

PANEL 1: Advances and Opportunities for New Technologies in Coal Mining and Extraction – *Drivers, Strategies and Challenges*

Dr. Michael Karmis,

Stonie Barker Professor, Mining and Minerals Engineering Department, &
Director, Virginia Center for Coal & Energy Research
Virginia Tech

Progress, Challenges and Opportunities for Research and Upstream Aspects of U. S. Coal Production, Meeting of the Committee on Earth Resources, October 25, 2018, Washington, DC

Content

- The Upstream R&Dⁿ Paradigm
- Interruptive/Transformational Technology Drivers
- Implementation Strategies and Challenges
- Some Key Questions

A number of references were used to develop this presentation. A reference list can be provided by the author on request.

Mining Industry v. Coal Mining Sector

**Differences but also Common Technology
Drivers, Productivity Imperatives, Operational
Challenges, Environmental Concerns and
R&D Requirements**

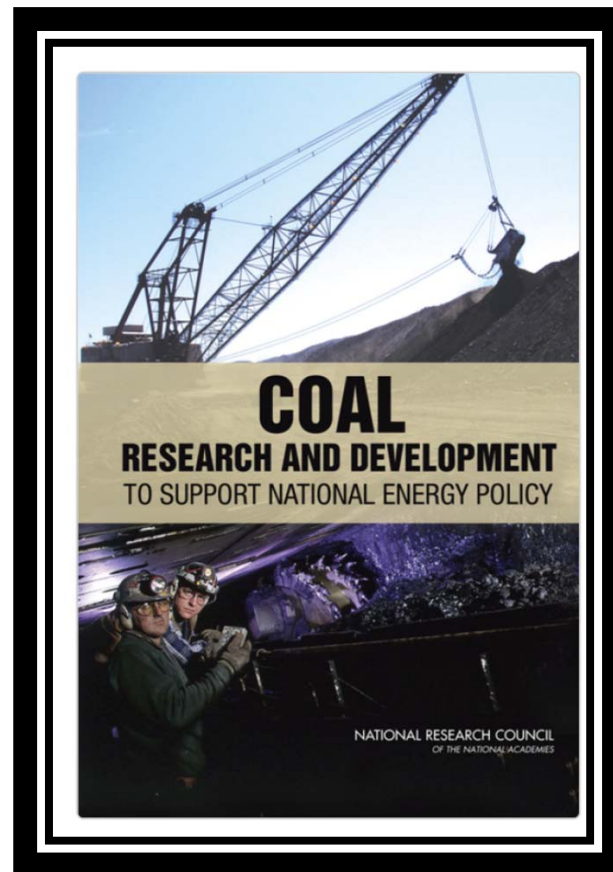
The Upstream R&Dⁿ Paradigm

The R&D Progression- From Concept to Implementation



1st Important NRC Report

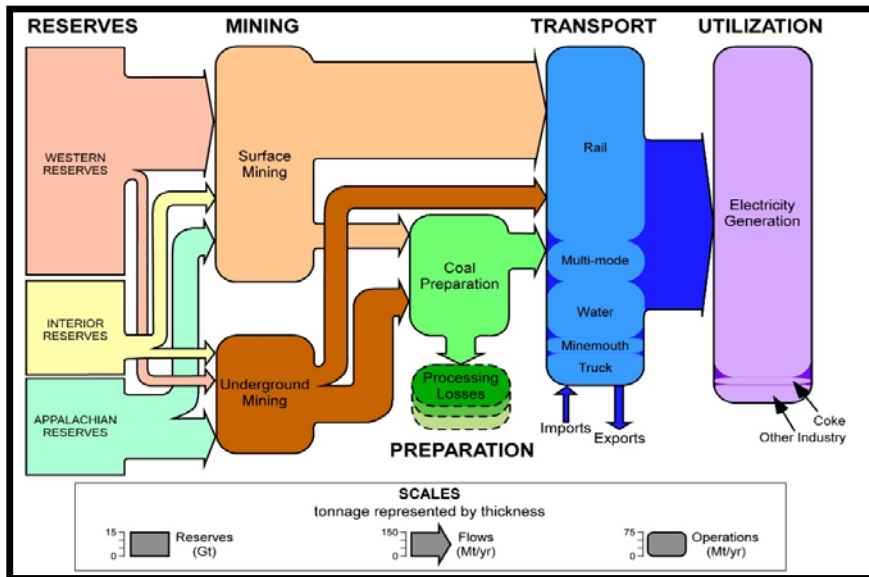
(Assumed a Coal Production of +1.2 billion tons!)



Coal Fuel Cycle

Upstream

Downstream



- **Upstream:** “Mining Cycle” Exploration, development, mining, processing, remediation, reclamation and post-mining land use
- Environmental impacts of coal mining operations on surface water, groundwater, fish, wildlife, blasting, ground disturbance, protecting or restoring streams and aquatic ecosystems.
 - **Mine permits - Operational permits**
 - **Social License**

- **Downstream:** Environmental and health impact in all aspects of plant siting, construction, operation and CWB disposal, e.g., major pollutants (Ozone, Particulate Matter, CO, SO_x, NO_x, Lead), ozone layer protection, toxic air pollutants, visibility, and GHG emissions
 - **Air Quality Permits and Plant Permits**

