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Technology's role in mineral criticality

WORLD MATERIALS FORUM

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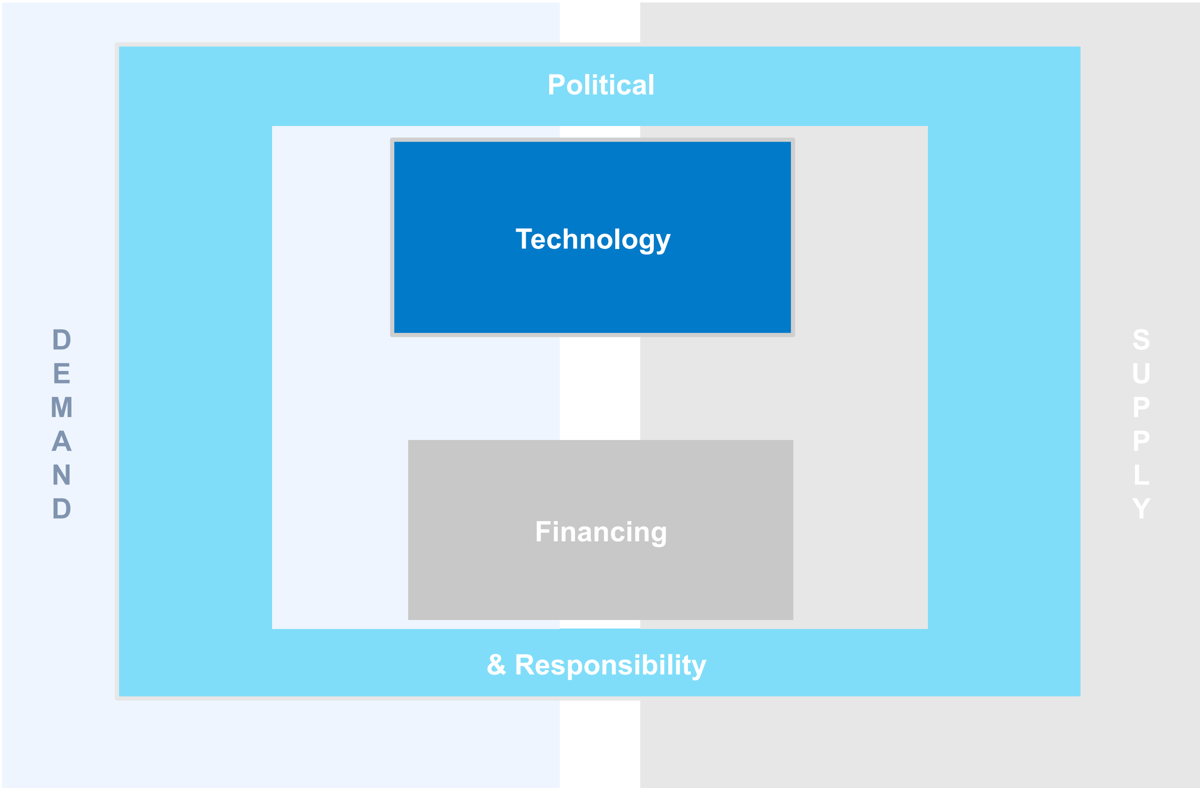
Technology's role in mineral criticality

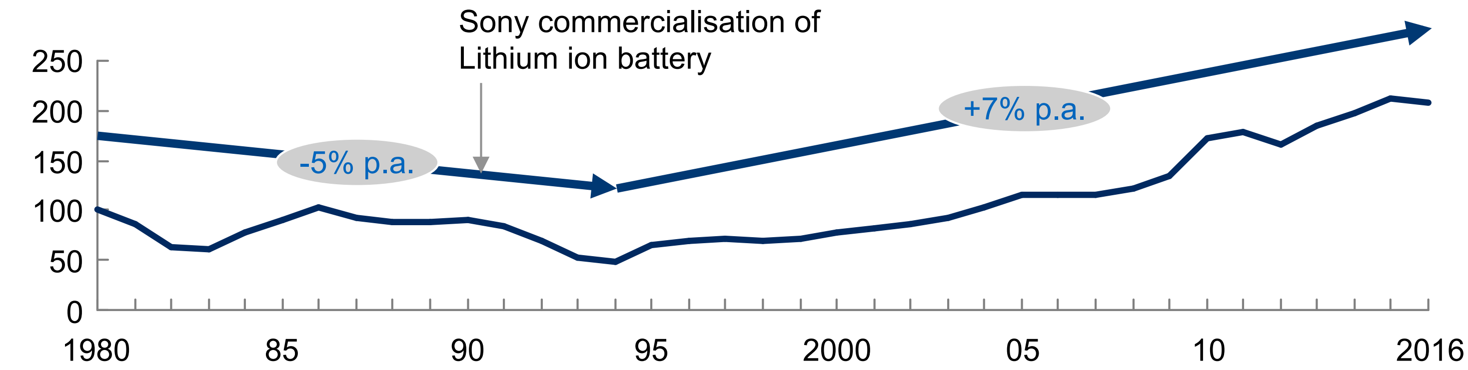


Contents

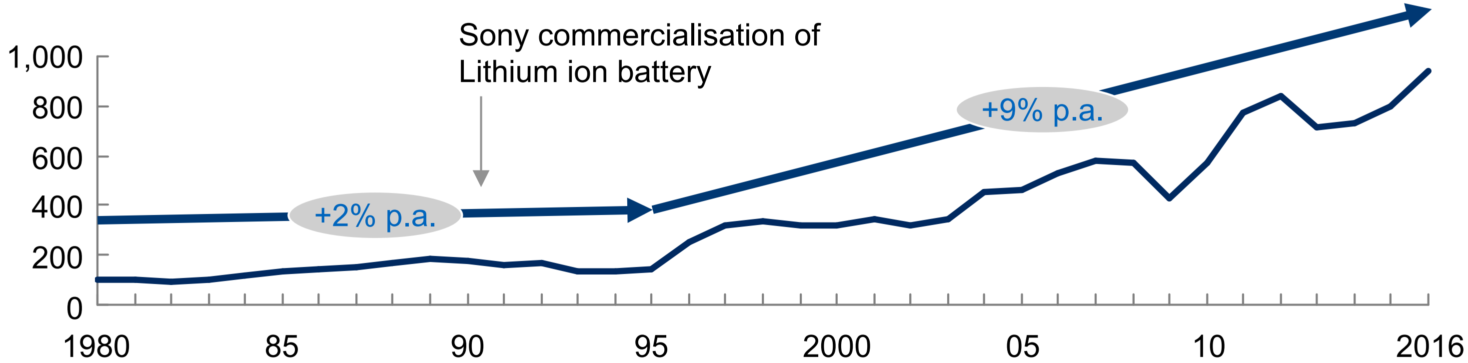
Historically, changing technologies have driven massive growth spurts in mineral demand

