FAST CHARGE BATTERIES AND IN ROUTE CHARGING – AN EMERGING OPTION FOR LOW COST FREIGHT ELECTRIFICATION

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Pressures for Electrification

Energy and Economic Security

Health, Safety, Environment and Social Licence

Performance

Oil import price for Australia – Data from http://www.indexmundi.com/commodities/
Challenges for Electrification

Infrastructure Investment

Locomotive Investment

Branch Lines/Sidings
Can emerging commercial automotive battery technologies deliver a new approach that is compatible with the existing locomotive duty cycle?
Battery Locomotive Approaches

Hybrid Locomotive

(See Frank Szanto Tomorrow)

2E1B Plugin Hybrid Electric Train

1E2B Plugin Hybrid Electric Train

Battery Electric Train

Tri-Hybrid Electric Train
Tracking Energy and Power
### Min. Battery Specifications for Electrification

#### 2E1B Plugin Hybrid Electric Train

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Battery Capacity (MWh)</th>
<th>Discharge Power (MW)</th>
<th>Charge Power (MW)</th>
<th>Volume (m³)</th>
<th>Weight (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Leg</td>
<td>&gt;7.5</td>
<td>&gt;9 (1.2C)</td>
<td>&gt;11 (1.5C)</td>
<td>&lt;28</td>
<td>&lt;45</td>
</tr>
<tr>
<td>Regen + Recharge</td>
<td>&gt;3</td>
<td>&gt;9 (3C)</td>
<td>&gt;11 (3.7C)</td>
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Li⁺ Battery Chemistry Advances

Cathode

\[
\text{LiCoO}_2 \rightleftharpoons \text{Li}_{1-x}\text{CoO}_2 + x\text{Li}^+ + xe^- + x\text{C}_6 \rightleftharpoons x\text{LiC}_6
\]

Advanced Cathode

\[
\text{LiFePO}_4 \rightleftharpoons \text{Li}_{1-x}\text{FePO}_4 + x\text{Li}^+ + xe^- + x\text{C}_6 \rightleftharpoons x\text{LiC}_6
\]

\[
\text{LiNi}_{a}\text{Mn}_b\text{Co}_c\text{O}_2 \rightleftharpoons \text{Li}_{1-x}\text{Ni}_a\text{Mn}_b\text{Co}_c\text{O}_2 + x\text{Li}^+ + xe^- + x\text{C}_6 \rightleftharpoons x\text{LiC}_6
\]

\[
\text{LiNi}_{a}\text{Al}_b\text{Co}_c\text{O}_2 \rightleftharpoons \text{Li}_{1-x}\text{Ni}_a\text{Al}_b\text{Co}_c\text{O}_2 + x\text{Li}^+ + xe^- + x\text{C}_6 \rightleftharpoons x\text{LiC}_6
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Anode

\[
\text{LiCoO}_2 \rightleftharpoons \text{Li}_{1-x}\text{CoO}_2 + x\text{Li}^+ + xe^- + x\text{Li}_4\text{Ti}_5\text{O}_{12} \rightleftharpoons x\text{Li}_{4+x}\text{Ti}_{5x}\text{O}_{12x}
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Advanced Anode

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\text{LiCoO}_2 \rightleftharpoons \text{Li}_{1-x}\text{CoO}_2 + x\text{Li}^+ + xe^- + x\text{Li}_4\text{Ti}_5\text{O}_{12} \rightleftharpoons x\text{Li}_{4+x}\text{Ti}_{5x}\text{O}_{12x}
\]

SEI Sensitive

(LiPo) (LFP) (NMC) (NCA) (LTO)
Matching Batteries to Applications

LFP

LTO
### 2E1B - Whole Leg?

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<tr>
<td>LFP, NMC, NCA</td>
<td>7.5</td>
<td>75</td>
<td>11 (1.5C)</td>
<td>34</td>
<td>75</td>
</tr>
<tr>
<td>LTO</td>
<td>7.5</td>
<td>75</td>
<td>22.5 (3C)</td>
<td>39</td>
<td>83</td>
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*ICE Battery ✔️*
2E1B – Regen + Recharge?

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<tr>
<td>LFP</td>
<td>4.2</td>
<td>19</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>LTO</td>
<td>3.9</td>
<td>22</td>
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**LFP**

**LTO**

**A123 Systems Li-Ion Cell Carbon-LiFePO₄ Cells**

- Charge (C, 2C, or 3C Rate) to 3.60 V
- C/50 Taper Current Cut-Off (0.044 A)
- Discharge (C, 2C, or 3C Rate) to 2.0V
- Temperature = 25°C

**Charge-discharge cycle life data**

- SCIB™
- 20Ah cell

Test condition:
- High rate charge-discharge (3C) cycles at 25°C
The 2E1B Enabling Question

Plugin Hybrid Train

(Locomotive Investment ↓ + Branch Line Interoperability)

Deliberately Discontinuous Electrification

(Electrification Infrastructure Investment ↓ + Cost Effective Branch Line Electrification)

How to fast charge without adding weight to the locomotive?
Adaptive DC Supply

Supply controlled by locomotive BMS at DC Bus Voltage

e.g. 1500V GE, 3,000V EMD

Overhead or 3rd Rail

Enabled by discontinuous electrification

WORLD'S SMALLEST FOOTPRINT

MULTI-STANDARD CHADEMO & SAE COMBO
Battery Electrification Looks Technically Possible

Infrastructure Investment ✔

Locomotive Investment ✔

Branch Lines ✔
Conclusions

• New commercially available battery technologies suggest the emergence of a fundamentally new path for freight rail electrification – but you need to know your tech

• Fast charge is a key enabler for reducing battery size

• Deliberately Discontinuous Electrification and Adaptive DC Supply are a key enablers of the 2E1B hybrid plugin train
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