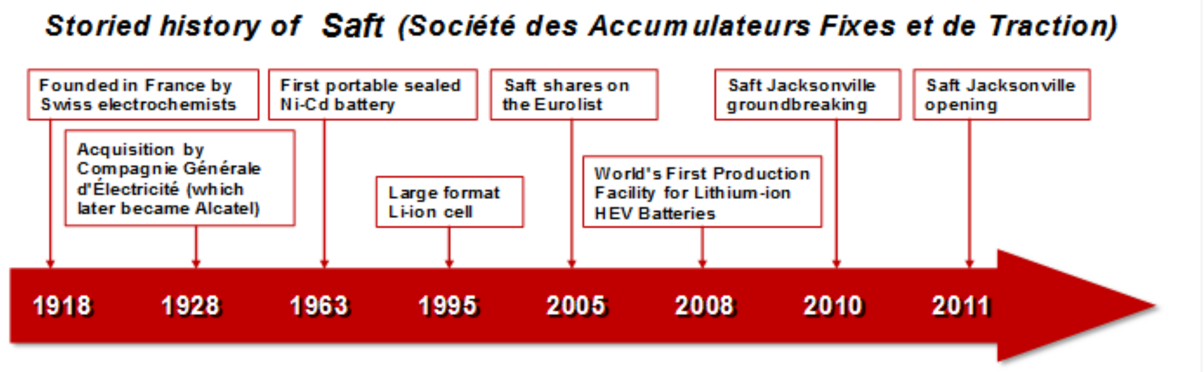
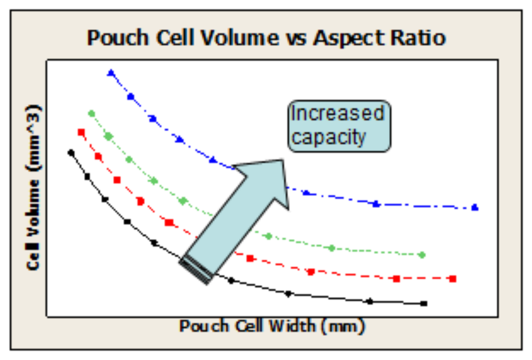
Saft Background



- Over 90 years of servicing industrial / professional markets
- Saft's stability is due in large part to a global presence in a variety of markets
- With around 4,000 employees worldwide, Saft is present in 18 countries

Li-Ion Cell Types

- Saft offers many cell size and shape options:
  - Cylindrical (from 3Ah to 80Ah)
  - Prismatic
  - Pouch – (currently specialty-use only)
- Cells can be customized for:
  - Power/Energy
  - Thermal management
  - Shape/size allowances
  - Safety management
  - System mass



Commercialized Li-Ion Chemistries

- Positive Chemistries:
  - NMC
  - NCA
  - LMO
  - Super Iron Phosphate (SLFP)
- Negative Chemistries:
  - Graphite
  - LTO (launch in 2015)

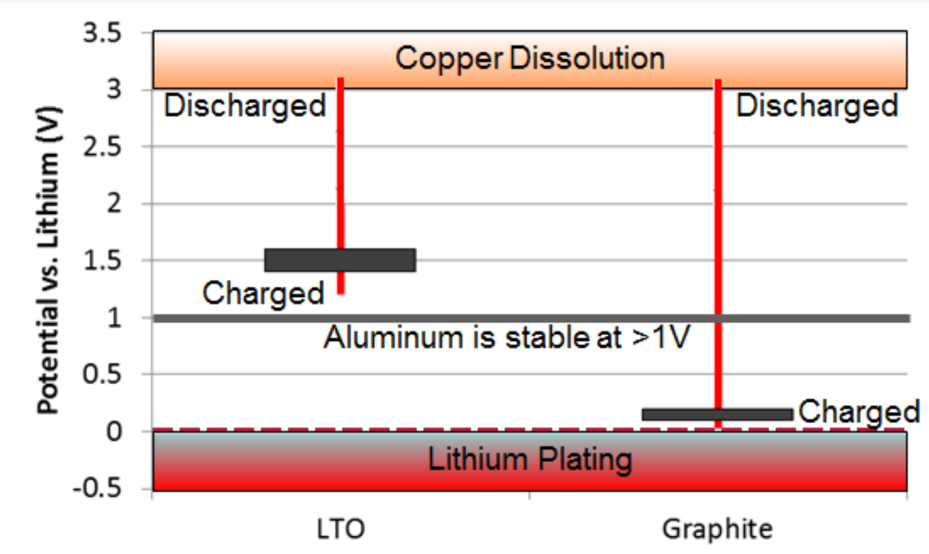
USABC 12 Volt Start-Stop Battery Program

