“Turbo-charging” Your Forklift Fleet: The Power of Industrial Lithium Forklift Batteries

Presented by:
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Agenda

• Navitas Introduction
• Market Review / Segmentation
• Technology Review
• NYSERDA Project Results
• Case Study Deployments
• Financial Outlook
• Additional Benefits
### Lithium Battery Solutions
- System Design and Assembly
- Electronics & Battery Management Systems (BMS)
- Custom Cell Development
- Analytical and Testing
- Cell Chemistry R&D

#### Capability

|-------|--------------------------|-----------------------------|-----------------------------------------------|-------------------------|------------------------|-------------------|
| • 12V NATO 6T Battery  
• 24V NATO 6T Battery  
• Multi-kWh motive application batteries | • In-house battery pack design development, prototyping, and manufacturing | • In-house BMS Design  
• In-house SMT line | • Various Li-ion chemistries developed  
• High power and High energy density chemistries | • 500+ MACCOR test channels  
• Cell tear down analysis  
• In-house UL/UNDOT testing | • Custom anode, cathode, and electrolyte development  
• Battery materials evaluation |
The material handling market is poised to capitalize on cost efficiencies created by the substantial investments in cell technology made by other industries.

### Lithium Battery Industry Spectrum

<table>
<thead>
<tr>
<th>Energy Applications</th>
<th>Portable Applications</th>
<th>Industrial and Motive Applications</th>
<th>Electric Vehicle</th>
<th>Grid Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium Battery Products</td>
<td>1 – 100 Wh</td>
<td>100 Wh – 1 kWh</td>
<td>1 kWh – 1 mWh</td>
<td>20 - 100 kWh</td>
</tr>
<tr>
<td>1 – 100 Wh</td>
<td>100 Wh – 1 kWh</td>
<td>1 kWh – 1 mWh</td>
<td>20 - 100 kWh</td>
<td>&gt; 1 mWh</td>
</tr>
</tbody>
</table>
9. What sources of motive power will show the most growth in electric forklift trucks in the next three years? Please rate the following on a scale of 1 to 3 (where 1=-10% to 0%, 2=>0% to 10%, 3=11% to 20%)

<table>
<thead>
<tr>
<th>Motive Power Source</th>
<th>1 -10% to 0%</th>
<th>2 &gt;0% to 10%</th>
<th>3 11% to 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium Ion</td>
<td>1</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Lead Acid Battery</td>
<td>5</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Fuel Cells</td>
<td>7</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

# of respondents
United States Factory Shipments

- Electric Rider
- Motorized Hand
- Internal Combustion Engine

Year:
- 1994
- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
Industrial Truck Association (ITA)

Class 1: Electric Counterbalance (Cushion or Pneumatic Tire)
Class 2: Electric Narrow Aisle
Class 3: Electric Pallet Jacks
Class 4: Internal Combustion, Cushion Tire Counterbalance
Class 5: Internal Combustion, Pneumatic Tire Counterbalance
Navitas Starlifter Lithium Product Overview

- **ESS Battery**
  - 24V, 36V, 48V Battery Packs
- **Counterweight Tray**
  - Weight and Footprint Replacement For Lead Acid battery packs
- **UIM (User Interface Module)**
  - Visual and Audio Indicator of lithium battery pack information for truck operators
  - Provides warnings for low state of charge and faults
  - Diagnostics information display
SOLVE FOR X.

Primary Lithium Applications

- Fast Opportunity Charging
  Capable of Charging in 1-2 Hours; Lead Acid Charger Compatible

- Superior Cold and Hot Performance
  40% Increased runtime of lead acid in freezer warehouse temperature

- Multi-Shift Operations
  High Performance, Long Run Time, Long Life
Lithium Value Propositions

- NO BATTERY ROTATION
- ONE-HOUR CHARGE TIME
- SEALED / NO MAINTENANCE
- REDUCED BATTERY INVENTORY
- ELIMINATE EXCHANGE SYSTEM
Lithium Forklift Battery Program
The objectives of the project were:
1. Demonstrate Lithium Battery is viable for lift truck applications through bench level performance and safety testing
2. Develop and release a public interface specification to include truck, energy storage system (battery) and charger;
3. Demonstrate a Lithium Battery’s performance in real-world, in-truck application including opportunity/fast charging (enabling one battery per truck), cold temperature robustness and reduced overall fleet operating costs;
4. Advance the technology from TRL4 (component level technology development) to TRL 6 (engineering scale technology demonstration).