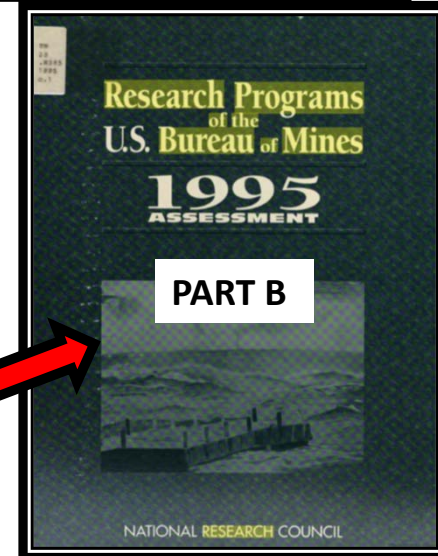
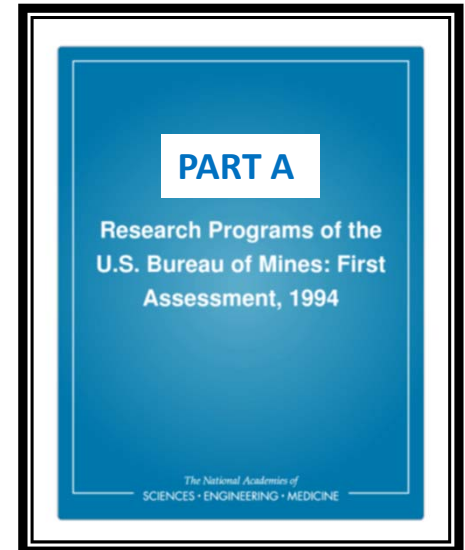
Upstream Share, Percent of Total Coal-Related R&D Budget (NRC Report v. **Today (reasonable guess!)**)

- Upstream Budget: 10% **(3%)**
- Downstream Budget: 90 **(97%)**
 - ✓ **Major DoE Initiatives, e.g.:**
 - ✓ **CCS/CCUS (Carbon Capture and Storage/Carbon Capture, Utilization & Storage)**
 - ✓ **HELE (High Efficiency Low Emissions)**
 - ✓ **Modular Plants**
 - ✓ **Demo-Scale Projects**

2nd Important NRC Reports & The Demise of the US Bureau of Mines!!

The USBM operated about 10 Research Centers (PA, CO, WA, MN, MD, OR, AL, MO, UT, NV) covered all aspects of the mining cycle, from H&S to In-Situ Mining to Operations & Efficiency and from Environmental Remediation to Hydro/Pyrometallurgy

“Committee reached consensus of the findings and recommendations in the report prior to the Fall 1995 action by Congress to abolish the bureau...The committee did not change its report to reflect this political events.”



**Upstream Coal MINING Research Budget -
Possible Comparative Budget Expenditures
(Arbitrary but Indicative!!!)**

Funding Share, Government/Private

- **H&S: 50% (60/40)**
- **Environment: 25% (30/70)**
- **Operations/Productivity: 25% (10/90)***

*** Excludes vendors and equipment suppliers**

Examples of Successful but Terminated Government and Industry R&D Programs

1. Are You Old Enough to Remember the Industries of the Future Initiative of DoE? Government/Industry Partnership

Documents for historical reference:

Water Use in the Industries of the Future: Mining Industry, July 2003; Exploration and Mining Roadmap (2002); Education Roadmap for Mining Professionals (2002); Energy and Environmental Profile of the U.S. Mining Industry (2002); Mineral Processing Technology Roadmap (2000); Mining Industry Roadmap for Crosscutting Technologies (1999); The Future Begins with Mining: Vision (1998)

2. Appalachian Research Initiative for Environmental Science (ARIES) Industry/Academic Partnership



- Industrial Affiliate Partners Program at VT
- Commitment of +\$10million over Five Years (2011-2016)
- **Transparent:** Industry Funded but Organized and Performed by the Academic Community

Accomplishments of **ARIES**-Four Broad Topics

1. Impacts on Ecosystems
2. Waste and Water Management
3. Environmentally Responsible Mining
4. Health, Social and Economic Impacts

- Addressed critical environmental needs
- Contributed to science-based regulations
- Developed best practices and innovation
- Informed the public and all stakeholders
- Provided feasible, cost effective solutions

- Since 2011, ARIES researchers produced +120 peer-reviewed publications and numerous conference presentations and papers
- ARIES research involved +80 undergraduate and graduate students
- Participation of +60 faculty and research associates
- ARIES fostered long-term partnerships that continued into the future

**Need a New Paradigm for Research
on Mining Productivity/Efficiency and
Environmental Management/Responsibility**

Interruptive/Transformational Technology Drivers

The coal/minerals development process is becoming increasingly complex!!!

- **Technical**: deeper deposits/seams, “poorer” quality or concentrations, difficult extraction conditions, large-scale v. small-scale trends
- **Environmental**: impacts on land/water/air, reduce footprint, waste management, permitting issues, community engagement
- **Economic**: increased capital expenditures, price uncertainties, energy cost, taxation/royalties, access to capital

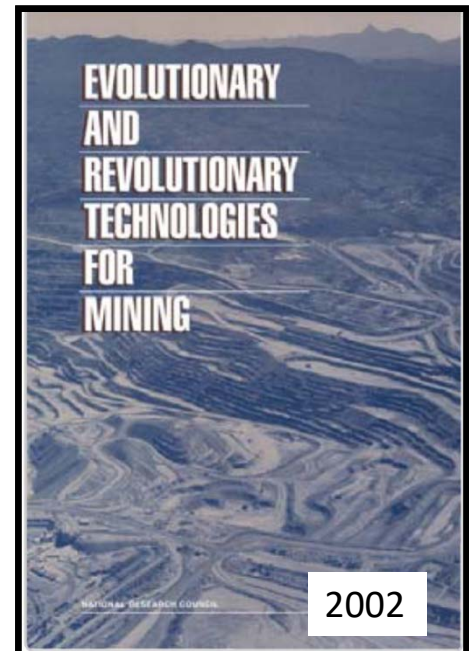
“Operational excellence” and “Innovation-Preparing for exponential change” emerge as the top issues facing mining companies in 2016 (*Source: Report, Deloitte Touche Tohmatsu-Global Mining*)