- Saft aims to develop an advanced, high-performance battery module for 12V Start-Stop vehicle applications, based on its proprietary LTO lithium-ion battery technology
- This 2½ year program will result in the delivery to USABC of 12VSS module assemblies with cells in a prismatic format placed in thermoplastic module along with battery management electronics

USABC Requirements:

End of Life Characteristics	Units	Target	
		Under hood	Not under hood
Discharge Pulse, 1s	kW	6	
Max discharge current, 0.5s	A	900	
Cold cranking power at -30 °C (three 4.5-s pulses, 10s rests between pulses at min SOC)	kW	6 kW for 0.5s Then 4 kW for 4s	
Min voltage under cold crank	Vdc	8.0	
Available energy (750W accessory load power)	Wh	360	
Peak Recharge Rate, 10s	kW	2.2	
Sustained Recharge Rate	W	750	
Cycle life, every 10% life RPT with cold crank at min SOC	Engine starts/miles	450k/150k	
Calendar Life at 30°C, 45°C if under hood	Years	15 at 45°C	15 at 30°C
Minimum round trip energy efficiency	%	95	
Maximum allowable self-discharge rate	Wh/day	2	
Peak Operating Voltage, 10s	Vdc	15.0	
Sustained Operating Voltage – Max.	Vdc	14.6	
Minimum Operating Voltage under Autostart	Vdc	10.5	
Operating Temperature Range (available energy to allow 6 kW (1s) pulse)	°C	-30 to + 75	-30 to +52
30 °C – 52 °C	Wh	360 (to 75°C)	360
0 °C	Wh	180	
-10 °C	Wh	108	
-20 °C	Wh	54	
-30 °C	Wh	36	
Survival Temperature Range (24 hours)	°C	-46 to +100	-46 to +66
Maximum System Weight	kg	10	
Maximum System Volume	L	7	
Maximum System Selling Price (@250k units/year)	$	$220	$180

LTO (Lithium Titanate) Development at Saft



LTO and graphite potential vs. lithium in reference to lithium plating, aluminum stability and copper dissolution

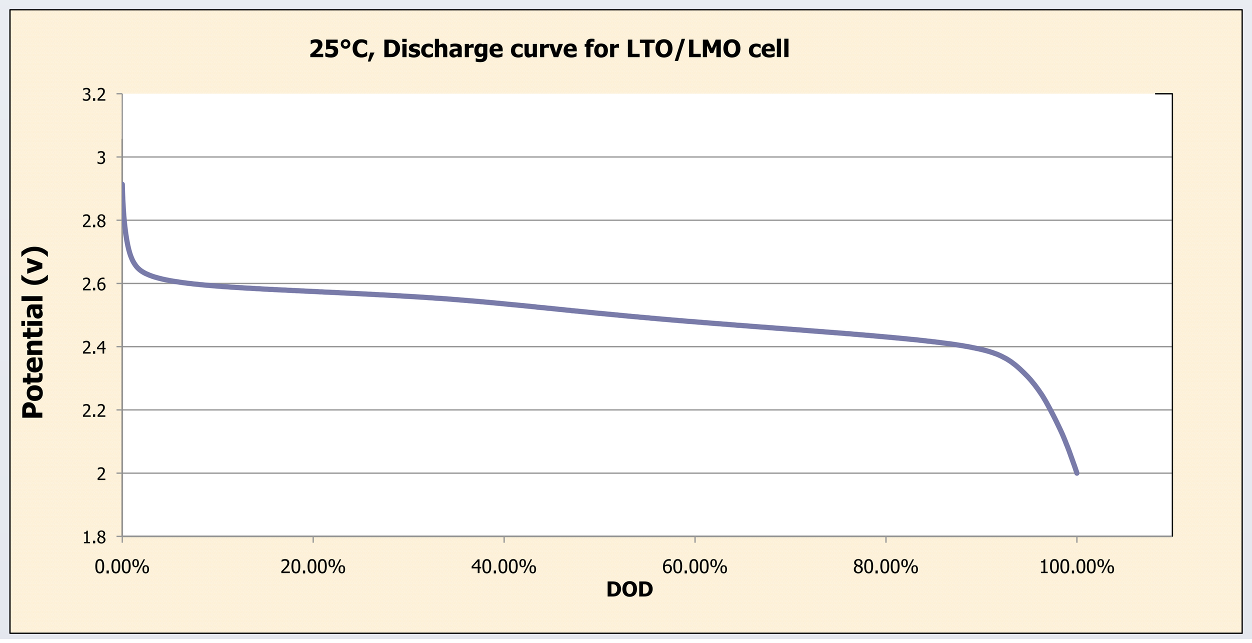
The red line is the total potential range (including first charge and complete discharge) while the black rectangle is the typical operating potential.