Upon completion of the project, the summary results were:
1. Developed and published a Public Standard Interface Specification for all trucks, batteries and chargers
2. Successfully demonstrated LIB as drop-in replacement for LAB in a Reach Truck
3. 17% productivity improvement with LIB and opportunity/fast charging (pallet moves per operational hour) demonstrated at customer site
4. Demonstrated ability to operate with reduced lithium nameplate capacity of 40-50% of lead acid
5. Developed comprehensive ROI calculator to determine payback period for single truck (16 months) and full fleet (10 months) conversions from LAB to LIB. Installing a new fleet of truck with LIB over LAB results in a 9% overall savings (capital investment and labor) over a six-year period.
6. Advanced the technology to a TRL 8 (actual system qualification)
1. Requirements and Specification Development
   1. Standard Communication Interface between lithium battery, forklift and charger
   2. Mechanical Design Requirements (Wide Range of Battery Sizes)
   3. Truck Energy Demand Profile
   4. Charging Cycle Definition

2. Module Level Battery Evaluation and Testing
   1. Bench Testing
   2. Performance Baseline (Various Temperatures)
   3. Heavy Duty Cycle with Opportunity/Fast Charging

3. System Design (Battery to Truck and Charger)
   1. Electrical/Communication Systems
   2. Mechanical System Design
   3. FEA and Mechanical Modeling

4. Battery Integration and Qualification
   1. Battery Install, Integration and Check Out
   2. In Truck Confirmation Testing

5. Customer System Evaluation
   1. Lithium vs Lead Acid Battery Testing Summary
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Ah Capacity Under Real World Forklift Load vs. Manufacturers Ah Nameplate</td>
<td>✔</td>
<td>Measured 109%</td>
</tr>
<tr>
<td>Ability to Support Real World Forklift Load in Hot Ambient Temperature</td>
<td>✔</td>
<td>Measured 112%</td>
</tr>
<tr>
<td>Ability to Support Real World Forklift Load in Freezer Warehouse Ambient Temperature</td>
<td>✔</td>
<td>Measured 40% increase over Lead Acid</td>
</tr>
<tr>
<td>Ability to Support Real World Forklift Operation for 14 Continuous Shifts with No Battery Change-Outs Utilizing Opportunity Charging</td>
<td>✔</td>
<td>Completed 14 continuous shifts</td>
</tr>
</tbody>
</table>
## Maines Field Trial Success & UL Safety Validation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Testing – Thermal Runaway</td>
<td>✔️</td>
<td>Exceeded expectations with no cell propagation and 2 minute venting</td>
</tr>
<tr>
<td>MAINES FIELD TRIAL</td>
<td>✔️</td>
<td>Drivers loved the LIB</td>
</tr>
<tr>
<td>Forklift driver reaction</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Lift Speed and Truck Acceleration</td>
<td>✔️</td>
<td>Notable increase by drivers, especially at bottom of SOC vs. lead acid</td>
</tr>
<tr>
<td>Productivity vs. Lead Acid Truck</td>
<td>✔️</td>
<td>17% increase in pallets/hour using LIB due to faster trucks and no battery swaps</td>
</tr>
<tr>
<td>LIB Zero-Maintenance</td>
<td>✔️</td>
<td>5 weeks field operation without maintenance</td>
</tr>
<tr>
<td>Opportunity Charging</td>
<td>✔️</td>
<td>700Ah LIB battery with no swap-outs did the job of a 1240Ah lead acid</td>
</tr>
<tr>
<td>Battery Efficiency</td>
<td>✔️</td>
<td>50% less waste heat from LIB vs. LAB 2% more work done with 10% less Ah’s with LIB</td>
</tr>
</tbody>
</table>
# Duty Profile and Test Set Up

