Benchmarking & Sustainability in Iron Ore Mining & Beneficiationin India

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Private & Confidential

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Why the need for Mineral Industry

IF YOU CANNOT GROW IT,

THEN MINE IT

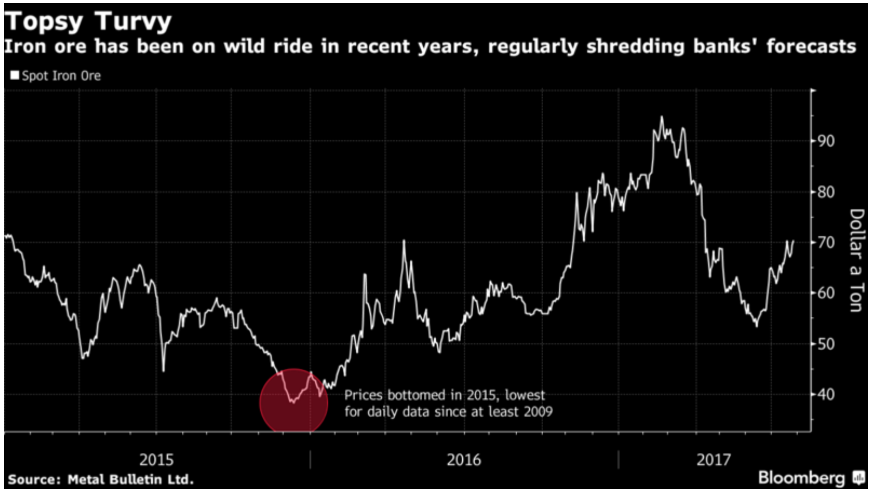
Background

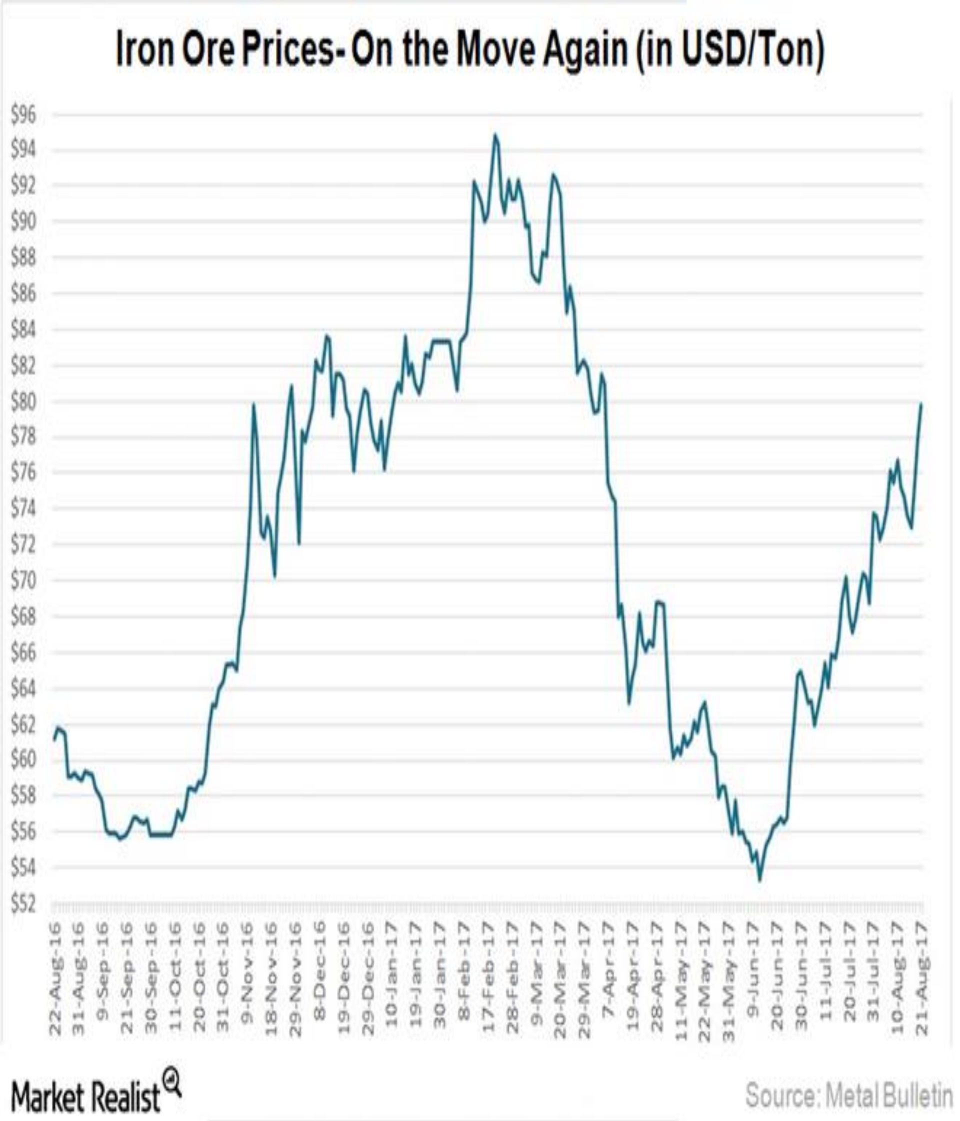
- Benchmarking is a decision making support tool enabling mine management to determine the relative performance of their mine with respect to other mines of **SIMILAR SCALE OF OPERATION AND DEGREE OF MECHANIZATION/ TECHNOLOGY**.
- It helps mine management to identify the key areas requiring performance improvement to achieve the best practice of the industry.
- Benchmarking can be done either internally by comparing the past performance level of its own mine with respect to selected KPI's or strategic benchmarking carried out by comparing the performance level of a mine with other national or global mines **HAVING SIMILAR WORKING IN TERMS OF SCALE OF OPERATION, TECHNOLOGY/ MECHANIZATION, AUTOMATION, WORK CULTURE ETC**.

Benchmarking is comparing one's business processes & performance metrics to **industry** bests & best practices from other **companies.** Dimensions typically measured are quality, time and cost.

Compete to excel

A new sine wave?



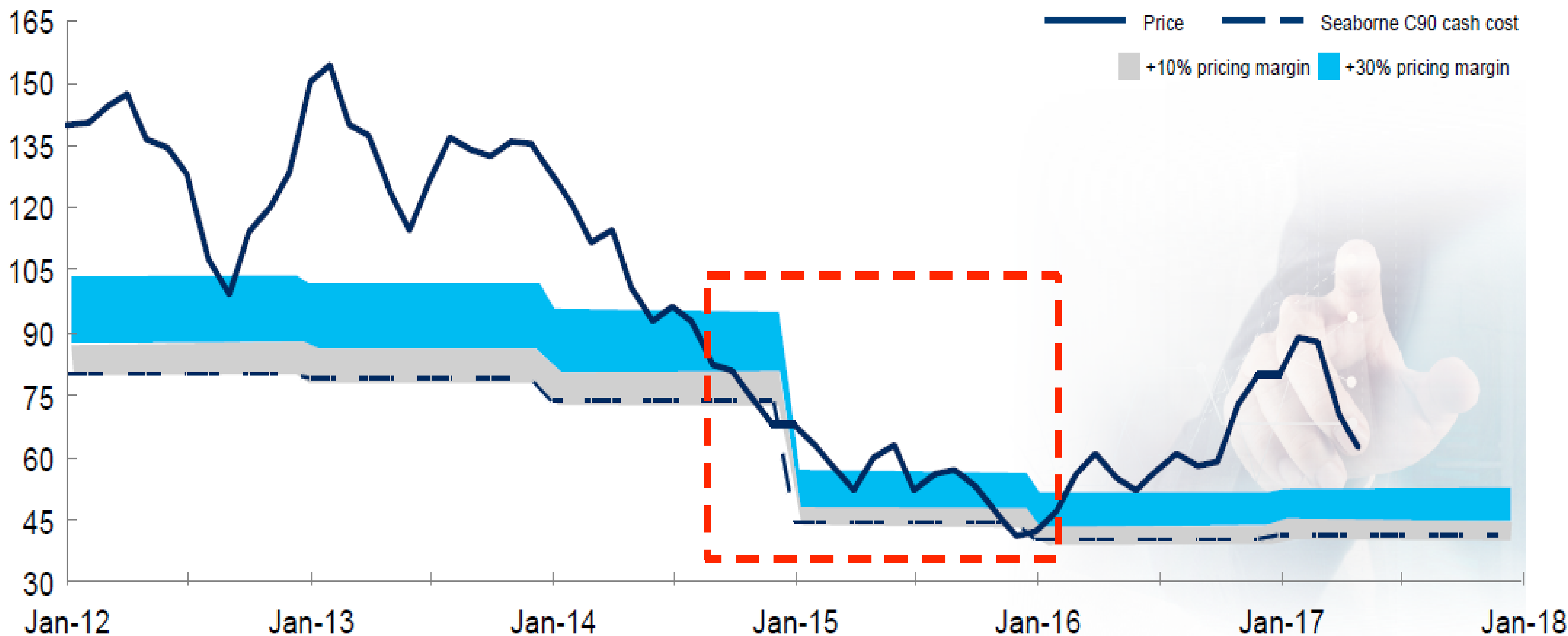


Tremendous volatility

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

Q1 2017

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



Average margin, %						
	37	42	22	20	30	49[2]

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

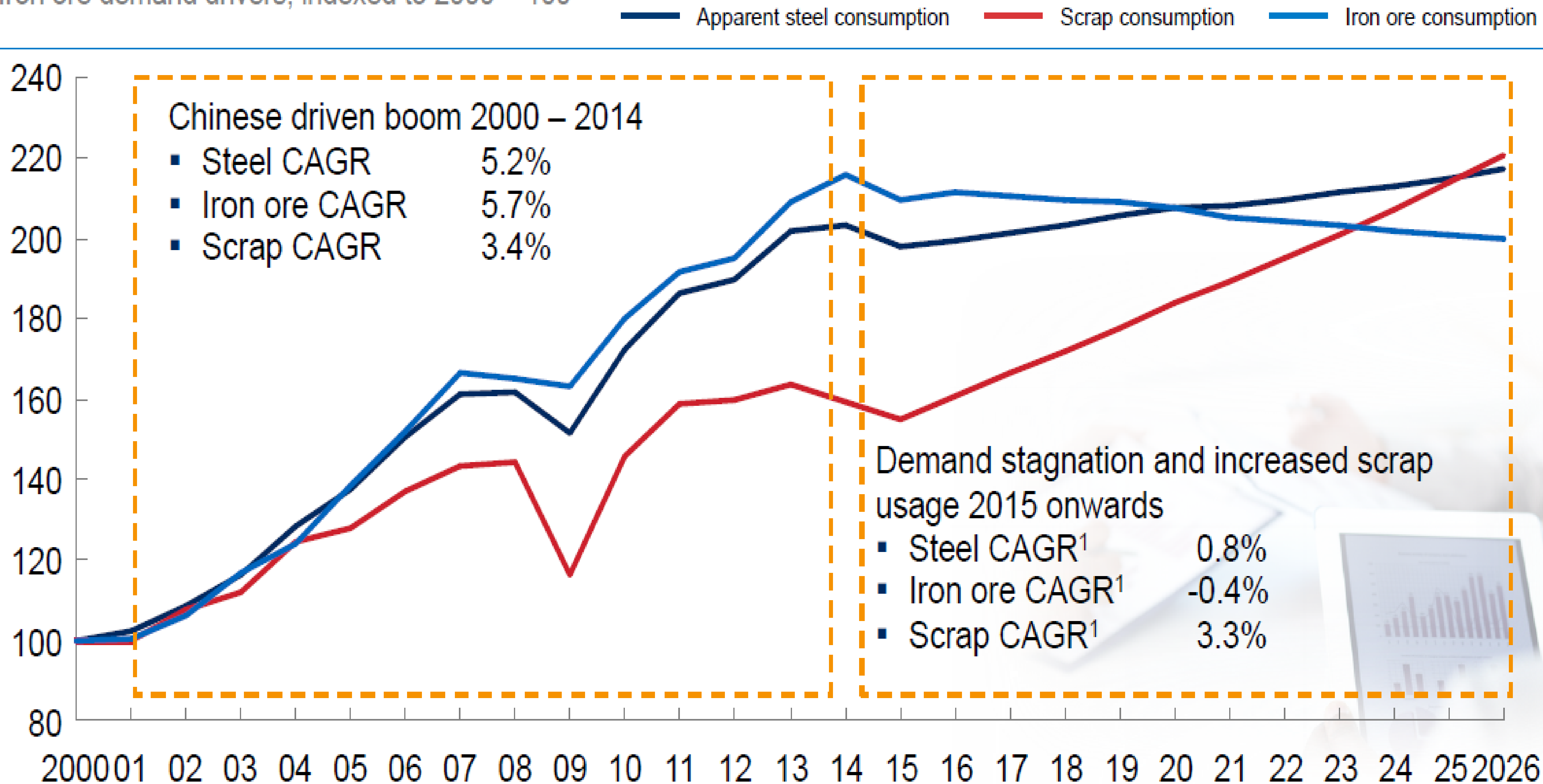
SOURCE: MineSpans 2016 Q3, Consensus Economics, McKinsey iron ore team analysis

