Electric Vehicle Revolution and Implications for the Nickel Market

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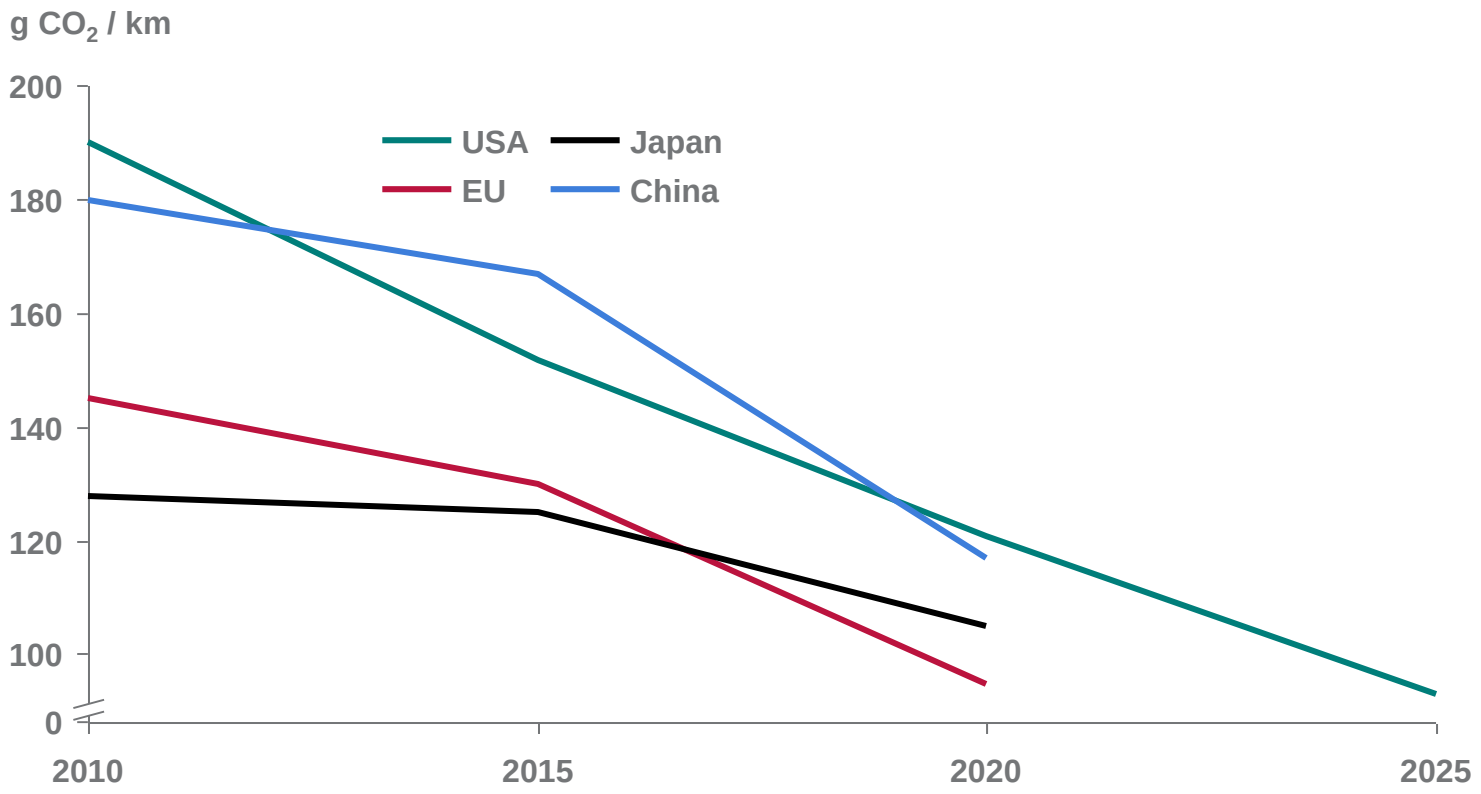
Government regulation is the key driver towards electrification

Planned emission standards in select regions, total fleet average for new sales



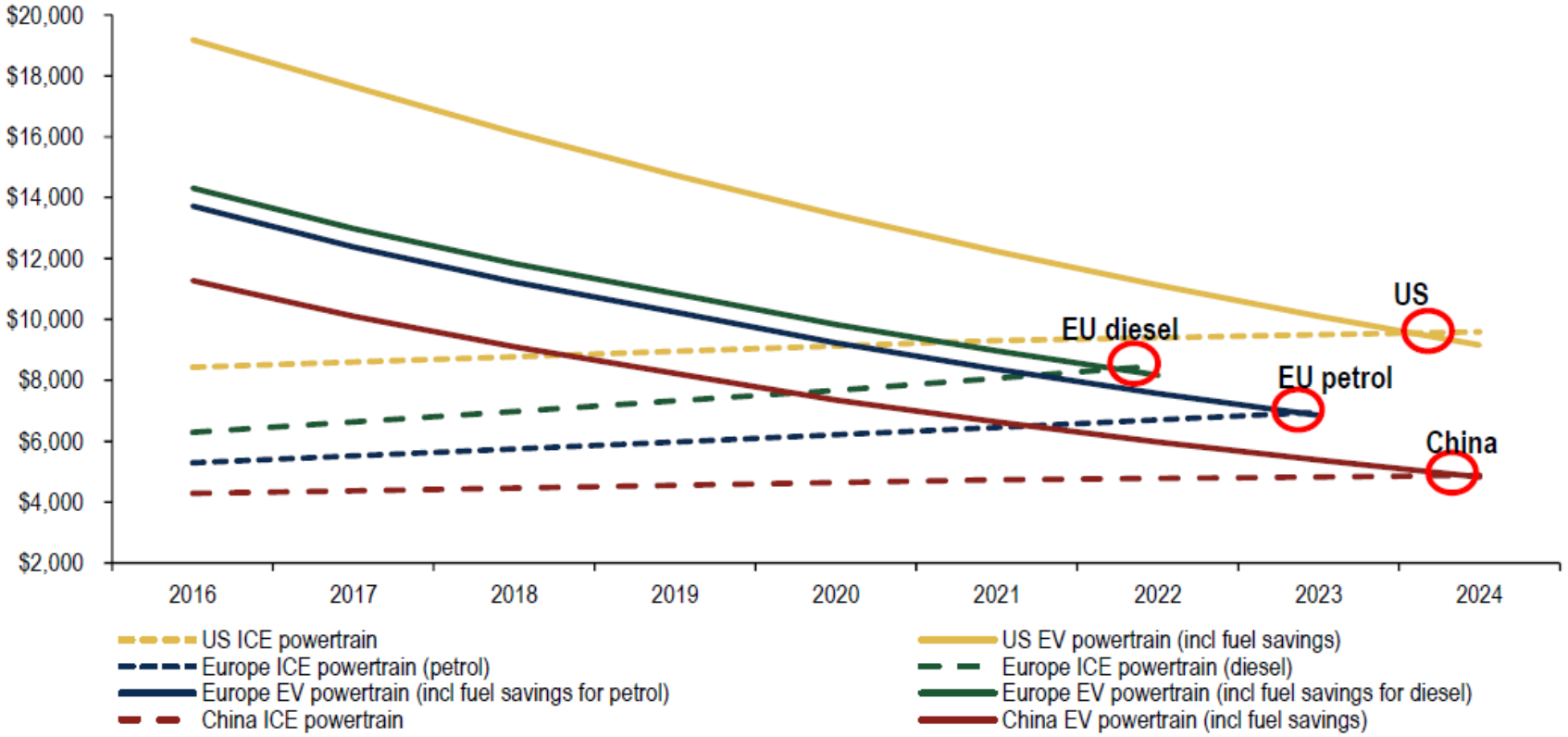
Current standards:
China: China 5
EU: Euro6
Japan: JPN2009

