Ultra-Capacitor Energy Storage
A Mature and Powerful Technology

International Workshop on Super capacitors and Energy Storage 2018

Eng. Jan-Hendrik Ernst I Key Account Manager
Maxwell Technologies – At a Glance

### Business Highlights

**Overview**
- Founded 1965; IPO 1983 (NASDAQ: MXWL)
- Energy storage & power delivery solutions
- Headquarters: San Diego, CA
- Locations: U.S.A., Switzerland, China, South Korea, Germany
- Employees: 456

**Products & Markets**

<table>
<thead>
<tr>
<th>High Voltage</th>
<th>Energy Storage</th>
<th>Dry Battery Electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit Breakers • Metering • Converters</td>
<td>Automotive • Grid • Rail • Industrial</td>
<td>Lithium-Ion Battery</td>
</tr>
</tbody>
</table>

### Financial Highlights

- 2017 Revenue: $130M
- 2017 Adjusted EBITDA: ($9.6M)
- FYE 2017 Cash Balance: $50M

### Headquarters

- Corporate: San Diego, CA USA
- High Voltage: Rossens, Switzerland

*Revenue from external customers in ROW does not individually comprise of more than 12% of total
*See Appendix for GAAP to non-GAAP reconciliation of EBITDA
Nesscap: Leveraging Key Synergies to Extend Market Leadership

**Optimize Portfolio**
- More New Products & Technologies, Faster

**Streamline Operations**
- Increases Scale for volume Expansion

**Solidify Leadership**
- Expands Markets & Diversifies Revenue Streams

Nesscap Acquisition Strengthens Leadership, Progressing to Market Inflection Points; Accelerates Growth
Proprietary Dry Electrode Fabrication & Differentiated Ultracapacitors - Significant Cost & Performance Advantages

Industry’s Most Extensive, Best-in-Class Portfolio of Technology, Protected IP, & Value Added Solutions

Expanding Strategic Partnerships & Customer Relationships to Develop Differentiating Platforms & Accelerate Adoption

Building on Strong Foundation of Core Competencies; Increasing Value Creation & Differentiation in the Commercial Ecosystem
### Product Trends

#### Ultra High Capacity

<table>
<thead>
<tr>
<th>State of the Art</th>
<th>Cells (W)</th>
<th>Modules (kW)</th>
<th>Systems (kW-MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>2.7 V / 2.85 V</td>
<td>12V to 160 Volt</td>
<td>Up to 1300V</td>
</tr>
<tr>
<td>Capacitance</td>
<td>From 1F to 3400F</td>
<td>6F to 500F</td>
<td>7.1 F</td>
</tr>
<tr>
<td>Temperature</td>
<td>65°C</td>
<td>65°C</td>
<td>65°C</td>
</tr>
<tr>
<td>Monitoring</td>
<td>x</td>
<td>Analog / Digital</td>
<td>Digital (optical)</td>
</tr>
<tr>
<td>Balancing</td>
<td>x</td>
<td>Pseudo Active</td>
<td>Active</td>
</tr>
</tbody>
</table>

#### Easy Integration

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</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>2.7 V / 2.85 V / 3V</td>
<td>12V to 480 Volt</td>
<td>Up to 1300V</td>
</tr>
<tr>
<td>Capacitance</td>
<td>From 1F to 3400 F</td>
<td>6F to 500 F</td>
<td>7.1 F</td>
</tr>
<tr>
<td>Temperature</td>
<td>85°C</td>
<td>65°C/85°C</td>
<td>65°C</td>
</tr>
<tr>
<td>Monitoring</td>
<td>x</td>
<td>Analog / Digital</td>
<td>Digital</td>
</tr>
<tr>
<td>Balancing</td>
<td>x</td>
<td>Pseudo Active</td>
<td>Active</td>
</tr>
</tbody>
</table>

#### Multiple Service Storage

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</thead>
<tbody>
<tr>
<td>Voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td></td>
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<td></td>
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<tr>
<td>Balancing</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Ultra-Capacitor Success Story
Transportation
## Maxwell Designed into 2M+ vehicles since 2011

### 1. FUEL ECONOMY / CO₂ REDUCTION

<table>
<thead>
<tr>
<th>AERODYNAMICS</th>
<th>VEHICLE MASS</th>
<th>ICE TECHNOLOGY</th>
<th>TRANSMISSION</th>
<th>POWER MGMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag coefficient</td>
<td>Lightweight material</td>
<td>GDI</td>
<td>Improved control of automatic transmission</td>
<td>Switching from mechanical to electrical subsystems</td>
</tr>
<tr>
<td>Tires</td>
<td>Manufacturing technologies</td>
<td>VVT</td>
<td>Continuously variable transmission</td>
<td>Optimization of accessories electricity consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cylinder Deactivation</td>
<td>Dual clutch</td>
<td>Regenerative power</td>
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<td></td>
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<td></td>
<td>Boardnet stabilization</td>
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<td></td>
<td></td>
<td>Engine Downsizing + Turbocharging</td>
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<tr>
<td></td>
<td></td>
<td>Micro, Mild, and Full Hybrids</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>HCCI Technology</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2. PRODUCT INNOVATION