## 95% percentile user duty profile

<table>
<thead>
<tr>
<th>Description</th>
<th>Est Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Place module in environmental chamber. Soak until battery stable at 20 $\pm^1$ C</td>
<td>&lt;1 hr</td>
</tr>
<tr>
<td>2. CC charge at 72A until Max Voltage (43.8V) reached, then CV charge at 43.8V until Current &lt;2A</td>
<td>2 hrs</td>
</tr>
<tr>
<td>3. Run sequence A (500 second drive cycle) until lower voltage limit reached (30 V). Estimated at 34 cycles</td>
<td>5 hrs</td>
</tr>
<tr>
<td>4. Repeat charge and discharge (steps 2 &amp; 3) 3x</td>
<td></td>
</tr>
<tr>
<td>5. Set chamber to 20°C, soak until stable</td>
<td></td>
</tr>
</tbody>
</table>

![Current Profile for 100Ah (1/7th Scale) Module Testing](image)
• Lithium battery maintained good temperature over forklift duty cycle
• Lithium battery discharged total 109% of manufacturers Ah nameplate rating over forklift duty cycle
• Lithium battery maintained in-spec temperatures over forklift duty cycle when starting hot-soaked at 40 degrees Celsius (104 Fahrenheit)

• Lithium battery discharged total **112%** of manufacturers Ah nameplate
Lithium battery provided forklift power requirements with no problems when cold soaked in -20 and -10 degree Celsius "freezer" type environments

Lithium battery discharged total 70% of manufacturers Ah nameplate while cold vs. typical 50% effective capacity with lead acid
Key value add from Navitas lithium battery is ability to utilize 1 battery per truck for 3-shift per day operation with short high-power opportunistic charging during worker breaks – **NO BATTERY CHANGES**

Testing simulated actual forklift load and opportunity charging profile on Navitas lithium battery module

Battery forklift load was supplied by Raymond as typical customer use case profile

The testing results (next slide) support continuous 24-hour 3 shift per day operation using opportunity charging

<table>
<thead>
<tr>
<th>Time</th>
<th>Load Profile Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75 hours</td>
<td>Simulated forklift battery operating load profile from Raymond: typical work period</td>
</tr>
<tr>
<td>15 minutes</td>
<td>Opportunity charging profile for 15 min workers break 1</td>
</tr>
<tr>
<td>1.75 hours</td>
<td>Repeat work sequence</td>
</tr>
<tr>
<td>30 minutes</td>
<td>Opportunity charging profile for 30 min workers lunch</td>
</tr>
<tr>
<td>1.75 hours</td>
<td>Repeat work sequence</td>
</tr>
<tr>
<td>15 minutes</td>
<td>Opportunity charging profile for 15 min workers break 2</td>
</tr>
<tr>
<td>1.75 hours</td>
<td>Repeat work sequence</td>
</tr>
<tr>
<td>15 minutes</td>
<td>Run opportunity charging profile for 15 min at shift change</td>
</tr>
</tbody>
</table>

**TOTAL:**

- 8 hours
- Total work: 7 hours
- Total break + opportunistic charging: 1 hour
Opportunity Charging Validation

- Lithium battery completed **14 continuous shifts** using simulated forklift duty cycle and short opportunity charging during worker break periods
- Beginning battery capacity start of first shift: 100% SOC
- Ending battery capacity at 14th continuous duty shift: 7% SOC
- Test was performed on Navitas lithium cells without Navitas active balancing BMS – **Results would have been even better with active balancing turned ON**
Starlifter Lithium Power Equals Increase Productivity – Lithium Lifts Loads Consistently Faster

Lift Speed Comparison

- Lifts to 100"
- Lifts to 300"

Lift Speed

- New LIB
- New LAB
- Old LAB

Cycle number
Starlifter Lithium Power Equals Increase Productivity – Lithium Lifts Loads Consistently Faster

Lift Duration with 1000 lb load

- **New LIB**: 100" (300" - 200"
- **Old LAB**: 100" (300" - 200"
- **New LAB**: 100" (300" - 200"

**Cycle number**

**Lift Duration, sec**

**1 second**

**MHI**

*The Industry That Makes Supply Chains Work®*
• Highest Demand Conditions Testing – lifting max load to the max height at full speed – lifting a 4500lb load to 300”

<table>
<thead>
<tr>
<th></th>
<th>Starlifter Lithium</th>
<th>Lead Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Output Current</td>
<td>750A</td>
<td>810A</td>
</tr>
<tr>
<td>Energy Consumption</td>
<td>2.56Ah</td>
<td>3.35Ah</td>
</tr>
<tr>
<td>Lift Time</td>
<td>12 seconds</td>
<td>15 seconds</td>
</tr>
</tbody>
</table>