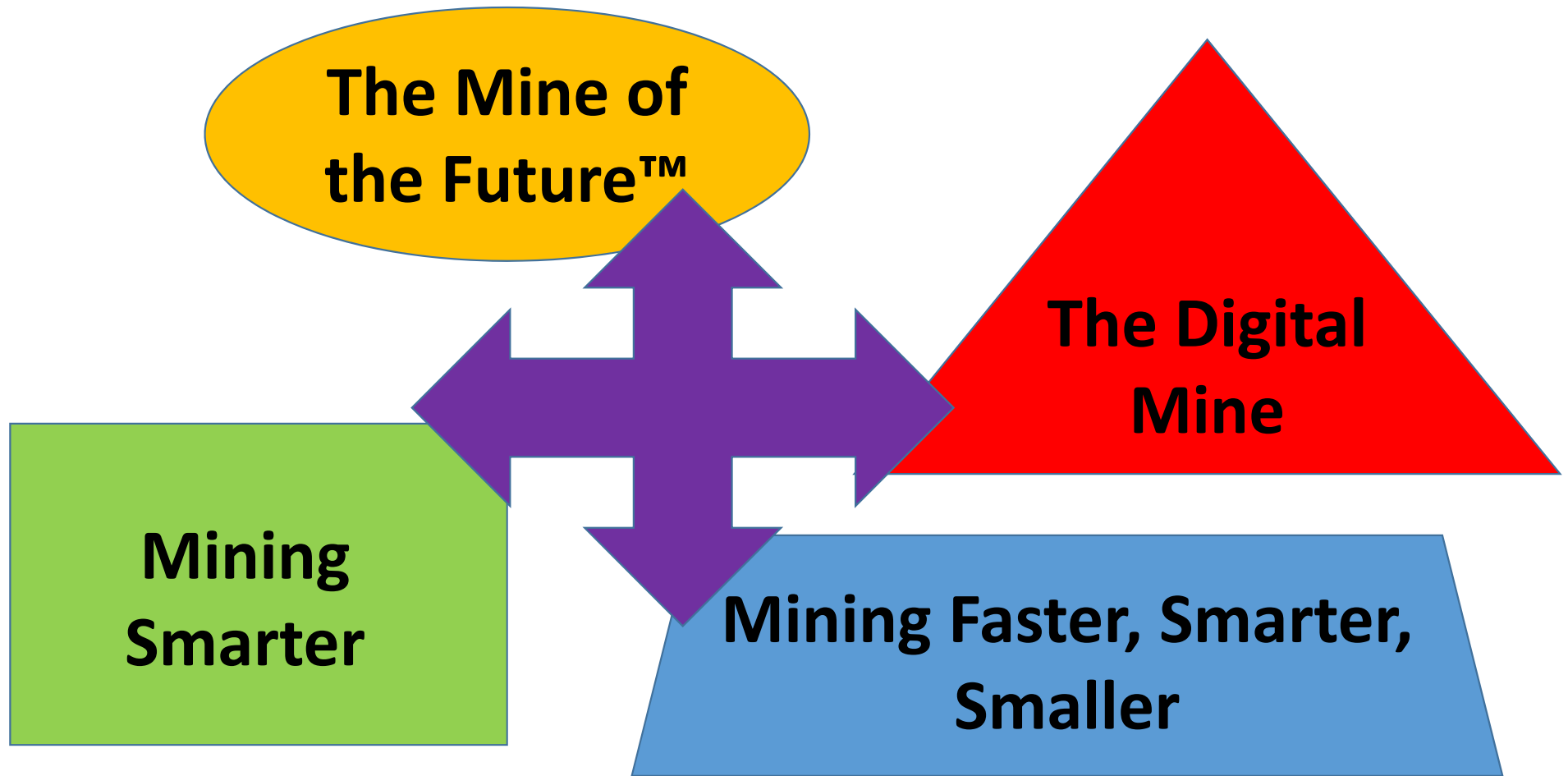
From Evolutionary to Revolutionary Change

- Traditionally “...most of the innovation is focus on technological optimization of old techniques rather than looking for new ways to configure and engage externally” (*Tracking the Trends, 2016 Report*, Deloitte Touche Tohmatsu-Mining)

Tinkering and tweaking won't suffice:

“...companies must look beyond incremental performance improvement to determine how they can revise their systems to embrace the broad theme of innovation”
(J.Beier, Deloitte-Canada)