Changing demand scenario

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

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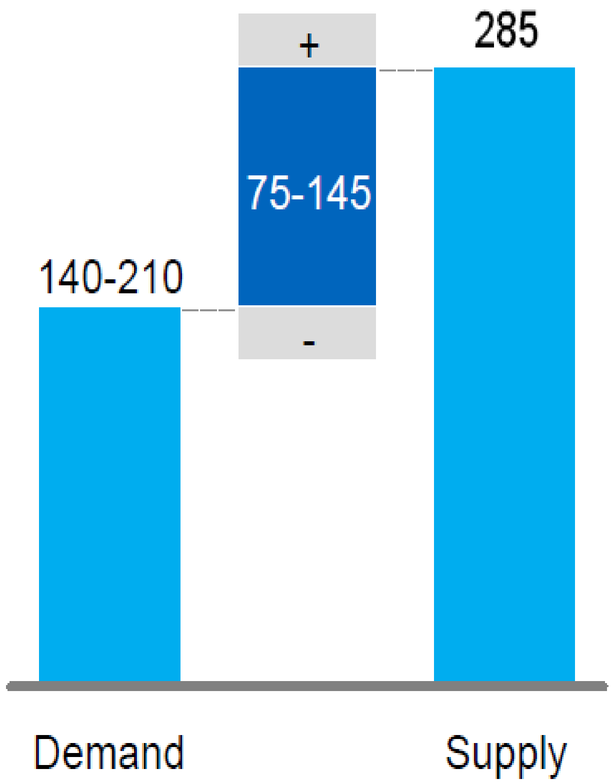
Different scenarios could be considered by which China's future scrap supply demand mismatch gets balanced

- Detailed on next page

NOT EXHAUSTIVE

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?

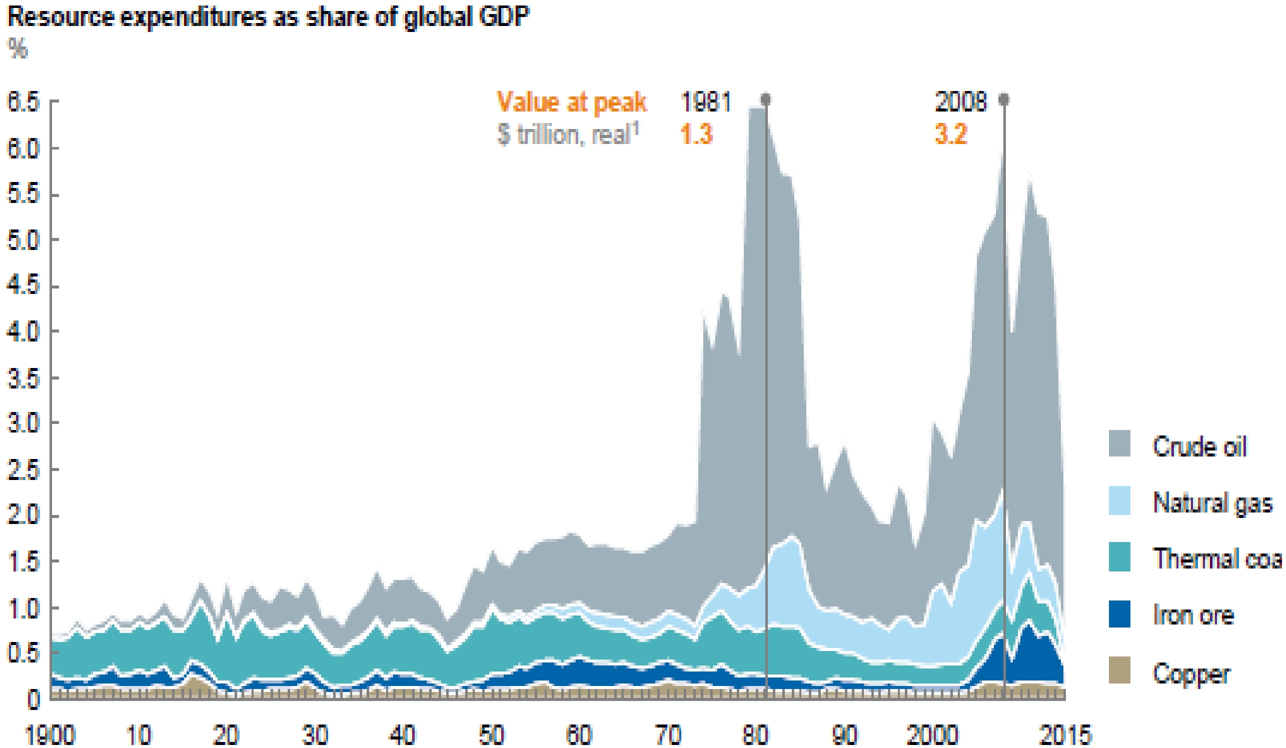
To what extend is the country ready to allow the steel industry to make the **switch from BOF to EAF** and hence closing more BF-BOF capacity while investing in new EAF facilities?

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

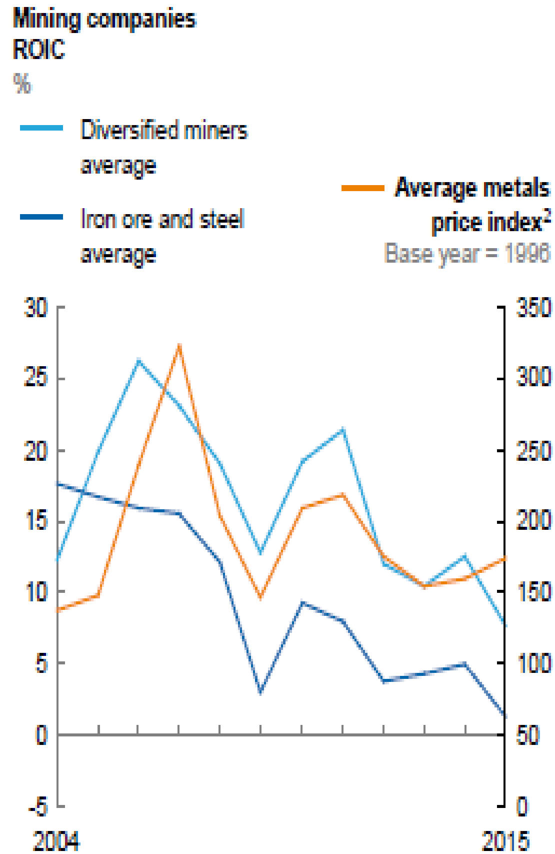
Changing growth model

Spending on resources during the 2003–15 supercycle exceeded 6 percent of global GDP for only the second time in a century



1 Indexed to 1990 dollar values.

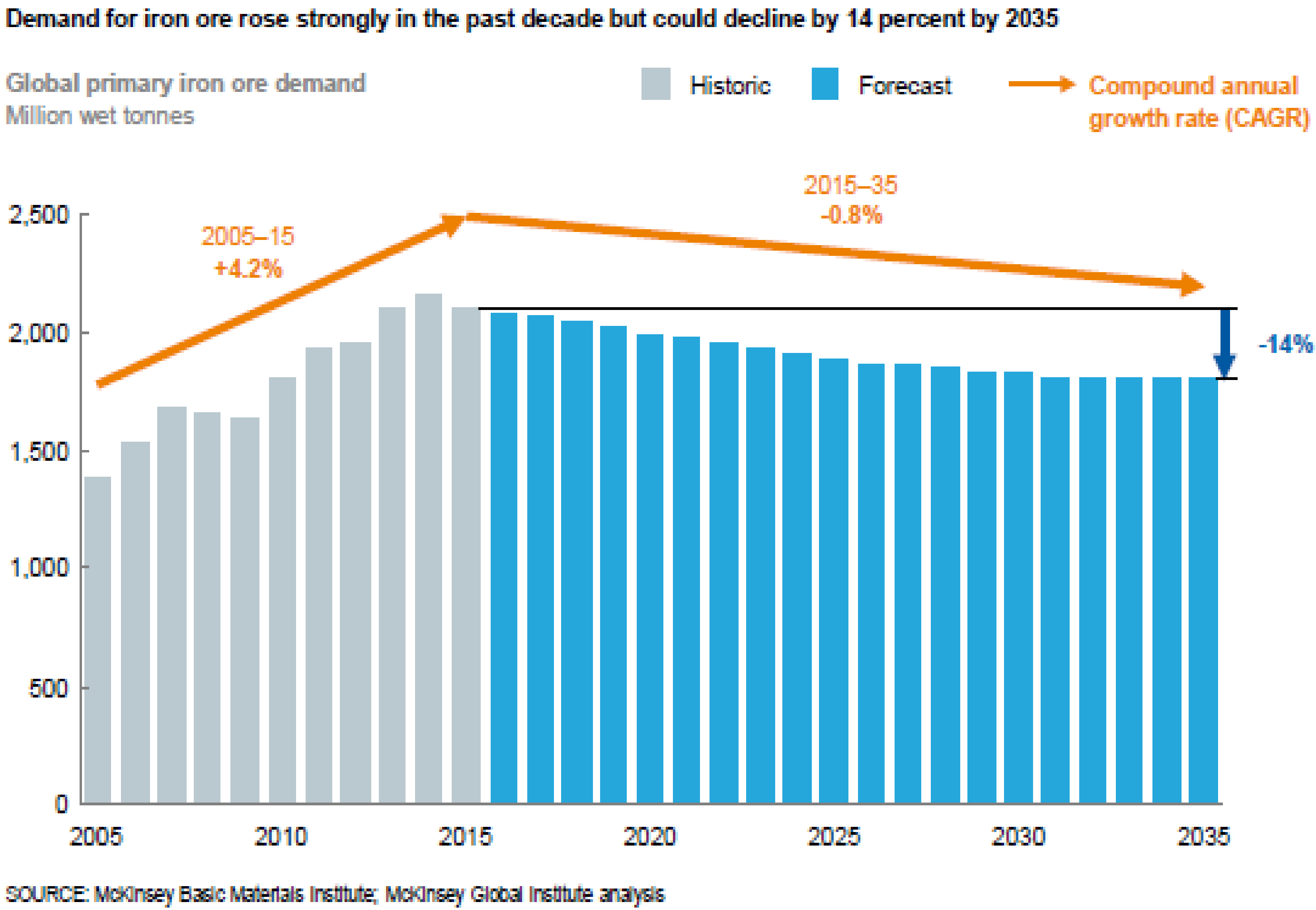
SOURCE: Rystad Energy; *BP statistical review of world energy*, 2015; World Bank; The Madison Project; USGS; McKinsey Global Institute analysis



