Challenges in Mining: Scarcity or Opportunity?

Contribution of Advanced Technologies

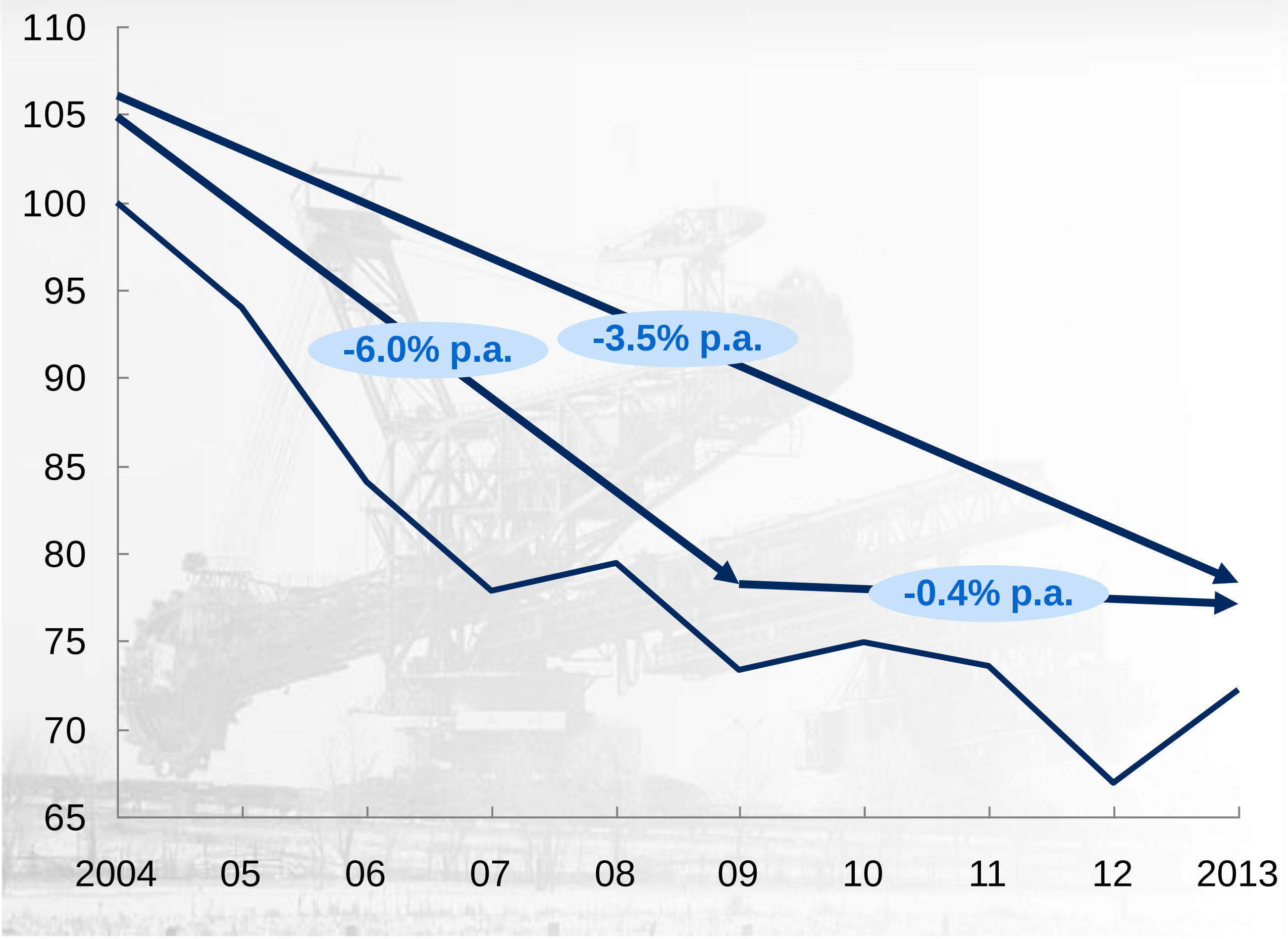
World Materials Forum

June 23, 2015

McKinsey&Company

Mining productivity globally has declined ~30% over the past decade

McKinsey Mining Productivity
Index, 2004 = 100

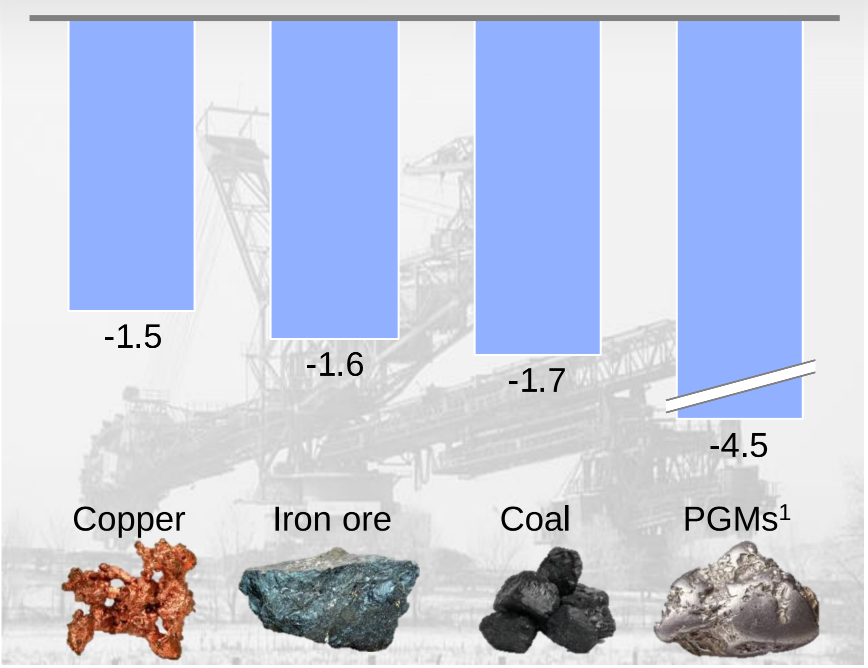


- Between 2004 and 2013, global mining productivity has fallen ~30%, or 3.5% p.a., even after accounting for geological degradation

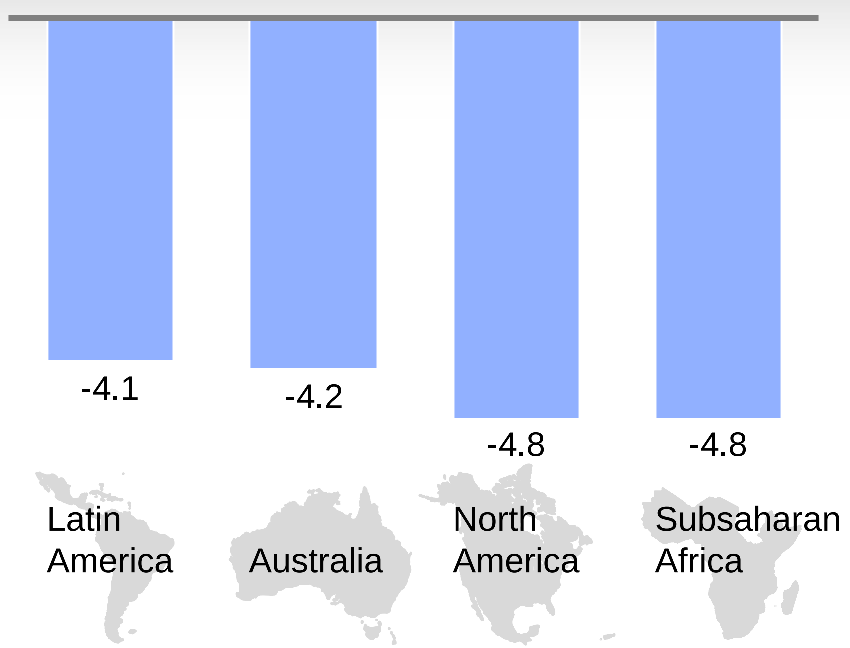
SOURCE: Company annual reports; McKinsey analysis

The decline prevails across most commodities as well as across all major mining geographies

McKinsey Mine Productivity Index
CAGR, 2009 - 2013



McKinsey Mine Productivity Index
CAGR[2]



- Almost all commodities registered declines in mining productivity - the trend is apparent across precious commodities as well as bulk minerals, indicating a more systemic shift that cuts across different mining methods or processing techniques

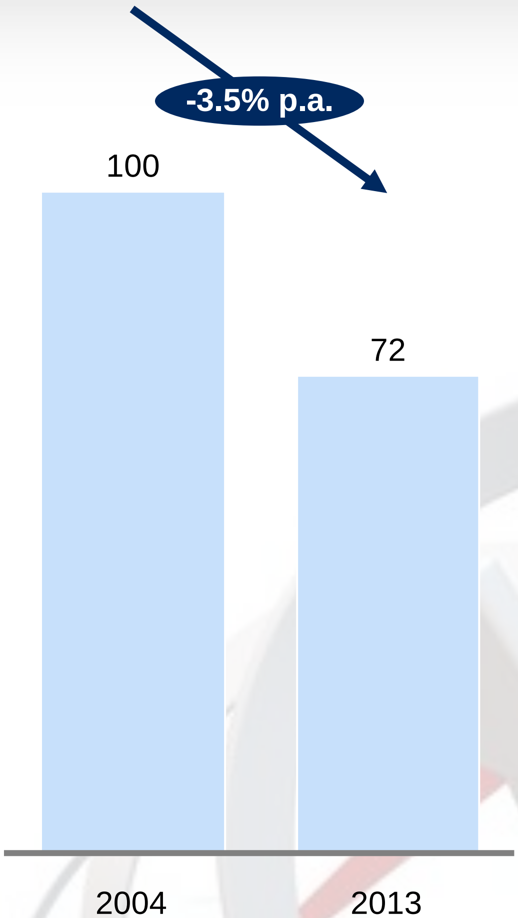
- North America and Sub-Saharan Africa experienced the biggest declines in productivity over the period

1 Platinum group metals
2 For Latin America CAGR is for 2005 to 2012, for Australia and Subsaharan Africa CAGR is for 2004 to 2013 and for North America CAGR is for 2006 to 2013