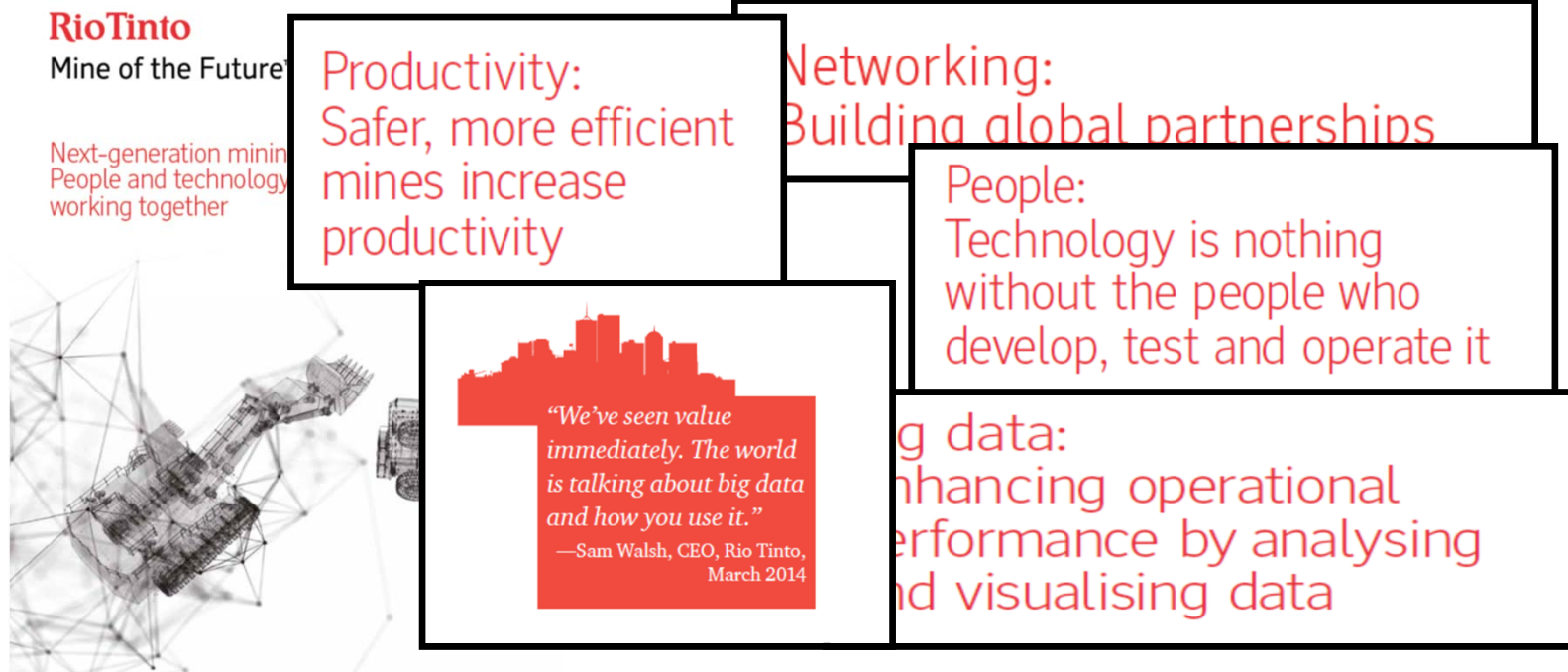




Numerous Initiatives: Industry, Consultants, Academia and Government

The Mine of the Future™

“People and technologies working together-safer, smarter, better” (Rio Tinto Report, 2014)



RioTinto
Mine of the Future

Next-generation mining
People and technology
working together

Productivity:
Safer, more efficient
mines increase
productivity

Networking:
Building global partnerships

People:
Technology is nothing
without the people who
develop, test and operate it

Big data:
Enhancing operational
performance by analysing
and visualising data

*“We’ve seen value
immediately. The world
is talking about big data
and how you use it.”*
—Sam Walsh, CEO, Rio Tinto,
March 2014

The Digital Mine (4.0 Industrial Revolution)

We are entering an “era of automation, constant connectivity, and accelerated change, in which the Internet of Things meets the Smart Factory”

Klaus Schwab, Founder of the World Economic Forum

1.0 | 1784 | based on mechanical production equipment driven by water and steam power 

2.0 | 1870 | based on mass production enabled by the division of labor and the use of electrical energy 

3.0 | 1969 | based on the use of electronics and IT to further automate production 

4.0 | today | based on the use of cyber-physical systems 

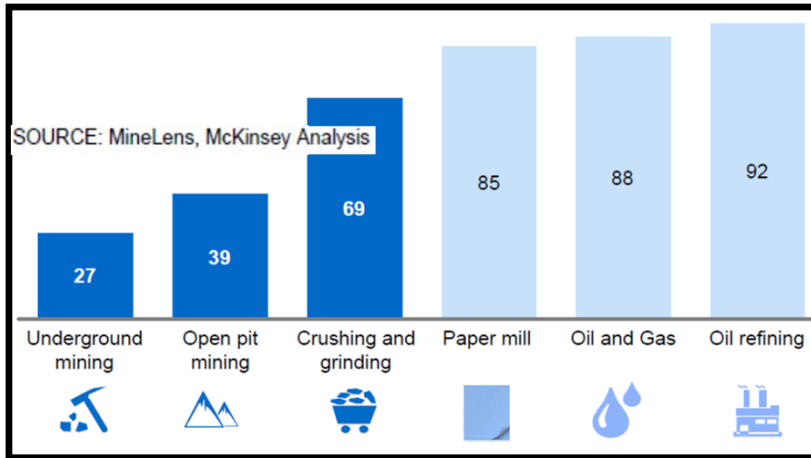
The Mining Industry is Ready for a Massive Change, Driven by Digital Technology

(Australian Mining, Digitising the mining industry, June 22, 2017)

- ✓ Industry has transitioned through a 5-Year downturn
- ✓ Digital technologies continuing to become more affordable
- ✓ Industry leaders understand that digitization is here and mining should move forward
- ✓ BUT, but they also want to be sure that the process is implemented to produce value-The Business Case!