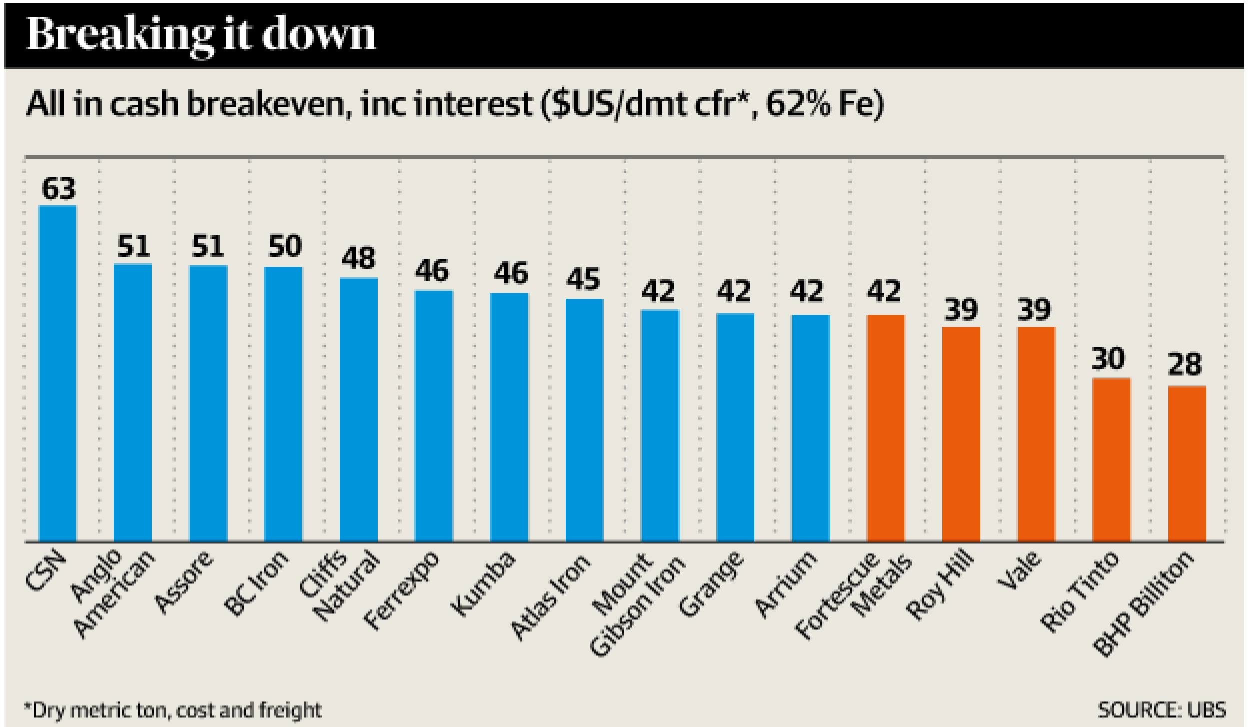
McKinsey MineLens productivity index
100 = 2004

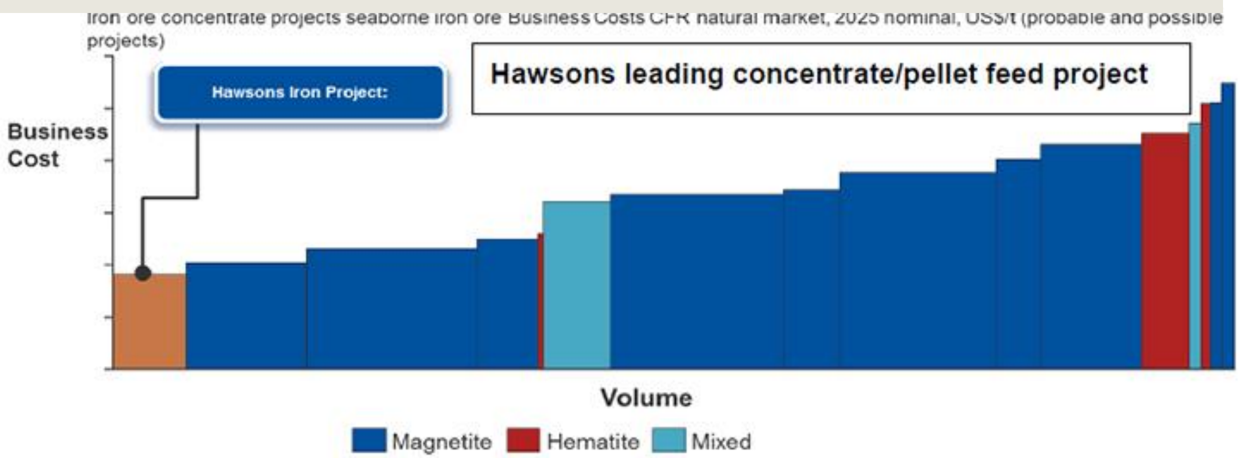
China's changing growth model and global demographic and energy consumption trends will affect future resource demand

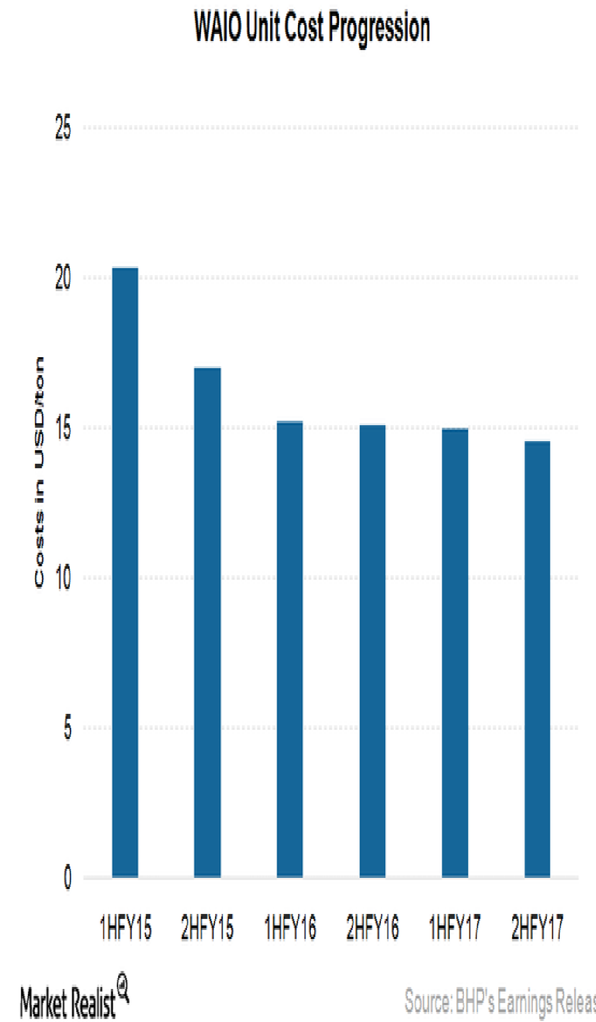
Iron ore demand



Iron Ore cost curve







Source CRU, July 2017, iron concentrate business cost curve for possible and probable projects. CRU's Business Cost is all operations up to delivery at the buyers' ports and also includes a value in use adjustment that normalises all operations to the benchmark 62% iron ore price delivered to China, to allow for direct comparison.

Mining in India

- The mining sector is an important segment of the Indian economy and every 1% increment in the growth rate of mining results in 1.2 – 1.4% increment in the growth rate of industrial production and correspondingly, an approximate increment of 0.3 percent in the growth rate of India's GDP.
- Demand for minerals, as well as for mining services, is robust in the country.
- However, despite having abundant mineral deposits figuring in the top 5 or 6 reserves globally across commodities such as thermal coal and iron ore, the mining industry has remained relatively stagnant in the past.
- Moreover, despite India's significant geological potential, the country does not rank very high in terms of its mineral resource base amongst similarly geological endowed nations.
- Public sector continues to play a dominant role accounting for +70% of mineral production during 2014-15. Clearly policies and incentives have not been conducive for the private sector players to participate more actively so far.

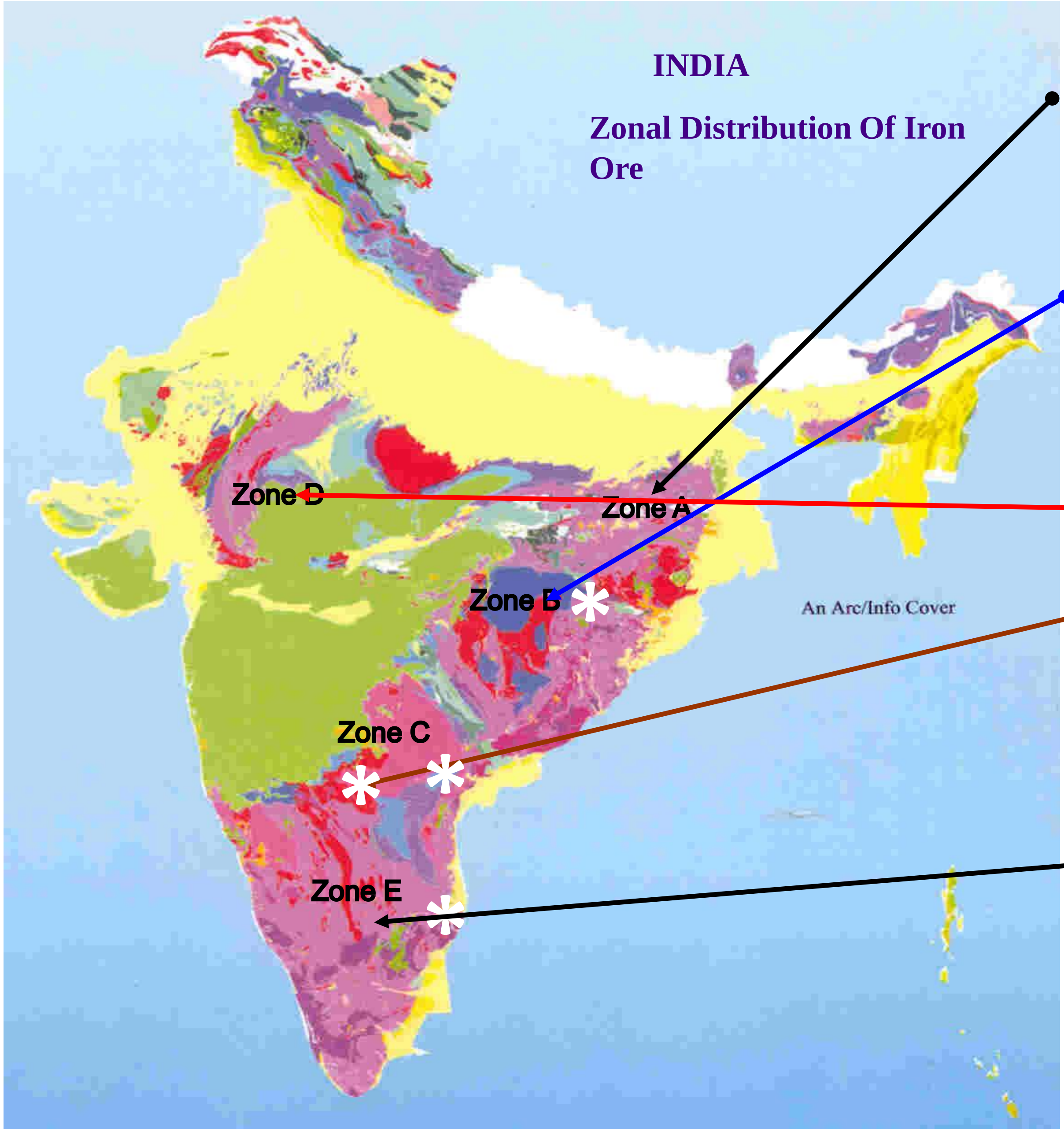
A brief about Indian iron ore scenario

- The ores and minerals are site specific, non-renewable and finite.

