

VALUE CREATION IN MINING 2019

RETURN TO STRATEGY



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EXECUTIVE SUMMARY

AFTER a deep five-year slide, the mining industry began to recover in 2016, aided by substantial increases in commodity prices. Yet by mid-2018, the rebound began to encounter significant headwinds.

- In 2016 and 2017, the median total shareholder return (TSR) of the 63 leading mining companies in our study was 41% and 23%, respectively. This, after the industry had turned in the lowest median TSR of any industry sector from 2011 through 2015.
- In 2017 and 2018, revenues and margins grew simultaneously for the first time in seven years. Cash flow from operations also increased.
- Higher cash flows and valuations bolstered companies' balance sheets, enabling companies to pay down debt. More recently, however, concerns over future demand have dampened valuations, sending the 2018 TSR into negative territory.
- Operating costs are once again creeping up, owing to less favorable macroeconomics and to tightening supplier markets.

Mining companies have become more prudent in their cash allocation practices, despite the growth in cash reserves over the past two years. The companies have focused on completing ongoing capital projects and returning excess cash to shareholders, a shift that accelerated in 2018.

- Most operating cash flow was directed either at completing capital projects begun during the boom years or at pursuing more measured expansion and replacement projects.
- CapEx has dwindled considerably; as a proportion of cash flow from operations, it remains near ten-year lows for the companies in our study.

- As project spending has declined, so has the capital intensity of projects being pursued. Companies with attractive projects and sufficient funding capacity are thus well positioned to pursue a countercyclical growth strategy.

Exploration is on the rebound. Since hitting a low point in 2016, exploration budgets have been growing, though they remain well below their 2012 peak. Juniors are once again playing a bigger role, now accounting for almost a third of total exploration expenditure.

- So far, however, discovery rates have remained under pressure. From 2002 to 2012, the number of giant and major discoveries declined, despite a tenfold increase in spending, and discoveries were generally lower grade. This trend appears to be holding: while unit discovery costs are declining, they remain high by historical standards.
- To succeed against these challenging odds, companies must adopt disciplined approaches to exploration strategy and management, look to innovative technologies to improve targeting and discovery rates, and redouble their efforts to attract and retain top talent.

M&A activity remains subdued, but a few acquirers have struck pay dirt.

- Although asset prices bottomed out in 2015, the anticipated rebound in M&A activity never materialized. The number of deals valued at more than \$1 billion has declined; and among the majors, divestments outnumbered acquisitions.
- Still, some acquirers took advantage of poor market conditions and did particularly well, affirming BCG research showing that deals made in a downturn create more value.

One major lesson of the last cycle involves the importance of developing a value creation strategy that is independent of commodity prices. The tentative nature of the current recovery only underscores this lesson. To weather the full cycle, mining companies must explore holistic ways to activate the key drivers of TSR.

- Targets for productivity—a major path to profitable growth (which is itself a key contributor to long-term value)—must be set at ambitious levels.
- New and emergent technologies, such as machine learning and autonomous equipment, along with improvements in processing equipment and data analytics, offer fresh and powerful ways to unlock value.
- Companies that take a value-driven approach to project evaluation, selection, and execution are stronger and more sustainable. For example, lean design principles can bolster construction planning and productivity.

Mining executives should also consider new approaches to social and policy challenges—in particular, the resurgence of resource nationalism. Political and economic dynamics may be shifting more rapidly than they realize.

- In the near term, new regulations aimed at boosting citizens' asset ownership have increased the complexity and uncertainty surrounding operations and planning.
- Longer term, companies should consider the impact of automation on labor needs, and the implications of these effects on local economies and on their relationships with governments. At the same time, the reduced environmental impact that emergent technologies promise can open new opportunities. These and other considerations will figure in companies' exploration and operational strategies.