“Digital disruption is one of the top five risks in the mining industry...Where some see risks I also see opportunities. Technology and digital pioneering is really about people and it is up to each of us to manage the change required as sensitively as we can”

J-S Jacques, CEO, Rio Tinto, Business to People: A new era, Lecture, March 20, 2018



Innovation deployment at slow pace-Learn from other industries

Towards the Digital Mine

Need to Accelerate Innovation and Technology Deployment in the Mining Process

Four major developments will accelerate change in the mining industry towards the Digital Transformation

	Data, computational power, and connectivity	90%	Data in the world today has been created in the last two years
	Analytics and intelligence	1015	More computer operations per second than since the 1960s
	Process digitization	250k x	More RAM in iPhone 5 than in the Apollo 11 computer which took it to the moon and back
	Robotic and Automation	50%	Reduction in cost of robots since 1990 vs. 80% increase in US labour costs

Source: McKinsey & Company; Harvard Business Review 6/15/2015

Innovative (Disruptive) Technologies: Transforming traditional mining functions and processes into digital operations

- Big Data/Analytics/Machine Learning
- Autonomous Systems and Robotics
- Virtual/Augmented Reality (VR, AR), Artificial Intelligence (AI)
- Cloud-first Solutions for Mining
- Distributed Sensing/Biosensing
- Wearable Computing
- Satellite and Drone Surveillance and Monitoring
- The Internet of Things (IoT) Solutions
- 3-D Printing
- Battery Management System
- Circular Economy-Coal/Mine Waste By-products (e.g., rare earths from coal)

THE FUTURE IS ALREADY HERE!!!

Autonomous Systems and Robotics: Human/Machine Interaction

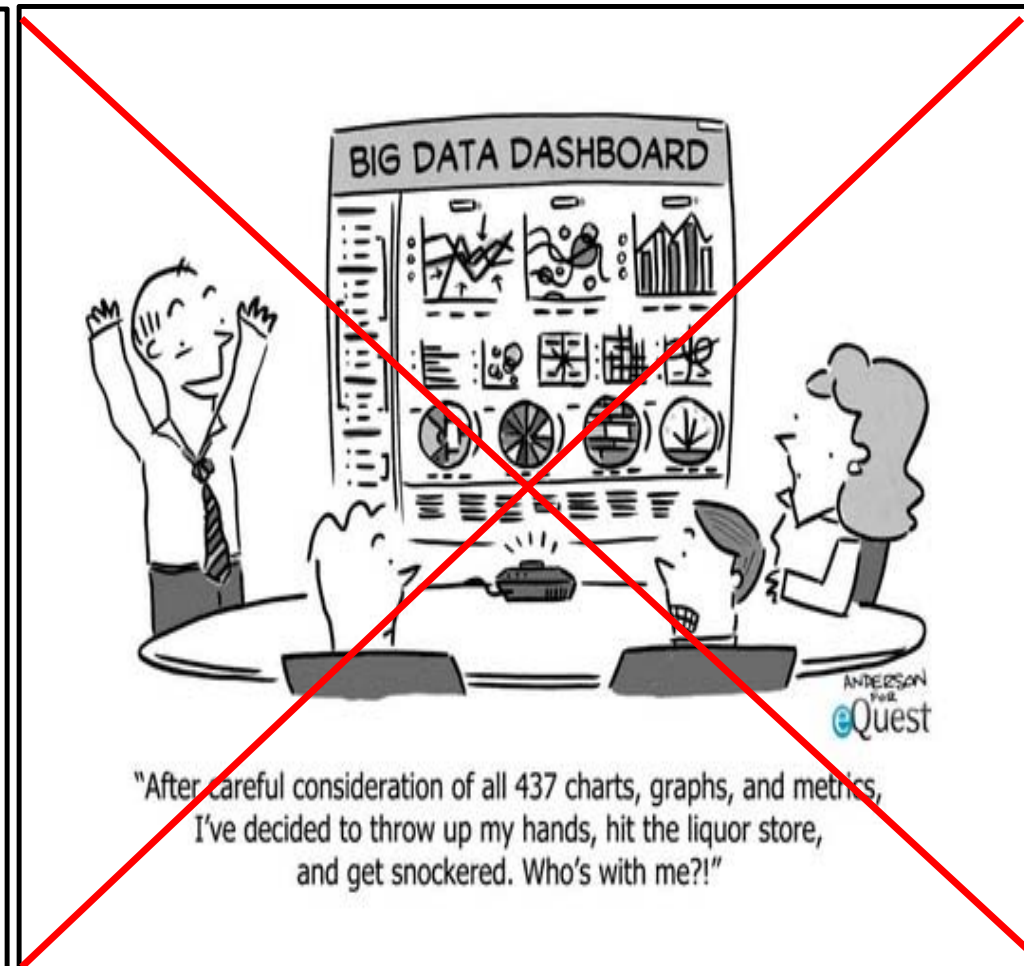
- Autonomous ground, marine, and air vehicles, will transform conventional mining/energy operations
- Will radically improve safety and efficiency and enable new capabilities for monitoring, inspection and maintenance
- Autonomous systems will revolutionize mining and energy operations of the future, from exploration to end-of-life land use, and lead to commercial Marine and Off-Earth Mining