- India is endowed with significant iron ore reserves (BIFs), estimated at **25.25** Billion tonne apart from Banded Haematite-Quartzite (BHQ) and Banded Haematite-Jasper (BHJ). However, the proven economically mineable reserve is only **8.1** billion tonne (+45% Fe), of which the high reserve grade is only **1.3** billion tonne.

- Considering around 200 MTPA addition in existing steel production by 2030-31 (NSP 2017), there is an urgent need for conservation and sustainable use of our natural resources. More than that, there is also a need for effective utilization of low-grade iron ore and fines, through suitable beneficiation technologies & benchmarking the same to the best in the world.

Occurrences Of Iron Ore In India



Chiriya, Noamundi,Kiriburu, Meghataburu, Gua, Malangtoli, Thakurani, Bolani, Gandhamardhan, Daitri

Bailadila, Dalli, Rajhara, Rowghat, Mahamaya, Aridongri, Surajgarh

N.Goa, S.Goa, MP, Maharashtra

Donimalai, Ramandurg, Kumaraswamy, NEB Range, Ettinahatti, Tunti, Belegal

Kudremukh, Bababudan, Kudachari

Iron ore processing

- **Present Practices of Iron Ore Processing**

The abundant resources of high grade Iron ore in India have restricted the processing to simple crushing and screening to a large extent and produce Lump /CLO and fines suitable for blast furnace application, Direct Reduced Iron process and Sinter making. Some of the plants utilize scrubbing prior to screening.

- **Challenges in Processing of Low Grade Iron Ores**

With increasing demand in the international market as well as growing economy, it has become area of national interest to go for beneficiation of huge resources of low grade iron resources. Extensive work has already been initiated by adopting gravity separation, magnetic separation and flotation processes.

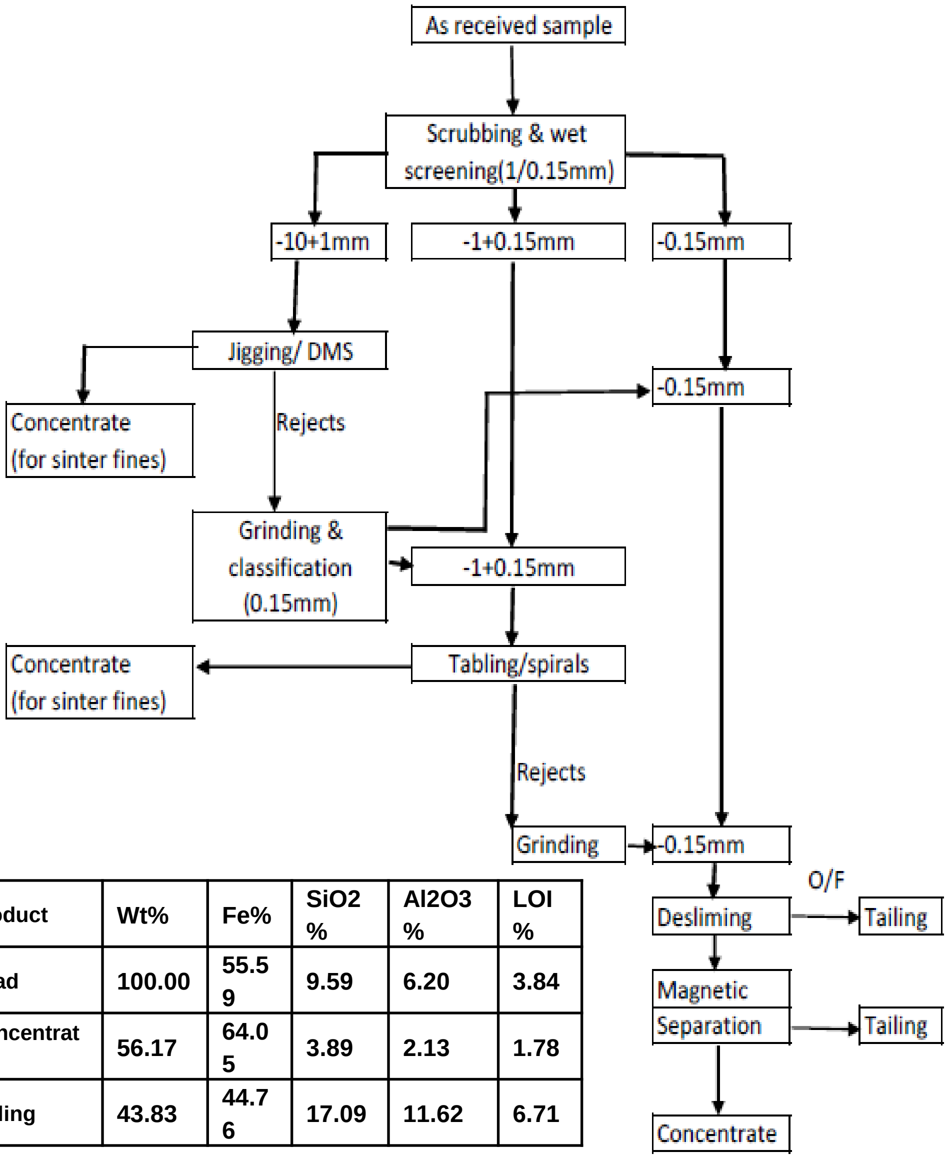
Problems in Indian iron ore processing

- Decreasing % of lump in product
- The problem of alumina & Beneficiation of alumina rich iron ore slimes
- The economic consideration in utilization of low grade reserve
- Problems involved in handling, disposal of tailings (slimes)
- Overcoming the infrastructure bottlenecks
- Deeper & complex deposits & Declining Productivity
- Lower Commodities Prices & Declining profit margins
- High taxes and Royalties
- Social and Geopolitical risks

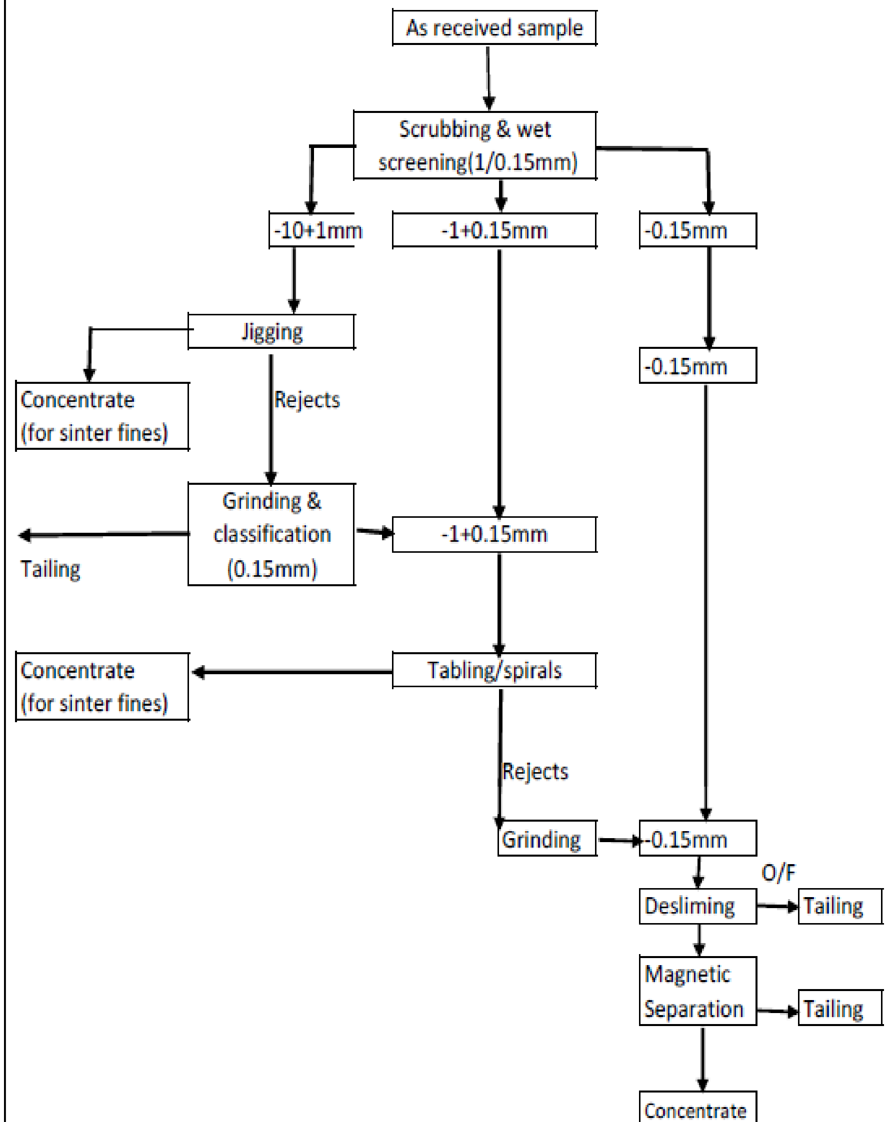
Points of interest/ concern

- Wastes associated with iron ore extraction and beneficiation
- Tailings (Processing Waste)
- Environmental Impacts of Mining; Water Pollution
- Following principal process technologies/equipments are available for iron ore beneficiation:
  - ✓ Scrubbers (Attrition & Drum) and Log Washers
  - ✓ Heavy Media Separation & Jig;
  - ✓ Teeter Bed Separators (like Flotex density separator, Allflux Separator etc.);
  - ✓ Centrifugal concentrator, Spirals & Reichert cone;
  - ✓ Magnetic separation (LIMS, MIMS, WHIMS, HGMS & VPHGMS); Floatation (conventional& Column) & Selective Flocculation;
  - ✓ Pelletisation and Roasting

Conceptual flowsheet development



Product	Wt%	Fe%	SiO2 %	Al2O3 %	LOI %
Head	100.00	55.59	9.59	6.20	3.84
Concentrate	56.17	64.05	3.89	2.13	1.78
Tailing	43.83	44.76	17.09	11.62	6.71