Canada/USA: Tier2
South Korea: Kor 3

Source: McKinsey, EU Commission

Battery electric vehicles are becoming cheaper faster

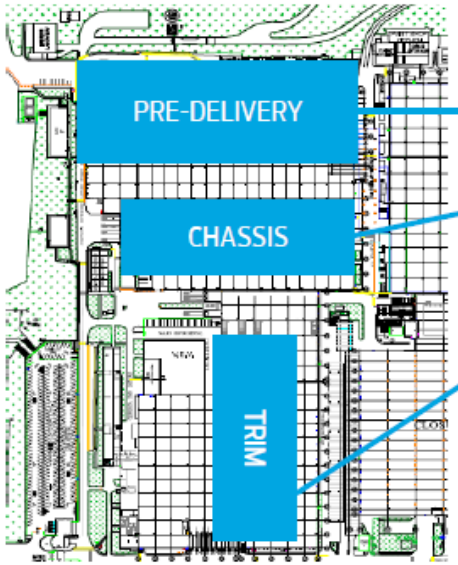
Chart 19: Global break-even points move closer when including net fuel savings. This is still excluding subsidies.



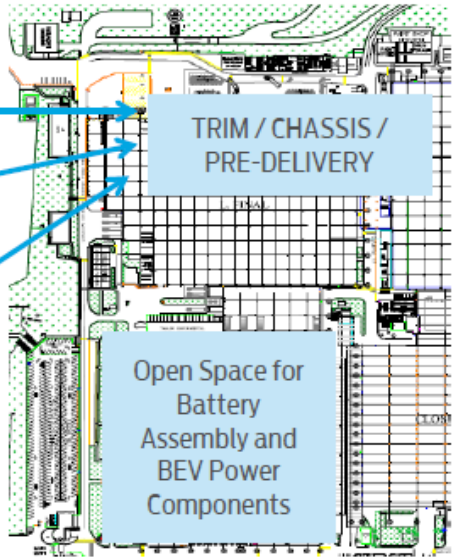
Source: Bank of America Meryl Lynch "Global Electric Vehicle Primer: Fully Charged by 2050" October 4, 2017

Electric vehicles are simpler and faster to build compared to internal combustion engines

Current State – Final Assembly



Future State – Final Assembly



Benefits vs. ICE

- 50% reduction in footprint
- 50% reduction in capital investment
- 30% reduction in hours per unit
- Flexible tooling / process fully scalable and reconfigurable to support increase in demand

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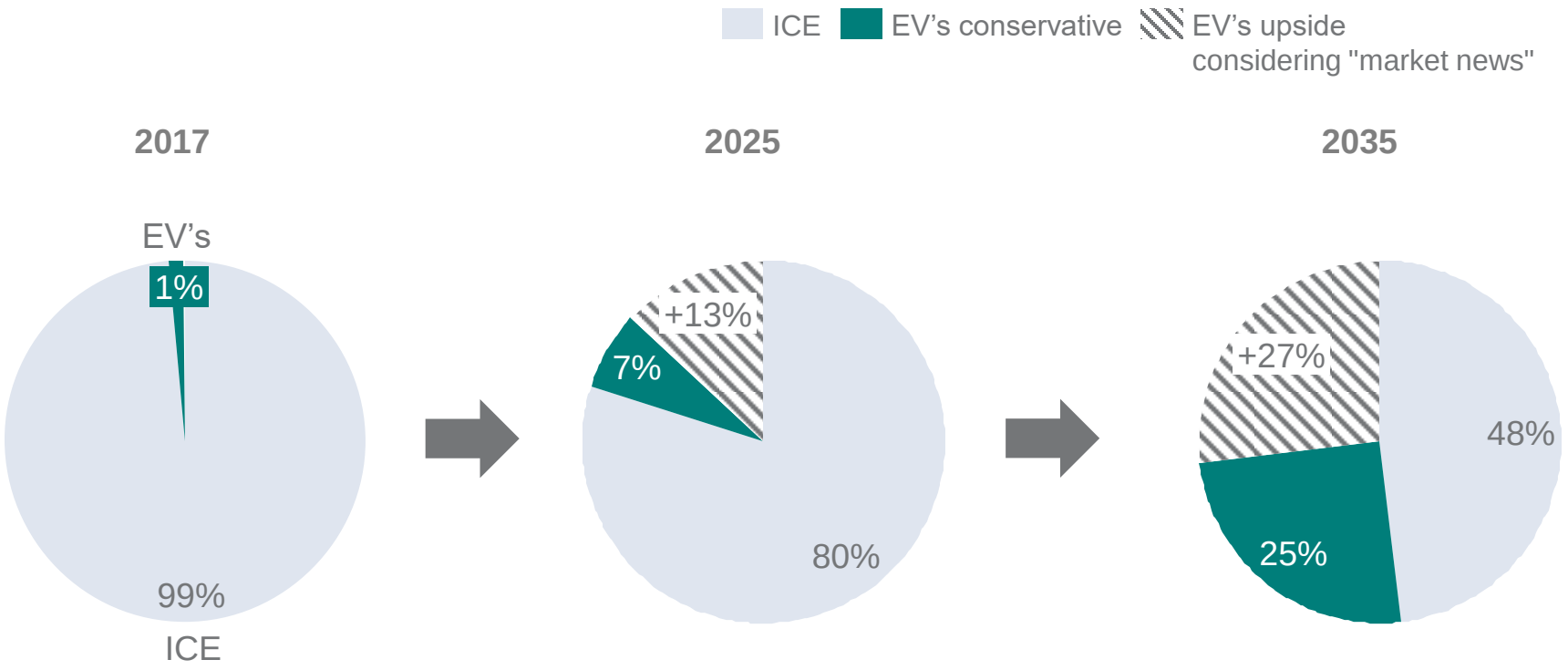
Source: Ford Motor Company 'CEO Strategic Update", October 3, 2017