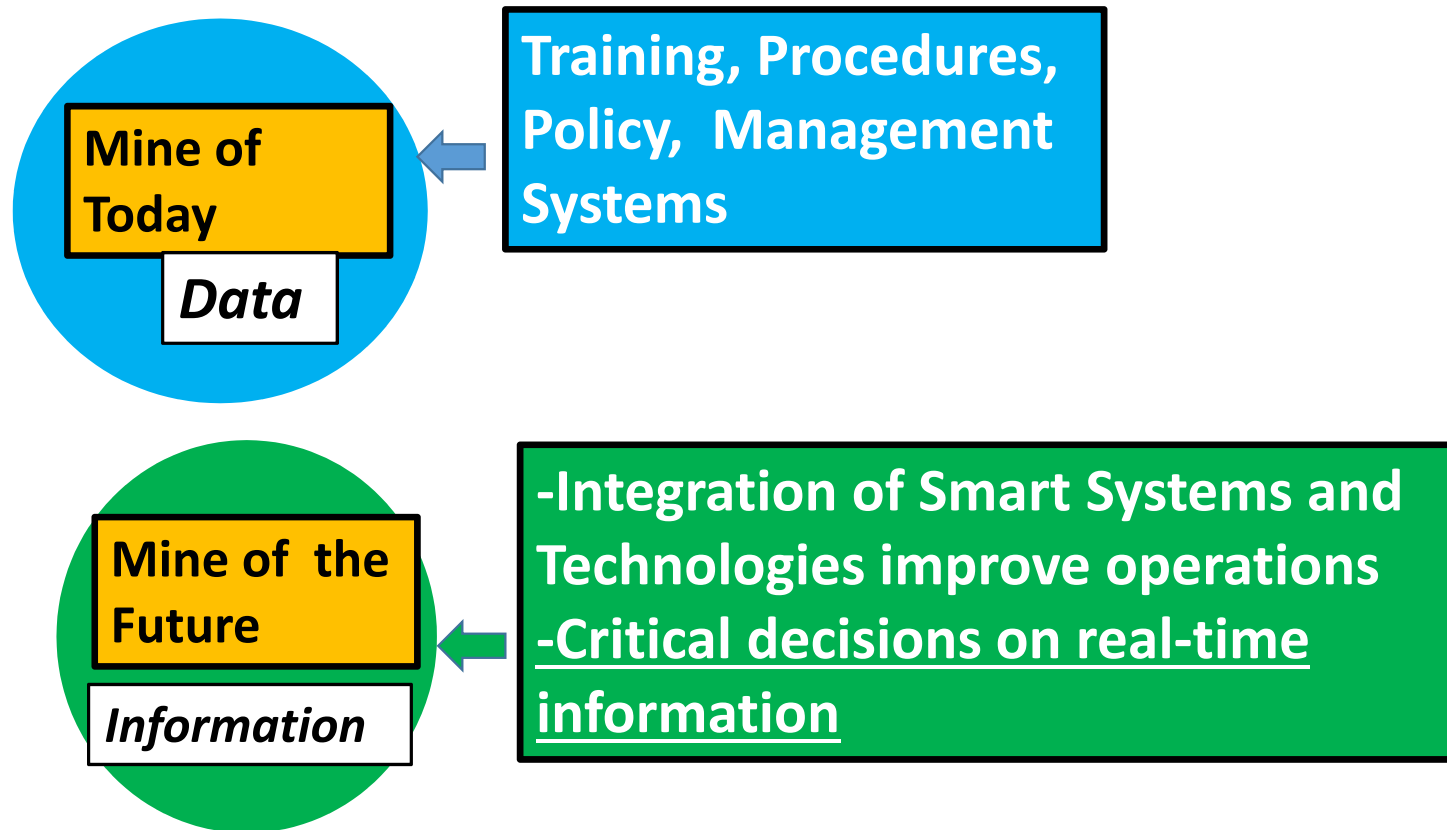
Rio Tinto's Autonomous Haul Trucks Achieve One Billion Tonne Milestone in Pilbara mines!!! (News release, January 29, 2018)

Big Data: Data Rich Information Poor!!

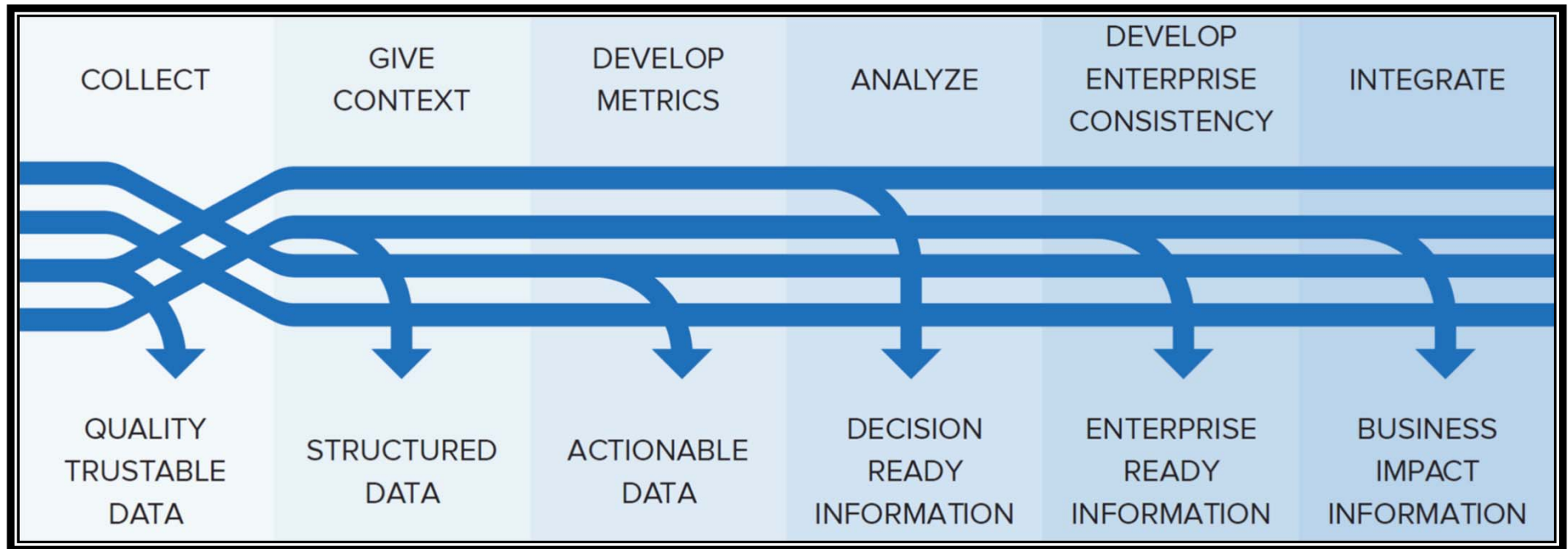
- Pervasive sensing, computing, network communication
- Data storage capacity doubling every 3 years - daily data production surpassed 2.5 exabytes (2.5 million terabytes) in 2015!
- Technologies such as distributed sensing, the internet of things (IoT), to wearable computing will fuel proliferation of data
- New analytics tools to identify trends and anomalies in support of human, or automated, decision making



