AHS International

*Transformative Vertical Flight Concepts*

NASA Ames

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Moore’s Law

![Moore's Law Graph](image)
Moore’s Law in batteries?
Power versus Energy: Mature Technology

- Batteries are all about compromise and lithium ion is the primary choice for most applications
- No one-size-fits-all battery chemistry, even within the lithium ion category
- Cycle life, cost, and safety are also important considerations

Source: Lawrence Berkeley National Laboratory
Power versus Energy: Next Gen Technology

Source: Lux Research
Can next gen technology compete with Li ion?

Lithium Sulfur
- Pro: High gravimetric capacity, low cost
- During discharge lithium polysulfides tend to dissolve from the cathode in the electrolytes and react with the lithium anode, decreasing cycle life
- Volume expansion of sulfur electrode upon repeated cycling
- Safety concerns

Lithium Air
- Pro: Very high theoretical energy density
- Power is lower than lithium ion
- Cycle life issues as a result of dendrite formation, volume expansion, lithium peroxide byproducts
- Safety concerns
Envia’s Approach

HCMR™ Cathode Phase Diagram

- XP Cathodes (lower Li₂MnO₃)
- XE Cathodes
- XLE Cathodes (higher Li₂MnO₃)

HCMR™ Cathodes

Electrodes with Carbon Fibers

Si-based Anodes

Nanocoating to enhance cycle life & safety
Envia Anode Strategy

Si needs to replace Gr-based anodes to enable high energy density cells (>300Wh/Kg)

Challenges with Si-based Anodes:

1. Cycle life
   - Pulverization
   - Li consumption
   - Resistance increase
   - Phase transformations
2. IRCL (prelithiation)
3. Swelling

Optimization of Si-based anodes

Envia develops proprietary Si anodes for automotive & consumer applications by using commercially available materials and applying its electrode formulation, processing, and coatings know-how
Discontinuity of Industry Trend

And batteries used in many mass market UAVs and EVs are lower energy density than the State of the Art trend.
UAV cell

Cell Capacity: 10 Ah
Test Protocol:
Charge to 4.47V @ C/6 rate with CV=C/50
Rest for 10 minutes
Discharge to 2.5V @ C/10 rate
Rest for 10 minutes
Temperature: 25°C±3°C

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1) Specific energy 348 Wh/kg
2) Energy density 840 Wh/L

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<table>
<thead>
<tr>
<th>C/10 Typical Capacity (Ah)</th>
<th>C/10 Energy (mWh)</th>
<th>Cell weight (g)</th>
<th>Wh/kg at C/10</th>
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<tbody>
<tr>
<td>10.6</td>
<td>38.72</td>
<td>111.2</td>
<td>348</td>
</tr>
</tbody>
</table>
UAV cell Rate Capability

4.47~2.5V
RT (27°C)
Reached 47°C at 5C rate

Voltage/V

Energy Density, Wh/kg

0.5C
1C
2C
3C
4C
5C
Current drone/UAV projects

• High altitude
  – Applications aimed at bringing network capability or communications to rural areas without strong connectivity
  – Low rate applications so Wh/kg is by far the most important factor

• Low altitude
  – Delivery, leisure, or connectivity purposes
  – More complex energy storage needs
    • Smaller battery, so higher power needs (per battery) especially for take off or windy conditions
    • Hybrid battery options
UAV battery Considerations

- **Energy density**
  - The most important metric to increase run time/distance
  - Weight reduction causes a non-linear reduction in power requirements
- **Power density**
  - Very application dependent
- **Cycle life**
  - Typically high power batteries have better cycle life (but energy is much lower so cumulative Wh may be similar to high energy cells)
- **Safety**
- **Cost**
  - Increasing Wh/kg to reduce $/kWh is Envia’s strategy to reduce total pack cost but there are other strategies
### Envia Product Roadmap

<table>
<thead>
<tr>
<th></th>
<th>GEN 1</th>
<th>GEN 2</th>
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<tbody>
<tr>
<td>Mobile Devices</td>
<td>700 Wh/L</td>
<td>750 Wh/L</td>
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<tr>
<td>Drone</td>
<td>350 Wh/kg</td>
<td>400 Wh/kg</td>
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<tr>
<td>EV</td>
<td>215 Wh/kg</td>
<td>300 Wh/kg</td>
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<tr>
<td>PHEV</td>
<td>180 Wh/kg</td>
<td>200 Wh/kg</td>
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- Energy density by application is determined by other performance needs like cycle life and power.
- Critical that cells are designed with an application in mind.
Cells for Wearable Device

80% Capacity retention @C/5 rate = ~500 cycles
### Cells for Electric Vehicles

#### EV Cell

<table>
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<th>Metric</th>
<th>Metrics</th>
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<tbody>
<tr>
<td>Capacity</td>
<td>40 Ah</td>
</tr>
<tr>
<td>Nominal Voltage</td>
<td>3.74 V</td>
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<tr>
<td>Specific Energy @ 1C</td>
<td>215 Wh/Kg</td>
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<tr>
<td>Power Density (EVPC Test) @80% DOD in 1C-30 Sec test</td>
<td>3300 W/L</td>
</tr>
<tr>
<td>Cycle Life (1C/1C) @ 80 % DOD</td>
<td>&gt;1000</td>
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#### PHEV Cell

<table>
<thead>
<tr>
<th>Metric</th>
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<tbody>
<tr>
<td>Capacity</td>
<td>27 Ah</td>
</tr>
<tr>
<td>Nominal Voltage</td>
<td>3.74 V</td>
</tr>
<tr>
<td>Specific Energy @ 1C</td>
<td>180 Wh/Kg</td>
</tr>
<tr>
<td>Power Density (HPPC Test) @80% DOD in 5C-17 Sec test</td>
<td>4900 W/L</td>
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<tr>
<td>Cycle Life (1C/2C) @ 80 % DOD</td>
<td>&gt;4500</td>
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PHEV Cell Cycling

1C charge & 2C discharge cycling (90% DOD)

- 80% retention (3300 cycles)
- 75% retention (5000 cycles)
Summary

• Advanced high energy density lithium battery technology
  – Develop custom high energy electrode materials and cells
  – 350 Wh/kg cell for UAV applications

• Leveraging government grants
  – USABC ($7.7M contract)
  – EERE ABR ($3.8M contract): General Motors, LBNL, ORNL

• Addressing key markets – automotive, consumer, UAV
  – Beta stage products in both automotive and consumer electronics markets
  – UAV beta stage product by Q4 2015