- Before 1991 demand for cobalt and lithium was driven by industrial purposes
- In 1991 Sony introduced a commercial lithium-ion battery
- The rapid demand growth in batteries drove production growth

Cobalt production, Tons indexed to 100 in 1980



Lithium production, Tons LCE[1] indexed to 100 in 1980



1 Lithium carbonate equivalent

SOURCE: USGS, WBMS, Press-search

New technology trends will be driven by changing social-economic dynamics…

Indicator	'15	'20

Middle class explosion
Mostly in Asia – and can afford to spend significantly more than their parents (China's average wages at ~45% of US vs. 15% today)

Aging population
Global median age will increase by 4 years by 2030, driving growth in health & wellness products spending

Millennials taking over
Millennials will be the largest age cohort in spending in 5 years: internet natives desiring instant gratification and personalized products

Shrinking household size
Average household size continues to fall, especially in developed markets (US average household fell from 3.67 to 2.55, 1948 to 2012)

Urbanization
Globally, 60% of people will live in urban areas in 2030, compared to 53% in 2013

North America

Population, m	358	371
GDP, $b	16,400	18,300
GDPPC[1], $	45,810	49,326
Av. age	38.3	38.9
Child / woman	1.9	1.9

Europe

Population, m	738	740
GDP, $b	23,100	25,200
GDPPC[1], $	31,301	34,054
Av. age	41.7	42.7
Child / woman	1.6	1.7

Asia Pacific

Population, m	4,393	4,598
GDP, $b	16,100	19,700
GDPPC[1], $	3,665	4,284
Av. age	30.3	32.1
Child / woman	2.1	2.1

South America

Population, m	418	438
GDP, $b	3,700	4,200
GDPPC[1], $	8,852	9,589
Av. age	30.2	32.0
Child / woman	2.0	1.9

Africa & Middle East

Population, m	1,186	1,340
GDP, $b	1,500	1,800
GDPPC[1], $	1,265	1,343
Av. age	19.4	19.8
Child / woman	4.4	4.1

1 Gross Domestic Product per capita

McKinsey – Consumer Trends 2030, UN World Population Prospects, EIU database

…however, it is tough to predict which technology trends will prevail and how these will impact the minerals industry

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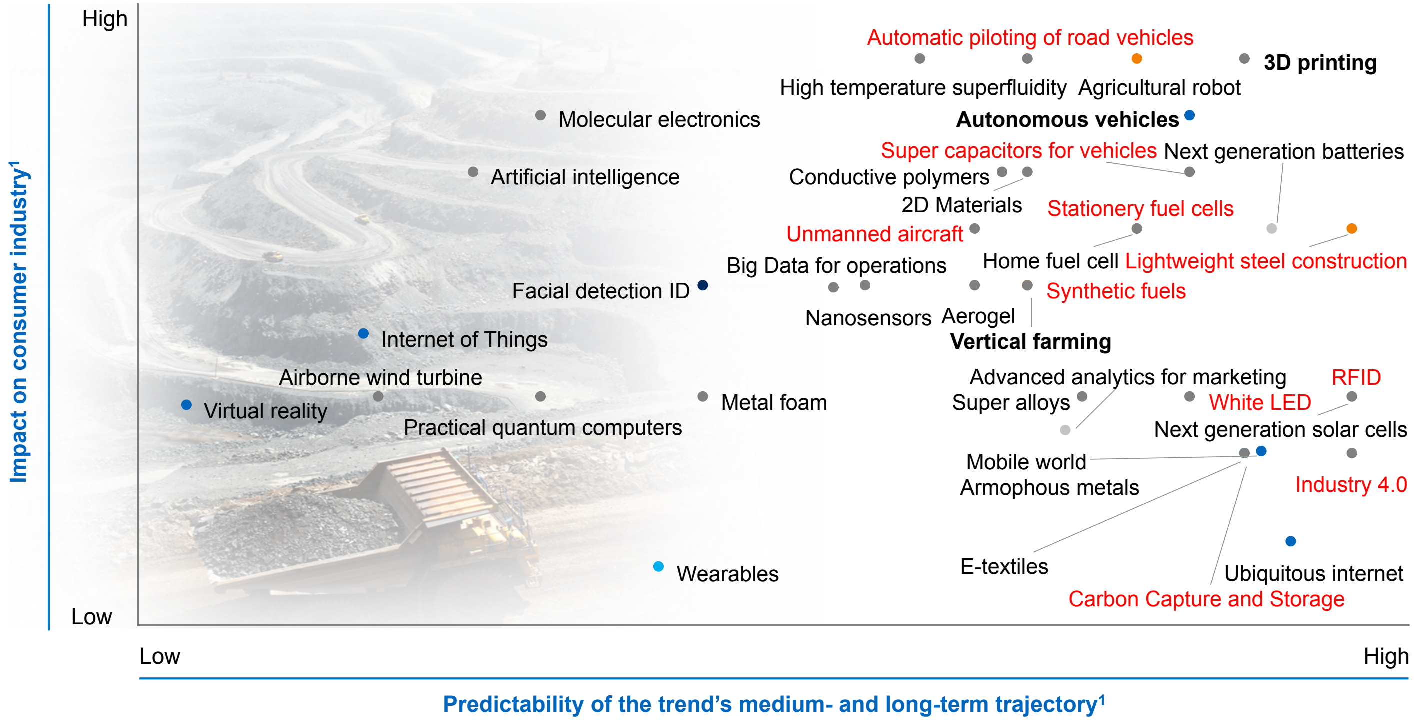
Most important driver

Middle class explosion · Aging population · Millennials taking over · Shrinking household size · Urbanization · Other such as productivity · Identified by DERA



Broad industry trends will translate into a variety of new technologies

Predicting what materials these new technologies will consume is next to impossible

These industry trends will also directly impact mineral demand

3D Printing

Increased demand for rare metals , replacement of existing demand from manufacturing

Autonomous vehicles

Increased lifetime of vehicles, lower demand from heavy industry

Vertical farming

Increased demand for fertilisers, Increased demand for light weight structures

1 Based on analysis of third-party projections, publicly available reports, and expert opinions

Source: McKinsey, DERA (Deutsche Rohstoffagentur) Rohstoffinformationen 28

Without additional developments and investment many commodities would not be able to sustain a rapid demand boom

Investment requirements by commodity, Commodity lifetimes on current economically viable reserves[1]

