Projected battery minerals and metals global shortage

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Summary

• The Electric Vehicle revolution
  • Make lots of batteries
• What makes up the existing global transport fleet
  • Cars
  • Trucks HCV Class 8 Semi Trailers
  • Trucks LCV
• Battery chemistry and metals
• Minerals needed to make the required batteries
• Global production, reserves & resources
• Prognosis
• Possible solutions
Forecast for electric cars production

Source: Bloomberg
There is now a global push to replace Internal Fossil Fuel (ICE) transport fleet with Electric Vehicle (EV) technology. The next 10 years is to be dominated by the manufacture of Li-ion battery technology. Battery Minerals:

- Cobalt (Co)
- Lithium (Li)
- Graphite
- Nickel (Ni)
- Manganese (Mn)
- Copper (Cu)
- Aluminium (Al)
Global battery minerals demand for electric vehicles

- Global race for raw materials already begun
- Particularly China has made strategic acquisitions and investments
- EC has a strategic action plan for batteries, emphasising availability of raw materials from EU sources
Global Passenger Car Fleet

A car (or automobile) is a wheeled motor vehicle used for transportation. Most definitions of car say they run primarily on roads, seat one to eight people, have four tires, and mainly transport people rather than goods.

In 2016 global Passenger Vehicles fleet registered was 973,353,000, or a little under 1 billion cars (Source: Statistica)
2019 BMW i3 passenger car EV

- 42.2 kWh battery.
- 8 modules with 12 cells each (120 Ah lithium-ion cells)
- Typical range 260 km (162 miles), expected EPA result of around 246 km (153 miles)
- 0-100 km/h: 7.3 seconds / 6.9 seconds

Source: BMW Pres release 2019
Batteries used in trucks have similar chemistries to those of passenger cars, but the size and shape of battery packages can vary with application.

Currently NMC chemistry most commonly used for electric vehicles: **NMC442**, 523, 622 and 811 mostly used.
## Battery Component Mass Proportions

<table>
<thead>
<tr>
<th>Mass</th>
<th>LCO-G</th>
<th>NMC333-G</th>
<th>NMC442-G</th>
<th>LFP-G</th>
<th>LMO-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode</td>
<td>25 %</td>
<td>27 %</td>
<td>34 %</td>
<td>24 %</td>
<td>25 %</td>
</tr>
<tr>
<td>Al Foil</td>
<td>14 %</td>
<td>15 %</td>
<td>13 %</td>
<td>16 %</td>
<td>14 %</td>
</tr>
<tr>
<td>Anode</td>
<td>16 %</td>
<td>16 %</td>
<td>14 %</td>
<td>14 %</td>
<td>10 %</td>
</tr>
<tr>
<td>Cu Foil</td>
<td>21 %</td>
<td>18 %</td>
<td>16 %</td>
<td>22 %</td>
<td>27 %</td>
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<tr>
<td>Binders</td>
<td>4 %</td>
<td>4 %</td>
<td>4 %</td>
<td>4 %</td>
<td>4 %</td>
</tr>
<tr>
<td>Electrolyte, Salt and separator</td>
<td>11 %</td>
<td>11 %</td>
<td>10 %</td>
<td>11 %</td>
<td>11 %</td>
</tr>
<tr>
<td>Case and terminals</td>
<td>9 %</td>
<td>9 %</td>
<td>8 %</td>
<td>9 %</td>
<td>9 %</td>
</tr>
</tbody>
</table>

Estimated metal content of a BMW i3 EV battery pack

- Copper: 30kg
- Lithium: 6kg
- Graphite: 35kg
- Nickel: 12kg
- Manganese: 12kg
- Aluminium: 27kg
- Cobalt: 12kg

Total estimated battery pack mass: 134 kg

Source: Rystad Energy

Battery Chemistry: NCA LiNiCoAlO$_2$
Global Heavy Commercial Vehicle (HCV) Class 8 Semi fleet

A commercial carrier vehicle with a gross vehicle weight more than 3.5 metric tons (tonnes)

- Termed Class 8 HCV or 18 wheeler Semi (63% of global truck fleet)
- The 8 refers to that 80,000-pound (36,287 kg) total vehicle GVW weight.
- Approximately 21,772 kg (48,000 pounds) of freight capacity for the truck.
- Approximate 2000 mile range (2x150 gallon tanks at an average 7MPG)

In 2016 global HCV registered fleet was 219,818,970, or a little under 220 million

Source: Global Truck Study – the truck industry in transition 2016 Deloitte & Statisticia
Tesla Semi Class 8 HCV specifications as promoted

- 80,000-pound capacity (GVW)
- 0 to 60 mph in 20 seconds with 80,000 lbs (20 tonne payload)
- 300 to 500 mile range
- Charging adds 400 miles of range in 30 minutes
- Four independent motors
- Less than 2kWh/mile energy consumption
Tesla Semi battery pack specifications (ESTIMATED)

- If the Tesla Semi uses 2kWh (0.503 miles/kwh) to travel a mile, then going 500 miles at 2kWh/mile would require **1,000kWh** (1MWh) of power.
- The conditions for using 2kWh/mile are unclear, so let’s assume it’s a value that’s representative of typical use.
- To add 400 miles of range in 30 minutes, the Tesla Semi would need 1.6MW of charging power.
  - It could achieve this by breaking up a 1-MWh battery into four 250-kWh batteries and charging each separately.