SOURCE: Company annual reports; McKinsey analysis

The industry also faces dramatic capital and operating costs escalations

MineLens Productivity Index
indexed, 2004 = 100



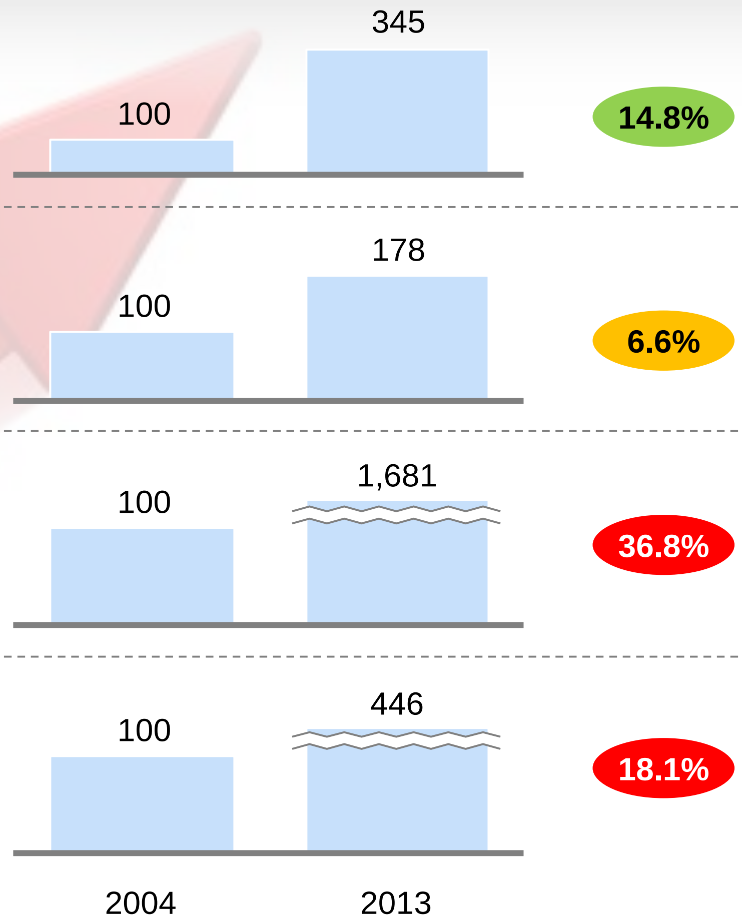
CAGR,[1] 2004-13
%

Production, mined volume
indexed, 2004 = 100

Employment, number of workers
indexed, 2004 = 100

Capital expenditures, asset value
indexed, 2004 = 100 in real terms[2]

Operating expenditures, excluding labor cost
indexed, 2004 = 100 in real terms[2]



1 Compound annual growth rate
2 Capital expenditures and operating expenditures adjusted for mine cost inflation

SOURCE: Company annual reports; McKinsey analysis

Mining companies can pursue 4 levers to thrive in tomorrow's challenging and uncertain mining environment

Focus of this document

Embed effective Management Operating systems
Free people and resources to prioritize productivity and operational excellence, drive robust performance management, working across silos and data-driven decision making

Focus on innovation
Adopt fresh mindset to innovation, including technology adoption, advanced analytics and use of big data

Levers for unlocking value

Operations excellence
Relentless focus on eliminating waste and variability, and improving productivity of assets through advanced reliability and maintenance approaches.

Capability building
Upgrade individual and organizational capabilities to deliver the above

SOURCE: McKinsey Basic Materials Practice

Mining companies are increasingly looking at technological innovations to address the declining productivity trends

"Now we need to protect our operating margins, we have to improve our working practices",. "**The company is moving towards full automation at it's mines**, "something we have been slow to progress in the past"

– Diego Hernandez, CEO Antofagasta

ANTOFAGASTA PLC

SANDVIK

"Progressive mining companies are beginning to implement automated systems, with the **rest of the industry expected to follow suit**"

"Autonomous technologies represent a class of innovation that will profoundly change how minerals are mined and processed"

– Ken Stapylton, Vice President surface drilling, Sandvik

SOURCE: Press search

Advanced technologies are being developed and implemented across all stages of the mining value chain

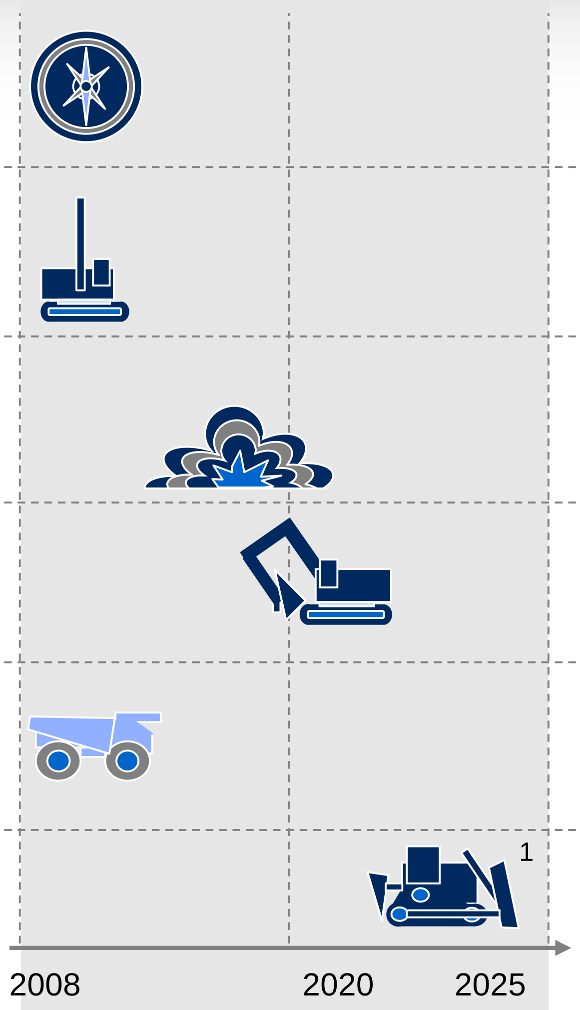
NOT EXHAUSTIVE

Focus of this document

● Commercially available ◑ In testing ◔ In development

		Examples	OEMs	Status
Exploration		▪ Computer algorithm automatically detects patterns in exploration data indicative of mineralisation	GEOSOFT	Commercially available
Drilling		▪ All major OEMS offer products with various level of automation ▪ Other firms specialize in retrofitting existing drills for automation	SANDVIK, CAT, Atlas Copco, FLANDERS	Commercially available
Blasting		▪ The charging process can be automated, with the required amount of explosive being entered beforehand	AEL Mining Services	In development
Loading		▪ OEMs developing autonomous shovels	HITACHI, CSIRO	In testing
Hauling		▪ Komatsu and Caterpillar have commercial offerings ▪ Hitachi running field trials	HITACHI, CAT, KOMATSU	Commercially available
Other support equipment		▪ All major OEMs developing are developing autonomous solutions for support equipment like dozers, shearers, etc.	HITACHI, KOMATSU, CAT	In testing

Expected commercial availability

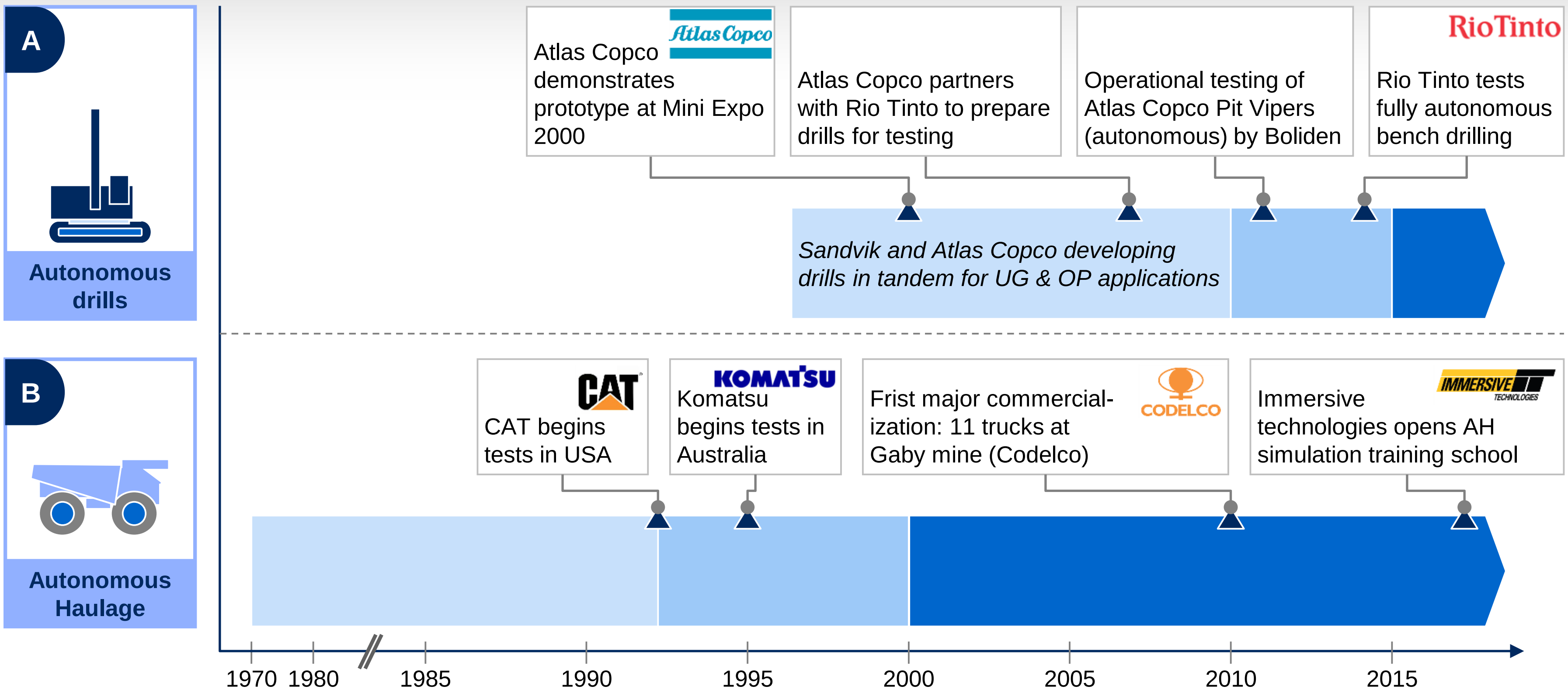


1 Tele-remote dozers are already in quite extensive use; autonomous will take longer due to their irregular usage cycles

SOURCE: Expert interviews; Press search

Multiple categories of advanced mining technologies are reaching commercialization and deployment stages

- Ideas and prototypes
- Field testing and early adoption
- Full scale commercialization



What next?