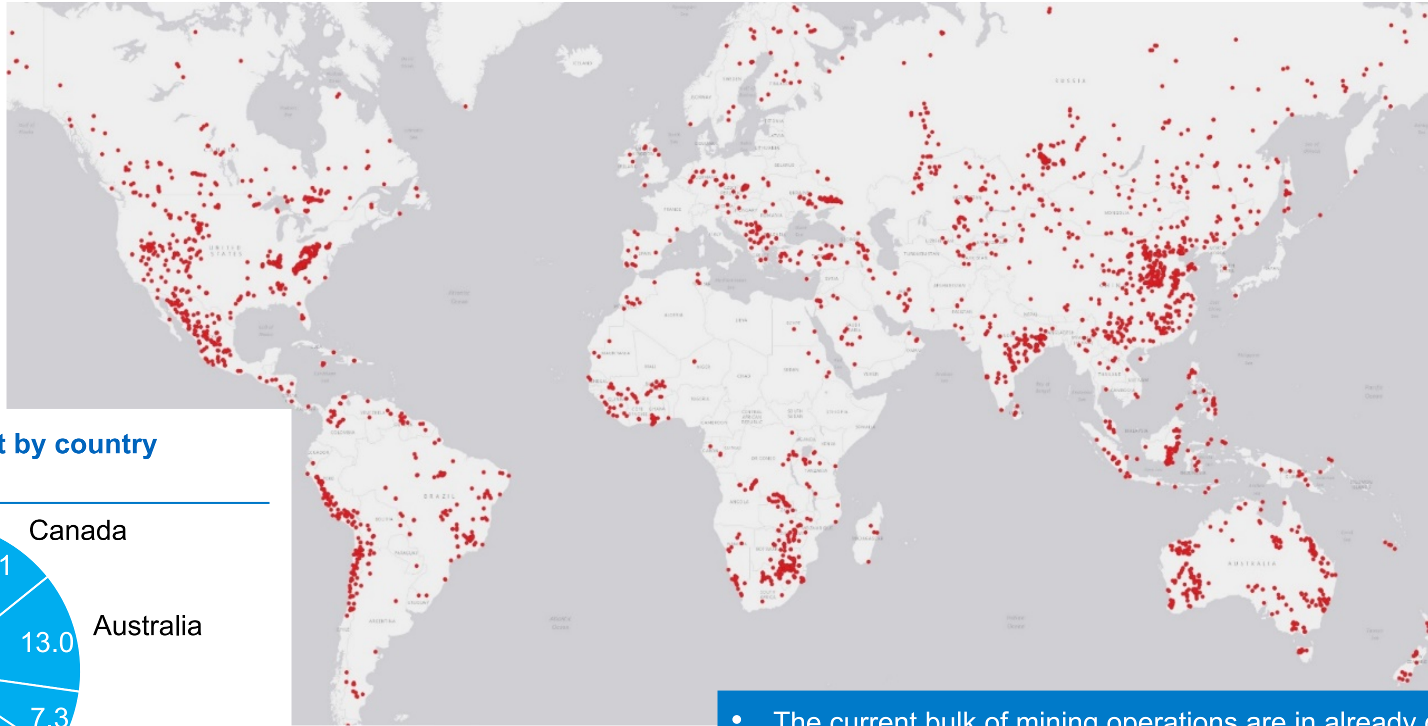
	Current rates of extraction	Short boom[2]	Sustained boom[3]	Potential future technology drivers
Antimony	12	7	4	Micro-energy harvesting of ambient energy
Tin	17	10	6	Lead-free solders
Lead	18	11	7	Thermoelectric generators
Gold	18	11	7	
Zinc	18	11	7	
Strontium	19	12	7	Stationary fuel cells
Silver	21	13	8	RFID
Nickel	35	22	13	Carbon Capture and Storage
Tungsten	36	22	14	Superalloys
Bismuth	36	23	14	High-temperature superconductors
Copper	37	23	14	Ultra efficient industrial electric motors
Boron	40	25	16	
Fluorspar	41	25	16	
Manganese	43	27	17	Microelectronic capacitors
Selenium	45	28	18	Thin-layer photovoltaics
Rhenium	53	33	20	
Cobalt	57	35	22	Thermoelectric generators
Iron ore	60	37	23	
Molybdenum	66	41	25	Seawater Desalination
Rutile	79	49	31	Microelectronic capacitors
Bauxite	107	66	41	Super capacitors for vehicles
Potash	110	68	43	Thermal storage
Ilmenite	131	82	51	
PGMs	176	109	68	PEM-fuel cells for electric vehicles
Natural graphite	208	129	80	
Iodine	237	147	92	
Vanadium	250	155	96	Infrared detectors
Phosphate rock	261	162	100	
Magnesium	307	191	118	Lightweight steel
Lithium	400	248	154	

1 Current known economical viable reserves divided by production rates
2 Commodity production grows by 10% CAGR over 5 years with reserves at current level
3 Commodity production grows by 10% CAGR over 10 years with reserves at current level

SOURCE: USGS, DERA (Deutsche Rohstoffagentur) Rohstoffinformationen 28

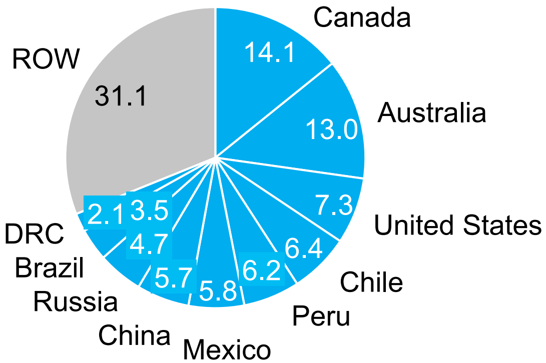
Currently, there exists a vast amount of untapped potential, however investments aren't being directed there