<table>
<thead>
<tr>
<th>ENHANCED SAFETY</th>
<th>NEW FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision mitigation</td>
<td>Active suspension (12V + 48V)</td>
</tr>
<tr>
<td>E-Call systems</td>
<td>E-Steering</td>
</tr>
<tr>
<td>Post-Crash Backup-Systems</td>
<td>(12V+ 48V)</td>
</tr>
<tr>
<td></td>
<td>Autonomous Driving (Back-Up)</td>
</tr>
<tr>
<td></td>
<td>GPS</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
</tbody>
</table>

- Ultracapacitor opportunity
- Advanced Evaluation

In Production: Micro Hybrid
In Production: Active Suspension
In Production: Back-Up Module for AD

Not public
Automotive: Vehicle Electrification Driving Adoption

- **2017**
  - Internal Combustion Engine
  - Hybrid Electric
  - Plug In Hybrid/EV

- **2022**
  - MILD HYBRID & BRAKING REGENERATION
  - BACKUP POWER & ENERGY STORAGE
  - ELECTRICAL SYSTEM STABILIZATION
  - ENGINE DOWNSIZING & PERFORMANCE FEATURES

- **Vendors**:
  - Continental
  - GM
  - PSA Peugeot Citroën
  - Cadillac
Automotive: Challenges and Support factors

- Long design in phases (5 years)
- Long business cycles (7 years)
- Customer highly integrated into designing process

Automotive is one of the industries with the most challenging qualification processes

- Robustness
- Reliability
- Safety
- COST!
- Financial stability
- Secure supply chain

- ISO/ISO 16949 Automotive certification
- Fulfilling most demanding shock and vibe profiles

Official Design-Wins by Maxwell

General Motors
Continental AG
PSA Peugeot Citroën
Lamborghini

... and many more

Maxwell signs $100m ultracapacitor deal with Volvo maker
Adoption of Success in to Transportation

Automotive qualification allows adoption of high quality and reliability into other industries

F.e.:
- Rail onboard
- Rail wayside
- Hybrid bus
- Aviation

Key Requirements:
- Sustainability @ Increased temperatures
- Good performance @ vibration-, shock environments
- Low weight
- Long life
- High reliability
- Low maintenance

Today's State of the Art Ultracapacitors Meet These Requirements
Vibration Test Qualification Comparison

<table>
<thead>
<tr>
<th>Test Summary</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 16750 Table 12</td>
<td>96 hours</td>
</tr>
<tr>
<td>ISO 16750 Table 14</td>
<td>96 hours</td>
</tr>
<tr>
<td>SAE J2380</td>
<td>38.2 hours</td>
</tr>
</tbody>
</table>
Ultra-Capacitor Success Story

Grid
Since 1999, Maxwell has shipped > 8M ultracapacitors into grid applications globally.
Grid Cell Pack

Specification Overview

- 64V 141F Open Cell Pack for Stationary Grid Market
- 24 x 2.7V 3,400F Cells
- Stored Energy: 80 Wh
- Max Operating Current: 1,900A
- Weight: 14.7 kg
- Smart CMS 3.1 balancing and cell monitoring
- String Voltage Rating to 1,500VDC (>400 MΩ IR)
Grid Energy Storage System

Ultracapacitor Module

Cabinet Controller/Gateway

Example 19” rack configuration (1.3MW)

Example 20” Containerized Solution

Differentiating Features/ Benefits

- Up to 1,000,000 duty cycles, 10 year DC life*
- 19” standard rack mountable
- Use of CMS 3.1 balancing and monitoring using internal proprietary CANbus communication
- Wide DC Bus voltage
- Rated to 2,000V basic & 1,350V reinforced insulation
- Cabinet Controller to enable integration of many UCAP modules into large control systems
- External Field bus interface, ProfiNet IRT Fiber Optic (DC-10), Modbus (DC-11)

<table>
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<tr>
<th>Key Applications (MW – 100’s MW)</th>
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<tbody>
<tr>
<td>Voltage support</td>
</tr>
<tr>
<td>Frequency response</td>
</tr>
<tr>
<td>Solar and wind firming</td>
</tr>
<tr>
<td>Bridging power</td>
</tr>
<tr>
<td>Stacked services</td>
</tr>
<tr>
<td>Continuous, pulsed power and/or transient applications</td>
</tr>
</tbody>
</table>

*Results may vary. Additional terms and conditions, including the limited warranty, apply at the time of purchase. See the warranty details for applicable operating and use requirements.
Thank You!

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