This enables electric vehicles to take a commanding share of the personal vehicle market

Market Share of Electric Passenger Vehicles (Battery Electric and Plug-in Hybrids only)



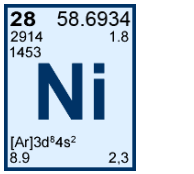
"Market News" refers to public commitments by various auto manufacturers as well as governments (such as UK/France committing to no ICE sales by 2040, California, China, etc.)

Source: Public Announcements, Media, Vale Analysis

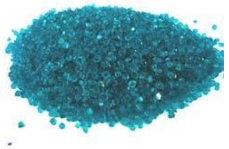
Implications for the nickel market

Nickel and cobalt are key ingredients for the manufacture of lithium-ion batteries

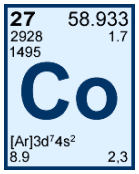
An example of a Nickel-Cobalt-Aluminum (NCA) battery



8 parts

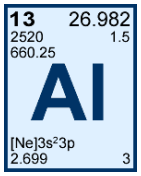


Nickel Sulphate



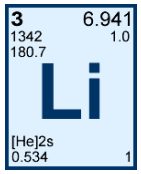
1 part

Cobalt Sulphate



1 part

Aluminum Sulphate



1 part

Lithium Carbonate

NCA Cathode Material

Cell
(shell is nickel plated)

Pack

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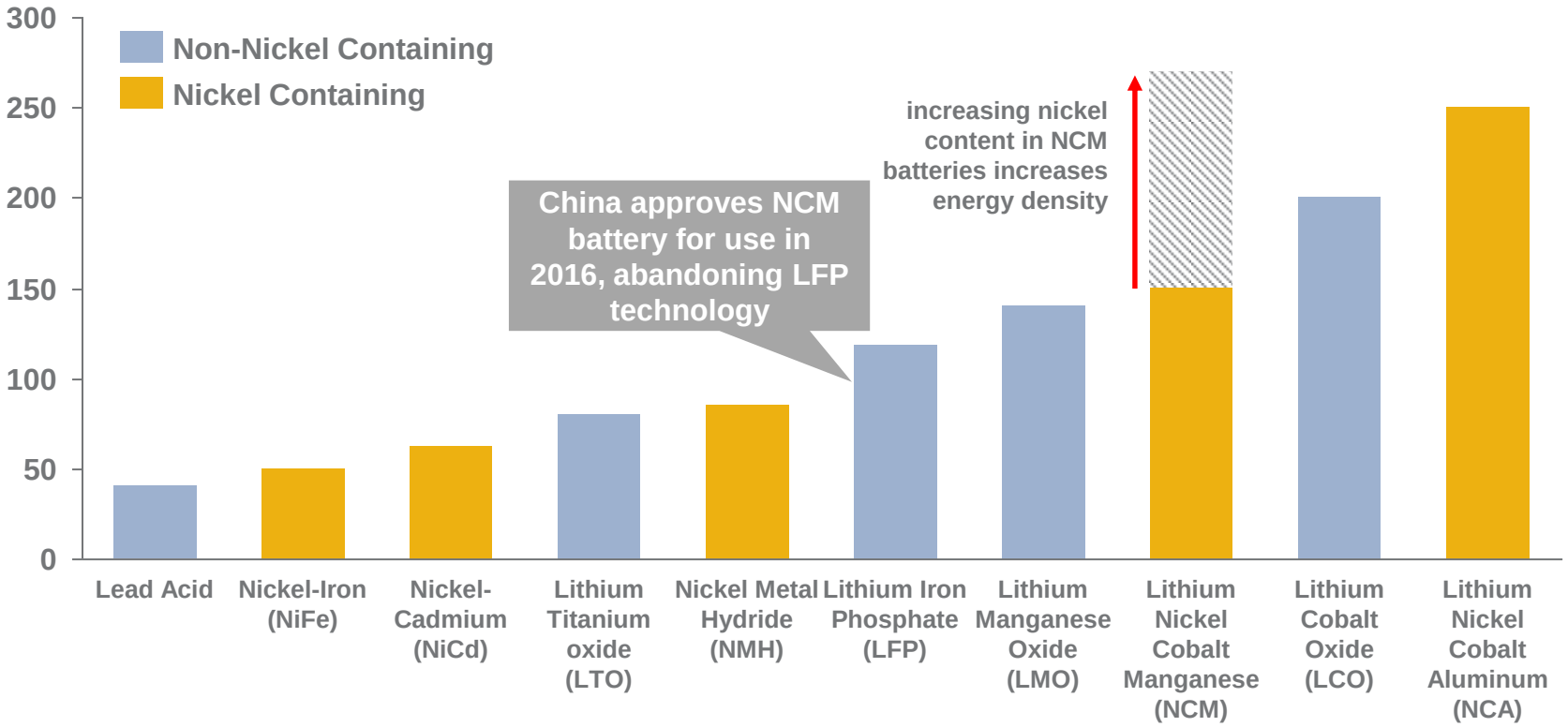
Source: Vale Analysis