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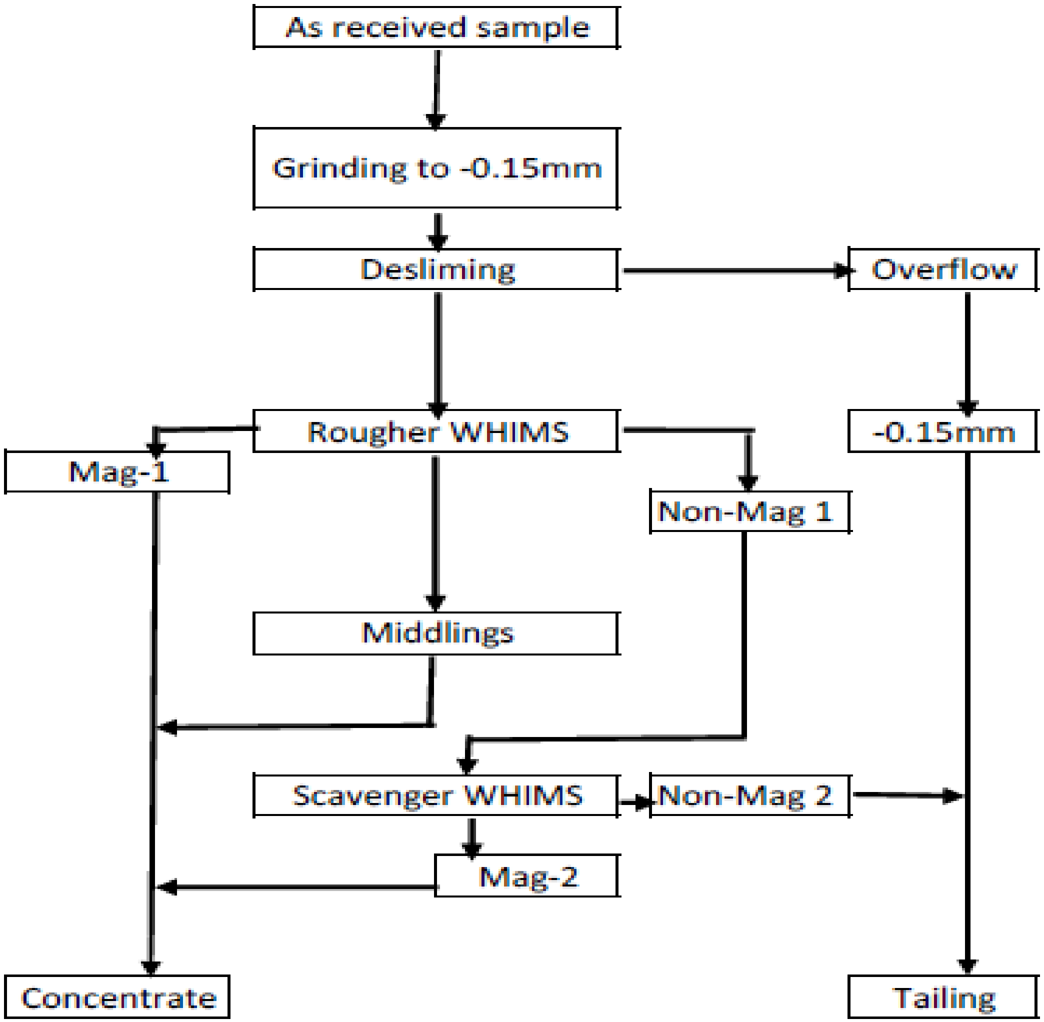
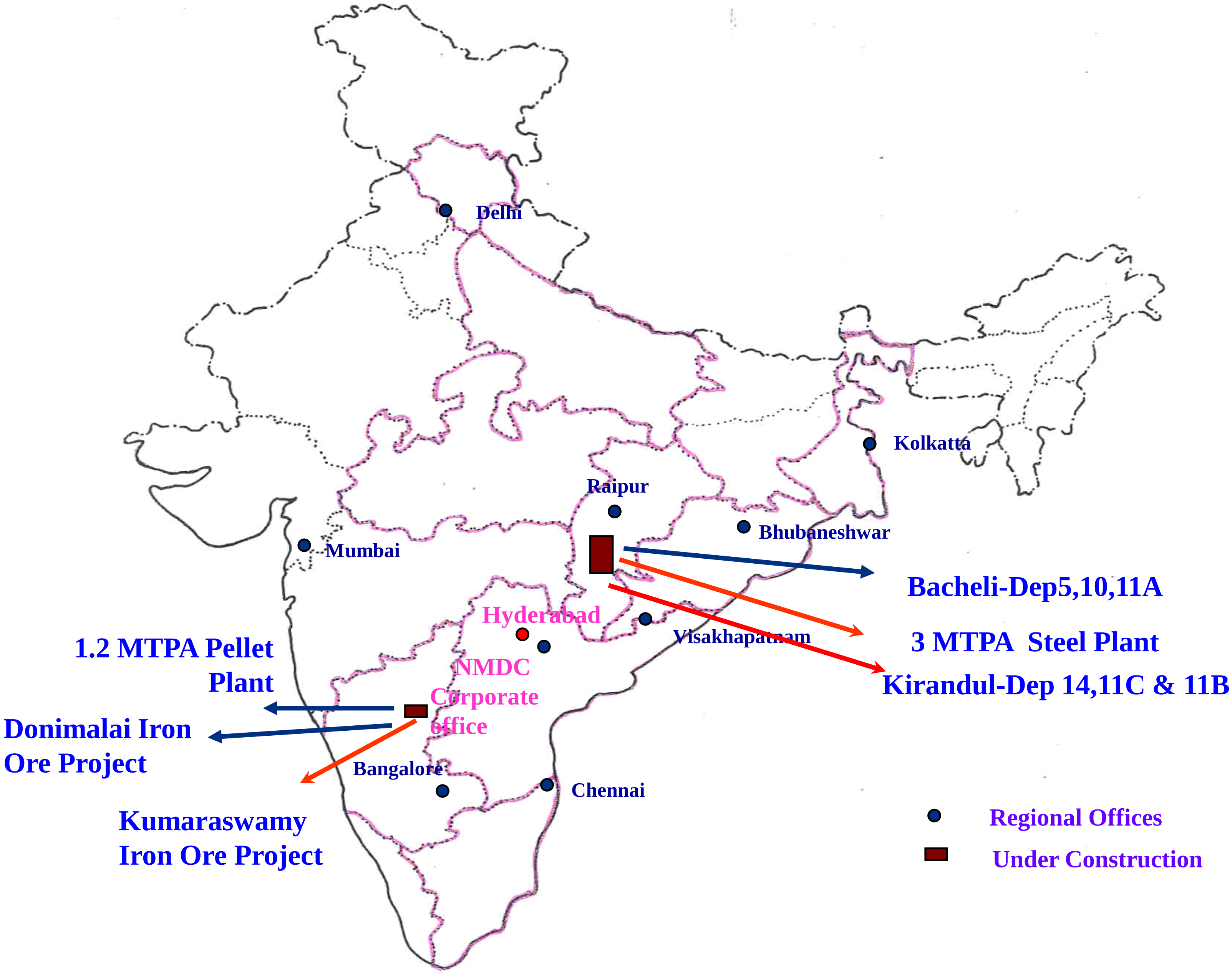
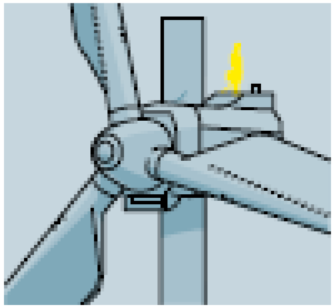


Product	Wt%	Fe%	SiO2%	Al2O3 %	LOI%
Head	100.00	55.59	9.59	6.20	3.84
Concentrate	63.95	65.05	2.73	2.07	1.93
Tailing	36.05	38.81	21.76	13.52	7.23

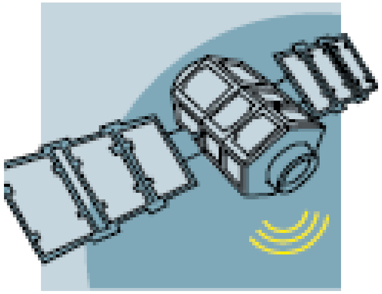
Up coming Projects of NMDC in India



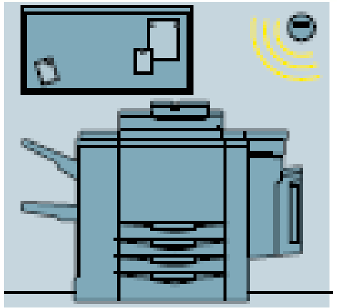
Technology will change the way consumers live



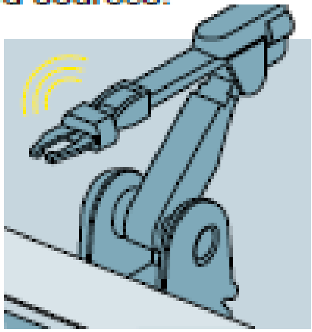
1. Renewable energy may become the cheapest form of power, used in a combination of decentralized and centralized sources.



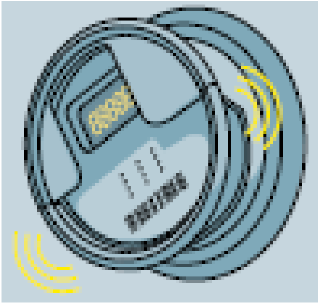
2. Long-haul transportation adopts greater levels of autonomy as **telematics of travel patterns**, platooning, and analytics enable greater fuel economy.



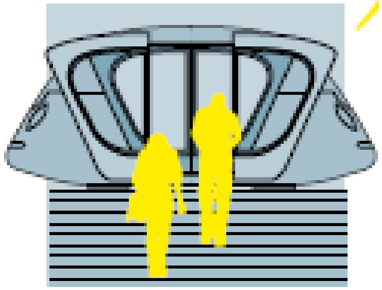
3. Electrical sensors in the office and home enable optimization of heat and light based on usage, weather, and occupancy data.



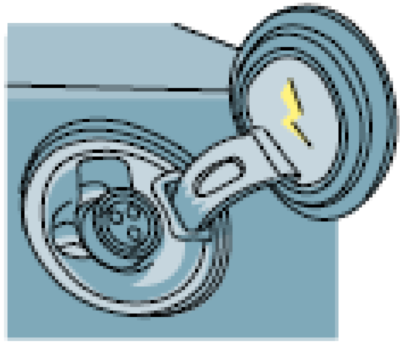
4. Industrial sites capture efficiency improvements with sensors, analytics, and automation, improving overall productivity and safety.



5. Utilities communicate with users and devices to identify optimization opportunities like retrofits or upgrades to new appliances.



6. Autonomous ride sharing services collect passengers at their homes, optimizing route and picking up other commuters to carpool, reducing number of vehicles on the roads.



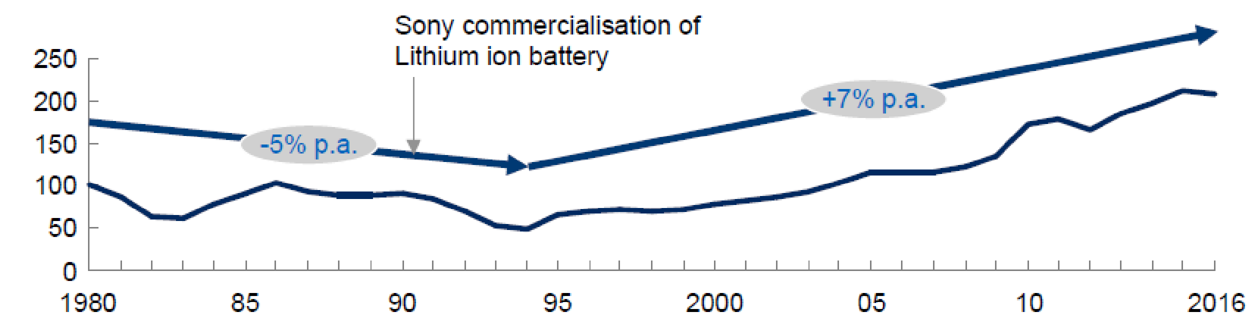
7. Electric vehicles may account for the majority of new car sales, taking advantage of their lower total cost of ownership.