- Hitachi is expected to make a number of autonomous solutions commercially available soon: AH trucks (2015), Shovels (2017), Graders and Dozers (2018)
- Many drills currently being operated semi-autonomously/tele-remotely (e.g., by Barrick, Codelco, Anglo American) but have capacity to be fully autonomous pending labor agreements and/or changes to operations

SOURCE: Expert interviews; Press search; McKinsey analysis

A Automated drilling is the latest step in the long evolution of drill and blast technology

2006

Rio Tinto began to explore autonomous drilling rigs at Australia's **Pilbara** iron ore region

2008

Rio Tinto and **Atlas Copco** formed an **alliance** to work together to develop autonomous drilling solutions for surface mining

2011

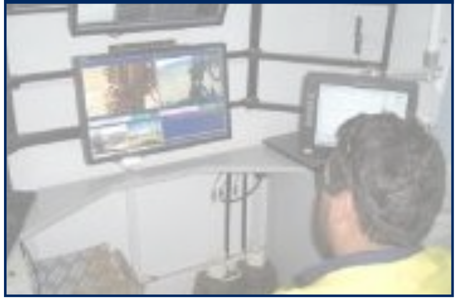
Sandvik and Flanders formed a formal **partnership** to **automate surface mining drill rigs** and provide autonomous operation

2013

Atlas Copco and **Rio Tinto successfully automated surface drilling**, completing a computer-generated drill pattern

2014

Rio Tinto became the **first** to achieve **fully automated** production bench **drilling** without human intervention at a test site in Australia



SOURCE: Press search; Company brochures

B Autonomous haulage has three key components

Description

1 Base vehicle & automation kit

- Standard **truck body**
- Onboard embedded systems and real-time **operating software** informing and controlling the truck's activities (e.g., **sensors**, computers, video system, traction control, **GPS tracking**, and **radio receptivity for remote inputs**)

2 Critical mine site infra-structure

- High-capacity **communications network**
- **GPS locators** for all vehicles within the orbit of AH trucks

3 Command and control centre

- **Headquarters** from which trucks monitored/remotely controlled
- Can be **on-site or off-site** (e.g., Rio Tinto is experimenting with controlling autonomous equipment from 1500km away)
- Operator ensures **adherence of vehicles to loading, dumping, and traffic management** plans, makes **adjustments** to vehicles' trajectories where necessary, and **restarts** the trucks in case of automatic shutdown triggered by trucks' safety protocols
- 1 operator can track the progress of **numerous vehicles**

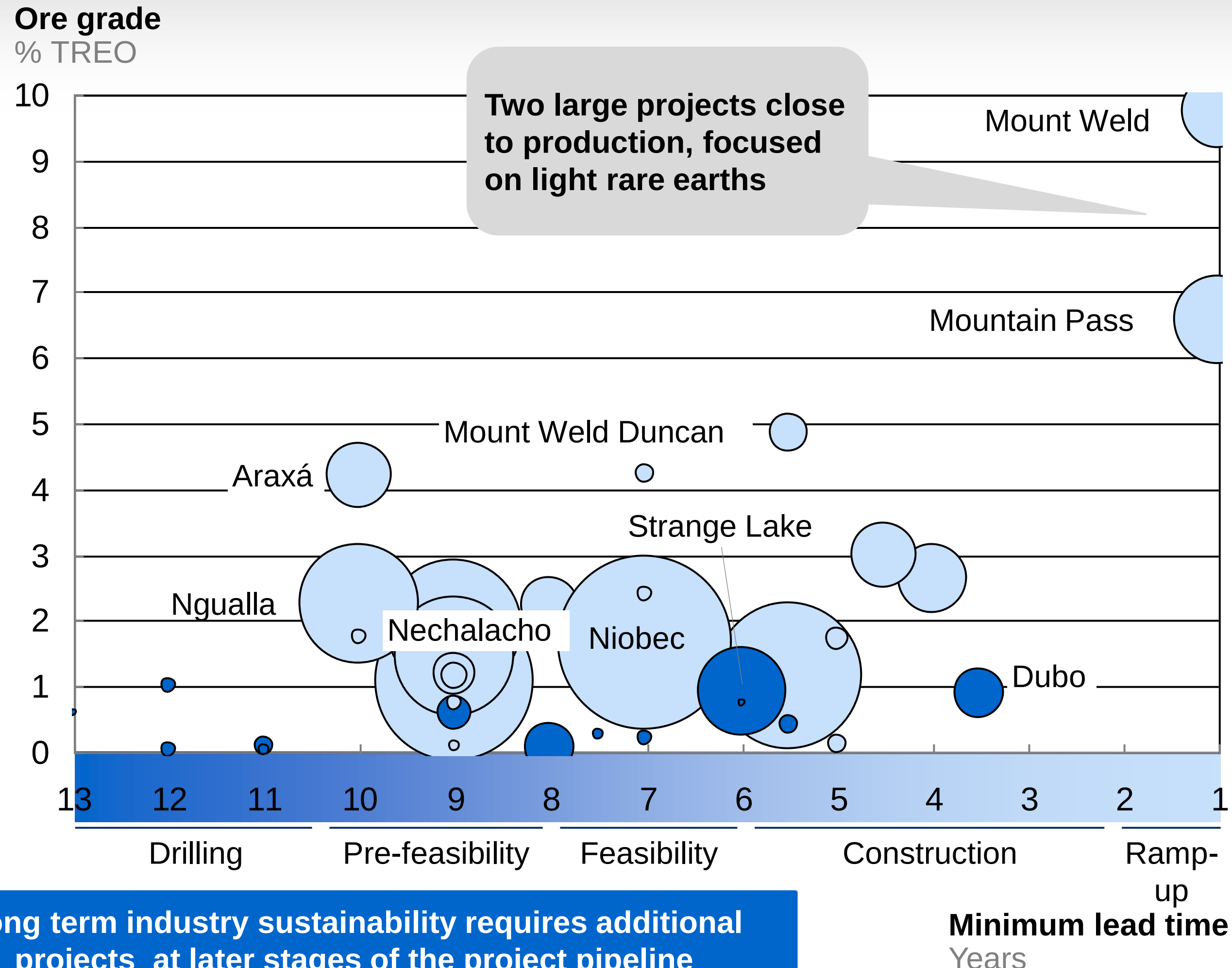
SOURCE: Expert Interviews; McKinsey Analysis

Innovation is key to overcome scarcity issues in rare raw materials

NON-EXHAUSTIVE

Levers to drive change

- Effective management systmens
- Operational excellence
- Innovation across the whole supply chain
- Capacity building



Long term industry sustainability requires additional projects at later stages of the project pipeline

1 Heavy rare earths projects are the ones with more than 15% of total rare earth content of heavy elements

SOURCE: Technology Metals Research, expert interviews

BACKUP (Presented on ad-hoc basis if there are questions)

Executive summary

- Multiple forces at work, such as labour scarcity, rising costs of inputs, increased health and safety standards, and declining productivity, have been putting **significant pressure on the mining industry** in the last decade, e.g.,
  - Average copper mine input costs have risen ~150% in the past 15 years
  - In 10 years, productivity in some of the world's major mining hubs has declined by up to 50%
- Mining **companies are increasingly looking at technological innovations** to address these trends, with a view to reducing costs and increasing productivity
- **Development, testing and implementation** of high-tech solutions in mining have **exploded in the past 15 years**, with advanced technologies being developed and implemented across all stages of the mining value chain, from exploration to hauling and dozing
- There is an increasing sense among all sizes of mining companies that "**the future is now**", and that the best-performing companies in the next decades will be the one willing to assume the costs of implementing advanced technologies during this challenging period
- Examples of the most promising and most developed advanced technologies include
  - **Autonomous haulage**, which has been implemented at ~25 sites and can **reduce overall haulage costs 10-40%**
  - **Autonomous or tele-remote drilling**, which has been trialled at nearly 20 sites, with demonstrated increase of both available drilling time per shift and **drilling/blasting accuracy**, leading to a **knock-on impact on downstream processes**

The mining industry faces multiple forces which will adversely impact industry economics going forward

These forces will have determine how mines are set up and run in the future

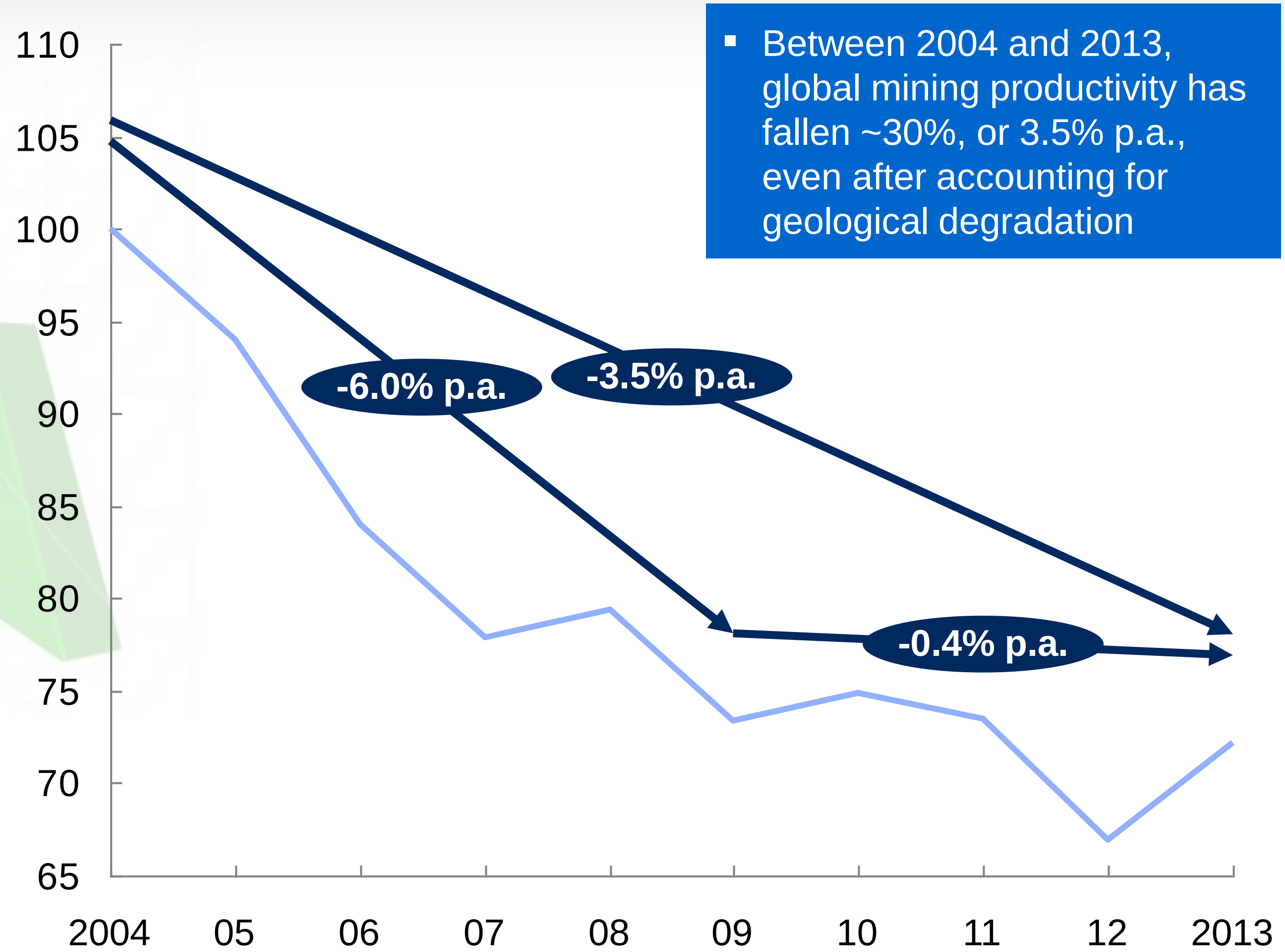
SOURCE: McKinsey Basic Materials Practice

The McKinsey Mining Productivity Index reveals that mining productivity globally has declined 3.5% p.a. over the past decade

Approach

- McKinsey Mining Productivity Index computed using global data set comprising
  - Detailed data at mine-site level for ~50 mines from all major mining jurisdictions
  - 10 years of performance data
- All values indexed to 2004 = 100

McKinsey Mining Productivity
Index, 2004 = 100



SOURCE: Company annual reports; McKinsey analysis

Mining companies are increasingly looking at technological innovations to address the declining productivity trends