Currently operating mines global



2016 exploration budget by country

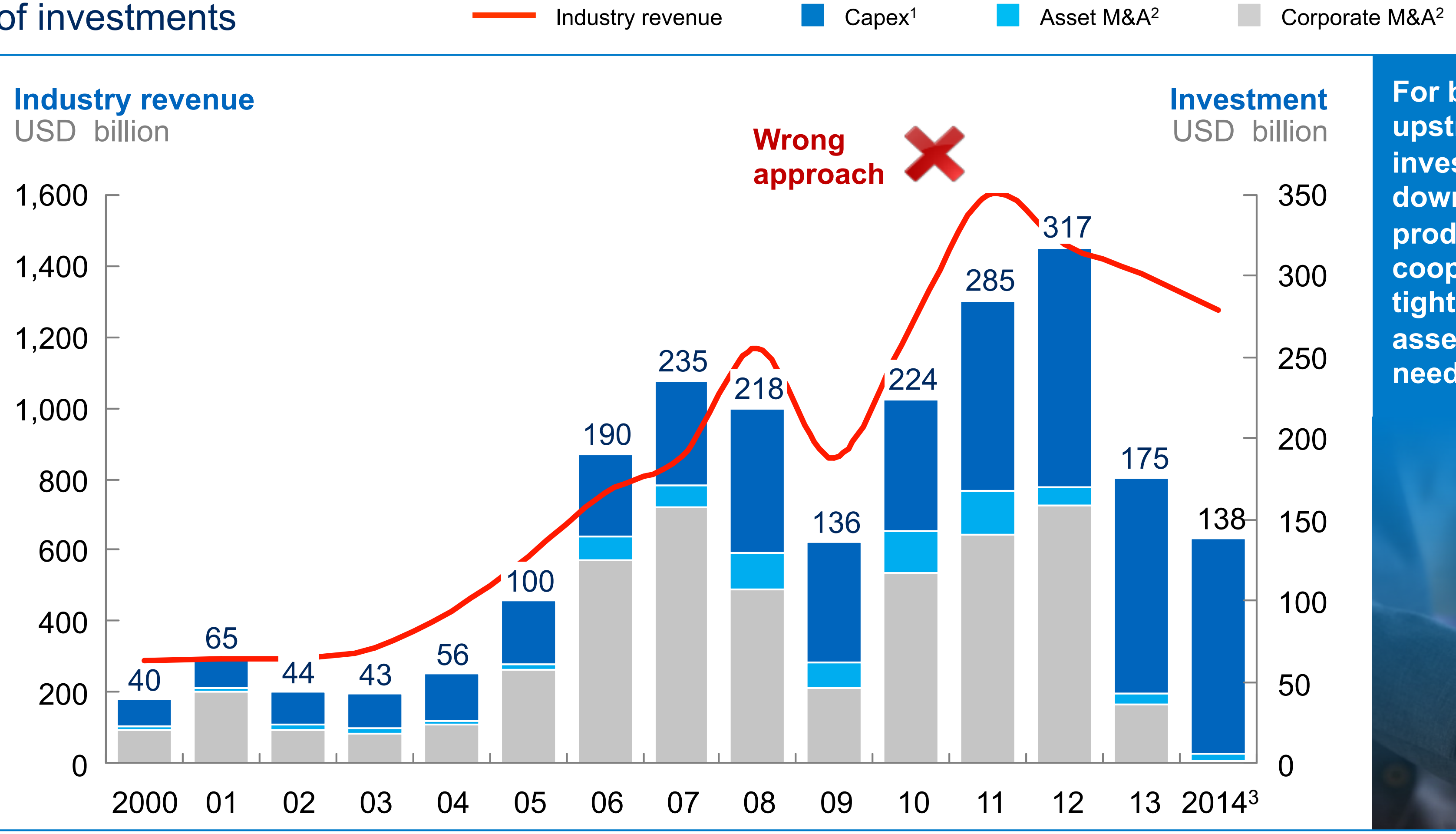
100% = 6.9 billion US$

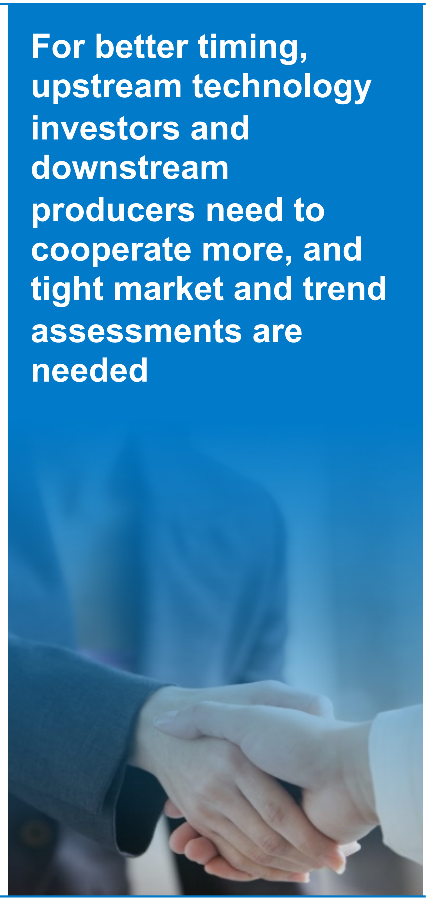


- The current bulk of mining operations are in already developed mining regions
- Currently ~70% of exploration spend is occurring in 10 countries representing only ~45% of explorable land areas
- Africa and Asia (excluding China) see lower interest from investors

SOURCE: SNL MEG

Increased cooperation between all stakeholders is required to ensure the correct timing of investments





1 Sample of 144 mining companies

2 Considering deals equal or higher than USD 100 million

3 Annualized

SOURCE: Bloomberg; Dealogic; Value Pools 3.0

The industry can employ a number of strategies to ensure that a potential demand boom is met

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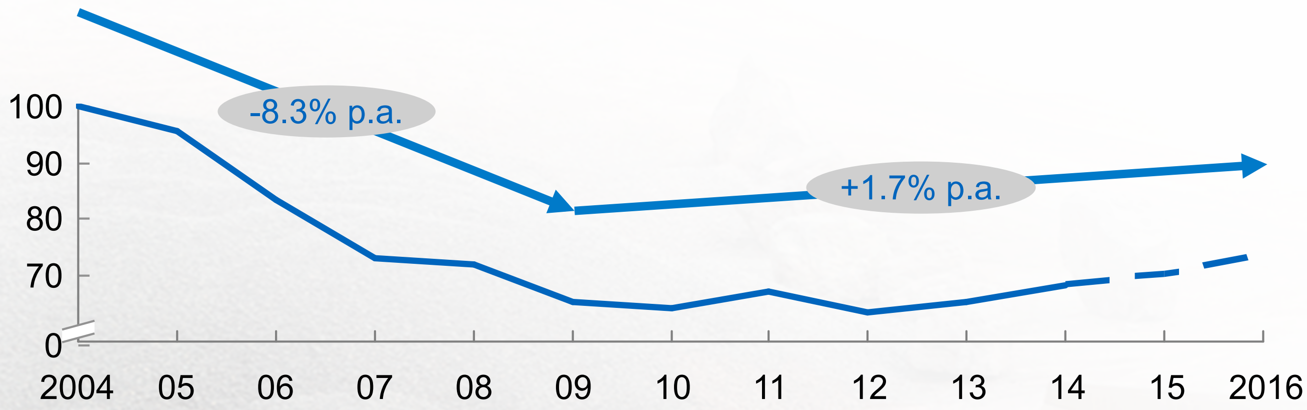
	Description	Example of actions	Time required to implement	Difficulty to implement
Optimising existing operations	Ensure that current operations are operating at maximum efficiency	▪ Use advanced analytics to identify areas of low productivity and improve them ▪ Employ advanced analytics in processing to improve yield	Low	Low
Expanding current operations	Where possible expand on current projects to expand their nameplate capacity	▪ Use newer processing methods to use lower quality ores ▪ Introducing automation where possible to improving productivity	Moderate to high	Moderate to high
Fast tracking projects	Bringing existing projects to fruition sooner	▪ Decrease ramp-up times ▪ Use more advanced project management programs to better manage projects	Low to moderate	Moderate to high
Expanding the project pipeline	Adding additional projects to the overall pipeline	▪ Acquire high quality assets from exploration companies earlier on in the project cycle ▪ Invest in newer and more comprehensive exploration techniques while investigating newer areas	Low to moderate	Moderate to high