Technology enhancement

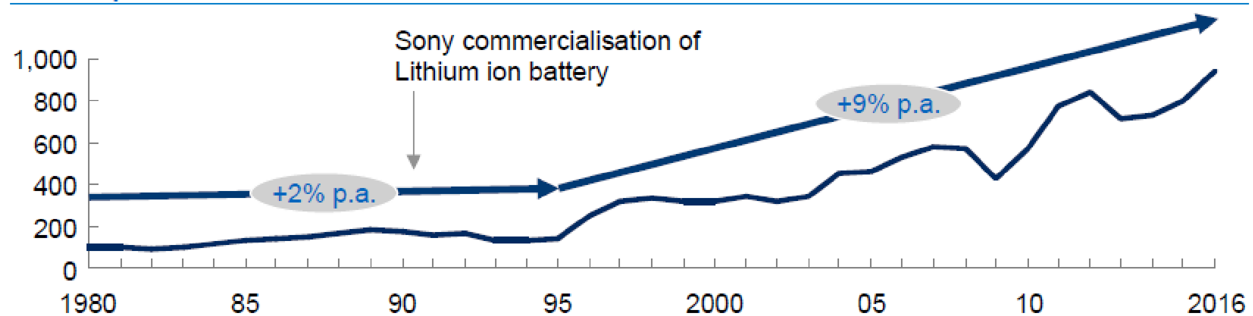
Historically, changing technologies have driven massive growth spurts in mineral demand

- 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

Validation through practising

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

1. Robotics
2. Internet of Things
3. Advanced airborne gravity gradiometer technology for mineral exploration
4. 3D imaging technologies
5. Automated drilling
6. Efficient shaft and tunnel boring system
7. Autonomous haulage
8. Plasma technology for increasing precious metal yields
9. Bacteria leaching
10. Remote operating and monitoring centres

1. Large Capacity mines.
2. Augmenting of reserves with lower Fe cut off.
3. Beneficiating lower grade iron ore.

Mining has a large opportunity to improve productivity by closing the gap to global best practice

Average Overall Equipment Efficiency
Percent

SOURCE: MineLens, McKinsey analysis

Need for a change

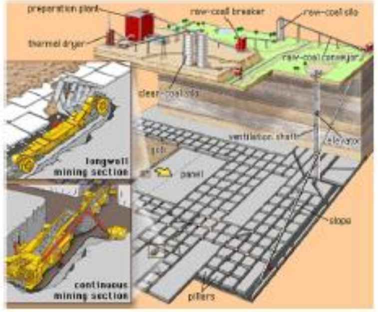
Traditionally, mining has been more insulated from digital than other industries

Geological uncertainty

Even with developments over the last decades, accuracy of modelling and predicting quality of resource base & geology still poses a challenge

Complexity of operations

Mining operations include multiple pieces of mobile and fixed equipment & infrastructure



Challenges of underground mining

Underground mining poses unique challenges, e.g., low or no real time transparency of equipment usage & location, difficulties in data transmission and communication

Changing location of production process

A mine is a system with ever changing production location and moving production equipment

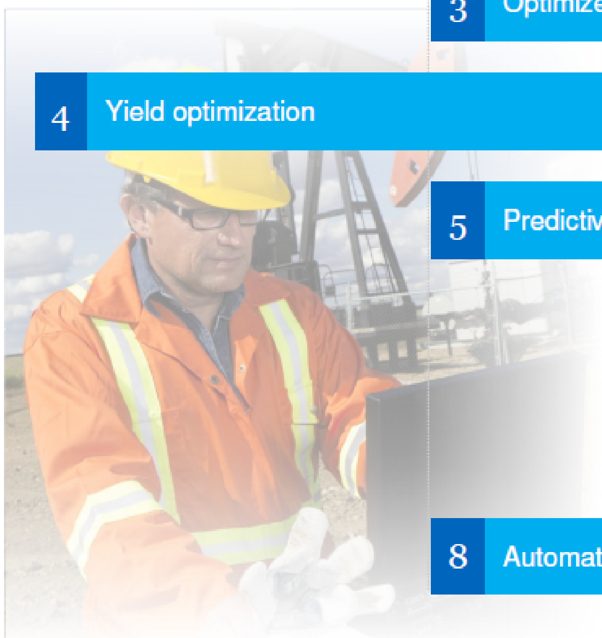
Reserve value
Lifetime value of resource

Volume
Tonnes through constraint

Cost
Pit-to-port operating cost

Safety
Total injury frequency rate

1. Stochastic geological modelling
2. Pit-to-port supply chain
3. Optimized scheduling and control
4. Yield optimization
5. Predictive maintenance strategies
6. Digitized maintenance planning
7. Digitally-enabled maintenance execution
8. Automated equipment



Available for use, but how old??

It is available technology but not necessarily new technology

LKAB launches a project with ARA (currently **Sandvik**) named **SALT I**, to implement **remotely controlled loaders and trucks** operated out of a control room

First **semi-autonomous Tamrock 2500 machines** start operations in **Kiirunavaara Mine**, owned by LKAB in Sweden

Olympic Dam mine owned by BHPB introduces **remotely controlled CAT R2900**, with autonomous ladle loading

LKAB **fully replaces its fleet** with remotely controlled CAT in Kiruna

1987 | 1990 | 1998 | 1999 | 2003 | 2004 | 2008 | 2010

Brunswick branch of **Noranda** launches a **remote loading system** in **Wagner ST-8B** machines (1997)

BHPB implements the **Dynamic Automation System** (DAS) in its ageing fleet of **Elphinstone R2900** in Olympic Dam mine

El Teniente mine in Chile is the first to use **advanced autonomous machinery on a large scale**

Boliden introduces **remotely controlled Sandvik loaders** at Garpenberg mine in Sweden

SOURCE: Press, web and literature search

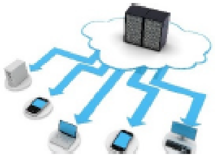
Raw Materials Demand at 6.5 per cent GDP growth Scenario			
	2013-14	2025-26	2032-33
Crude Steel Production	81	185	287
Iron Ore Demand	132	295	454
Coking Coal Demand	54	133	206
Non-coking coal demand for Steel industry	23	47	80
Steel Melting Scrap demand	9.4	21.4	33

Raw Materials Demand at 8 per cent GDP growth Scenario			
	2013-14	2025-26	2032-33
Crude Steel Production	81	219	375
Iron Ore Demand	132	346	584
Coking Coal Demand	54	144	244
Non-coking coal demand for Steel industry	23	83	150
Steel Melting Scrap demand	9.4	25	43.4

Future mine redesigned across full digital platform

Integrated Data Platform & Visualisation » Real time operations monitoring » Predictive optimization » Automated equipment

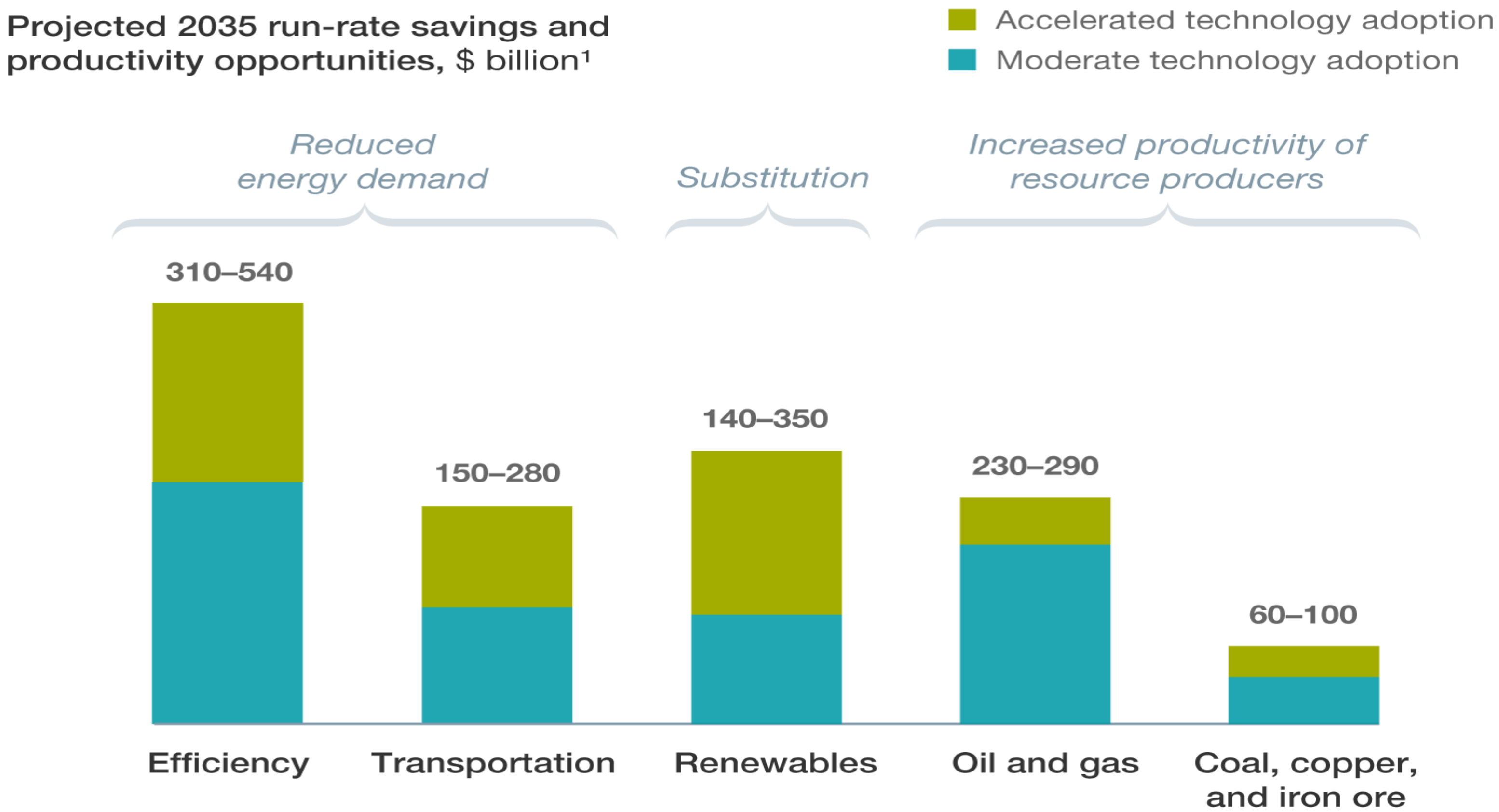
Continuous learning

Description	**Optimisation of material and equipment flow** One open, integrated, easy to access data architecture platform used as a foundation for both operation and supply chain	**Deeper understanding of resource base** Real time mine modeling to increase exploration and drilling success, hence optimizing business performance	**Improved anticipation of failures** All equipment data embedded in the architecture to predict and optimize performance across plant (e.g., eliminate unexpected idle time through predictive maintenance)	**Increased mechanisation** Automated drilling and hauling integrated into the platform to feed useful productivity information (e.g., schedule optimization). Analytical models for optimized scheduling and yield management
Illustration				

The future mine is safer, more predictable and sustainable, built on automated and integrated analytical platforms

Is it answering the HOW??

Technology will create opportunities for energy savings and increased resource productivity.



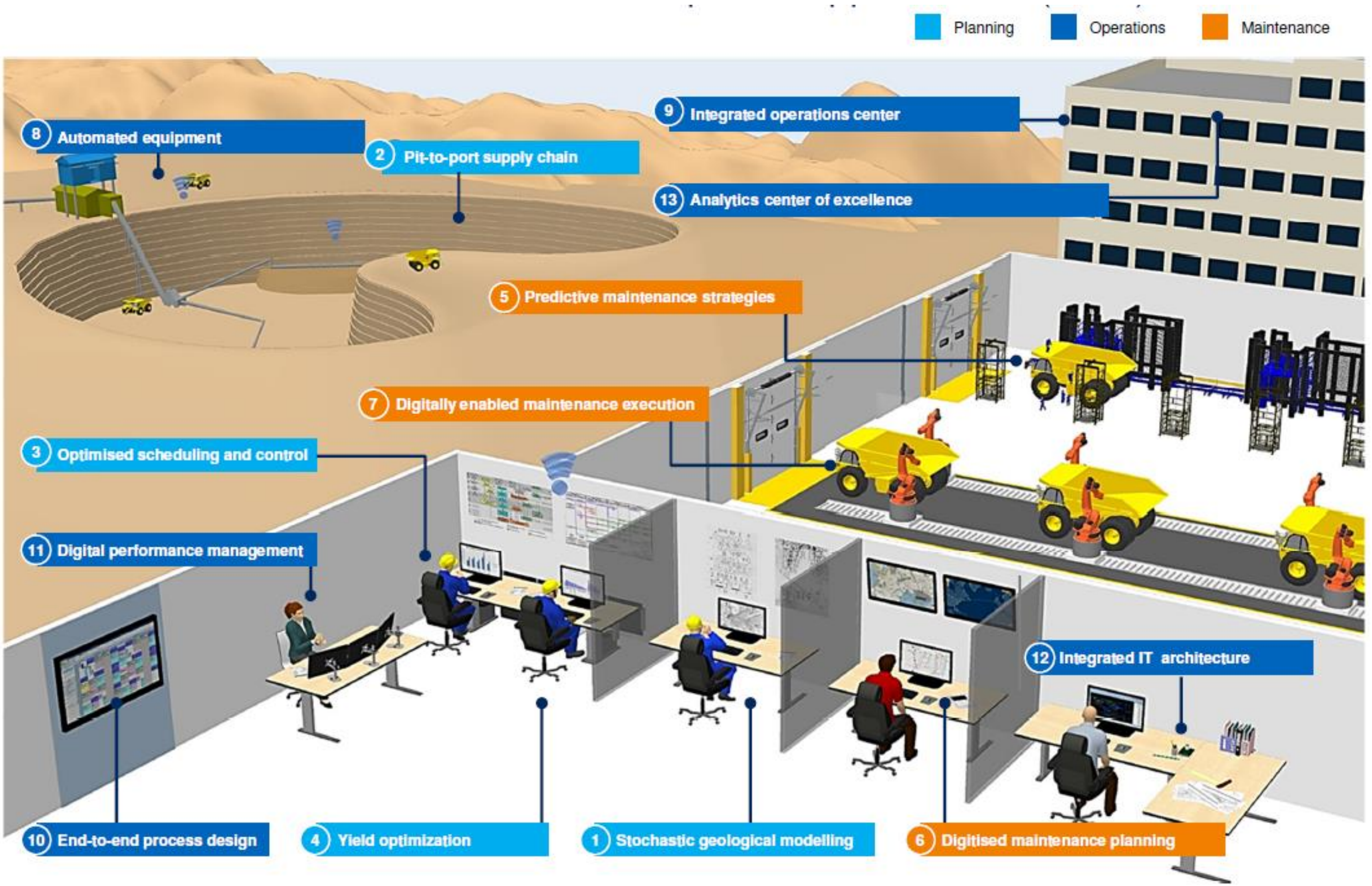
[1] In 2015 US dollars.

