Vertically-Integrated Drivetrain/Systems

Electric Drive Services Group
Moline, IL

- Power Systems
  Waterloo, IA

- Electronic Solutions
  Fargo, ND

- Power Systems
  Coffeyville, KS

- Construction
  & Forestry
  Dubuque, IA

Diesel Engines & Controls
Electronic Hardware & Software
Gearboxes, Transmissions
Four Wheel Drive Loader
JDES Power Electronics Systems - Dynamometers
JDES Power Electronics Systems – Test Facilities

Large Vehicle Bay

Combined Environment

HALT

EMC

Vibration & Shock
Construction Application – John Deere 644K Hybrid Wheel Loader

• World’s 1st E-drive Construction Production Wheel Loader

• Hybrid version uses 6.8L vs. 9.0L engine

• Productivity/Uptime/Operating costs
  o Estimated 25%+ fuel savings
  o Easier to use/lower operator skill level/less fatigue
  o Higher performance/more productive
  o Allows use of engine’s max efficiency operating point

• -3dBa sound reduction (plus even more perceived)
Turf Application – John Deere Golf Course Mowers

- Electric cutting reels
- Consistent reel speed, optimal cut in all conditions
- Improved turf appearance and even playing
- Allows lower engine speed
- Quieter operation
- Reduction of potential hydraulic leak points
- Easier maintenance
- Fuel savings
Seeding Application – John Deere ExactEmerge™

- 10mph planting with accurate seed singulation, population, spacing, and uniform depth
Customer Value From Electric Drive Planting

Emerged Plant Spacing (CoV)

<table>
<thead>
<tr>
<th>Conventional Industry Planter</th>
<th>John Deere ExactEmerge™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Yield Potential</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td></td>
</tr>
<tr>
<td>5 mph</td>
<td></td>
</tr>
<tr>
<td>7½ mph</td>
<td></td>
</tr>
<tr>
<td>10 mph</td>
<td></td>
</tr>
</tbody>
</table>

Yield Loss After Optimum Planting Day

Bushels/AC yield potential

Optimum Planting Window

Yield Loss

Weeks after optimum planting day
Tractor-Implement Problem Statement

Productivity Increase
- Size/Payload/Functions Increase
  - Power Growth
  - Traction Limitation
  - Weight Increase
    - Soil Compaction
    - Max Vehicle/Drawbar/Axle Weight
  - Unproductive Cost

Additional Implement Power Issues:
- Mechanical PTO has high efficiency but fixed speed
- Hydraulics are variable speed but low efficiency

Profitability
- Yield Optimization
- ...
Functionality:
Power of the tractor is additionally transmitted to the trailer axles to increase traction of the vehicle combination

Use cases:
• Very hilly areas, bad soil conditions/bad weather assist
Power Generation

• Front hitch mounted and PTO driven
• 100kW electric power for implement
• Includes gearbox, cooling, everything for power generation and electric control
• Provides three independent controllable interfaces for traction or process drives
Electrification Expansion Opportunities

• Leveraging/increasing value of electric drive system

• Energy storage systems for increased energy recovery, performance boost, or engine off operation
  o Electrical (battery, ultracap)
  o Inertial (flywheel)
  o Pressure (hydraulic oil, compressed air)

• Alternator and/or starter replacement
  o Isolated DC/DC converter technologies

• Export power

• E-Turbo

• High temp Wide Bandgap (WBG) Power Electronics
  o U.S. Dept. of Energy PowerAmerica Institute

• Electrify auxiliaries (A/C, Pumps, Fans, Compressors)
  o Variable speed as needed
Opportunities for Further Improvement/Research

- Increased demand for multi-disciplinary engineers
- Cost
- Robustness in harsh environments
- Reliability
- Packaging
- Manufacturing
- System Advancements (Power Electronics, Electric Machines, Software/Controls, Energy Storage, Cabling, Diagnostics/Prognostics, etc.)