Premature Electrification:
The Future of Cars

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Consumer preferences in the age of climate awareness

Global Car Size Rising
SUV Share Up Everywhere

Driving Distances Rising
U.S. Nonmetro Population Up

SUV demand by 2040 “offsets 150 million EVs”
Super-commuter grew 3x workforce
The EV revolution is real ... 0 to 12 million EVs in 10 yrs

- 2012 Tesla: 0 to 1 million in 92 months
- 1964 Mustang: 0 to 1 million in 18 months

Graph showing sales projections for China, Europe, and North America from 2015 to 2023e.
EVs are a complexity swap

**PROPULSION**
Complex physical-chemistry
1000s of parts

**FUEL**
Simple

Simple

Complex electro-chemistry
1000s of parts
The minerals & metals needed to build a car

500,000 pounds mining to build one EV battery

Transport (kg/vehicle)

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<th>Copper</th>
<th>Lithium</th>
<th>Nickel</th>
<th>Manganese</th>
<th>Cobalt</th>
<th>Chromium</th>
<th>Molybdenum</th>
<th>Graphite</th>
<th>Rare earths</th>
<th>Silicon</th>
<th>Others</th>
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<tbody>
<tr>
<td>Electric car</td>
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<td>Conventional car</td>
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Guessing an EV’s lifetime carbon emissions

- Fuel cycle (well-to-wheel)
- Electricity
- Batteries - minerals
- Batteries - assembly and other
- Vehicle manufacturing

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<th>tCO₂-eq per vehicle lifetime</th>
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<td>Base BEV</td>
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<td>High-GHG minerals</td>
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<td>ICE</td>
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Battery 1/2 std size
EV elsewhere carbon emissions

Battery 1/2 std size
EV elsewhere variables

Battery 3/4 std size
EV CO$_2$ emissions: Known unknowns
’Hiding’ the real minerals costs

Digging up gigatons/yr of the earth -- somewhere
Iron Law of declining metal ore grades

Copper Ore Grades

Energy Cost vs Ore Grade
No energy ‘magic’ in mineral supply chains
The battery tech Moore’s Law trope
Green machine costs are rising not falling

Commodities: 60 – 70% cost of batteries & solar modules

[Graph showing the change in wind, solar, and battery capital costs from 2017 to 2023.]
Real EV costs if people’s time is valued . . .
Grid infrastructure costs hidden in plain sight

MW grid capacity per single fueling station
More known unknowns: temperature & fuel efficiency

**Engine**
-6%

**EV**
-30%

![Graph showing fuel economy vs. temperature for Engine and EV with regression equations and R² values.]
**ICE CO₂ Emissions: Known knowns**

![Diagram showing the known potential for Internal Combustion Engine CO₂ emissions per mile over years from 2018 to 2030, with lines indicating best, worst, and base case scenarios.](image-url)
Energy minerals will dominate all future uses
China dominates “energy minerals” supply chains
Mining in America: known unknowns

U.S. Federal Mine Approvals 2010-2022