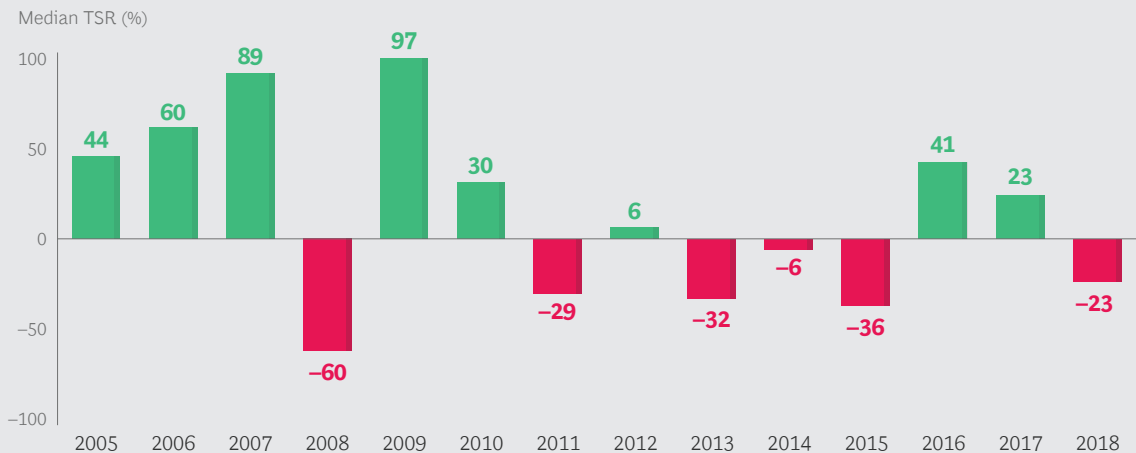
THE ROAD TO RECOVERY

THE return to financial health has been a hard slog for mining companies. Starting in 2011, the combined impact of waning price and production growth, sharp cost increases, and slackening capital discipline sent the industry into a steep slide. During the five-year period from 2011 through 2015, mining produced the lowest median total shareholder return (TSR) of any major industry. (See the appendix for an explanation of the components of TSR.) In all critical measures—revenues, margins, and cash flow—mining

companies suffered double-digit declines, hitting their lowest point since the global financial crisis in 2008.

In 2016, the industry finally turned around. The median TSR of the 63 leading mining companies in our study took a sharp turn upward that year, to 41%.¹ In 2017, the median TSR was 23%. But after a promising start, 2018 has proved to be another difficult year—a reminder that the recovery is still a work in progress. (See Exhibit 1.)

EXHIBIT 1 | The Rebound in Median Mining Company TSR Looks Tentative



Sources: S&P Capital IQ; annual reports; BCG analysis.

Note: Sample comprised 63 leading companies with a market value greater than \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.

Both Revenues and Margins Are Up

In 2017, for the first time in seven years, the revenues and margins of our sample companies grew simultaneously. From 2015 through 2017, EBITDA margin expanded by 5%, from 25% to 30%, although it fell short of the average margin of 35% logged during the preceding ten years. Many commodity prices retreated in 2018, even though the revenues and margins of our sample companies held steady for the most part. Meanwhile, absolute costs have begun to creep upward again, and they remain elevated as a percentage of revenues. (See Exhibit 2.)

Over the past three years (since 2015), the combined figure for cash flow from operations and EBITDA has increased by around 40%. While these results are still well below their 2011 highs, they have clearly improved since the downturn. (See Exhibit 3.)

Robust EBITDA and cash flow growth have also driven valuations higher, which in turn has enabled companies to pay down debt. From its low point in 2015, the aggregate enterprise value of our sample increased by nearly 50% by 2017, to \$1.12 trillion. This increase helps explain the sharp drop in the ratio of net debt to enterprise value, which fell by almost half, from a peak of 32% in 2015 to