Contents

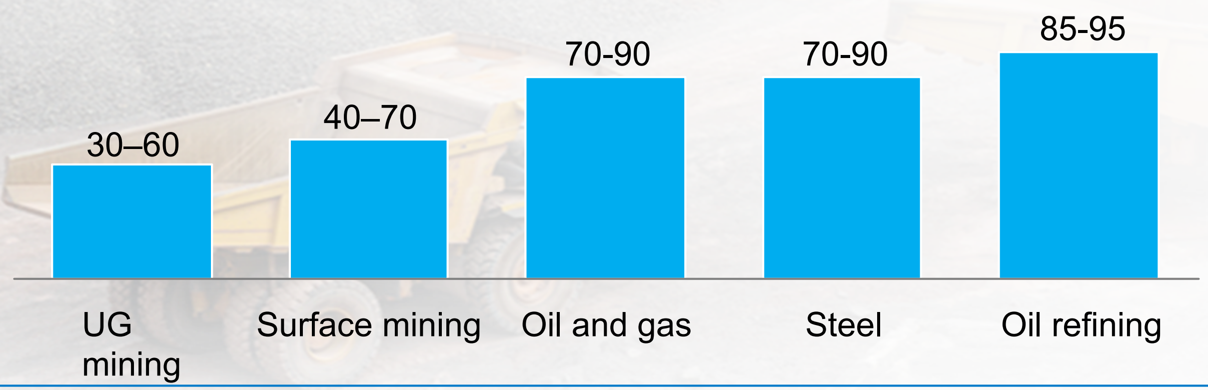
While mining productivity has been improving over the past decade, it still lags significantly behind its peer industries

MineLens Productivity Index[1], 2004 = 100



The decline in mining productivity has been driven by increased cost, worsening operations and a focus on volume over productivity

OEE of equipment assets, Percent of 24-hour period[2]



Compared to other industries mining is still lagging behind in terms of productivity

1 Proprietary productivity index for the mining industry that considers the impact of labour, assets and cost management while negating the impact of factors outside of the miner's control such as grade degradation
2 Estimate

SOURCE: Company annual reports; MineLens, McKinsey experts; interviews; team analysis

Existing and new technologies help deal with mining productivity issues

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● Single commodity ● A group of commodities ● Most commodities

Impact of new technology	Now (is used today)	Near term (technology exists, but not yet used full scale)	Technologies under development (R&D and/or small scale pilots)
Changes the way the industry operates	(Bio)leaching In-situ leaching/recovery	Seabed mining High pressure acid leaching VIBRO cone crusher	
Significant impact on existing practices	Block caving Continuous mining Targeted ventilation Drill and blast optimization (precision drilling & real time geological analysis)	Automation of vehicles / equipment Concentrated mining Dry concentration Early underground / in-pit separation Water head equipment drives Advanced sensor sorting Internet of Things	Artificial intelligence (AI) Microwave cracking Remote operating centers
Incremental continuous improvement	Advanced modeling & analytics Alternative fuels In pit separation High pressure grinding rolls In-pit crushing and conveying Micropelletising Predictive equipment health Slurry piping Ultrafine grinding UG water treatment systems	Directional drilling Distributed wireless sensor networks High-angle waste conveying	Energy regeneration

Maturity

SOURCE: PD772409 Expert Interviews; press search; team analysis

Implementation of Digital/Advanced Analytics such as our McKinsey Rapid Yield Boost approach can result in significant yield gains

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CLIENT EXAMPLES

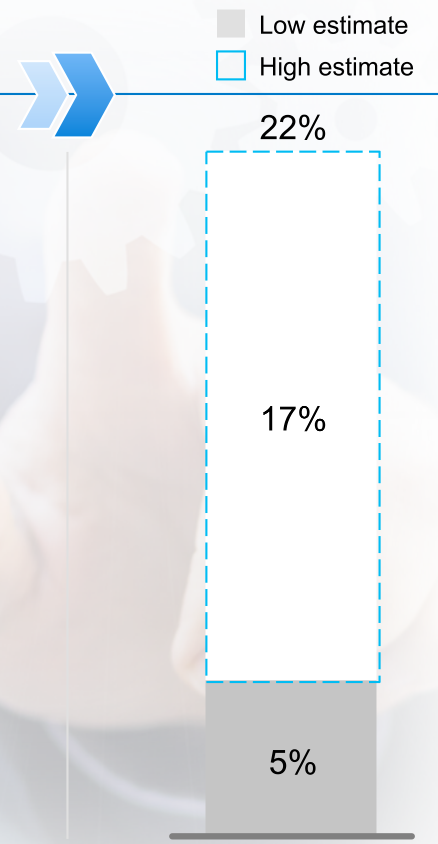
	Situation	Impact			
Nickel mine 	▪ Multiple **blind spots in understanding** drivers of yield (e.g. in electrode set point, reagent consumption)	**Yield improvement potential (concentrator and smelter),** %	93%  Observed	96%  Optimal	**3% more**
Phosphate mine 	▪ Plant did **not fully understand** drivers of the difference between its various mills	**Yield Improvement** Percent	 Baseline	 Optimised	**Plus 23%**
African gold mine 	▪ Plant was **focusing on grade and throughput** as key parameters that drive performance—limited **discipline on 2nd and 3rd** level parameters (e.g. dissolved oxygen)	**Profit per hour** $ Thousands/hour	35 	38 	**5–10% more**

SOURCE: McKinsey

Successful implementation of technology could generate up to 22% of additional value from productivity improvement for all stakeholders

Potential economic impact of sized applications in 2025
%, Share of 2016 mining revenue

Levers	Description
Operations management	Improved planning and management of operations due to technology such as scheduling programs
Improved equipment maintenance	Predictive maintenance using real-time condition monitoring
IoT enabled equipment selection	Better match equipment specs to mine site requirements
IoT enabled process optimisation	Link various parts of the operations through IoT to reduce bottlenecks
IoT enabled R&D	Redesign parts/system and reduce over/under design
Health and safety	Minimize exposure to dangerous conditions