- 7.5% Lower Internal Resistance
- 23% Less Energy Consumption
- 20% Quicker Lift Duration

AH used: 4,500 lb through 300”
SOLVE FOR X

Lead Acid Vs Lithium Field Lift Test

Lithium Battery – ~12 seconds to lift load to 300”

~20% Quicker Lift Duration

Lead Acid Battery – ~15 seconds to lift load to 300”
UL Safety Video

- Starlifter Passed Short Circuit Test With Flying Colors
  - Slight smoke for 1 minute then nothing
Customer Evaluation Objectives

Customer Field Testing Objectives:

1. Demonstrate lithium technology with fast charging in a cold warehouse at a customer site
2. Quantify productivity improvements of LIB over LAB
3. Compare Truck and Battery Performances
4. Quantify Labor Hours Associated with Battery Changing
Successful Field Demonstration at Maines

<table>
<thead>
<tr>
<th>Truck #</th>
<th>Battery</th>
<th>Nameplate Capacity (Ah)</th>
<th>Calculated Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F105</td>
<td>LAB</td>
<td>1240</td>
<td>44</td>
</tr>
<tr>
<td>F102</td>
<td>LIB</td>
<td>700</td>
<td>28</td>
</tr>
</tbody>
</table>

The operators enjoyed using the LIB truck (F102) and commented that it was more responsive than the LAB system (F105), and maintained consistent performance even at low BSOC, versus the LAB which drops off significantly below 50% BSOC.

Maintained a high state of charge with opportunity fast charging
In a cold warehouse the practical capacity percentage seen:
- 70% of Starlifter Lithium Nameplate
- 40% of Lead Acid Nameplate
- Both result in ~500Ah practical capacity

- **Lithium Cycle = 80% DOD Cycle**
- **Lead Acid Cycle = Battery Change**
# Lithium Power Means More Productivity

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F105 - LAB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pallets moved (#p)</td>
<td>756</td>
<td>707</td>
<td>708</td>
<td>1060</td>
<td>760</td>
<td>3991</td>
</tr>
<tr>
<td>operational hours (hr)</td>
<td>42</td>
<td>37</td>
<td>42</td>
<td>53</td>
<td>42</td>
<td>216</td>
</tr>
<tr>
<td>avg #p/hr</td>
<td>18</td>
<td>19</td>
<td>17</td>
<td>20</td>
<td>18</td>
<td><strong>18</strong></td>
</tr>
<tr>
<td><strong>F102 - LIB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pallets moved (#p)</td>
<td>921</td>
<td>730</td>
<td>711</td>
<td>865</td>
<td>781</td>
<td>4008</td>
</tr>
<tr>
<td>operational hours (hr)</td>
<td>43</td>
<td>37</td>
<td>36</td>
<td>39</td>
<td>37</td>
<td><strong>192</strong></td>
</tr>
<tr>
<td>avg #p/hr</td>
<td>21</td>
<td>20</td>
<td>20</td>
<td>22</td>
<td>21</td>
<td><strong>21</strong></td>
</tr>
</tbody>
</table>

**17% Increased Pallets Moved Per Hour**
• Battery Changes occur approximately 1 time per shift
  – Sometimes more as the lead acid batteries age and performance decreases become more noticeable
• The *Lead Acid Truck averaged 12.6 minutes of lost time per lead acid battery changeout* over the program test period
2. How satisfied are you with the performance of lead acid powered forklift at the beginning of your shift or after a battery change/opportunity charge under the following categories using a scale of 1 to 5.

1 – Does not meet requirements
2 – Slightly meets requirements
3 – Moderately meets requirements
4 – Meets requirements
5 – Exceeds requirements

(circle your response)

f. Overall performance 1 2 3 4 5

*For the first 2 hours of a fully charged LAB that is in good condition. Due to lack of watering they don’t stay in good condition

g. Power 1 2 3 4 5

h. Forklift Range 1 2 3 4 5

i. Consistent speed 1 2 3 4 5

j. Load Capacity 1 2 3 4 5

3. How satisfied are you with the performance of lead acid powered forklift at the end of your shift or before a battery change/opportunity charge under the following categories using a scale of 1 to 5.