"Where we're really behind, shamefully behind, is in the issue of productivity"

– Thomas Keller, CEO Codelco; April 2014, CRU World Copper Conference, Santiago

“With our Southdowns project (Western Australia), we are able to vastly improve the economics by steepening the walls and improving the strip ratio because we have proven methods and [remote control drill, rock-breaker and explosives loader] technology to manage those steeper walls”

– Matthew Andersson, Mining Manager, Grange Resources

“Declining productivity is now a problem we share”

– Paul Dowd, Director OZ Minerals

“Progressive mining companies are beginning to implement automated systems, with the rest of the industry expected to follow suit”

“Autonomous technologies represent a class of innovation that will profoundly change how minerals are mined and processed”

– Ken Stapylton, Vice President surface drilling, Sandvik

“Now we need to protect our operating margins, we have to improve our working practices”,. “The company is moving towards full automation at it’s mines, “something we have been slow to progress in the past”

– Diego Hernandez, CEO Antofagasta

SOURCE: Press search

Autonomous equipment-enabled open-pit mines rely on the careful and coordinated interplay of the mine-wide control systems and equipment

SOURCE: Expert Interviews; Sandvik webpage; Caterpillar webpage; Metso webpage; Transmin webpage

Different degrees of autonomy in haul trucks

Semi-autonomous trucks

- Driver still present in vehicle
- Vehicle has a form of "cruise control" for the length of the haul route
- Driver tends to reassume control for loading and dumping, and whenever an obstacle presents itself (e.g., manned vehicle, obstruction in the road)

Fully autonomous trucks

- All stages of haul cycle are autonomous
- No operator is required in vehicle
  - One operator can oversee multiple trucks simultaneously from a remote control centre
  - Command centre can be on- or off-site
- There are currently 3 archetypes of fully autonomous trucks *(detailed next page)*

SOURCE: Expert interviews

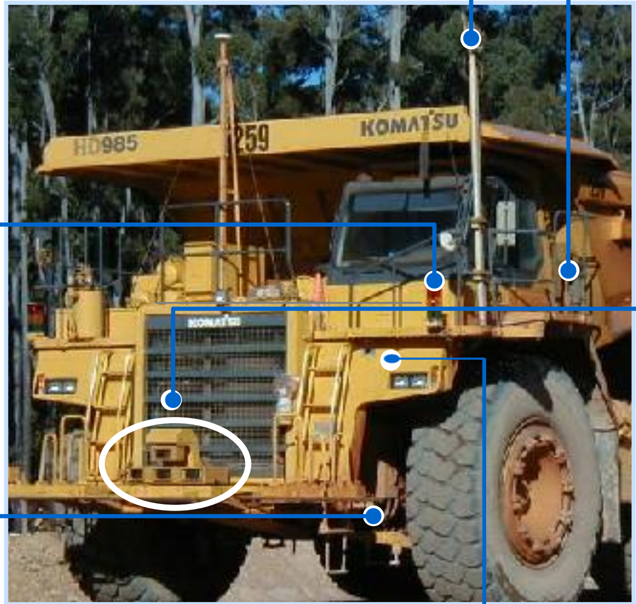
Key on-board components of autonomous haul trucks

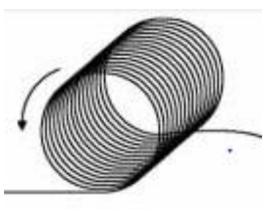
Autonomous Control Cabinet
Sealed hydraulic and electronic controls

GPS
GPS technology is combined with a tracking system to accurately monitor location of vehicles

Autonomous Status Lights
Mounted on all sides of the truck to safely display truck operating status

Road Edge Guidance (REG)
A mounted laser guidance system measures the distance to the road berm to provide additional navigation accuracy





Optical fiber gyro
Senses changes in orientation using interference from light

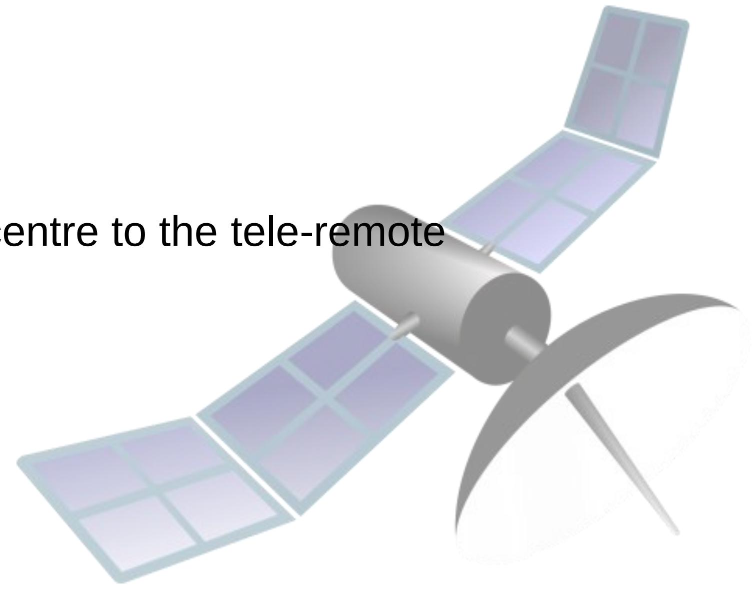
- **Object avoidance** (e.g., radar with 80m range, LIDAR with 20m range at sides and rear)
- These sensor technologies are still in their infancy
  - Overall they have been working effectively in dry, clear climates such as in Australia or the Atacama desert
  - They have much lower reliability in fog or rain, which has impeded adoption of AH technology in more temperate climates
  - In the next few years, some AH sensor manufacturers will likely turn to military sensors to improve availability and reliability; however, doing so is currently cost-prohibitive

SOURCE: Expert Interviews; University of British Columbia; Caterpillar; Komatsu

Communications technology is vital for relaying commands from the control centre to the vehicles, and for managing vehicle interactions

Communications technology

- Open-pit communications tend to rely on **satellite/GPS**, **wi-fi** and/ or **RFID**
  - This requires antennas / **boosters** around the site
  - Each individual vehicle, and possibly personnel, must also be **tagged** (tele-remote and manned) with **positional trackers**, in order to minimize interactions with operational tele-remote vehicles (for reasons of safety and productivity)
- System must have enough **bandwidth** to
  - Relay **live video** feeds to the central control room
  - Provide up-to-date tracking of all **vehicle locations**
  - Convey **real-time commands** from the command centre to the tele-remote or autonomous systems



Autonomous haulage has multiple safety and efficiency benefits

● Favourable impact on economics
● Adverse impact on economics

Category	Lever	Impact	Impact range	Rationale for impact
Safety	Safety	Favourable		▪ Fewer people in dangerous areas
Mine design	Strip ratio	Favourable	- 0-5%	▪ Fewer people in pit enables steeper pit walls and thus ability to reduce strip ratio
OEE[1]	Utilization	Favourable	- 10-30%	▪ Eliminate shift-change delays; reduce delays due to traffic congestion
	Availability	Favourable	- 10-30%	▪ Reduced unscheduled downtime from more consistent usage cycles and reduced damage
	Truck speeds	Favourable	TBD	▪ Higher truck speeds as fewer people in mine areas; truck speeds more consistent
Operating and mainten-ance costs	Labor	Favourable	Up to -95%	▪ Fewer (or zero) operators
	Fuel	Favourable	- 5-10%	▪ Lower fuel consumption from more consistent driving cycles
	Tires	Favourable	- 5-10%	▪ Improved tire life due to more consistent speeds and driving patterns
	Maintena-nce	Favourable	- 10-20%	▪ Lower maintenance parts and labour costs from reduced wear and accident damage
Capex	Truck capex	Adverse	~500k autonomy kit	▪ Higher truck cost due to additional equipment and sensors on trucks
	Infrastruc-ture capex	Adverse	▪ Hub ~$1m ▪ Communica-tions upgrade ~$15k	▪ Infrastructure costs for communications infrastructure, refueling system

"The main benefits are in operating labour costs (down about 2/3) and optimized productivity (avoiding downtime and operating at a faster and safer cycle time)"
- AH electrical systems specialist

"During our first trials, we were already able to reduce exposure of our workers to danger areas by ~70%"
- Mine manager

"Capex costs are high, though of course they also depend on the pre-existing level of infrastructure, like for communications. That said, the upside of AH is significant"
- AH developer

1 OEE: Overall Equipment Effectiveness

PRELIMINARY

Autonomous haulage can be a game changer in mining productivity: 10% to 40% reduction in haulage costs

Hauling costs – USD c/ton

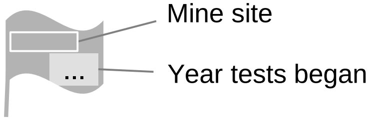
		High labor cost locations, e.g. remote Australian mines, Canadian oil sands $350K fully loaded, operator cost	Low labor cost locations, e.g. Africa, Asia $35K fully loaded, operator cost
Mine design	Manual Fleet	67.47	45.41
	Strip ratio	0	0
		67.47	45.41
OEE[1]	Availability	-0.72	-0.27
	Utilization	-3.82	-1.41
	Truck speeds	0	0
		62.93	43.74
Operating and maintenance costs	Labor	-20.37	-2.04
	Fuel	-1.72	-1.72
	Tires	-0.50	-0.50
	Maintenance	-0.64	-0.64
		39.69	38.83
Capex	Truck	0.96	0.96
	Infrastructure	0.08	0.08
	Autonomous fleet	40.74	39.88
		-40%	-12%