Nickel based lithium-ion batteries offer the highest energy densities on the market today

Comparing Energy Density for a range of Battery Technologies (Wh/kg)



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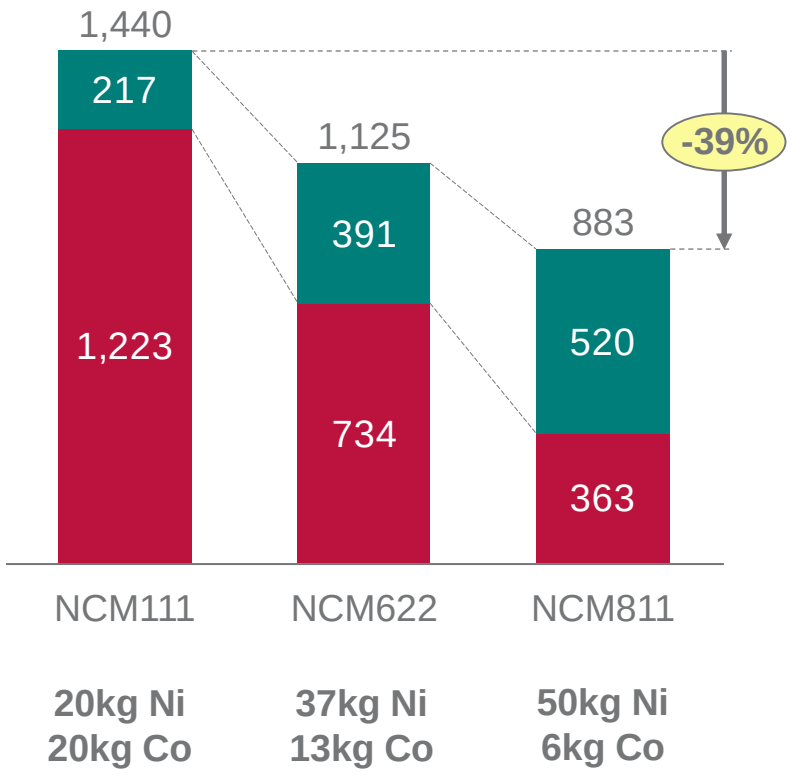
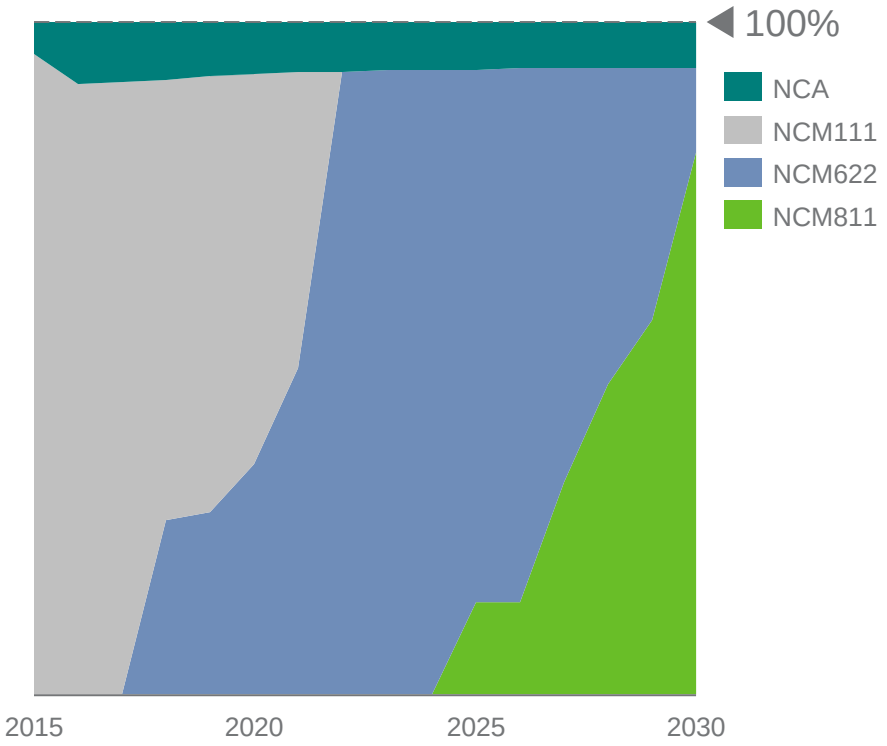
Source: batteryuniversity.com

The transition to higher nickel content batteries is accelerating due to cost benefits as well as concerns with securing cobalt

Nickel and Cobalt costs for a 60kWh battery (USD at Q3 2017 average LME prices)



Distribution of Battery Chemistries (%)