New Operational Environment: Working on Real Time!



Making the Business Case: Turning Information to Business Value



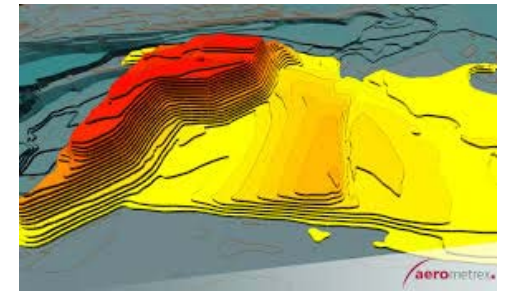
“Real productivity gains will only come from a whole-of-business, end-to-end transformation”



(Source: Seven Ways Metals, Mining, & Materials Companies Turn Data into a Sustainable, Competitive Advantage, OSIsoft, LLC, 2015)

From VR to AR and AI: From Virtual to Mine Reality

- Virtual Reality (VR), Augmented Reality (AR) and Artificial Intelligence (AI) will be systematically introduced in mining
- Visualization, conceptual/innovative design and assessment of risks are integral components of the complex geological and mining environment/systems
- Improve assessment of the economic viability of a mineral resources, enhance mine monitoring and control, optimize fleet management, improve efficiency and H&S of an operation
- Facilitate training of employees, communities and the general public



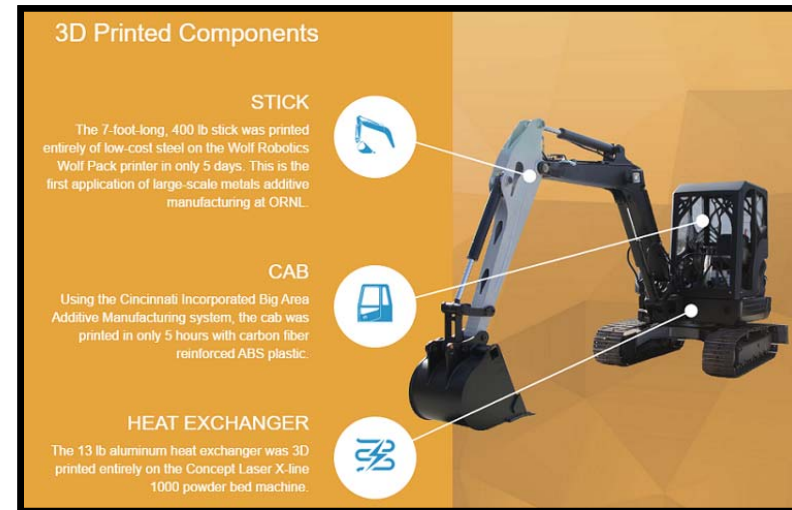
Next-Generation Battery Technology: *On the verge of a power revolution!*

- Ventilation represents a significant energy costs of underground mining (~50%) and demand will continue to increase, as mines are going deeper and operate under more challenging environments
- Miner health requirements demand reduction of fine diesel particulate matter from the work environment
- Next generation high energy and power density battery technology could power a wide range of electric-drive vehicles and revolutionize underground mining

“Electric vehicles for construction, agriculture and mining will be a \$81 billion market in 2027”



World's First 3D Printed Excavator to Debut at CONEXPO-CON/AGG and IFPE 2017



- The world's first 3D printed excavator was displayed at the CONEXPO-CON/AGG and IFPE 2017 show in Las Vegas (March 7-11, 2017)
- This excavator is the first large-scale construction and machinery application of 3D printed steel

<https://3dprint.com/167232/3d-printed-excavator-unveiled/>

<https://3dprint.com/131777/first-3d-printed-excavator/>

Implementation Strategies and Challenges

The Corporate Digital Strategy

- Develop a holistic digital strategy for the organization
 - Digitize the mining value chain
 - Integrated with intelligent business decisions
 - Enhance supporting platforms and (IT)/(OT) backbones.
 - Enable the diverse connected workforce
- (Source: Deloitte, Tracking the Trends, 2017)

OPERATING PRACTICES & TECHNOLOGY	
Key takeaways on operating practices and technology	
	In the short term extraction and exploration will see the biggest advances through automation and digitisation
	Technology will give us the edge to fundamentally change our cost structures and make our mines safer
	Partnerships with OEMs and IT companies will be critical if mining is to benefit from the latest technologies
	Human resource and mine management will have to change to reflect new operating practices and technologies

Digital technology can generate significant productivity gains only if enhances coordination across the value and supply chains. Applying digital technology to specific points in the value chain will have limited impact.