Autonomous trucks can reduce surface haulage costs by up to 40%

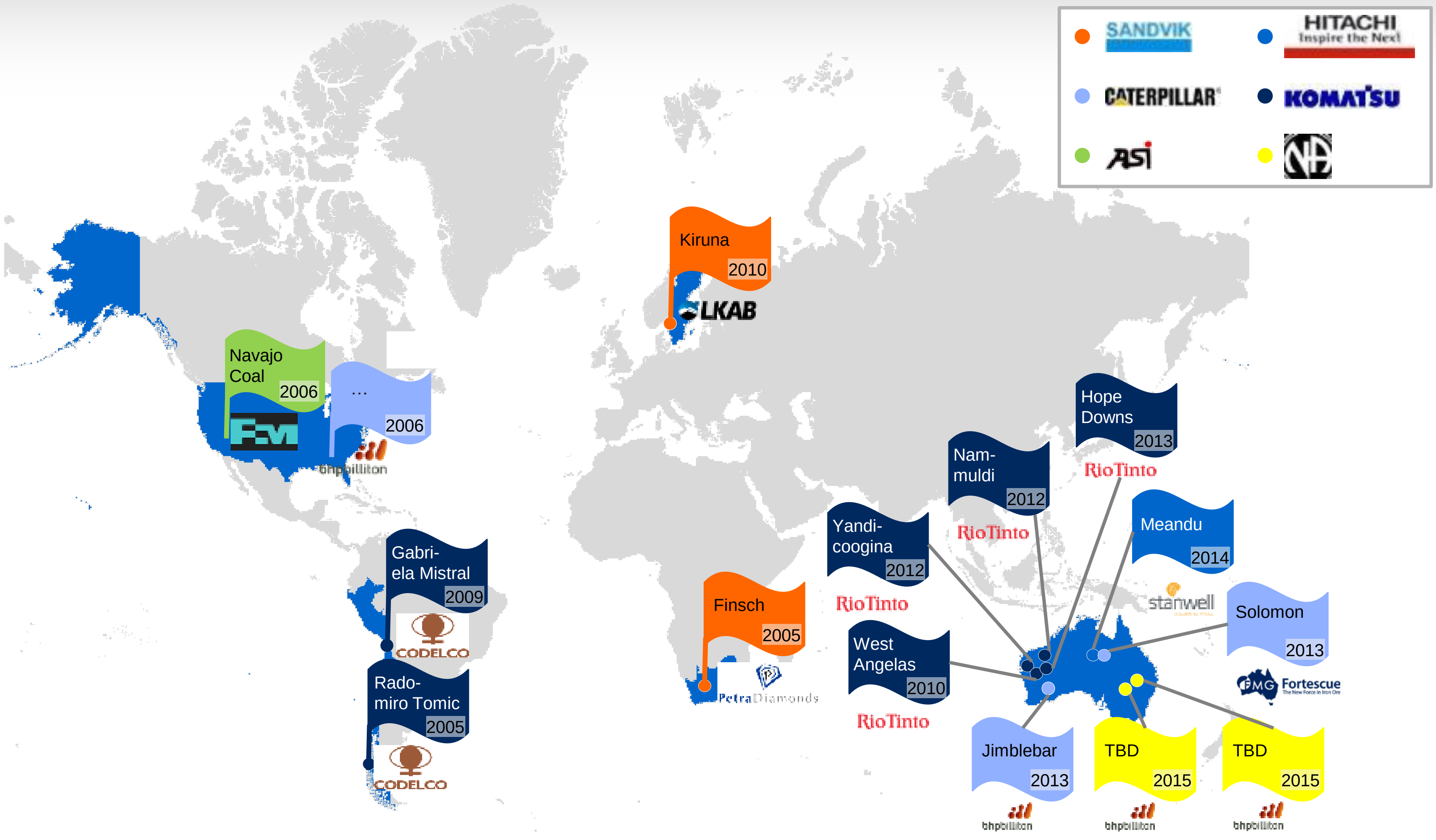
1 OEE: Overall Equipment Effectiveness

SOURCE: Team analysis; based on client mine plan

To date, there have been ~25 autonomous haul truck trials, most of which have taken place in Australia



Current trial and/or implementation locations



SOURCE: Press search

Automated drilling is the latest step in the long evolution of drill and blast technology

Manual drilling and blasting

- **Gunpowder** invented ~1000AD, but are no references to applications to mining until 16th century
- One man drilling (using a **steel drill and sledgehammer**) most common approach into the 20th century

The beginnings of mechanization

- First **steam driven percussion rock drills** were invented in early-1800s, but adoption slow
- Alfred Nobel invented the **blasting cap** and **safer dynamite explosives** through the 1860s
- However, mechanized drill productivity still low. In 1870, at a US drilling competition,
  - John Henry hammered through 14 ft of rock in 35 minutes
  - His steam drill “competitor” only managed 9 ft

Towards current-day drills

- Late 1800s-early 1900s: **steam replaced by compressed air**, and invention of the **jackhammer**
- 1945: Sandvik, Atlas and Fagersta designed a **cemented tungsten carbide drill bit** as economical to use as the conventional steel bits
- Post-war, drill **rig mechanization** sped up, with a strong emphasis on increasing **mobility**
- **Hydraulic technology** for **rotary and downhole** drilling also became available in the 1960s

Drill-assist and autonomous drills

- Drive towards automated drills picked up momentum with unveiling of the Atlas Copco Pit Viper 351 with CAN-bus control and 7 on-board computers at **MineEXPO 2000**
- **Sandvik and Atlas Copco lead** the pack, with automated drills (with various degrees of automation) being tested and implemented around the world

SOURCE: Atlas Copco Blasthole Reference Book 2013, Sandvik

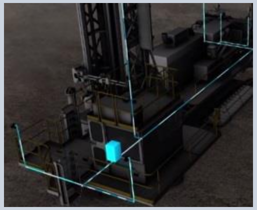
Tele-Remote/Autonomous Drill

Hazard avoidance cameras
See depths details and determine hidden range of obstacles

High-resolution video
Transmit video back to the command center
- Enhance visibility
- No blind spot

Geo-fencing sensors
Prevent tramming into hazards

High-speed on-board computer control
- Geological information
- Drilling times
- Penetration rates
- Navigation & traffic
- Machine diagnostics



Tele-Remote and Autonomous drilling have significant potential

Favorable / Adverse

Category	Lever	Impact	Impact range: Tele-remote	Impact range: Autonomous	Rationale for impact
Safety	Safety	Favorable			▪ Fewer people in dangerous areas
OEE[1]	Availability	Favorable	0-10%	0-15%	▪ Reduced unscheduled downtime from more consistent usage cycles and reduced damage
	Utilization	Favorable	0-10%	0-15%	▪ Eliminate shift-change delays; reduce time lost to blast cycle
	Drill speeds	Favorable	0-3%	0-3%	▪ Algorithm reduces variation across fleet
	Redrilling and over-drilling	Favorable	50%	75%	▪ Algorithm controls drilling reduces chances of error
Operating and maintenance costs	Drill rig labor	Favorable	Up to 75%	Up to 95%	▪ Operator:Machine ratio reduced to 1:3 for Tele-remote and 1:5 for autonomous
	Surveying labor	Favorable	100%	100%	▪ GPS positioning system eliminates need for floor demarcation tasks
	Fuel	Favorable	0-5%	0-10%	▪ Lower consumption from more consistent operation
	Lubricants	Favorable	0-5%	0-10%	▪ Lower consumption from more consistent operation
	Drilling consumables	Favorable	0-10%	0-10%	▪ Lower consumption due to algorithm controlled, more consistent drilling operation
	Maintenance	Favorable	0-10%	0-20%	▪ Lower maintenance parts and labour costs from reduced wear due to more consistent operation
Capex	Drill rig capex	Adverse	5-10%	15-20%	▪ Higher drill costs due to additional equipment and sensors on drill
	Infrastructure capex	Adverse	~$0.5M	~$1M	▪ Infrastructure costs for communications infrastructure, refueling system

1 OEE: Overall Equipment Effectiveness

SOURCE: Expert interviews; Press search

PRELIMINARY

OEE improvements account for more than 50% of the productivity gains with labor savings being the next largest contributor

Drilling costs – USD $/m

		Tele-Remote Drilling Total Cost of Ownership 3 drilling rigs per operator	Autonomous drilling Total Cost of Ownership 5 drilling rigs per operator
	Manual drilling	9.76	9.76
OEE[1]	Availability	-0.16	-0.33
	Utilization	-0.18	-0.38
	Drilling speed	-0.22	-0.22
	Redrilling and over-drilling	-0.20	-0.30
		9.00	8.54
Operating and maintenance costs	Drill rig labor	-0.41	-0.49
	Surveying labor	-0.24	-0.24
	Fuel	-0.05	-0.10
	Lubricant	-0.02	-0.03
	Drilling consumables	-0.08	-0.08
	Maintenance	-0.01	-0.11
		8.19	7.47
Capex	Drill rig capex	0.17	0.41
	Infrastructure capee	0.15	0.30
		8.52	8.18
		-13%	-16%

In addition to increasing safety by removing personnel from dangerous locations, autonomous drills can reduce drilling costs by up to 15%

1 OEE: Overall Equipment Effectiveness

SOURCE: Team analysis; based on client mine plan

Tele-Remote and autonomous drilling scenario assumptions

Category	Lever	Units	Manual	Tele-remote	Autonomous
OEE[1]	Availability	%	80%	85%	90%
	Utilization	%	77%	82%	87%
	Drill speed	m/hr	40	41	41
	Redrilling (short holes)	%	3%	1.5%	0.8%
	Over drilling (refill long holes)	%	4%	2%	1%
Operating and mainte-nance costs	Drill rig operator	FTE / shift	1	33%	20%
	Drill rig operator salary	$/yr	50,000	50,000	50,000
	Number of shifts	Shifts / day	4	4	4
	Survey hours	Hr/yr	4,000	0	0
	Surveyor rate	$/hr	20	20	20
	Drilling consumables	$/meter	2.5	2.4	2.4
	Fuel	$/hr of operation	118	115	112
	Lubricants	$/hr of operation	41	40	39
	Over drilled (long hole) fill cost	$/meter	5	5	5
	Maintenance and overhaul parts	$/hr	72	68	61
	Maintenance and overhaul labor	$/hr	50	48	43
	Infrastructure/drill rig IT maintenance	$/yr		31,000	62,000
Capex	Drill rig initial cost	$	5.2m	5.5m	6.0m
	Infrastructure initial cost	$		310,000	620,000