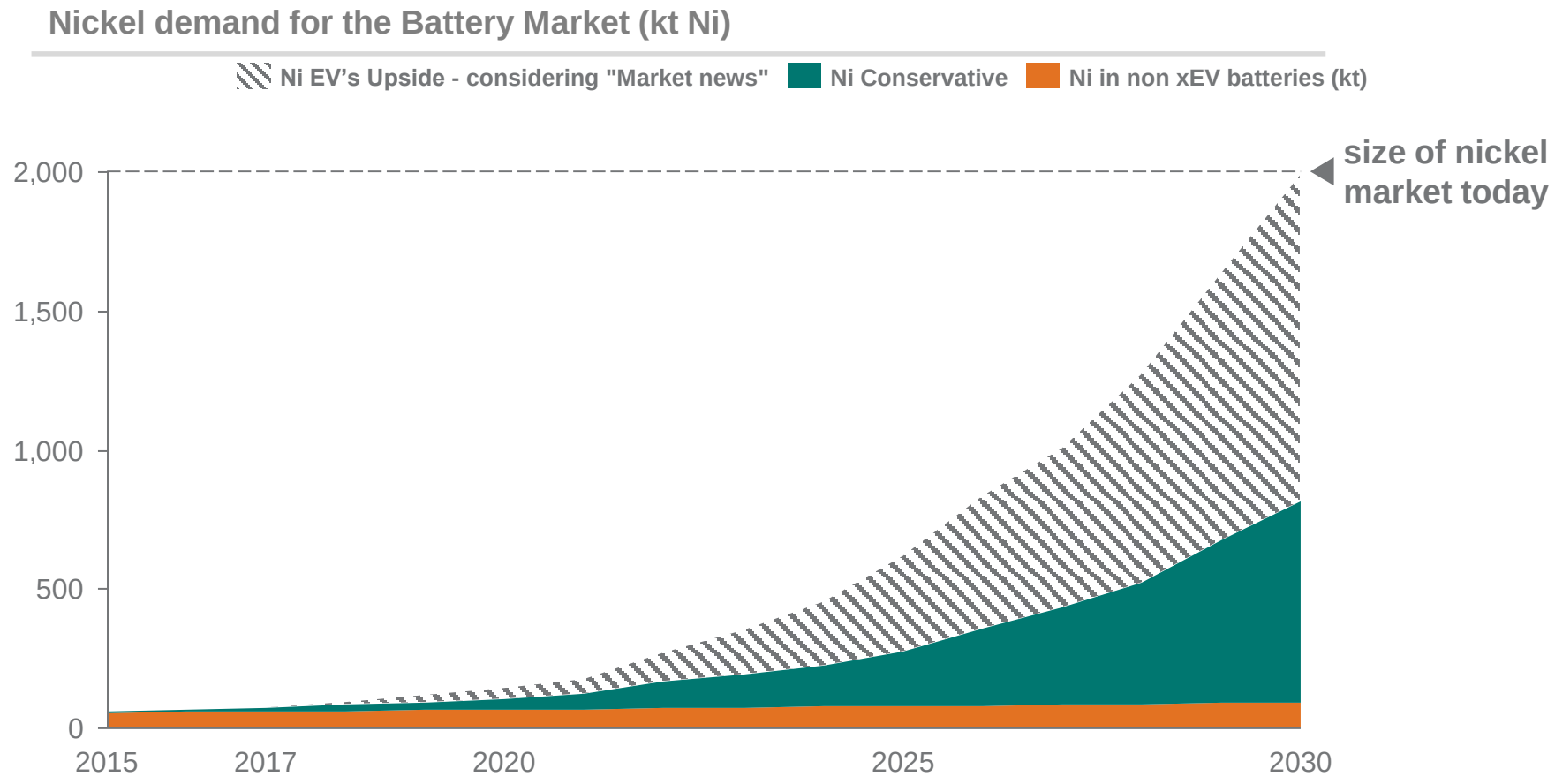
Source: Vale Analysis

The size of the battery is increasing as well – another large impact on commodity demand

OLD Pure EV		NEW Pure EV	
	Old Nissan Leaf 30 kWh		Nissan Leaf 2019 60 kWh
	Hyundai Ioniq 28 kWh		Tesla Model 3 50-75 kWh
	Ford Focus 23 kWh		Chevrolet Bolt 60 kWh
Drive Range (km)	150-200 km		350-400 km

Source: Public Announcements

As a result, the nickel demand for battery manufacturing is expected to increase



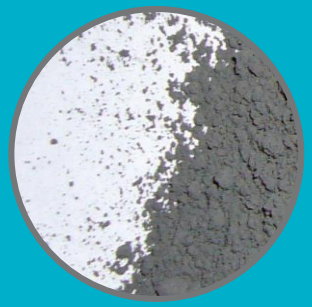
"Market News" refers to public commitments by various auto manufacturers as well as governments (such as UK/France committing to no ICE sales by 2040, California, China, etc.)

Source: Public Announcements, Media, Vale Analysis

Same Language

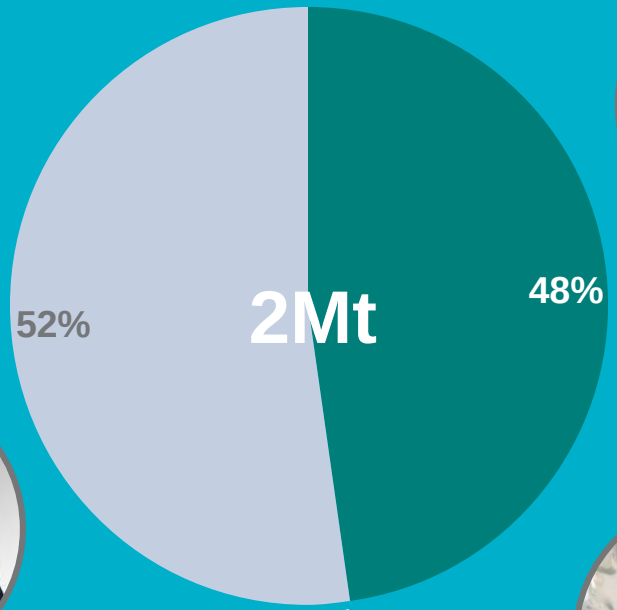
The nickel market is made up of two very different classes of product

FeNi
(15-30% nickel, balance iron)

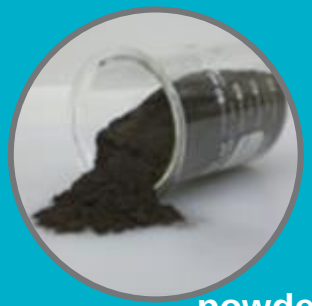


Nickel Oxide Sinters
(>70% nickel)

Nickel Pig Iron
(2-12% nickel, balance iron)