Source: Engineering & Electronics Design
Estimated metal content of a Tesla Semi HCV EV Battery Pack (1000kWh)

- Cobalt: 440kg
- Lithium: 160kg
- Graphite: 500kg
- Nickel: 440kg
- Manganese: 410kg
- Aluminium: 560kg
- Copper: 680kg

NCM442-G battery chemistry assumed

Estimated Battery Pack Mass 3190 kg, or 3.2 tonne
The Light Commercial Vehicle (LCV)

- A commercial carrier vehicle with a gross vehicle weight of no more than 3.5 metric tons (tonnes)
- 28% of the global trucking fleet in 2016
- An EV replacement estimated to have a 300kWh battery pack
- Tesla Roaster Model S has a 90kWh 540kg battery pack

In 2016 global LCV registered fleet was 97,697,320, or a little under 98 million

Source: Global Truck Study – the truck industry in transition
2016 Deloitte & Statisticia
Estimated EV Light Commercial Vehicle (LCV) Battery Pack Metal Content (300kWh)

- Cobalt: 132kg
- Lithium: 48kg
- Graphite: 125kg
- Nickel: 132kg
- Manganese: 123kg
- Aluminium: 118kg
- Copper: 149kg

Estimated Battery Pack Mass: 827 kg

NCM442-G battery chemistry assumed
Minerals Needed to Replace the 2016 Global Transport Fleet

Needed to make 973.3 million BMW i3 car batteries
Needed to make 219.8 million Tesla Semi HCV batteries
Needed to make 97.7 million LCV batteries

Needed to Replace the 2016 Global Fleet

('000s of tonnes)

Cobalt Lithium Nickel
Minerals Needed to Replace the 2016 Global Transport Fleet

- 121.3 million tonnes of Cobalt
- 45.7 million tonnes of Lithium
- 121.3 million tonnes of Nickel

Just to make enough batteries as part of the manufacture of passenger cars, HCV Class 8 trucks and LCV trucks in quantities large enough for the replacement of the 2016 transport fleet.
Reserves & Resources vs. Minerals Needed to Replace the 2016 Global Transport Fleet

<table>
<thead>
<tr>
<th>Metal/Mineral</th>
<th>Global Production in 2018 ('000 tons)</th>
<th>Global Reserves in 2018 ('000 tons)</th>
<th>Global Resources in 2018 ('000 tons)</th>
<th>Needed to Replace the 2016 Global Fleet ('000 tons)</th>
<th>Years of production at 2018 rates to replace 2016 transport fleet (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>140</td>
<td>6 909</td>
<td>25 000</td>
<td>121 297</td>
<td>866</td>
</tr>
<tr>
<td>Lithium</td>
<td>85</td>
<td>18 409</td>
<td>61 415</td>
<td>45 701</td>
<td>538</td>
</tr>
<tr>
<td>Nickel</td>
<td>2 300</td>
<td>73 830</td>
<td>130 000</td>
<td>121 297</td>
<td>53</td>
</tr>
<tr>
<td>Copper</td>
<td>21 000</td>
<td>794 000 000</td>
<td>2 100 000</td>
<td>193 234</td>
<td>9</td>
</tr>
</tbody>
</table>

The European Union wants to replace its transport fleet by 2030 (200 million registered EV passenger vehicles)

10 years and 7 months away

unlikely to go to plan
So release the global reserves & resources…

![Graph showing global reserves and resources in 2018 and needed to replace the existing global fleet for Cobalt, Lithium, and Nickel.](image)
So release the global reserves & resources…

Co Global Reserves 5.7% of what is needed to replace 2016 global fleet

Li Global Reserves 40.3% of what is needed to replace 2016 global fleet

Ni Global Reserves 60.9% of what is needed to replace 2016 global fleet

Co Global Resources 20.6% of what is needed to replace 2016 global fleet

What is needed to replace 2016 global fleet would consume 74.4% of Global Li Resources

What is needed to replace 2016 global fleet would consume 93.3% of Global Ni Resources
Projected copper supply/demand gap

Copper needed to make the batteries only for EV’s to replace the 2016 transport fleet will consume 9 years of production at 2018 rates.

This is a shortage in processing capacity as some mines decommission.