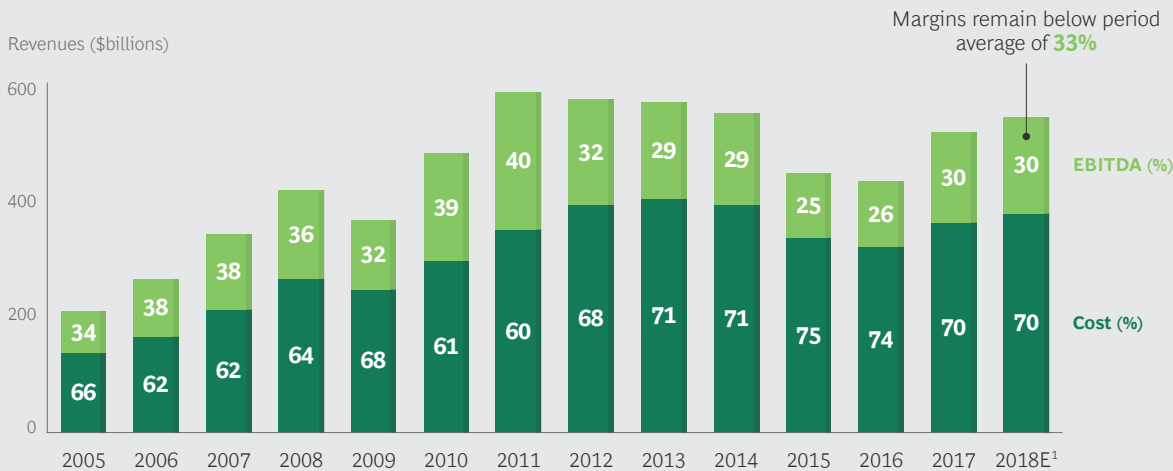
18% in 2017. (See Exhibit 4.) Diversified companies, along with copper and gold producers, enjoyed the biggest decline in gearing.

Hefty increases in commodity prices since 2015 were the main factor fueling these financial gains. Starting in late 2015, iron ore, copper, and thermal coal prices rose by double digits, as did prices of nickel, aluminum, and lead. Zinc more than doubled in price. Gold saw a more modest improvement, uranium sagged before picking up in 2018, and fertilizer minerals remained under continued pressure. Still, overall, commodity prices have played a major role in the industry’s rebound. Valuations, on the other hand, retreated in 2018, partly as a result of concerns about easing demand and its dampening effect on commodity prices.

Costs Are Mounting

After declining for three years, operating costs are beginning to creep upward again. From 2012 through 2016, the per-unit cost of producing copper fell by 20%, but by 2017 it began rising again. The unit costs of iron ore and gold—the latter measured as all-in sustaining cost (AISC)—also declined, although costs for both (as well as for other minerals) have begun to increase. Exhibit 5 shows the trend for gold production costs.

EXHIBIT 2 | Both Revenues and Margins Increased—and So Did Costs



Sources: S&P Capital IQ; annual reports; BCG analysis.

Note: Sample comprised 63 leading companies with a market value greater than \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.

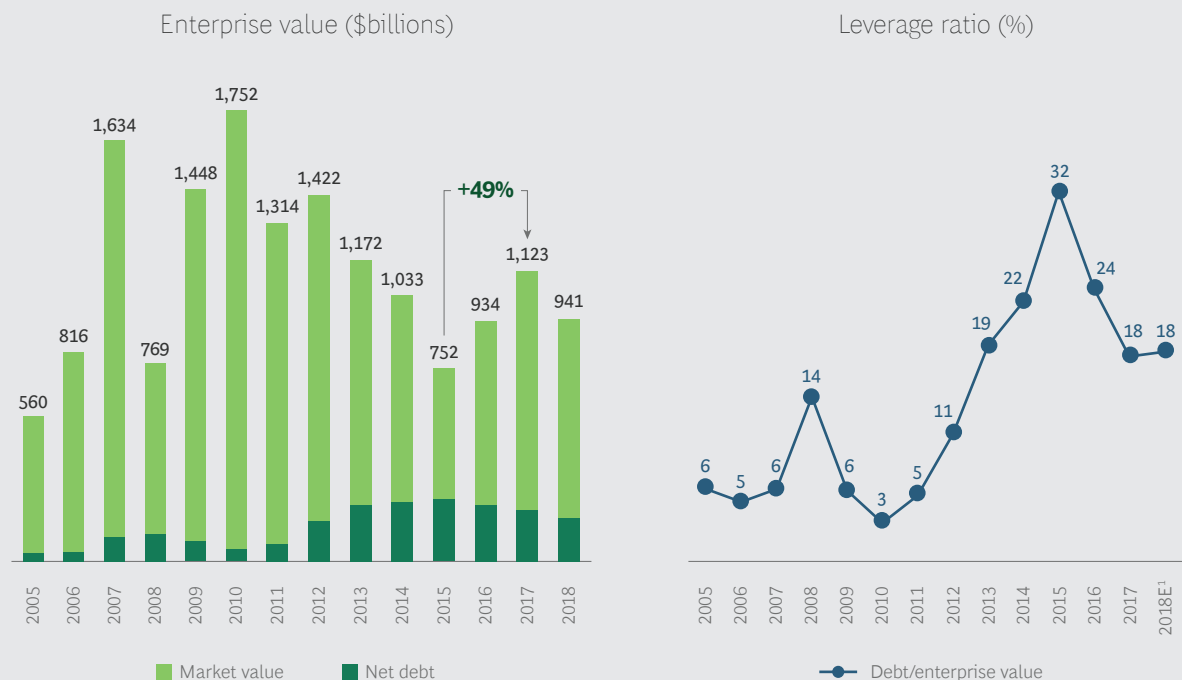
¹Trailing 12 months to Q3 2018 results.