1 McKinsey mine digitisation model, based on copper mine at middle of cost curve

SOURCE: McKinsey Global Institute research on Internet of Things

Contents

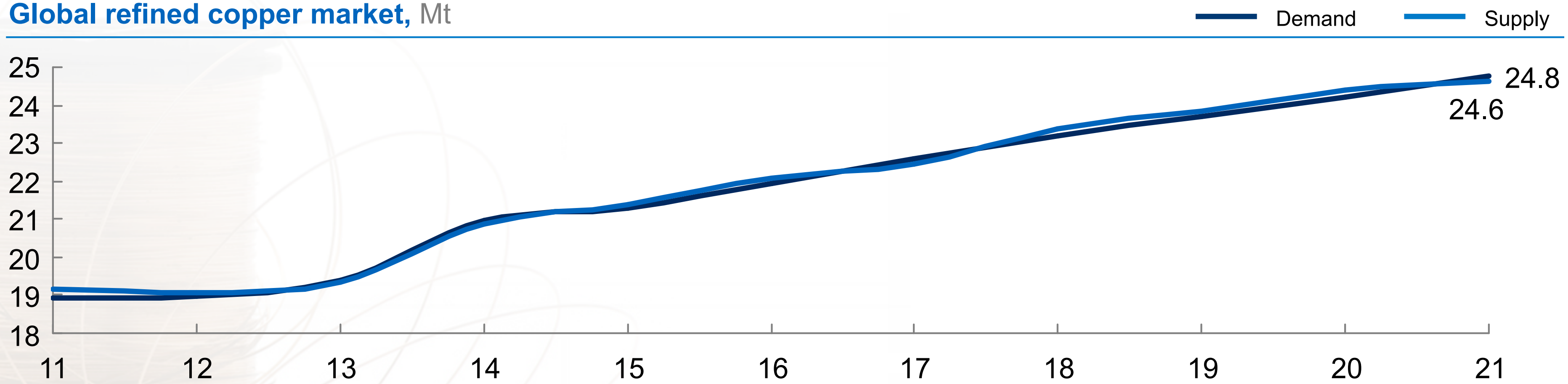
Contents

COPPER EXAMPLE

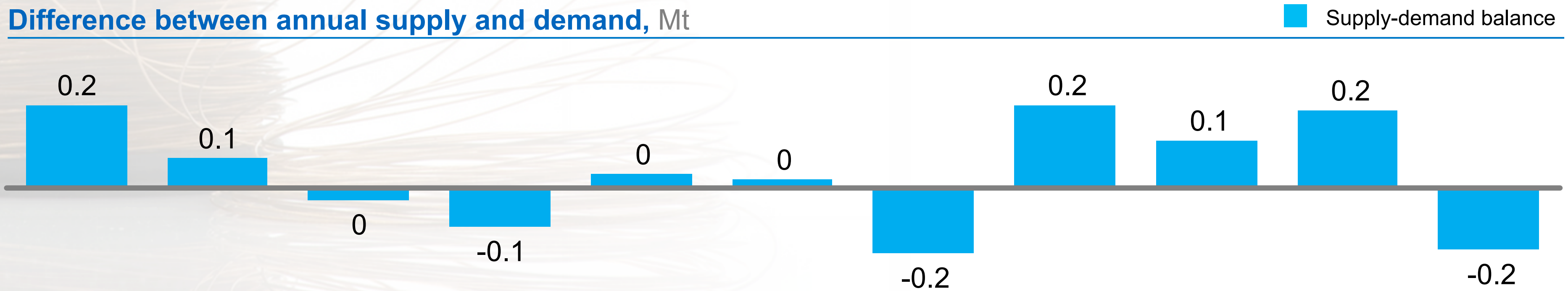
The copper market is expected to remain in a delicate balance between supply and demand

Q1 2017
BASE CASE

Global refined copper market, Mt



Difference between annual supply and demand, Mt



1 Grasberg assumed to operate at 40% until mid-year, back to capacity in the second half of 2017. Escondida strike assumed to be resolved by late March/early April

SOURCE: McKinsey copper team analysis

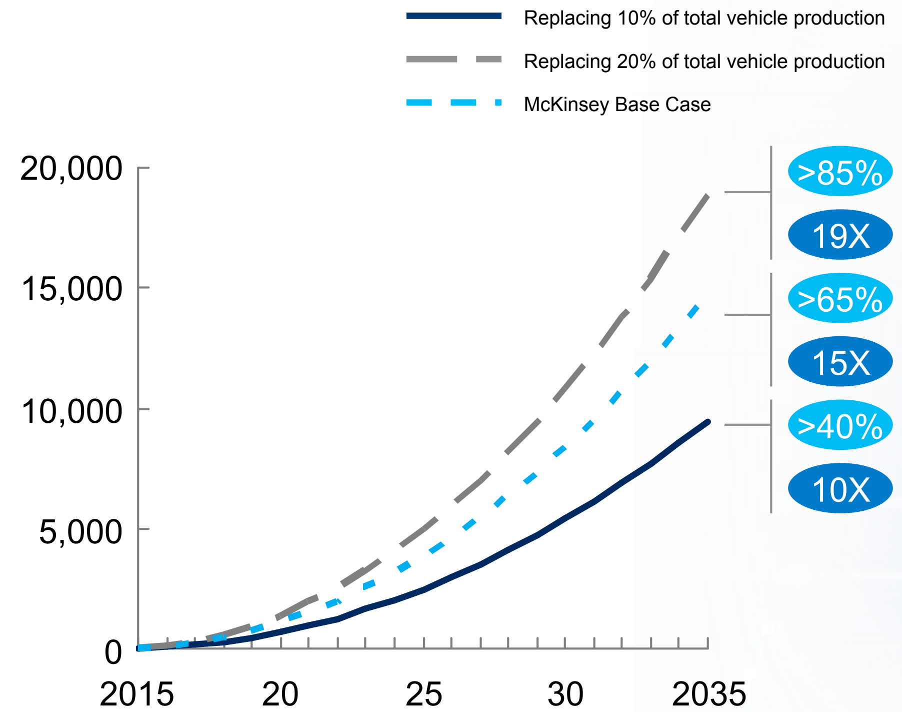
COPPER EXAMPLE

Emerging technologies can significantly raise copper demand requiring significant investment