LTO operates in a potential range far from lithium plating and where aluminum is stable providing cycle life and safety advantage plus indefinite 0V storage capability when coated on aluminum substrate.

- **Benefits:**
  - No SEI needed or formed
    - Results in extremely long cycle life – even when utilized at very high DOD
  - Excellent low temperature performance.
  - Very fast charge capability (>7C)
  - Enables use of aluminum in negative current collector
- **Drawbacks**
  - High temperature durability issues
  - Excessive gas generation
  - High impedance growth
  - Low energy density

LTO/LMO Cell development for USABC program

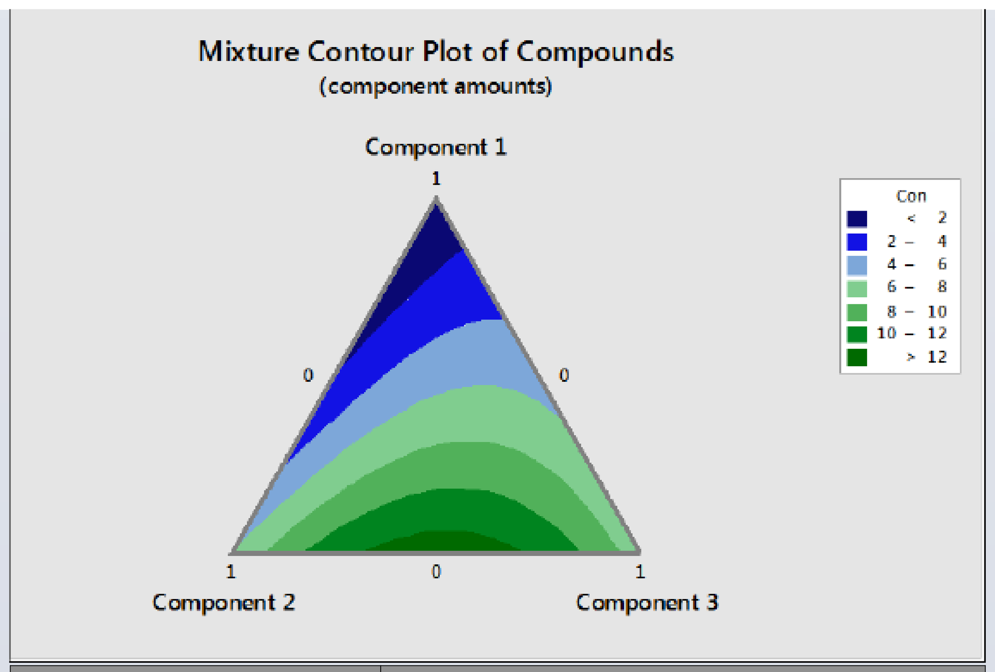
- Development on LTO cells has been ongoing at Saft for over six years
- Since July 2015 we have been working with the support of USABC/DOE funding to develop an all-aluminum prismatic PHEV2 size LMO/LTO cell optimized for low temperature (-30°C) operation



Discharge curve for a typical LTO/LMO cell demonstrating a relatively flat profile