99.98% nickel or higher
(also chemicals such as nickel sulphate)



powders

briquette

pellets

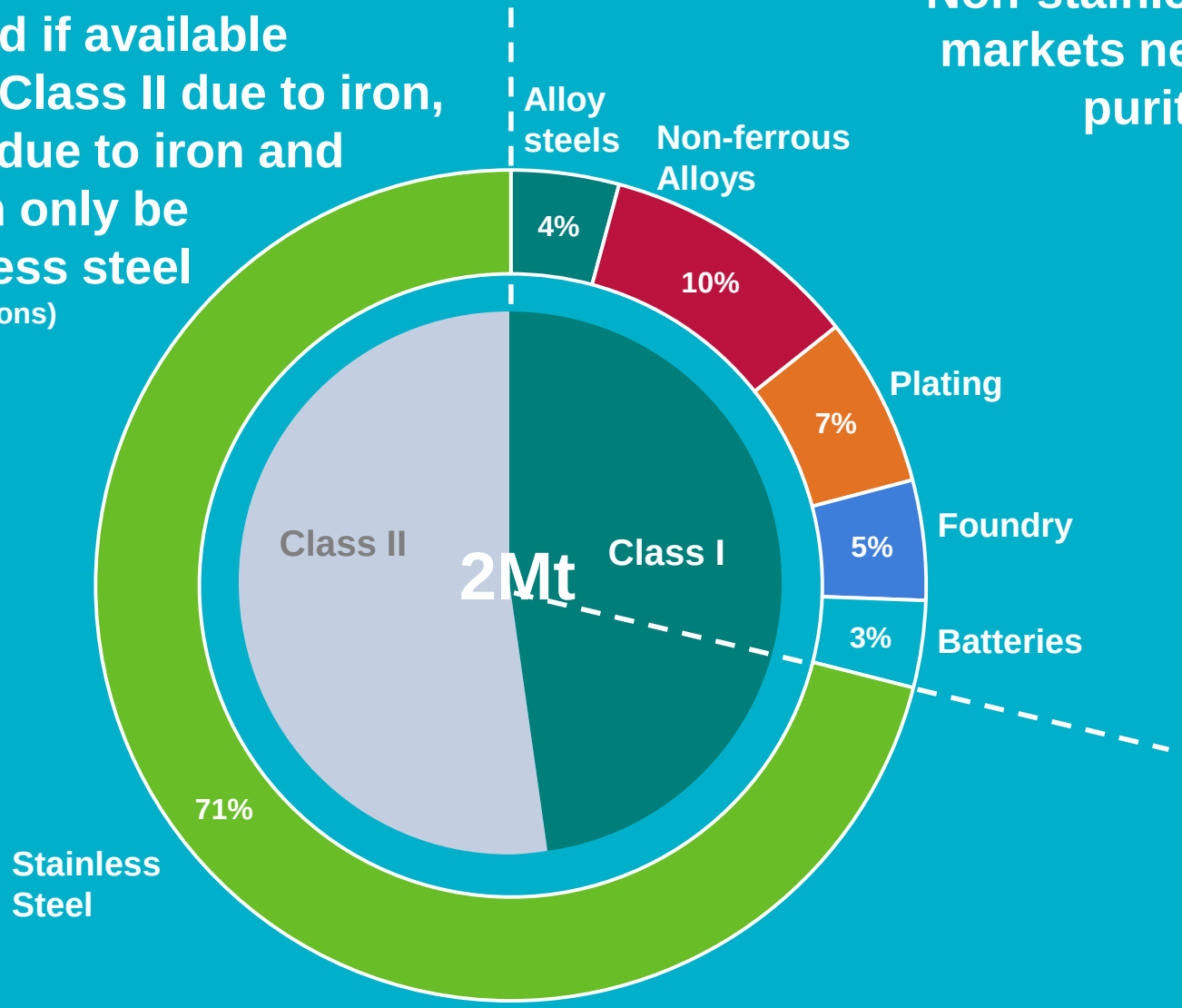
cathode

Source: Wood Mackenzie, CRU, Vale Analysis (statistics for 2017e)

Same Language

Stainless steel does not need the high purity and if available prefers using Class II due to iron, while Class II due to iron and impurities can only be used in stainless steel
(with few niche exceptions)

Non-stainless steel markets need high purity nickel



Source: Wood Mackenzie, CRU, Vale Analysis (statistics for 2017e)

Roughly half of the global nickel production is suitable for use to make batteries

suitability for battery market

dissolving metal

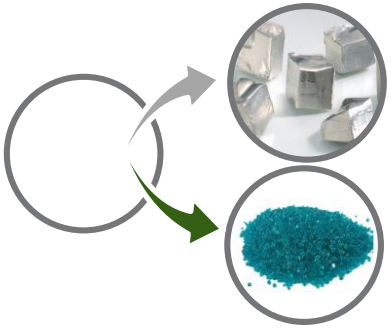
Class II

Class II products are too expensive to purify and dissolve although non-ferrous Class II a candidate

Class I

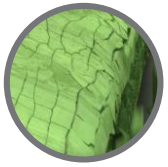
Not all Class I products are the same – dissolvability and impurities differentiate

refineries optimizing production



Shift existing production from nickel cathode to nickel sulphate

refining intermediates
(of acid leaching operations)