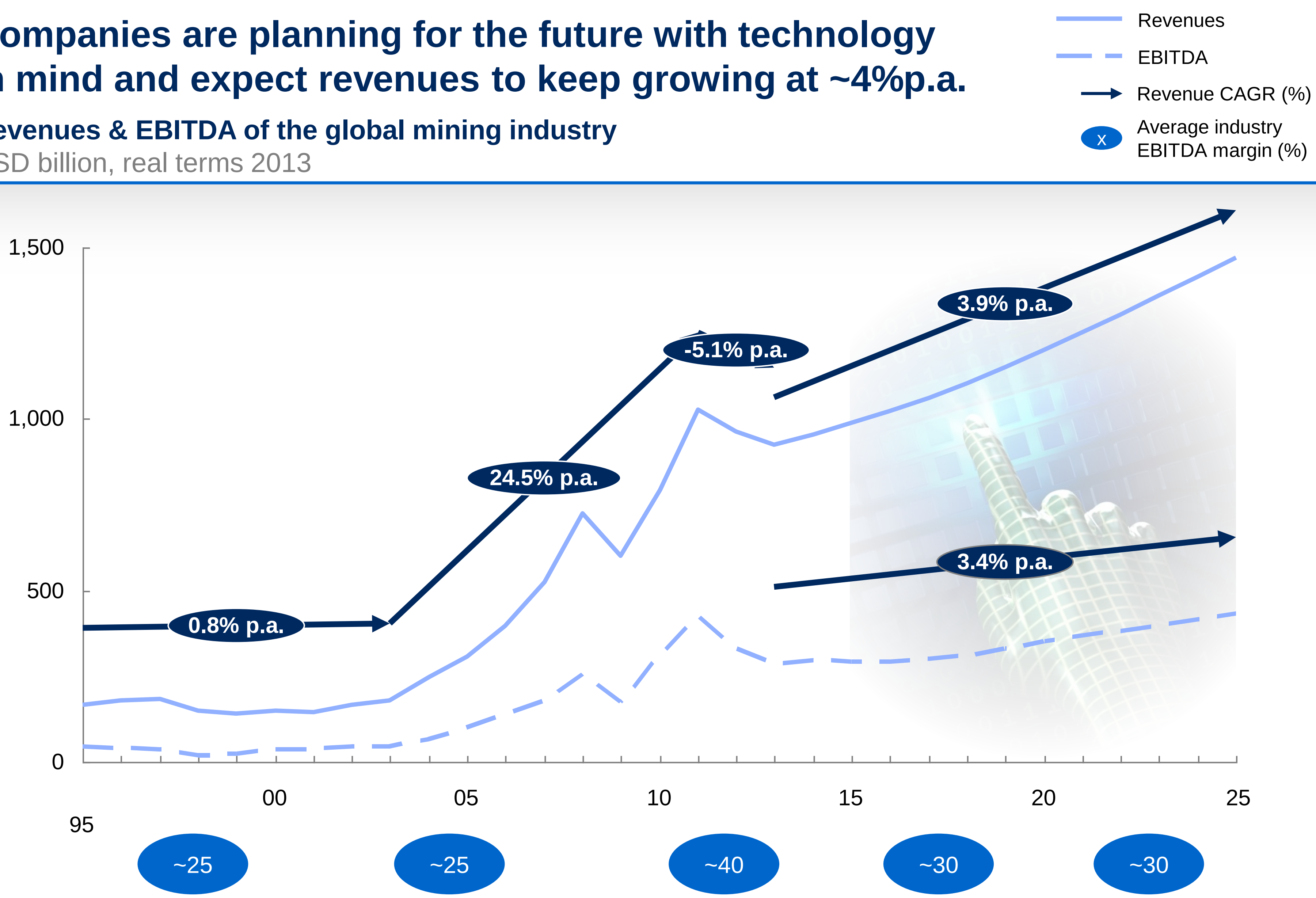
1 OEE: Overall Equipment Effectiveness

SOURCE: Expert interviews; Client Latin American Copper Mine parameters; Press search

Companies are planning for the future with technology in mind and expect revenues to keep growing at ~4%p.a.

Revenues & EBITDA of the global mining industry

USD billion, real terms 2013



SOURCE: Company annual reports; McKinsey analysis

How are you positioning yourself for the future?

“**I believe we need to hit the reset button in terms of how we think about innovation and mining in the future**”

– Mark Cutifani, CEO Anglo American

SOURCE: Press search

Summary of the rare earth market outlook

- Rare earths are a group of 17 elements, which are divided into light and heavy rare earths. They are used in a wide range of applications, such as **permanent magnets, metal alloys, catalysts and polishing powders**

- **The market is large and growing ($8B and ~113 ktons of demand after separation of individual oxides, growing at a 7% CAGR), with heavy rare earths representing <15% of the volume, but ~50% of revenues**

- **China holds most of the production along the value chain** (~80-100%), as well as most of the known reserves, letting it control prices through management of **export quotas**

- Outside of China, most projects are **focused on light rare earths**
  - **Rare earths expected to be critical are mainly heavies (Dysprosium, Yttrium, Terbium and Europium)**, together with the light element neodymium
  - The pipeline of heavy rare earth projects is limited to less than 10k tons and they are at **very early stages of development**

- If China continues to act rationally (and from expert interviews it seems that it will maintain quotas for heavy rare earths at present levels) **prices should continue at greenfield incentive** levels, allowing some penetration from the rest of the world

- Based on this, **a mine that is "heavy on heavies" would find itself in a privileged position**

RE are essential in the manufacturing of several products, used every day,which has led to a rapid increase in their demand

NOT EXHAUSTIVE

Applications of Light RE Elements

Lanthanum

- Used in electric and hybrid vehicles, laptop computers, cameras, high-end camera lenses, telescopes, binoculars – as lanthanum improves visual clarity;
- Used to reduce the level of phosphates in patients with kidney disease

Samarium

- Primary use is in the production of permanent magnets but also in X-ray lasers
- Precision guided weapons and white-noise production in stealth technology

Neodymium

- The principal use is in the manufacture of the strongest magnets in the world. These magnets are so strong that one the size of a coin cannot be removed from a refrigerator by hand
- Other important applications include laser range finders and guidance systems

Cerium

- Used to polish glass, metal and gemstones, computer chips, transistors and other electronic components
- Automotive catalytic converters to reduce pollution
- Added in glass making process to decolorize it, gives compact fluorescent bulbs the green part of the light spectrum

Applications of Heavy RE Elements

Dysprosium

- Most commonly used in the manufacture of neodymium-iron-boron high strength permanent magnets
- Injected into joints to treat rheumatoid arthritis
- Used in radiation badges to detect and monitor radiation exposure

Yttrium

- Used in energy efficient fluorescent lamps and bulbs
- Used in high temperature applications, such as thermal barrier coating to protect aerospace high temperature surfaces
- Can increase the strength of metallic alloys

Gadolinium

- Used to enhance the clarity of MRI scans by injecting Gadolinium contrast agents into the patient
- Used in nuclear reactor control rods to control the fission process

Europium

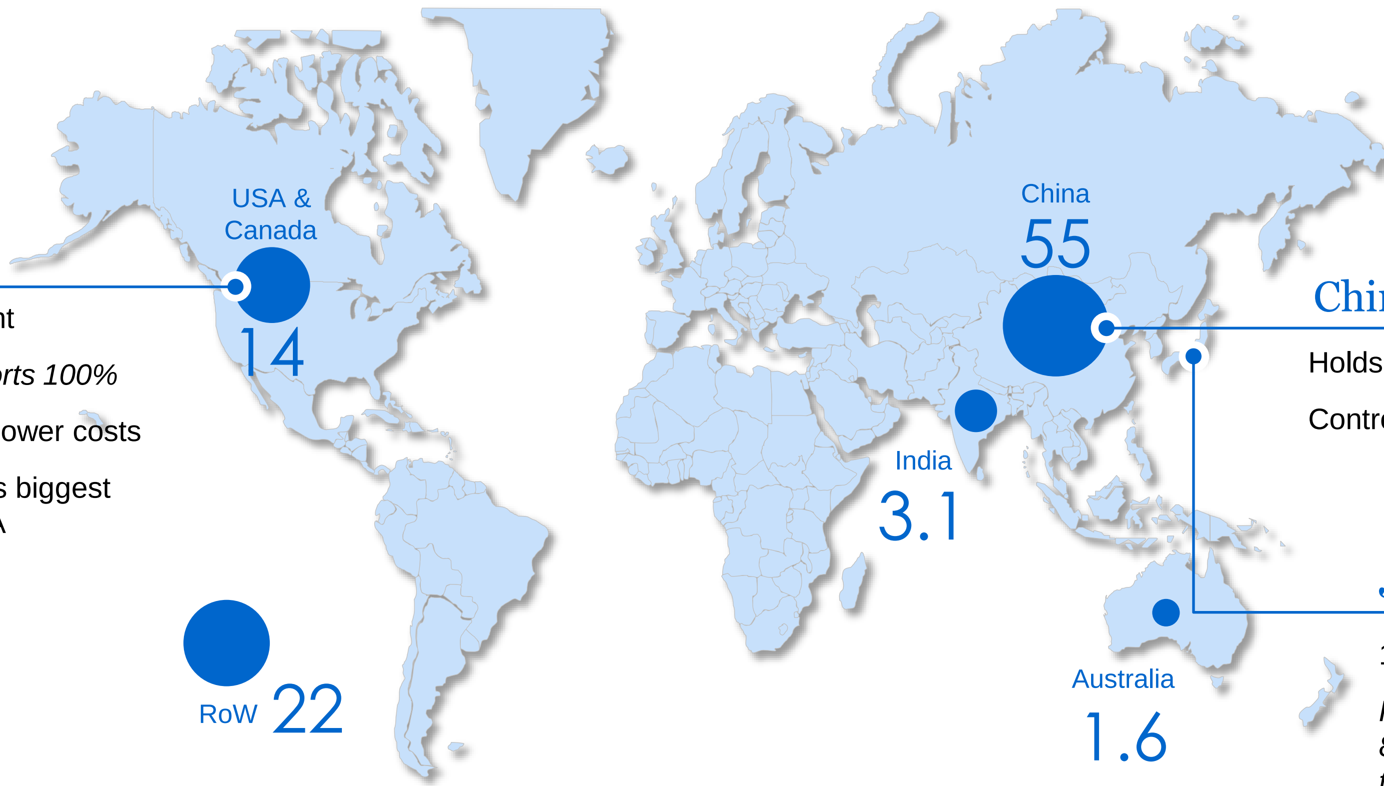
- Primarily used in phosphors used in pilot display screens, televisions and energy efficient fluorescent lights

SOURCE: IAMGOLD Report, General Web, team

Increasing demand for RE has led to other countries looking for potential reserves to reduce their dependency on China

Million metric tons

Rare Earth Reserves[1]



USA

Was self-reliant

Currently imports 100%

Mainly due to lower costs

Molycorp owns biggest deposit in USA

China

Holds 50% of reserves

Controls 90% of the supply

Japan

100% importer

Have recently found 80-100 mn metric tons of REE in the Pacific seabed

With the development of new projects, it is expected that this scenario, with China being the dominant player ,will also change

1 Referring only to the identified RE reserves

SOURCE: USGS, General web and press

There is a number of projects in the pipeline, but most focus on light rare earths