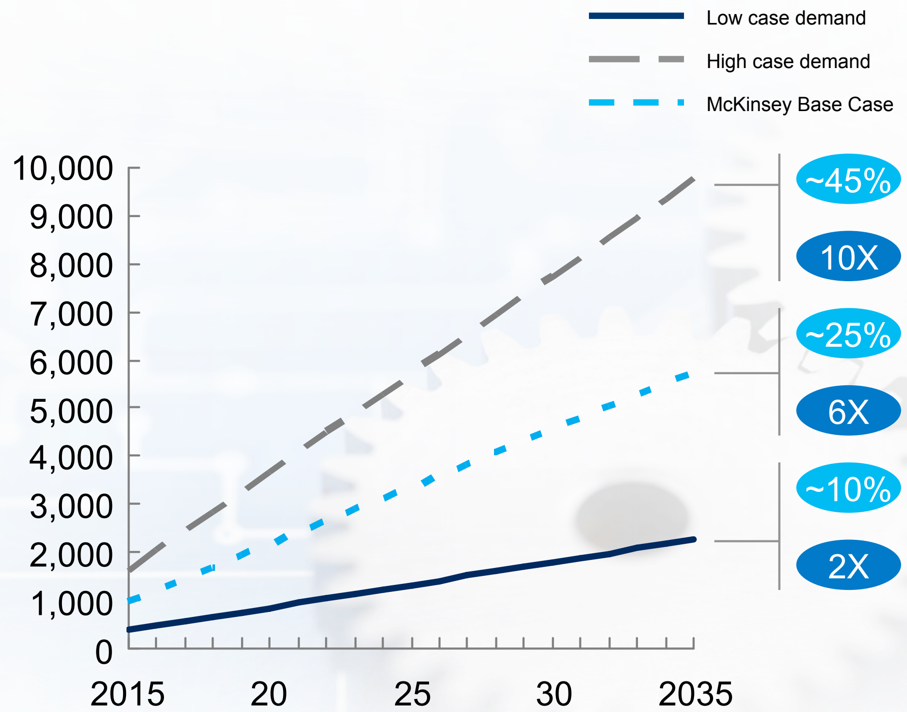
kt

Of current demand[1] | Of largest mine[2]

Cumulative copper demand from electric vehicles



Cumulative copper demand from wind turbines



1 2016 Demand
2 Escondida 2016 production

SOURCE: McKinsey Basic Materials Institute; McKinsey Global Institute analysis

In addition to technology demand drivers, a number of other trends could disrupt the copper industry

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Q1 2017 BASE CASE

◔ ◕ Low/high likelihood ↑ ↓ Price impact

	Trend		LT price impact	Trend		LT price impact
Demand	Trump infra spend	If Trump's investment plans and **policies to boost growth fail** to give results, incremental copper demand in US might be lower than base case assumptions	↓ ◕	Gov. Inter-vention	**Import curbs, increasing taxes and regulations** can structurally change the demand in key markets, like China and the USA	↓↑ ◕
Demand	Energy	Faster than expected **penetration of alternative 'green' energy production** and hybrid/electric vehicles, with a higher copper intensity	↑ ◔	Substitution	**A faster than expected rise in copper prices could result in an accelerated substitution of copper by e.g., aluminum**	↓ ◑
Supply	Pipeline	**Later than scheduled delivery of ongoing copper expansion and development projects** (e.g., delay decisions based on current price environment)	↑ ◕	China production	China's inability to economically maintain its current mine production level, given the geology, cost structure and reserve levels	↑ ◑
Supply	Africa production	**Africa's inability to maintain its copper production,** through power supply constraints, labour unrest and government red tape	↑ ◑	Rising strike action	**Increasingly violent protest actions** are no longer localised to a single operation and result in widespread disruptions and significant lost refined tonnes	↑ ◕
Supply	Currencies	**Weakening of local currencies** against the US dollar and hence increasing dollar denominated competitiveness; offset higher internal consumer inflation	↓ ◔	Challenges	**Long term industry depletion challenges** with technical limitations to decrease cut-off grades far below 0.3% copper content	↑ ◕

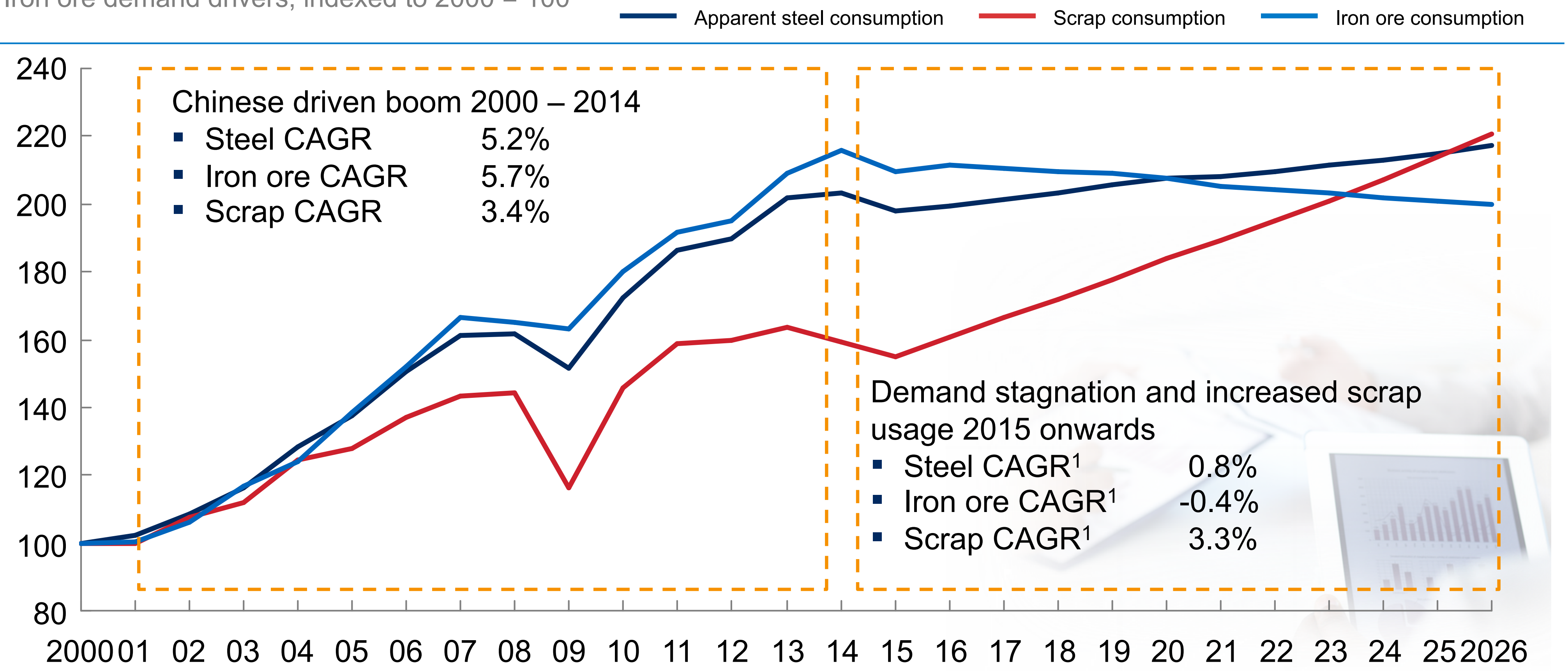
SOURCE: McKinsey copper team analysis

Contents

Iron ore will continue to face challenges driven by slowing steel demand and increased scrap consumption

Q1 2017
BASE CASE

Iron ore demand drivers, indexed to 2000 = 100



1 CAGR calculated between 2015 and 2026

The iron ore industry recently experienced a pricing collapse necessitating drastic cost cutting