EXHIBIT 3 | EBITDA and Cash Flow from Operations Have Rebounded by About 40% Since 2015



Sources: S&P Capital IQ; annual reports; BCG analysis.
Note: Sample comprised 63 leading companies with a market value greater than \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.
¹Cash flow from operations.
²Trailing 12 months to Q3 2018 results.

EXHIBIT 4 | Valuations Have Improved, Strengthening Balance Sheets



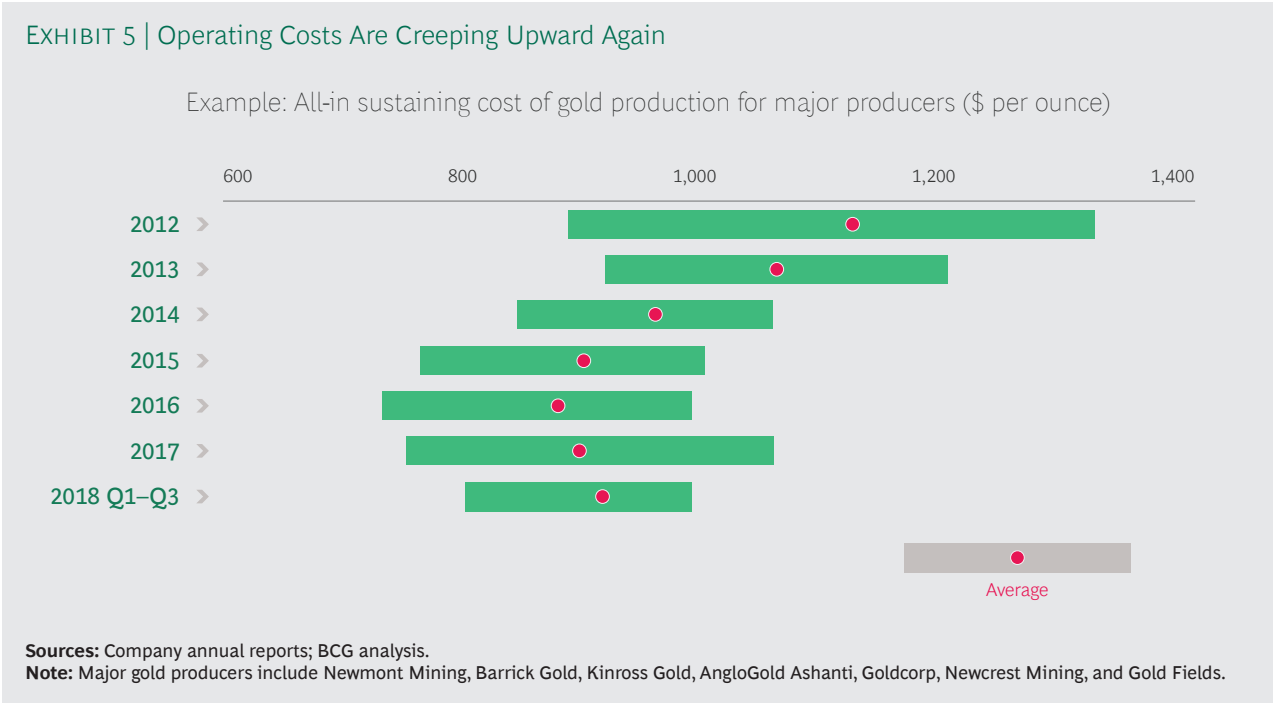
Sources: S&P Capital IQ; annual reports; BCG analysis.
Note: Sample comprised 63 leading companies with a market value greater than \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.
¹Trailing 12 months to Q3 2018 results.