HRE ● High
LRE ○ Low

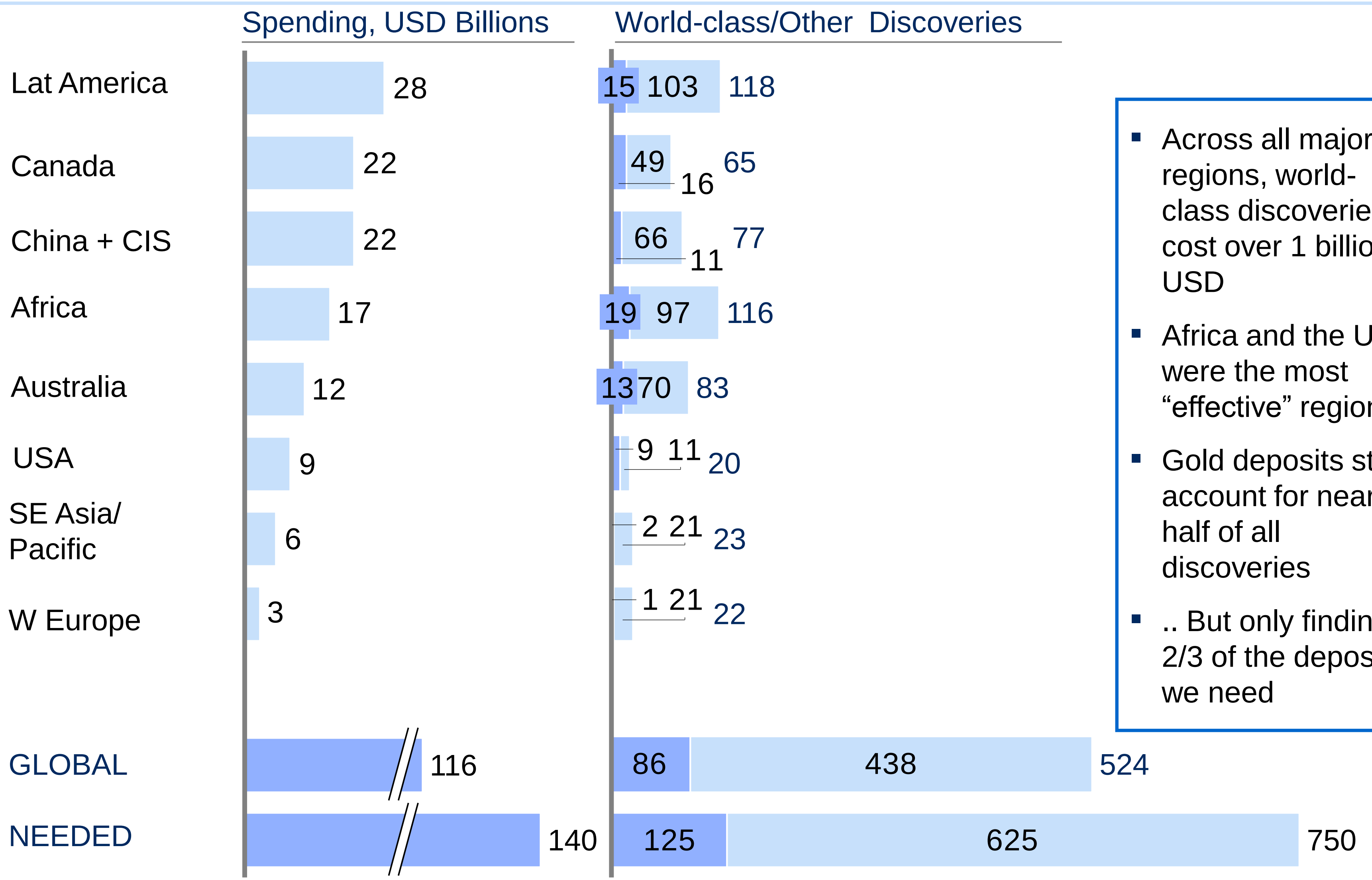
NOT EXHAUSTIVE

Company	Project	Resource TREO Mt	Capacity TREO tpa	HRE share %	Status	Likelihood
IAMGOLD	Niobec	7.70	139,597	1.76	Scoping	◔
Greenland Minerals and Energy	Kvanefjeld	6.55	51,900	11.80	Reserve devpt.	○
Avalon Rare Metals	Nechalacho	5.64	8,504	13.84	Feasibility	◑
Commerce Resources	Eldor	4.69	50,743	4.04	Reserve devpt.	○
Peak Resources	Ngualla	3.82	93,519	1.99	Reserve devpt.	○
Geomega Resources	Montviel	3.65	105,903	1.71	Reserve devpt.	○
Greenland Minerals and Energy	Sørensen	2.66	N/A	11.72	TBD	
Quest Rare Minerals	Strange Lake	2.10	10,652	39.03	Pre-feasibility	◔
Molycorp	Mountain Pass	2.07	40,301	0.60	Pre-production	●
Lynas Corporation	Mount Weld CLD	1.45	22,165	2.85	Pre-production	●
Arafura Resources	Nolans Bore	1.24	19,298	3.34	Pre-feasibility	◔
MBAC Fertilizer	Araxá	1.19	13,154	2.67	Reserve devpt.	○

SOURCE: Technology Metals research, expert interviews, companies' reports, press

However, exploration successes are becoming expensive and scarce

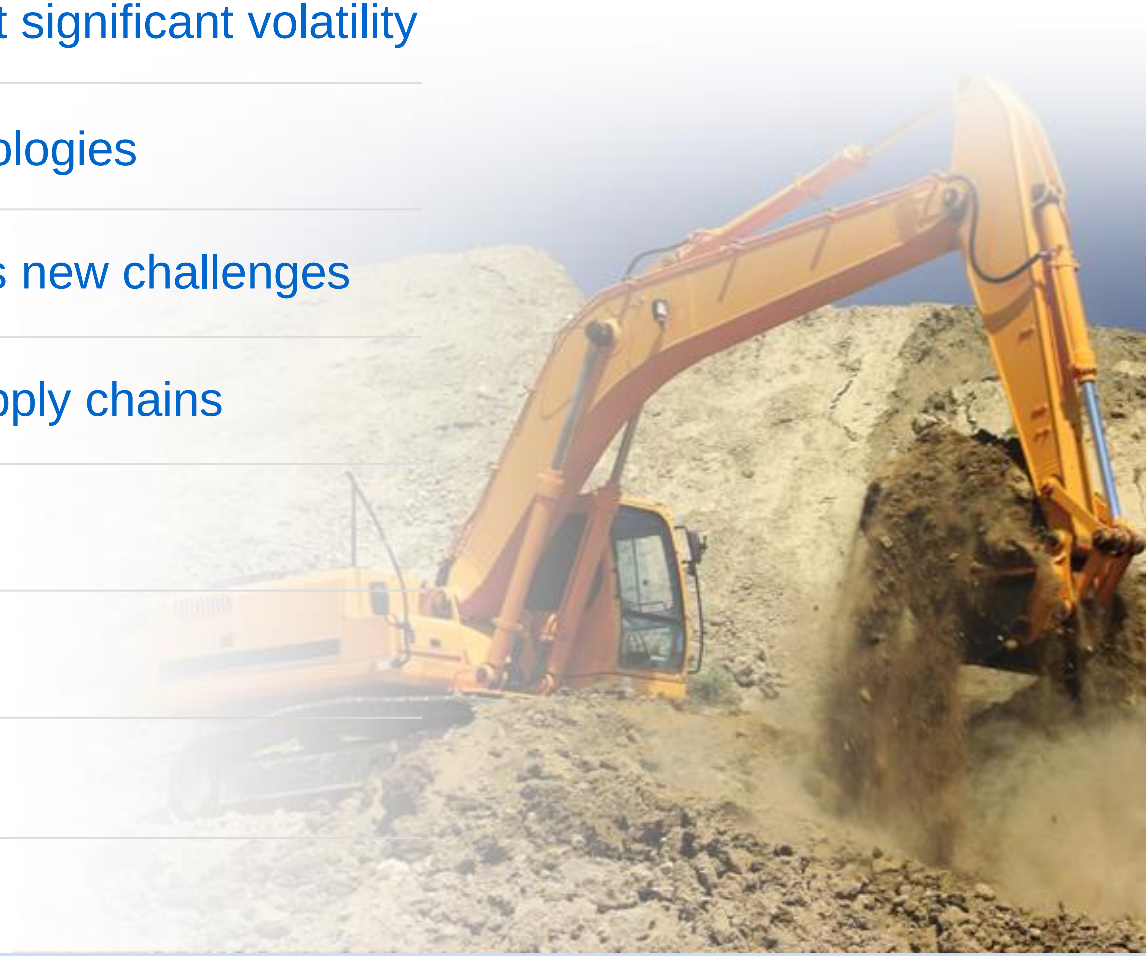
10 year period 2003-12



- Across all major regions, world-class discoveries cost over 1 billion USD
- Africa and the USA were the most "effective" regions
- Gold deposits still account for nearly half of all discoveries
- .. But only finding 2/3 of the deposits we need

New and current mining projects will be face strong market forces, which will have significant impact on the industry over coming decades

1. Continuously increasing safety, health and environment standards
2. High demand and prices but significant volatility
3. Increasingly challenging geologies
4. Polarization of scale creates new challenges
5. Increasingly challenging supply chains
6. Rising energy costs
7. Rising water costs
8. Scarcity of talent
9. Global sourcing



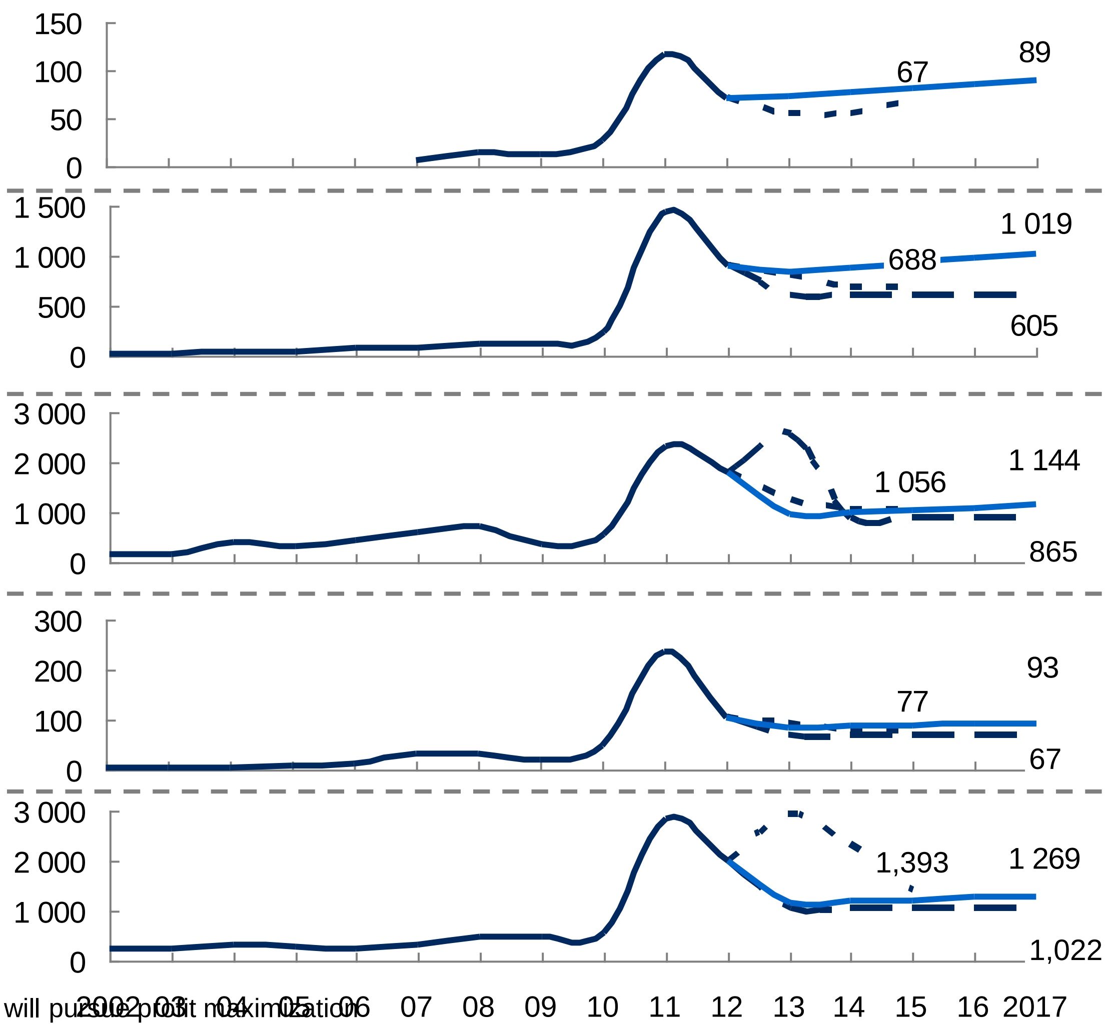
SOURCE: McKinsey analysis

Going forward, a greenfield incentive price scheme is expected for heavy elements and neodymium1