well suited although more costly than dissolving

~50% of world production is suitable

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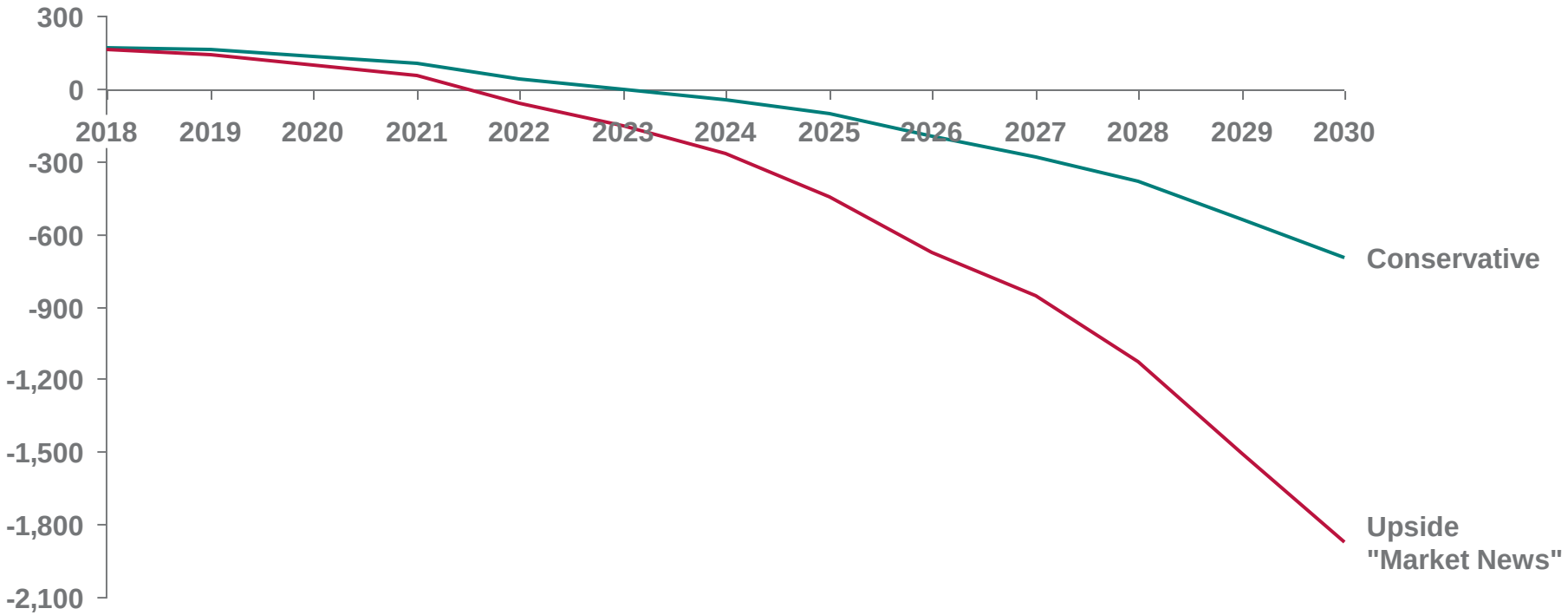
Source: Vale Analysis

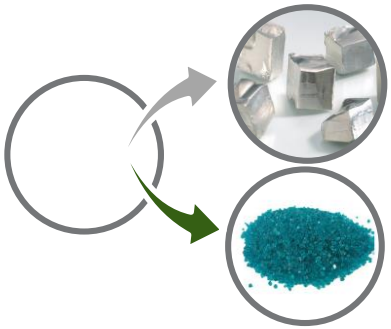
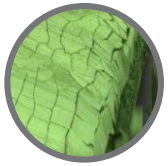
The nickel industry needs to grow in suitable units

Battery Suitable Nickel Market Balance (kt Ni)



Source: Wood Mackenzie, CRU, Vale Analysis (takes into account Alloy, Plating, Foundry and minimum Stainless Steel Class I load against expected Class I supply with remainder less Battery demand shown as balance above)

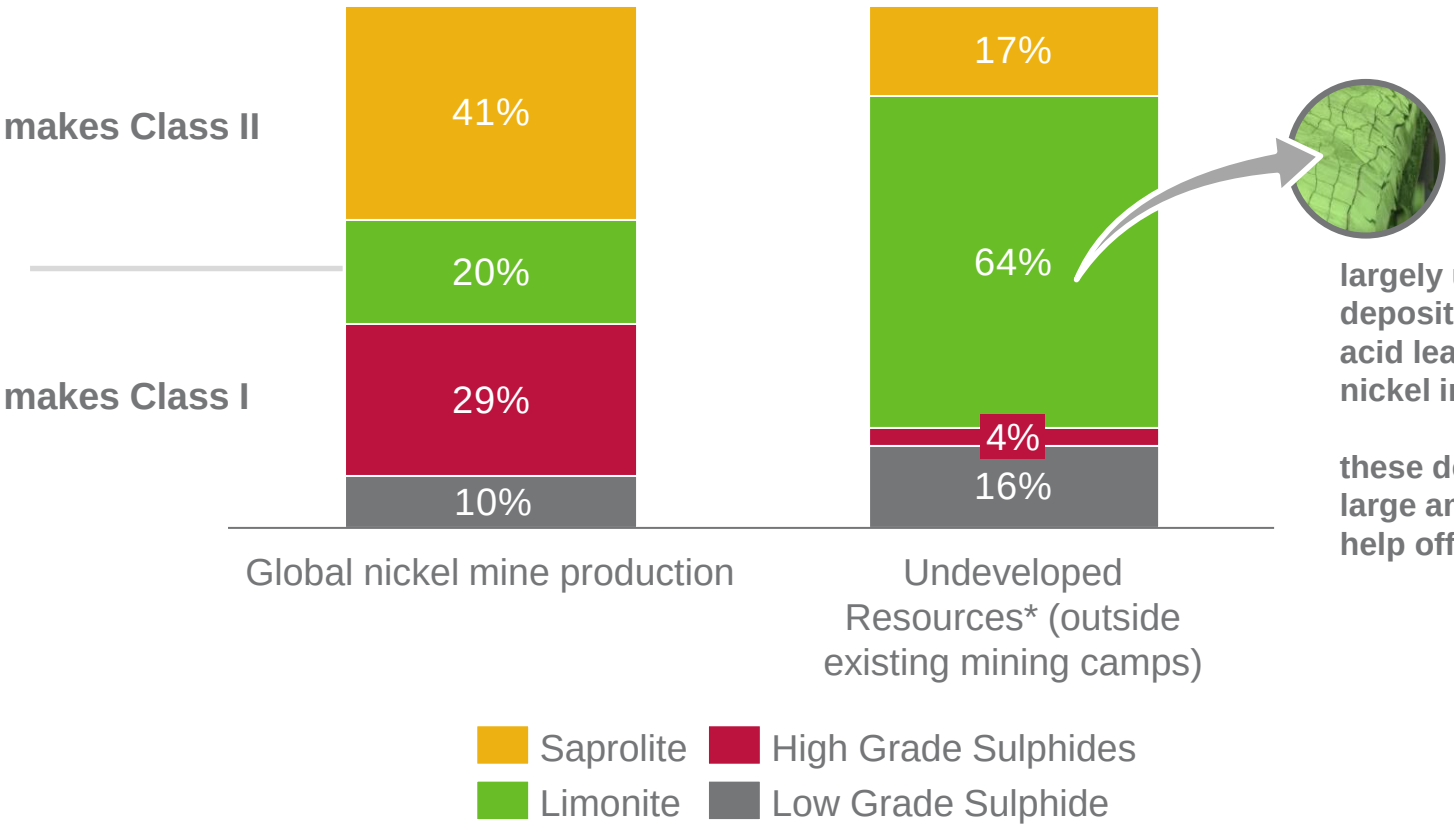
There are no easy ways to grow in battery nickel