The decline in costs earlier in the decade is attributable to a combination of such factors as tumbling fuel prices, a strengthening US dollar, mine-planning changes (including the deferment of overburden removal), and the impact of operating and productivity improvements. The macroeconomic benefits dwindled during 2017 and much of 2018, however, although oil prices again came under pressure later in the year. Still, obviously, companies cannot count on external inputs and the US dollar's fluctuations as key levers for cost control.

Meanwhile, supplier markets have begun to tighten. Although they are still well below their peak, backlogs for mining equipment have increased. Engineering and construction suppliers are likewise experiencing growing backlogs, but mining and drilling contractors are seeing the steepest climb—from an average of 34 months in 2016 to an average of

57 months just one year later. These trends suggest that costs could rise further.

NOTE
1. Our study sample consists of the 63 leading mining companies with an aggregate market value in excess of \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.



FOLLOWING THE MONEY

CASH FLOW AND CAPITAL SPENDING

AFTER THE BATTERING OF recent years and the exhaustive cost-cutting efforts that ensued, mining companies have become prudent about cash allocation, focusing their attention on completing existing capital projects and returning excess cash to shareholders. Overall, companies have begun reviving their exploration budgets, but the interest in M&A deals remains subdued, despite growing cash reserves and the ready availability of investment capital.

Cash Deployment and Its Production Consequences

From the end of 2012 through the third quarter of 2018, mining companies directed the lion's share of their operating cash flow—71%—toward capital expenditures (CapEx). M&A activity was light and, among the companies in our sample, tended toward divestments rather than acquisitions. After accounting for debt, net share repurchases, cash reserves, and other expenditures, the remaining 25% of cash went primarily to shareholders in the form of dividends. Buyback activity was mixed: some companies actively pursued it, while others continued to issue stock to fund acquisitions or growth projects, or to retire debt. (See Exhibit 6.) The shift toward returning capital to shareholders accelerated in 2018, as both dividends and buybacks increased. New-share issuance by established producers declined.

Thanks to stronger commodity prices and improved operating performance, cash reserves are once again growing; among our 63 sample companies, reserves grew by 30% (\$26 billion) in 2017 and then largely held steady in 2018. (See Exhibit 7.)