This is the price of not investing in CAPEX for process plants back in 2012-2016.

Source: Wood Mackenzie, CRU, ICSG, Teck
Copper grade decreasing (global)

Mudd, G. (2007, Revised April 2009) *The Sustainability of Mining in Australia - Key Production Trends and Their Environmental Implications for the Future*, Department of Civil Engineering, Monash University and the Mineral Policy Institute
Copper in major discoveries by year, 1990-2017
(Data as of July 18, 2018)

Source: S&P Global Market Intelligence
Controversial opinion coming
The European Union is not only unable to resource its EV battery revolution…

…but is also not understanding the true nature of the challenge
Lithium-ion Megafactories - Europe enters the game

- **Terra E**
  - 34 GWh in 2028 (financing status open)

- **CATL**
  - 24 GWh -> 60GWh 2026

- **Terra E**
  - 34 GWh in 2028 (financing status open)

- **Tesla**
  - TBC

- **LG Chem**
  - 4 GWh plant operational with planning to triple the capacity

- **SK Innovation**
  - 7.5 GWh by 2020

- **Samsung SDI**
  - 3 GWh plant operational

- **GS Yuasa**
  - TBC

- **Keliber**
  - TBC

**LIB Giga Factories Capacity by 2025**

- **US**
- **Europe**
- **China**

Source: Benchmark Minerals
## Sourcing Minerals for the Incoming Gigafactories

<table>
<thead>
<tr>
<th>Year</th>
<th>GWh</th>
<th>No: 30 GWh Gigafactories</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>2015</td>
<td>70</td>
<td>2</td>
</tr>
<tr>
<td>2020</td>
<td>250</td>
<td>8</td>
</tr>
<tr>
<td>2025</td>
<td>1000</td>
<td>30</td>
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<td>2030</td>
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<td>2035</td>
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<tr>
<td>2045</td>
<td>8000</td>
<td>250</td>
</tr>
<tr>
<td>2050</td>
<td>10500</td>
<td>350</td>
</tr>
</tbody>
</table>

Where will they get the mineral resources to feed these factories?

Things will progress to a certain point and then minerals to make batteries will no longer be just Co, Li and Ni
I call this the the known Black Swan
Batteries can be made from other materials

Electrode Materials from Minerals, Waste, etc.

Testing Mg as an anode against BiF3 and SnF2 cathodes for room temperature rechargeable fluoride ion batteries

Journal of Fluorine Chemistry, 182, 2016, 76

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Conclusions & Implications

1. There is not enough minerals to make the needed batteries to facilitate the EV revolution

2. Most of the proposals to roll out a new electric technology on a ubiquitous scale before 2030 is unlikely to go as planned

3. HCV Class 8 semi trailer trucks are the most important and decisively difficult transport group to resource

4. The European CRM list map is incomplete and requires surgery

5. The planned gigafactories will struggle to secure mineral concentrate supply

6. Metals, minerals and raw materials in general are about to become much more valuable than they are now in an inelastic supply market

7. Alternative minerals should be considered to manufacture batteries
Accept your past without regret, handle your present with confidence and face your future without fear!

INDUSTRIAL EVOLUTION IN PROGRESS
Thankyou (Kiitos)

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Finland has it all to make a complete battery ecosystem if we can get organized in time.

World class research

Leading recycling and technology operators

World class research

Largest European Li deposit in Finland

Rich raw materials, New mining operators

11% of global Co refined in Finland

4% of global Ni refined in Finland
The Finnish Battery Opportunity

• There is everything here in Finland that is needed for a complete self sufficient battery eco-system
  • Fully controlled by European nation states
• The battery eco-system and value chain will have to be much more organized and work to a very different mandate than it does now.
• The management of what resources are available has to be done to a new paradigm
• What gets mined and how it is processed has to be done to a new measure of efficiency
• How waste streams are recycled also has to be done to a new measure of efficiency
Global Cobalt 2018 Reserves

Source: USGS 2019 Mineral Statistics
Global Cobalt Production 2018

Source: USGS 2019 Mineral Statistics
Global Lithium 2018 Reserves

Source: USGS 2019 Mineral Statistics
Global Lithium Production 2018

World mine production 2018 (metric tons of Li)

- Chile: 51,000 metric tons; 60%
- Australia: 16,000 metric tons; 19%
- Argentina: 6,200 metric tons; 7%
- China: 8,000 metric tons; 1%
- Zimbabwe: 500 metric tons; 1%
- Portugal: 800 metric tons; 1%
- Brazil: 600 metric tons; 1%
- Namibia: 500 metric tons; 1%

Source: USGS 2019 Mineral Statistics
Global Nickel 2018 Reserves

Nickel reserves 2018

Source: USGS 2019 Mineral Statistics
Global Nickel Production 2018

Source: USGS 2019 Mineral Statistics