Source: Energy Insights Global Energy Perspective; McKinsey analysis; McKinsey Global Institute analysis

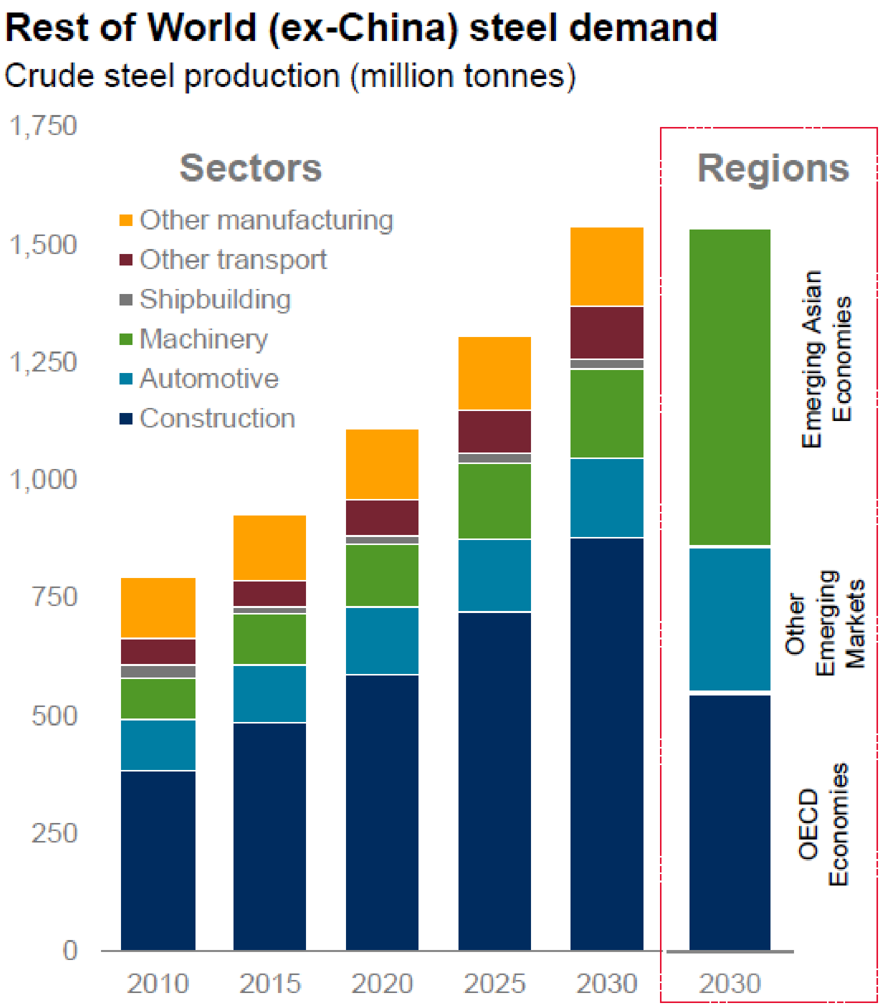
McKinsey&Company

Stochastic geological modelling	Optimized scheduling and control	Pit-to-port supply chain	Yield optimization	Predictive maintenance strategy	Auton equip
23% increase in NPV	250m saved through mine planning	20% throughput improvement	20% increase in NPV	20-30% decrease in costs	10-1 produc increa
					
African gold mine	Large Australian mine	South American copper mine	Nickel mine	Oil rig	Autom drilling

The overall specific mine vision



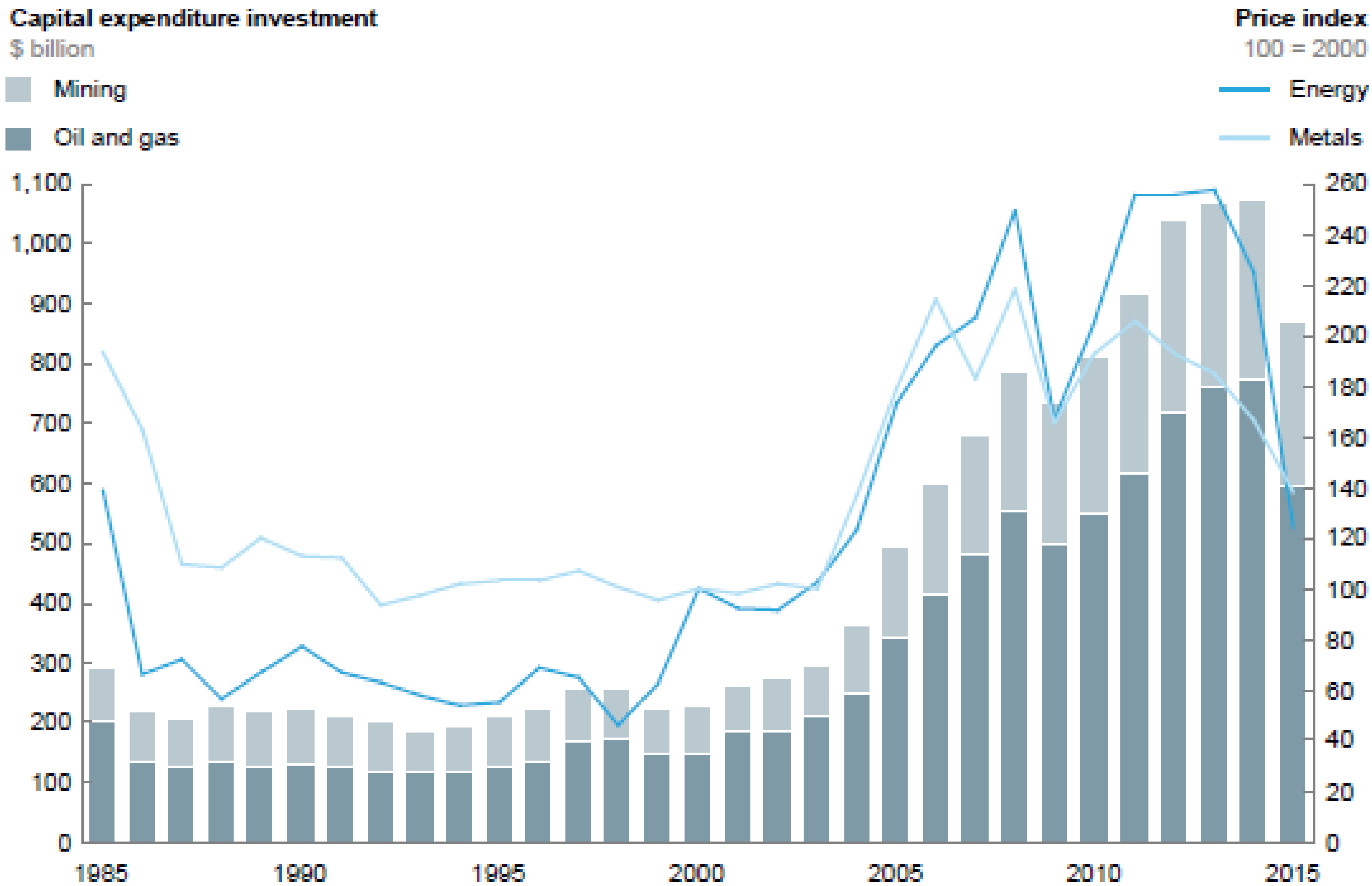
Robust growth in rest of the world demand



Note: Crude steel production basis and does includes steel trade

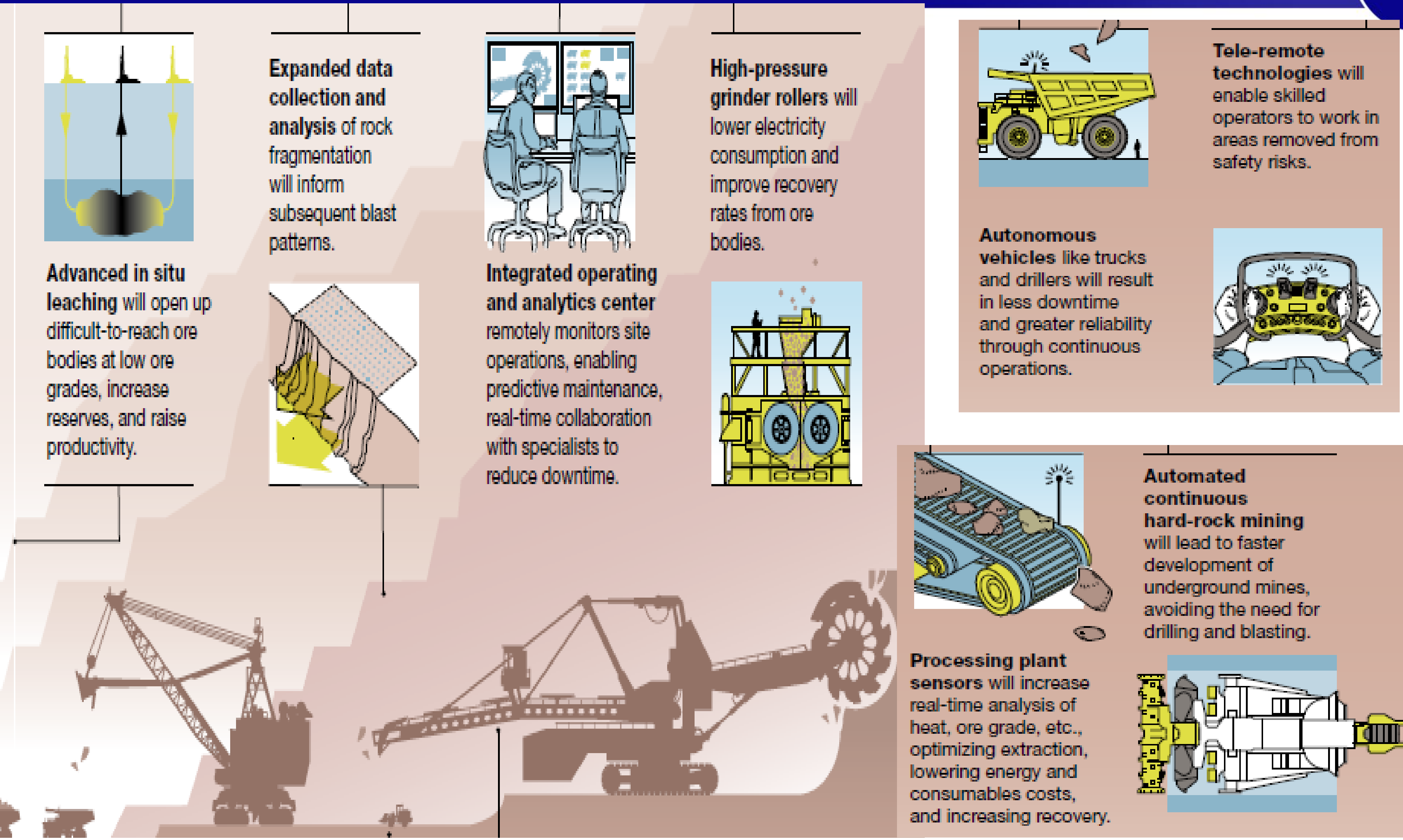
- Process of industrialisation and urbanisation in the rest of world will be highly steel intensive
- Rest of world steel demand to increase by 65% by 2030
- India's share of rest of world demand will double from 10% by 2030
- In 2030, China remains the largest demand region, followed by India and then ASEAN
- Construction of commercial and residential buildings and infrastructure supports Chinese exports of finished steel and machinery