Production Patterns Have Changed

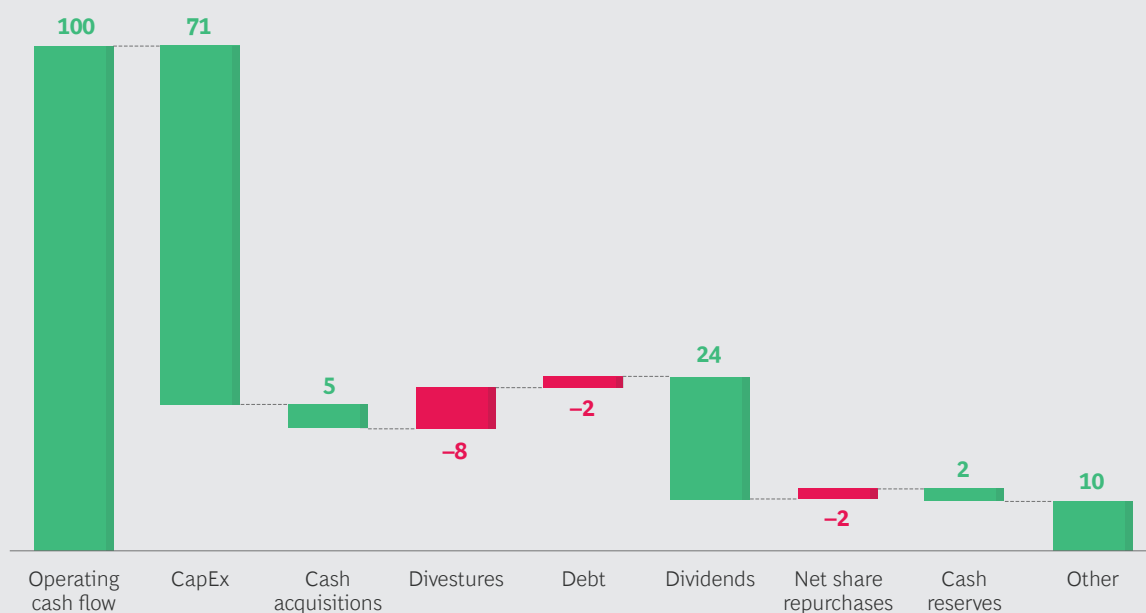
Capital spending during the boom years altered the production profile of the industry. In 2016, the global mining industry's iron ore and coal output was substantially greater than it had been in 2011, increasing by 21% and 43%, respectively. By contrast, global gold production fell by 3%, and global copper production grew modestly (by 8%).

In aggregate, these shifts are not particularly surprising. At the country level, however, a few distinct trends during this six-year period stand out:

- **Iron Ore.** Australia enjoyed significant growth in production (69%); Brazil enjoyed more modest growth (5%). India, meanwhile, experienced substantial declines.
- **Coal.** Output in China—the world's largest producer—fell by 9%; and in the US, by 34%. However, Australia, India, and Indonesia all saw double-digit growth.

EXHIBIT 6 | The Largest Companies Allocated Most of Their Cash Flow to CapEx and Dividends

Use of operating cash flow, 2012–2018E¹ (%)



Sources: S&P Capital IQ; annual reports; BCG analysis.

Note: Sample comprised 63 leading companies with a market value greater than \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.

¹Trailing 12 months to Q3 2018 results.

EXHIBIT 7 | Cash Reserves Grew by 30% in 2017

Cash and cash equivalents (\$billions)



Sources: S&P Capital IQ; annual reports; BCG analysis.

Note: Sample comprised 63 leading companies with a market value greater than \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.

¹Trailing 12 months to Q3 2018 results.

- **Gold.** Canada and China experienced the greatest growth (75% and 26%, respectively), followed closely by Russia (25%).
- **Copper.** Peru enjoyed the most spectacular increase (85%), followed by China (33%) and the US (27%). Chile, by far the world's largest copper producer, enjoyed 5% growth.
- **Bauxite.** China and Australia, the two biggest producers, saw gains of 44% and 17%, respectively.

The Capital Cycle Bottoms Out

Since the project activity of the boom era, capital spending has been dwindling. Current capital spending leans toward more modest expansion and replacement projects rather than megaprojects and flagship capacity additions. Although CapEx increased modestly in 2018 as a proportion of cash flow from operations (CFFO), it remains near ten-year lows for the companies in our study and has barely exceeded depreciation levels. (See Exhibit 8.)

As project spending has declined, so has the capital intensity of the projects that are un-

der way. During the previous boom period (from 2000 to 2015, excluding the temporary decline during the 2008–2009 financial crisis), capital intensity rose sharply. Copper projects, for example, required three times as much capital per unit of capacity in 2015 as they had in 2000. Since then, capital intensity has eased by about 20%. Gold projects followed a similar trend. Overall, capital intensity has lagged behind commodity price highs by from two to four years. (See Exhibit 9.)