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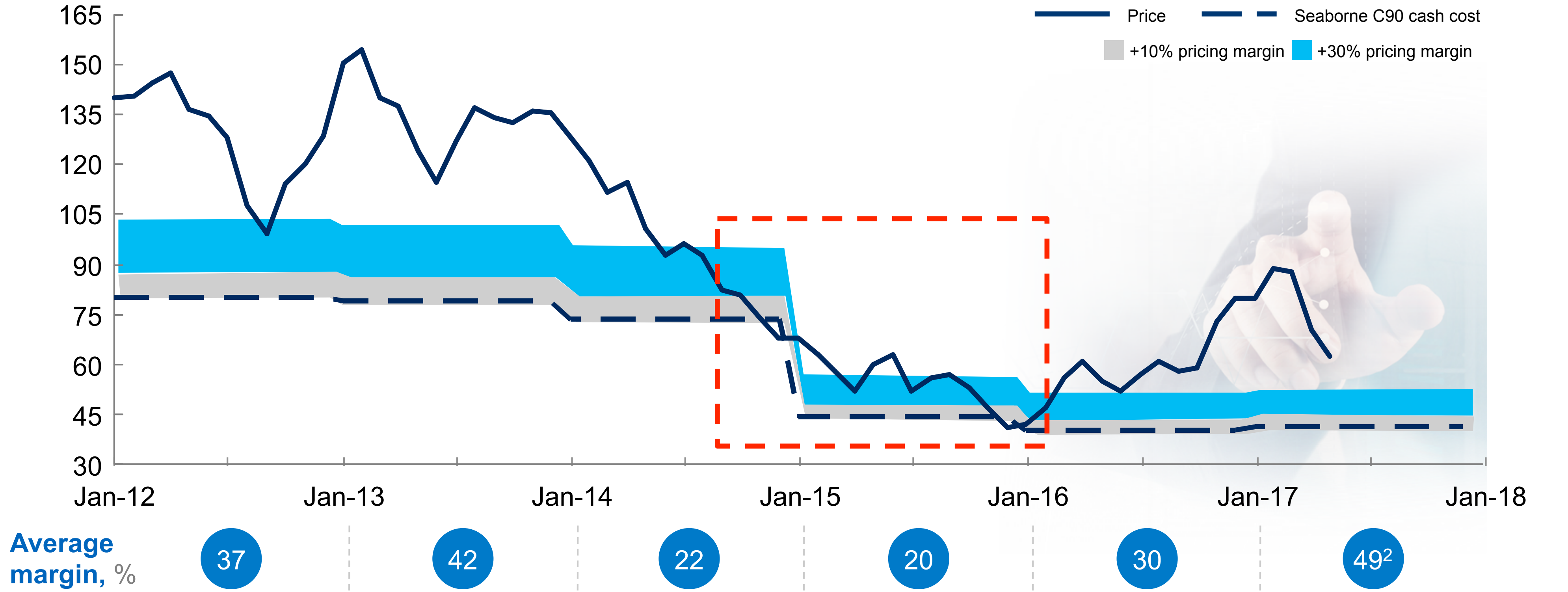
Q1 2017

Seaborne CFR China cash costs, 62% standard sinter feed equivalent, USD/t



1 For the full year starting in January till December, defined as (Price – C90 cost)/Price
2 Based on prices from January 2017 till end April 2017

SOURCE: MineSpans 2016 Q3, Consensus Economics, McKinsey iron ore team analysis

Iron ore players have been able to maintain profit levels and productivity through the successful implementation of new technologies

Introduction of autonomous haulage	20%	Productivity boost from using 54 autonomous trucks at FMG's operations
Introduction of autonomous drilling	20%	Improvement in the optimisation of BHP drills
Centralised remote operations	400	Data analysts working in the Rio Tinto hub

A single operations center that enables all mines, ports and rail systems to be operated from a single location. It should incorporates visualization and collaboration tools to provide real-time information across the demand chain.

- All of Rio Tinto's mines in Australia are conn-ected to a central operations centre in Perth
- BHP also has a smaller centre of operations in Perth

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Different scenarios could be considered by which China's future scrap supply demand mismatch gets balanced

- Detailed on next page

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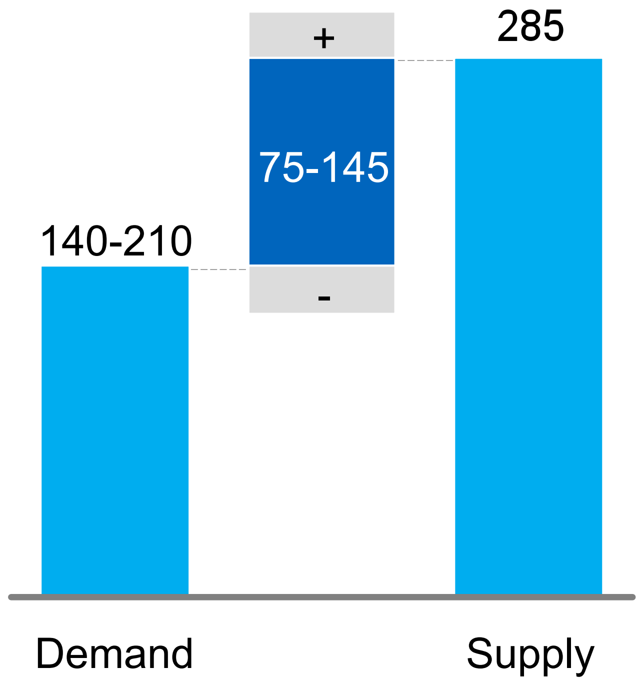
China scrap supply demand balance 2025E
mmt



Will there be **as much obsolete scrap available** and **enough incentives** in China to collect and recycle the scrap? How will scrap **recycling industry** evolve and what prices are needed to make the industry **profitable**?

Will **current BOF and EAF players** be able to **use more scrap** up to the standards typically observed in developed regions or above by applying new technologies?

To what extend is the country ready to allow the steel industry to make the **switch from BOF to EAF** and hence closing more BF-BOF capacity while investing in new EAF facilities?

If not all collected scrap can be consumed locally, **what measures** will be put in place to **support or discourage the exports** of scrap from China?

SOURCE: Worldsteel; McKinsey Analysis

The Chinese excess scrap problem could be reduced through a smart technology adoption strategy

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ROUNDED NUMBERS

	Scenario	BOF scrap intensity kg/mt	Excess scrap 2025E mmt
Current	Based on 2015 metallics balance: pig iron consumption, EAF/IF and BOF production	150	115
Typical standard	Aligned with regions with excess scrap available and high BOF steel production	210	75
Maximum	Highest scrap share without investments	275	35
New technologies	Application of new technologies that allow to preheat or melt scrap prior to BOF charging	300-500	-45

NOTE: Assuming maximum scrap intensities in EAF: 1100 kg/mt

SOURCE: McKinsey Analysis

Back-up

SOURCE: Source

A number of factors will determine the criticality of raw materials