An Electric Future for Mine Haulage

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Overview

• Social demands and key mining trends
  – Electrification/Automation/ Connection

• Path to Electrification
  – Electric Truck Roadmap
  – Batteries and Energy Storage
  – Charging and Trolley

• Value/Operations
  – Options
  – Simulations; Impacts on Fuel/Productivity

• Conclusion
“Mining is not a choice – the way we mine is.”
Dr. B. Banerjee

Social demands and key mining trends
Key Trends in Mining

The economic, environmental, and social benefits of sustainability

- Safety
- Utilization
- Throughput
- Asset life
- Safety
- System efficiency
- Optimization
- Emissions
- TCO
- Productivity

Source: A.T. Kearney analysis
Balanced Innovation Model

Feasibility
- Does this work?
- Is it functionally possible in the foreseeable future?
- Will it run a shift?
- Can it fit in the vehicle?
- Will it work in all environments?

Desirability
- What’s the unique value proposition?
- Do people want this product or service?
- Does it make sense for them?
- Eliminate diesel?
- Flexible?
- Fit the way mines operate?
- Will it meet production needs?
- Does it lower $/ton?

Viability
- Can we build a sustainable business?
- What has to be true for this business to work?
- What are the costs?
- How will you pay for it?
- Replacement frequency?
- CAPEX? OPEX?
- Does it lower $/ton?

IDEO
https://www.ideo.com/blogs/inspiration/how-to-prototype-a-new-business

GE Transportation
a GE/Toshiba company
Path to Electrification
Electrification Journey

- Decouple vehicle from engine RPM
- Electric Retarding... zero wear deceleration
- Gears
- Bearings
- Durability
Electrification Journey

- Parasitic cooling power matched to dynamic component needs
- Simplified ducting
- Increase HP to wheels
- Retard energy for cooling

- Improved Fuel Efficiency.... $
- Increased speed on grade...Tons

Productivity vs. Baseline

Fuel Consumption vs. Baseline

Base Truck

Optimized cooling

Inlet Airflow

Outlet Airflow
Electrification Journey

240t example

**DIESEL POWERED**

Current configuration:
- 2500 HP engine
- AC alternator

**HYBRID POWERED**

Configuration:
- 2500 HP engine
- AC alternator
- ES Boosts Performance
- ~200kWh

Benefits:
- ↓ emissions
- ↓ fuel
- ↑ productivity
- ↑ transient response

**ALL EV POWERED**

Configuration:
- Engine, alt, radiator eliminated
- 800 – 1200 kWh ES
- Trolley system or road And/Or
- Stationary charge system

Benefits:
- Zero emissions
- ↓ noise
- ↓ LCC
- ↑ productivity
Electrification Journey

- Electric Drive
- Optimization
- Prime Mover
- Non Traction

Radiator/Alt. losses

Equivalent Electric Power

Inverter & TM Cooling & Other Loads

Truck operation loads:
- Dump body hydraulics
- Steering
- Brakes
- Cab A/C
# Electrification

## Tradeoffs

<table>
<thead>
<tr>
<th>+</th>
<th>-</th>
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<tbody>
<tr>
<td><strong>Engine: fuel, maintenance</strong></td>
<td>CAPEX – Truck, Battery Life, Stationary Charger, Fleet Size</td>
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<tr>
<td><strong>Emissions</strong></td>
<td>Trolley: CAPEX, Mtce, Road &amp; Operations flexibility (Mtce, Width)</td>
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<tr>
<td><strong>Energy Costs</strong></td>
<td>Battery Disposal</td>
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<tr>
<td><strong>Noise</strong></td>
<td>Training</td>
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## KPI element

<table>
<thead>
<tr>
<th>KPI element</th>
<th>$/ton impact</th>
<th>Hybrid</th>
<th>Full EV</th>
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<tbody>
<tr>
<td>Productivity</td>
<td>Very High</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Availability</td>
<td>High</td>
<td>+ +</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>Medium</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Low</td>
<td>-</td>
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2008 DoE Hybrid Proof of Concept

Technology Demonstrator:

• Demonstrate Battery Diesel Hybrid technology

• Joint Effort between GE, Komatsu and US DoE... Primary goal – Fuel Savings

• Na-NiCl2 (ZEBRA) battery technology (~432kWh, 18000lbs/8180kg)

• Komatsu Arizona Proving Grounds

• Fuel Savings 3% to 5% realized

Successful Demo Jan. 2008
Energy Storage: Trends

- "NMC" (NMC/Graphite and derivatives) energy density and cost expected to continually improve
Trolley

What is Trolley Assist

System that delivers electric power to a haul truck from an overhead line. The electric power supplements power from the engine to increase speed on grade.

Benefits of Trolley Assist

- Increase speed on grade
- Decrease fuel consumption
- Charge while running
- Extend diesel overhaul schedule
- Reduce emissions

History

- First GE systems were installed at a Cement Company in the late 1950’s
- Majority of systems were installed during the 1980’s in response to the energy crisis of the 1970’s
- *Revitalization of Interest: Trolley is a key enabler for Battery Truck.. GHG, Environmental Impacts*
Stationary Charging

**Bus Charging**

- LV to ~600kW

**Ferry Charging**

- LV to 4MW
- MV to 8MW

Stemmann-Technik

- Required power transfer for trucks would exceed stationary systems developed for buses
- Power requirements more consistent with ferry (marine hybrid/electric ship) chargers
Value/Operations
Configurations

240t example

**Base Truck**
2500 HP Diesel Engine

**Hybrid**
2500 HP + 200 kWh battery

**All EV + Trolley**
800 kWh battery only

**All EV + Stationary Charging**
1200 kWh battery only
Energy Cost ($/ton) vs Productivity (ton/hr)

1. Hybrid
   - Incremental fuel and productivity improvement on Uphill and Downhill profiles
   - Highest operational flexibility

2. Downhill Hauls
   - No value to trolley
   - EV w/Stationary – high value even with time penalty

3. Uphill Hauls
   - Ideal EV + trolley... Flexibility impact
   - EV + Stationary... delivers flexibility... look at CAPEX

4. Flat Hauls
   - Trolley creates speed penalty...little value
   - EV + Stationary – best impact... look at CAPEX
Conclusion
The Future is Electric

• Substantial benefits
• Investments & Viability
• Technology trend

• No ‘universal’ cell
• Packaging is critical

• Application, Configuration and Value
• Flexibility vs. Benefit
Accelerating the future of transportation