Transition To a New Corporate Culture

Improving efficiency, productivity and growth will “*involve technology or process that has never been implemented before in the company, and internal stakeholder alignment will be critical to its success.*”

Report: “Identifying and implementing radical efficiency” (Clareo, 2016)

...more than a focus on the technology...companies need to adopt a holistic approach to transformation (<https://www.mckinsey.com/industries/metals-and-mining/our-insights/behind-the-mining-productivity-upswing-technology-enabled-transformation>)

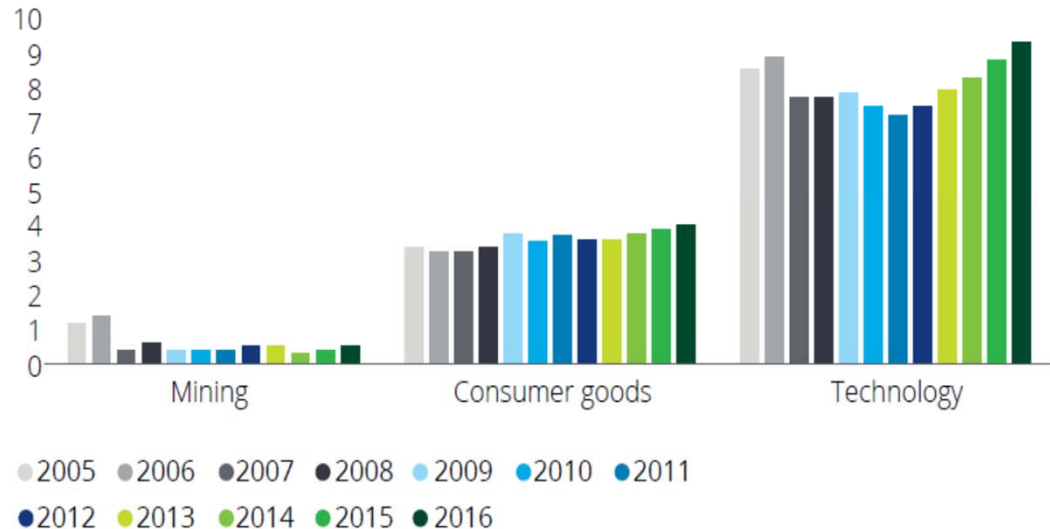
- Harness technology to solve the key challenges of the entire supply chain management
- Adapt the management systems to be responsive, realize the potential of the new technologies and create value

Industry Support of R&D-Need Significant New Investment

“...innovation in the mining industry is coming at too sluggish a pace, and the rising costs of extraction and transportation need to be addressed with new ideas.” M. Cutifani, CEO, Anglo American

Figure 2: Mining consistently underspends in innovation relative to other sectors

R&D/Sales



Source: Deloitte analysis

Source: Deloitte, Tracking the Trends, 2018

Manage the Shift from the traditional “Internal/Independent” R&D to “Externally” Produced Innovation

Sector (operators and suppliers) is fast track technology transformation by forming strategic partnerships with global technology leaders and developers:

Key Partnerships	Area
Barrick-Cisco	Digital Reinvention of Mining
Komatsu-BT	Global It Infrastructure
ABB-Microsoft	Digital Industrial Transformation
Microsoft-Snowden	Azure-Powered Intelligence/Cloud-First Solutions to the Mining Industry
Caterpillar-Newmont	Underground Vehicle Automation Technology

Enable the New Era Workforce

- Requires top to bottom organizational transformation
- The digital transition will create new needs, require new skills, and will transfer knowledge from other industries
- Will transform the blue collar mine worker to a white collar technician
- *“Technology changes roles, creates new opportunities and also requires a re-set. Just because a truck no longer has a driver doesn’t mean we don’t need engineers, and maintenance workers” (J-S Jacques, CEO, Rio Tinto, Business to People: A new era, Lecture, March 20, 2018)*
- But, recruiting and retaining Millennials and **Generation Z** talent in mining requires new ways of training, motivation and reward

“Miners have an important role to play in shaping the new digital ecosystem. Rather than being passive buyers of technology and services, they need to become system integrators to capture the value of innovation across the industrial network and consolidate their competitive position by leveraging the intellectual power of this network.”

Source: Extracting Innovations, Mining, Energy, and Technological Change in the Digital Age, University of Queensland, Taylor & Francis Group, LLC, 2018

And in closing,

“...success for mining companies won’t be about adopting the latest applications and technologies, but rather the embedding of digital and innovative thinking into the heart of their business strategy”

Source: Deloitte, Tracking the trends 2018, Executive Summary

Key Questions (Often Ignored!)

- How digital should the industry go?
- Are all miners, or just the majors, able to afford significant technological investments?
- When a mine is “too old” for a significant technological investment?
- Is the industry accepting a corporate culture for digital alignment across the entire value chain?
- What should be the new paradigm for research enabling the Digital Mine of the Future?
- Are we giving too much influence and bargaining power to “external” technology suppliers?
- Are we preparing the “digital” workforce?
 - What about the Generation Z?
- Is the digital mine an opportunity for job creation or a downward path to job losses?
 - Impacts on coalfields?