		suitability for battery market	supply ability to respond
dissolving metal	Class II 	Class II products are too expensive to purify and dissolve although non-ferrous Class II a candidate	All new nickel supply growth is in Nickel Pig Iron – **not suitable for battery use**
	Class I 	Not all Class I products are the same – dissolvability and impurities differentiate	Mines are closing, capital is being deferred. **Class I is too expensive to grow.**
optimizing production		Shift existing production from nickel cathode to nickel sulphate	Very limited, cannibalizing nickel cathodes **(not growth**)
refining intermediates		well suited although more costly than dissolving	**Very limited today while this is the most likely candidate for future supply growth**

Source: Vale Analysis

The nickel industry is likely to turn to Limonite deposits in order to meet battery demand

World nickel production and undeveloped resources



largely untapped limonite deposits are accessible via acid leaching to produce nickel intermediates

these deposits also contain large amounts of cobalt to help offset production costs

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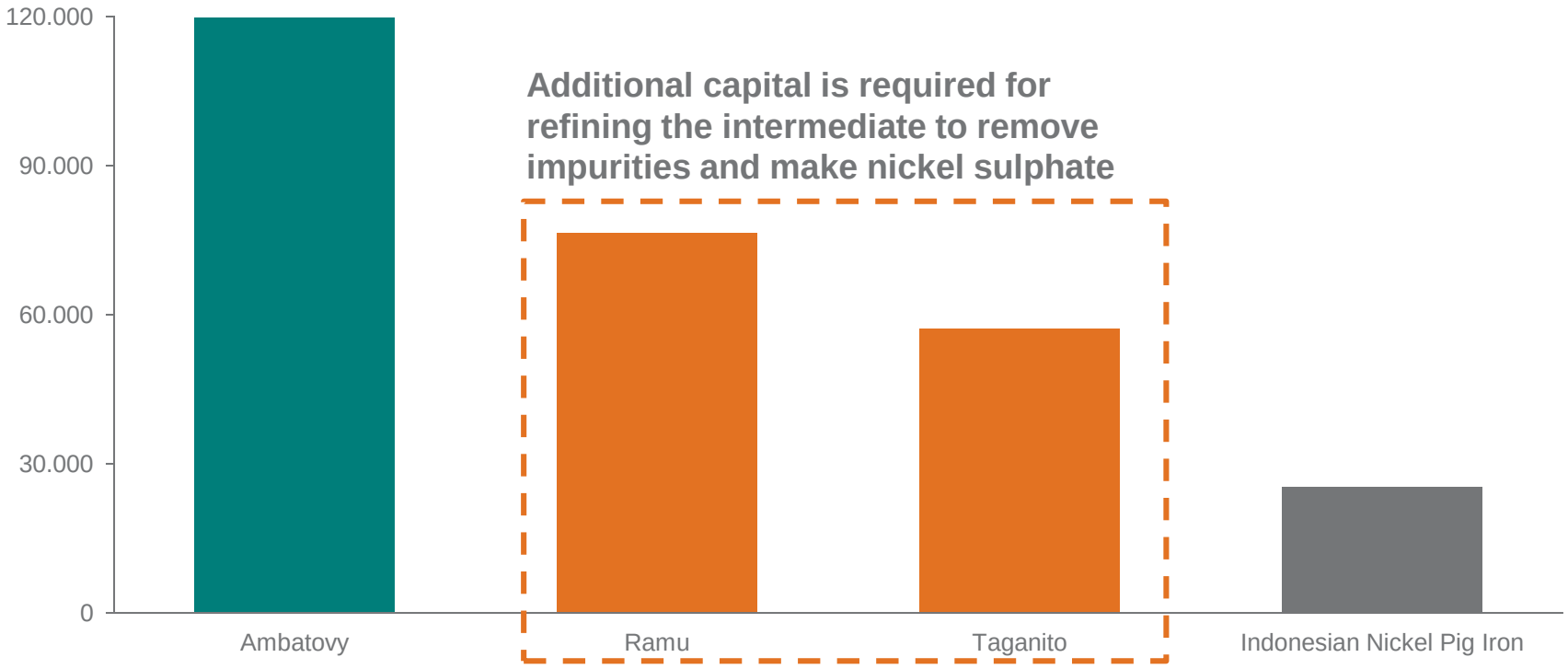
Source: SNL, Vale Analysis

However, it will be costly to increase production of suitable nickel units

Recent capital cost to bring nickel into production – comparing Class I vs. Intermediate vs. Class II (USD/t Ni installed capacity)



Source: Wood Mackenzie, Vale Analysis

Closing Remarks

- Electric vehicles will usher in a new age for nickel
- A more balanced nickel consumption profile between stainless and non-stainless applications
- Batteries need high purity nickel sulphate, cannot readily use Class II such as nickel pig iron or ferronickel units – today, only ~50% of global production is suitable
- Nickel industry needs to grow significantly in suitable units to meet demand for battery manufacture
- Growing in suitable nickel units is expensive

For a world with new values.