Electrolyte Studies

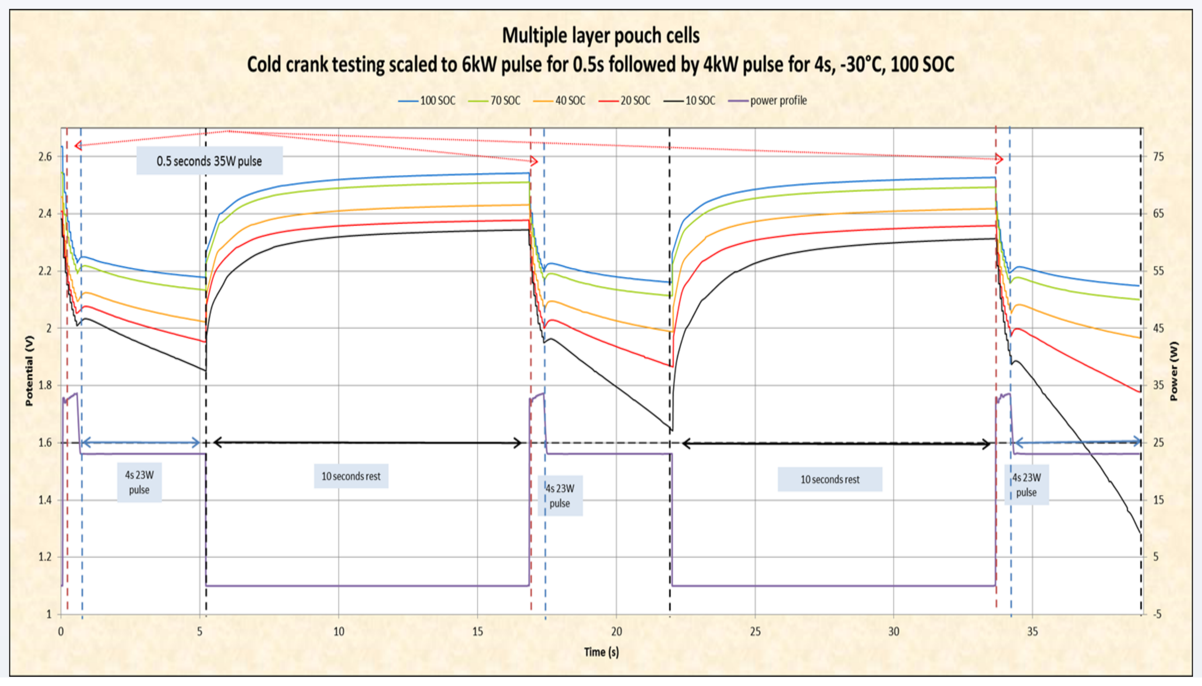
- A key requirement for the USABC program is to be able to achieve the cold cranking.
- Although chemistry and discharge profile is important as temperature decreases, a critical element to achieving the requirements is the electrolyte
- SAFT conducted a design of experiments on the electrolyte conductivity at -30°C, this enabled us to distinguish between the electrolytes and identify the most likely candidate for success
- By combining different solvents we can optimize the electrolyte for performance, conductivity studies on binary and ternary electrolyte composition were undertaken and revealed interesting results.



Electrolyte	Conductivity (mS/cm) at -30 °C
Saft Standard	2.43
Electrolyte 1	2.53
Electrolyte 2	5.69
Electrolyte 3	11.94
Electrolyte 4	13.36
Electrolyte X	6.84

As depicted in the diagram above, the highest conductivity is achieved using a binary solvent mixture rather than a ternary solvent. Component 2 and component 3 in a 50:50 ratio show auspicious conductivity measurements, however we found salt precipitation issues with this composition (electrolyte 4). Electrolyte 3, with an alternative binary blend, demonstrated the best performance with no precipitation issues. Electrolyte X is an novel composition containing component 2 and an alternative solvent.

USABC Cell/Module Performance and Design



Cold crank testing was performed on multi-layer pouch cells using LMO as the positive electrode and LTO as the negative electrode.