Surge in demand overwhelmed CAPEX



SOURCE: MGI Commodity Price Index; Rystad Energy capital expenditure data; IHS Markit; McKinsey Global Institute analysis

Technology will raise productivity & safety in mining oprn



Source: McKinsey Global Institute analysis

Need for Automation

- Technological advancement
- Commodity market depressions
- Increasing labor and maintenance costs
- Statutory & Contractual Obligations
- Difficult operating environments

Leads to Low Cost High Production Requirement

Challenges to the use of Large-Capacity Equipment

- Space limitation
- Weak overburden
- Weathered soils and rocks
- drainage and weather conditions
- Undulating / rugged terrains

- Technical
- Operating
- Safety
- Environmental
- Economic Requirements

Enormous challenges in the selection of appropriate process & equipment

Need for understanding the real issues that affect the selection of low cost operations & efficient bulk production is very important and critical for achieving economies of scale.

Need for Automation in the industry

Automated systems increase productivity and efficiency, thereby making projects more economically feasible.

Understanding the social, environmental and economic issues surrounding automation and its contributions to the extractive industry will make a mining project more successful.

The application of automated systems will improve the quality of work for employees by reducing exposure to unhealthy or unsafe environments. These systems are also eco-friendly and obtain social support.

There is a huge scope of automation of mining operations in the Indian mining industry. Keeping in view the future demand of minerals in the country, we expect a paradigm shift in the operations from manual to fully automated systems.

While thinking of innovation in the industry one should not limit his ideas within the limit of Pit or up to mine’s dispatch point, however, should think with a holistic approach with due consideration to life cycle of its products.

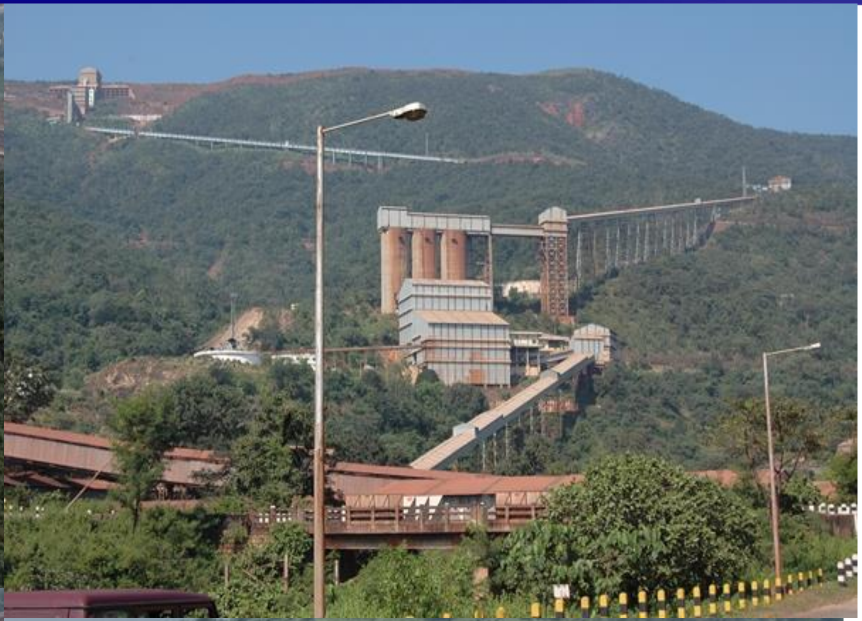
Also, with new Legislative Framework for Mineral Industry in India and introduction of District Mineral Fund, National Mineral Exploration Trust, sharing of revenue with State Governments etc., profitability of Mining Companies will certainly plunge down. To be more competitive Companies need to critically examine every cost head center in their Mining Operations.

Iron ore mining-global

LKAB's Kiruna Mine.

Iron ore being extracted at the massive Mikhailovsky Mine in Russia.

Iron ore mining-Indian



Access To High Quality Iron Ore Reserves And Resources

IRON ORE RESERVES AND RESOURCES OF NMDC LIMITED AS ON 01.04.2016 AS PER UNFC

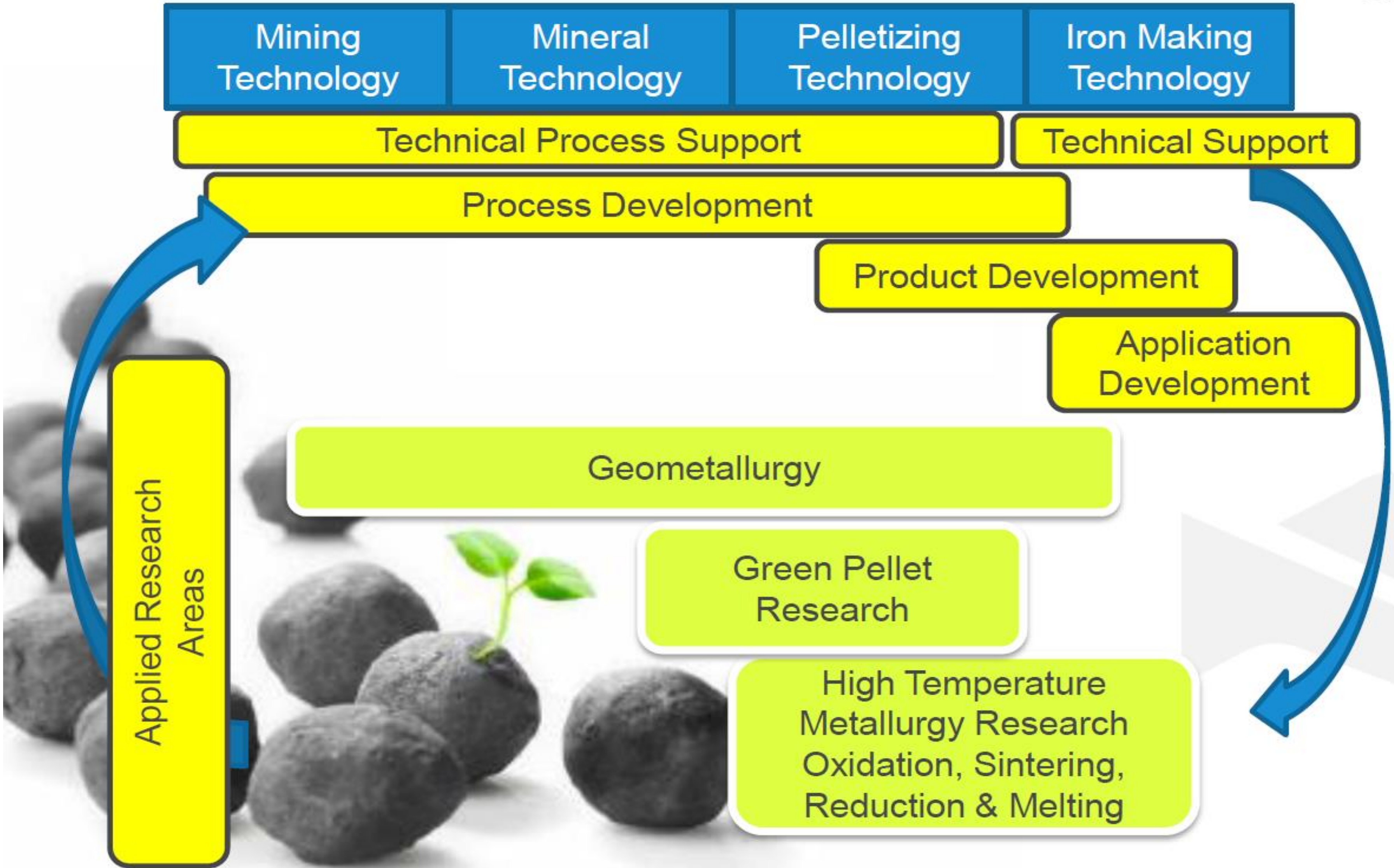
(Cut off grade - 45% Fe)

(Qty. in million tonnes)

Iron Ore Tenement	Proved Reserves (111)		Probable Reserves (121 & 122)		Total Reserves		Resources		Grand Total (Reserves+Resources)	
	Qty.	Fe%	Qty.	Fe%	Qty.	Fe%	Qty.	Fe%	Qty.	Fe%
Chhattisgarh										
Bailadila Deposit - 5	198.71	67.71	73.11	67.90	271.82	67.76	103.73	58.02	375.55	65.07
Bailadila Deposit - 10	186.39	63.12	36.18	60.02	222.57	62.62	105.71	63.17	328.28	62.79
Bailadila Deposit - 14	316.96	64.89	55.88	60.15	372.84	64.18	105.33	59.79	478.17	63.21
Bailadila Deposit - 14 NMZ	110.57	65.62	28.06	63.59	138.63	65.21	67.10	62.99	205.73	64.49
Sub-Total -Chhattisgarh	**972.97**	**65.37**	**344.86**	**64.12**	**1317.83**	**65.05**	**536.30**	**62.04**	**1854.13**	**64.18**
Karnataka										
Donimalai	43.16	65.84	34.70	64.50	77.86	65.24	26.00	61.50	103.86	64.31
Kumaraswamy	120.11	64.12	0.00	0.00	120.11	64.12	60.05	62.00	180.16	63.41
Sub-Total -Karnataka	**163.27**	**64.57**	**34.70**	**64.50**	**197.97**	**64.56**	**86.05**	**61.85**	**284.02**	**63.74**
Total Working Mines	**1136.24**	**65.26**	**379.56**	**64.16**	**1515.80**	**64.98**	**622.35**	**62.01**	**2138.15**	**64.12**
IRON ORE LEASES IN JV WITH CMDC (NMDC-CMDC LIMITED)- NMDC SHARE 51%										
BAILADILA DEPOSIT - 13	324.69	67.24			324.69	67.24	37.64	67.01	362.33	67.22
BAILADILA DEPOSIT - 4	107.59	65.39			107.59	65.39	14.50	65.45	122.09	65.40
Sub-Total of Bld. 13 & Dep.4	**432.28**	**66.78**			**432.28**	**66.78**	**52.14**	**66.58**	**484.42**	**66.76**
NMDC's Share (51%)	220.46	66.78			220.46	66.78	26.59	66.58	247.05	66.76
Grand Total (includes 51%of JV)	**1356.70**	**65.50**	**379.56**	**64.16**	**1736.26**	**65.21**	**648.94**	**62.20**	**2385.20**	**64.39**

R&D to lead benchmarking & growth

R&D CROSS FUNCTIONAL WORK AREAS



Conclusion/ recommendation

- Integrated iron ore mining approach, zero waste concept---- lump (???), fines, PFC/ pellet+ refractory
- Continuous internal exploration for resource/ reserve augmentation
- R&D-more focus on utilisation of available technologies with better characterization
- R&D, R&D and R&D for mine to (metal) to market

Worcestershire

Wor-ches-ter-shire

Available Resources In R&D Centre

Total Manpower 47= 28(Exe.) + 19 (Staff)

THANK YOU

for

such a patient hearing