ESTIMATES

Deutsche Bank
CIBC
McKinsey greenfield incentive

Historical and future price estimates
Dollars per kg



Yttrium
- Should be in a greenfield incentive regime in the short-medium term, until some of the new capacity eases the supply/demand tightness

Dysprosium
- Expected to remain in greenfield incentive for the foreseeable future, with eventual fly-ups depending on China's export policies

Terbium
- Should be in a greenfield incentive regime in the short-medium term, until some of the new capacity eases the supply/demand tightness

Neodymium
- Tightness to be eased with volumes from Lynas and Molycorp
- Should be back to greenfield/fly-up in longer term

Europium
- Expected to remain in shortage in the foreseeable future, with demand growth out-spacing supply additions

1 Assuming that China will pursue profit maximization

SOURCE: Analyst reports, team analysis

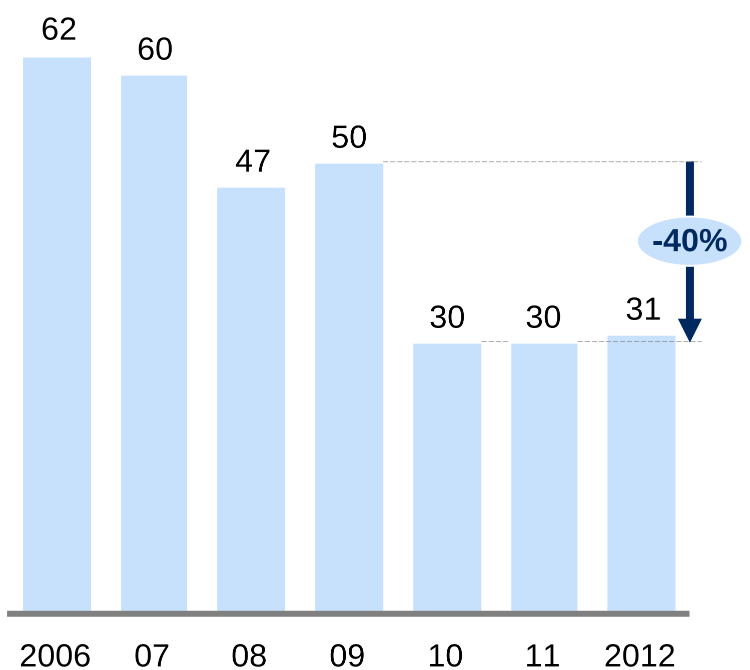
Mines holding considerable quantities of these five elements will be in a good position in the future

Element	
Y	▪ Yttrium is expected to be in shortage in the short term, with most of the new supply only coming online through the end of the decade ▪ Expert opinions: "I don't see relevant new capacity outside of China coming online in the next few years"
Dy	▪ Dysprosium is expected to remain in shortage in the foreseeable future, with demand growth out-spacing supply additions ▪ Severe shortage could trigger investments in magnet recycling technology or even partial substitution/decrease in intensities
Tb	▪ Slower demand growth for Terbium when compared to Dysprosium and Yttrium could lead to a balanced market already in the short term ▪ Given the relatively low volume of the global terbium market, small amounts as by-product from large light-focused projects such as Mountain Pass and Mount Weld could ease the tightness
Nd	▪ Relevant volumes of Neodymium coming from Mountain Pass and Mount Weld in the short term should ease the tight supply-demand balance ▪ In the longer term, new projects will probably be needed to meet Nd demand
Eu	▪ Europium is expected to remain in shortage in the foreseeable future, with demand growth out-spacing supply additions ▪ Severe shortage could trigger investments in phosphors recycling, such as the research conducted by Rhodia in France in the last few years

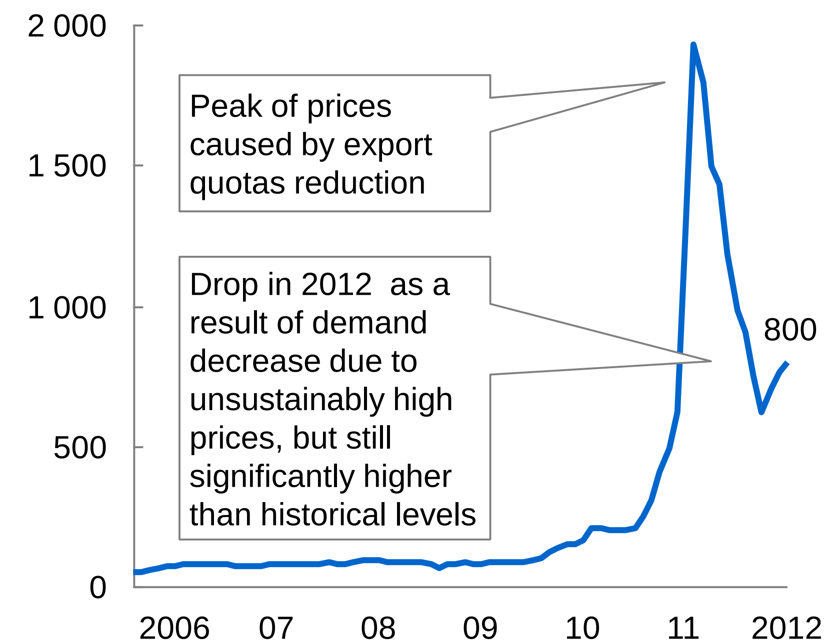
SOURCE: Expert interviews, McKinsey

With this relevant position, China controls the current price dynamic

Export quota evolution of rare earth in China
Thousand tons



Prices of dysprosium oxide in China
$/kg



- In 2010, China tightened export quotas for heavy and light rare earths; in the future:
  - Light quotas could be eliminated as new light REO sources are coming online
  - Heavy quotas should remain as China does not have enough reserves and few new heavy rare earth sources are coming online in the future
- If China acts rationally, it will look to maximize profits which would maintain prices at higher than historical levels letting smaller players into the market. However they hold the power to avoid the entry of other players if they wanted to.

SOURCE: MOFCOM, Press search

This has resulted in companies looking for different avenues to meet their growing requirements; for which substitution seems best suited

Fuller the moon, more viable

Best way forward

3 best measures to adopt to avoid falling into supply shortage problems

Reduction in the usage of RE is a process that is not yet economically tested by many companies

Some areas where this has come useful is in LED television sets, which require lesser RE than LCD sets

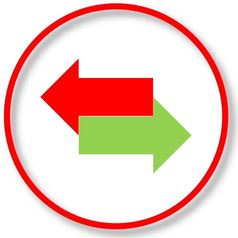
Recently, generator manufacturers have reduced RE content and have used other metals like nickel, which provides similar levels of performance

RE used in fluorescent lighting and computer hard drives, can be **recycled**

Extract RE from used hybrid motors and lithium-ion batteries in addition to nickel-metal hydride batteries

Benefits of recycling RE from batteries is that a supply of recycled lanthanum should be more reliable than relying on new Chinese sources

Recycling also uses less energy and emits less carbon di than mining



Motor companies are looking towards creating new techniques to **substitute** RE, like induction motors and nickel-hydride batteries

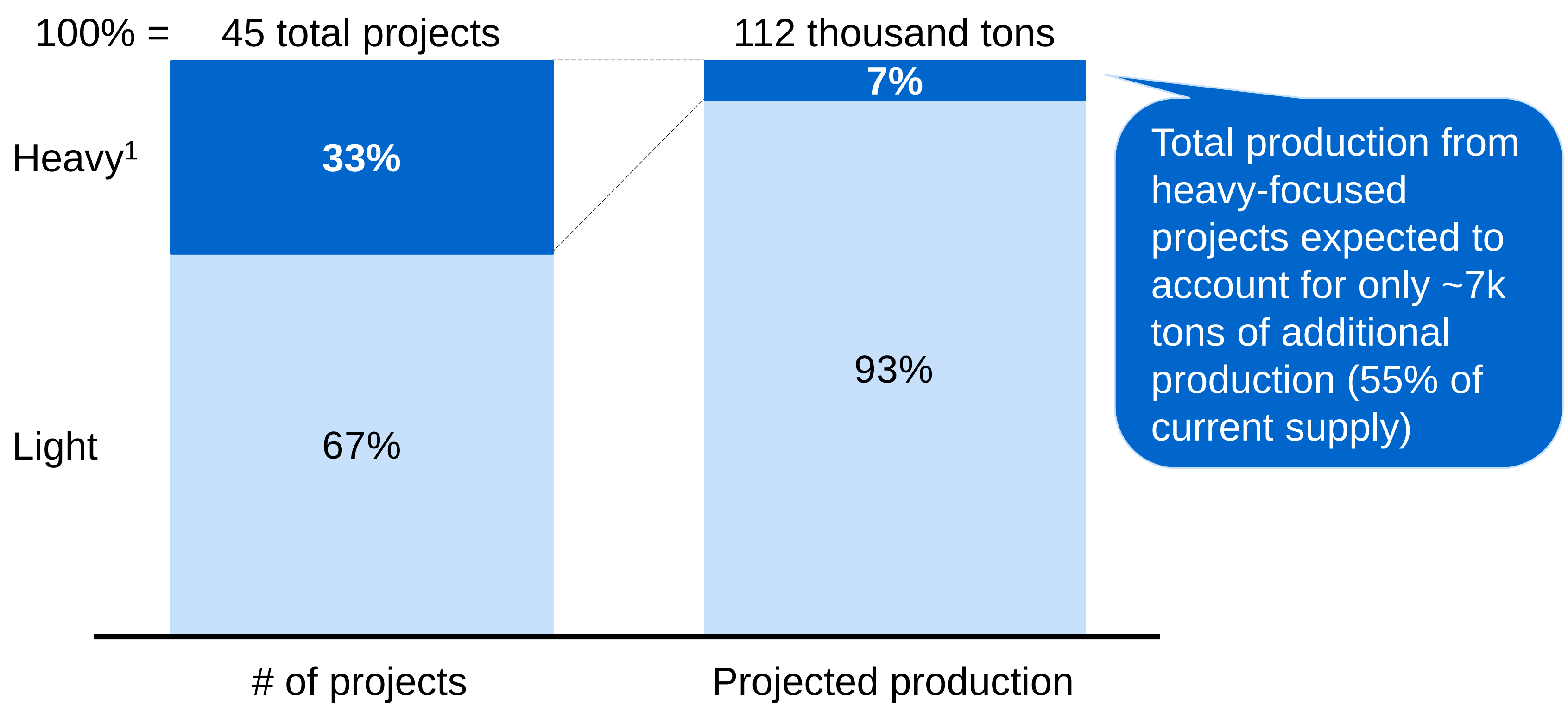
Some companies have also substituted RE with iron based amorphous core for motors which is 5% more efficient

Companies who are taking the initiative towards substitution are Hitachi, Ford, Continental AG and Honda

SOURCE: General web and press, team

In the rest of the world the pipeline of heavy projects is limited to less than 10k tons

Projects in the pipeline by type
Percent, number of projects, TREO ktpa



1 Heavy rare earths projects are the ones with more than 15% of total rare earth content of heavy elements

SOURCE: Technology Metals Research, expert interviews, companies' reports, press