Electrolyte 3 offers impressive performance for the cold crank testing with the capability to pass the USABC requirements below 20% SOC

Although these results are very promising for the performance requirements, once we evaluated high-tempertature stability and gassing rates, we found results that were not so promising

LTO//Electrolyte 3//LMO Gassing studies

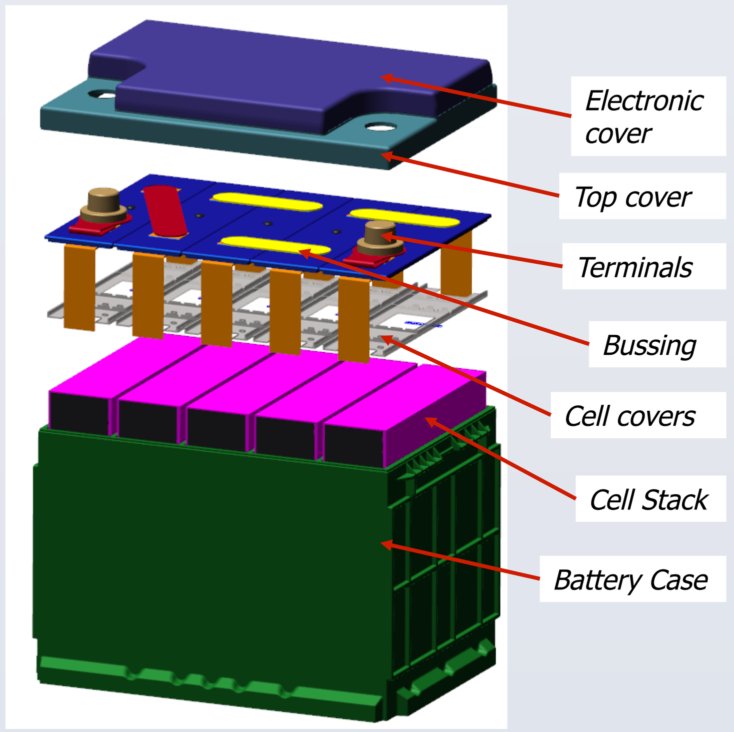
- Gassing issues were prevalent when using the LTO/LMO set up with electrolyte 3
- Through our investigations we have found that the negative LTO electrode affects the gas generation behavior more significantly than the positive electrode, however the overall gassing rate is significantly higher than that which was desired. This will have a negative effect on the lifetime of final module
- For this reason we began concurrent investigations into using additives to stabilize electrolyte 3, as well as investigating the gassing rates of the other promising electrolyte compositions
- The stabilization efforts were quite successful for gassing but have such a significant effect on the performance and it was decided to investigate other electrolyte compositions with decent performance
- The ultimate goal is to identify an electrolyte with low gassing rates that still offers low temperature performance capabilities, currently the best candidate is electrolyte X

Electrolyte	Gassing Rate at 60°C (ml/Ah-hr)
Saft Standard	0.005
Electrolyte 3	1.2
Electrolyte 3 + Additives	0.08
Electrolyte X	0.03

In this table we can see the gassing rates from some of the electrolyte compositions we have investigated

Module Design and Development

- An image of the 3D model of the module that Saft is developing for the USABC program can be seen on the right
- It will contain five cells with the chemistry developed from the research discussed above
- We will target low cost and minimal control electronics to achieve the cost targets outlined by USABC
- It is expected the final module should be a drop in replacement for lead acid batteries and eliminate the need for a dual battery in a stop-start system



System Development

- A significant aspect of the development is the incorporation of a system control into the battery to ensure optimum performance, as well as longevity
- It is expected that this will ultimately entail a cost-effective battery monitoring system that provides voltage measurement, temperature measurement, cell balancing and data communication

Conclusions & Future Work

- Saft has developed LTO based cells with LMO positive electrodes that are optimized for high power and low temperature operation.
- The cells pass Cold crank testing at -30°C.
- R&D effort has been focused on determining the root cause for gas generation in an LMO/LTO cell
- Moving forward SAFT 's goal is to prevent and/or diminish gas generation in the LMO/LTO cell design whilst concurrently identifying an alternative electrolyte that achieves the cold cranking requirements
- Ultimately, we aim to develop and manufacture over 20 fully operational batteries with an integrated electronic system contained in a novel architecture, and identify a path to full commercialization

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