(circle your response)

a. Overall performance 1 2 3 4 5

b. Power 1 2 3 4 5

c. Forklift Range 1 2 3 4 5

d. Consistent speed 1 2 3 4 5

e. Load Capacity 1 2 3 4 5
4. How satisfied are you with the performance of the lithium battery powered forklift **at the beginning of your shift or after a battery change/opportunity charge** under the following categories using a scale of 1 to 5.

   1 – Does not meet requirements  
   2 – Slightly meets requirements  
   3 – Moderately meets requirements  
   4 – Meets requirements  
   5 – Exceeds requirements

*(circle your response)*

<table>
<thead>
<tr>
<th></th>
<th>Overall performance</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>p.</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q.</td>
<td>Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r.</td>
<td>Forklift Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>s.</td>
<td>Consistent speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t.</td>
<td>Load Capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. Answer the following question comparing Lead-acid battery against Lithium Ion powered forklifts using a scale of 1 to 3.

1 – Lead-acid batteries outperform Lithium Ion Batteries
2 – No difference
3 – Lithium Ion Batteries outperform Lead-acid batteries

(circle your response)

a. Overall performance 1 2 3
b. Power 1 2 3
c. Forklift Range 1 2 3
d. Consistent speed 1 2 3
e. Load Capacity 1 2 3

Comments/Observations:

7. Did you feel overall the lithium battery improved your productivity on the job? (circle your response)

1) No, it was worse 2) Hard to tell 3) Definitely

8. After your experience with Lithium batteries, given a choice between a lead acid powered truck and lithium truck, which one would you request? (circle your response)

a. Lead Acid
b. Lithium

*For this project the lithium battery was appropriately sized to match the operation for cost effectiveness, not necessarily to extend range in this application although it might be a sought-out feature by the driver
• Cold Storage Distribution Facility – 24/7 Operation
  – Productivity measurement by quota % expected by baselined lead acid performance and assigned tasks then compared to historical performance data by driver
    • Employee’s driving the forklift saw an average 7% increase – LMS Data Analyst
• Trucking / Third Party Logistics “Fresh” Distribution Center – 24/7 Operation
  – Productivity measured by driver as pallets per hour
    • 211 pallets per day historical performance with lead acid, 226 pallet per day with Starlifter lithium battery = 7% productivity improvement
    • +3 Hours / Day increased uptime for lithium truck, the lead acid truck wasn’t able to support the operations needed and required additional “jumper” trucks to support the operation
*Both facilities already had fast charging – the data displayed is compared to lead acid with fast charging, no battery changing operation
Consumer Goods Distribution Center – 24/7 2 Shift Operation
  - Currently performing lead acid battery changing because of the limited amount of charging time available, <3 Hours Per Day
    • **Lithium will enable them to maintain full uptime with a single battery per truck and charge during just breaks, lunches and shift change**

Government Defense Logistics – 2 Shift Operation
  - Currently in process of transitioning from lead acid battery changing to fast charging lithium
    • **Enabling the increase of operational readiness for peak demands while maintaining or reducing fleet size and reducing overall operational costs**
Answer the following question comparing Lead-acid battery against Lithium Ion powered forklifts using a scale of 1 to 3.

1 – Lead-acid batteries outperform Lithium Ion Batteries
2 – No difference
3 – Lithium Ion Batteries outperform Lead-acid batteries

(circle your response)

a. Overall performance 1 2 3
b. Power 1 2 3
c. Forklift Range 1 2 3
d. Consistent speed 1 2 3
e. Load Capacity 1 2 3

Comments/Observations:

Did you feel overall the lithium battery improved your productivity on the job? (circle your response)

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After your experience with Lithium batteries, given a choice between a lead acid powered truck and lithium truck, which one would you request? (circle your response)

a. Lead Acid
b. Lithium

Survey Completed by:
Facility Maintenance Manager
For More Information:

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Or visit ProMat Booth #S5630
Even with the variation in travel and lift distances, the LIB clearly demonstrates a productivity increase over the LAB. This is due to the higher performance of the LIB truck (faster lifts and faster acceleration), and the performance drop off seen in a LAB at lower BSOC.