The combination of low spending and low capital intensity has positioned mining companies to pursue a countercyclical strategy of developing growth options in settings where mineral deposits and product markets justify investment. But first movers have a clear advantage: should companies resume heavy spending on new projects, bargain prices for projects won't prevail for long.

Global demand trends are highly unpredictable, and we do not intend to speculate on such indicators as overall GDP growth, China's growth ambitions, or the prospects for large-scale infrastructure spending in major economies. Nonetheless, we can ask a crucial question: is there an imminent shortage of

EXHIBIT 8 | CapEx Remains Near Its Ten-Year Low (and Just Above Depreciation)



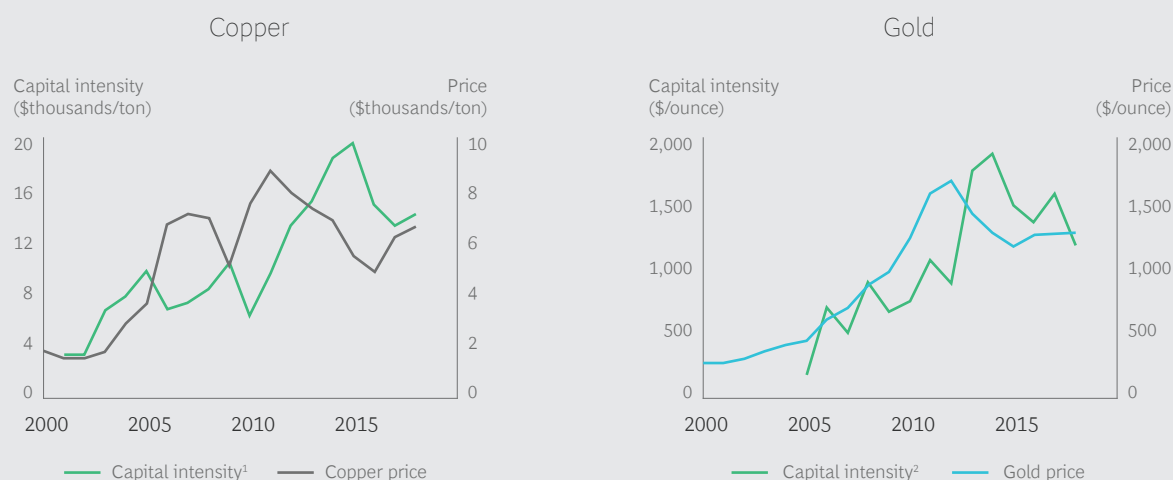
Sources: S&P Capital IQ; annual reports; BCG analysis.

Note: Sample comprised 63 leading companies with a market value greater than \$5 billion (and at least 20% free float) at the end of 2017 and/or a market value greater than \$5 billion at the end of 2007.

¹Cash flow from operations.

²Trailing 12 months to Q3 2018 results.

EXHIBIT 9 | Capital Intensity Has Declined with Prices



Sources: Wood Mackenzie; S&P Global Market Intelligence; BCG analysis.

¹Based on 190 projects between 2001 and 2018 YTD.

²Based on 122 projects between 2005 and 2018 YTD.

mineral reserves that justifies a major increase in project spending?

Reserves for many basic commodities—iron ore, copper, coal, and bauxite—though declining incrementally, remain sufficient at the global level to ensure supply over a relatively long period (from 35 to 150 years). Reserve lives for gold are shorter—roughly 15 to 20 years—which suggests that the gold market has the potential to disrupt supply, although this situation has persisted for some time. Of course, reserve lives vary substantially from company to company, making the need for new project development more critical for some than for others.

Battery metals such as lithium and cobalt have captured considerable investor interest recently, especially as major developments in electric vehicle technology have emerged. If demand were to increase significantly faster than expected (say, through the accelerated adoption of electric vehicles), available supplies of battery metals could quickly become constrained. Trends of this sort are important for companies with significant exposure to these markets—but in terms of absolute volume, such metals constitute niche markets. Indeed, neither cobalt nor lithium has escaped the downdraft in commodity prices in 2018, suggesting that imminent supply shortages are not yet apparent.

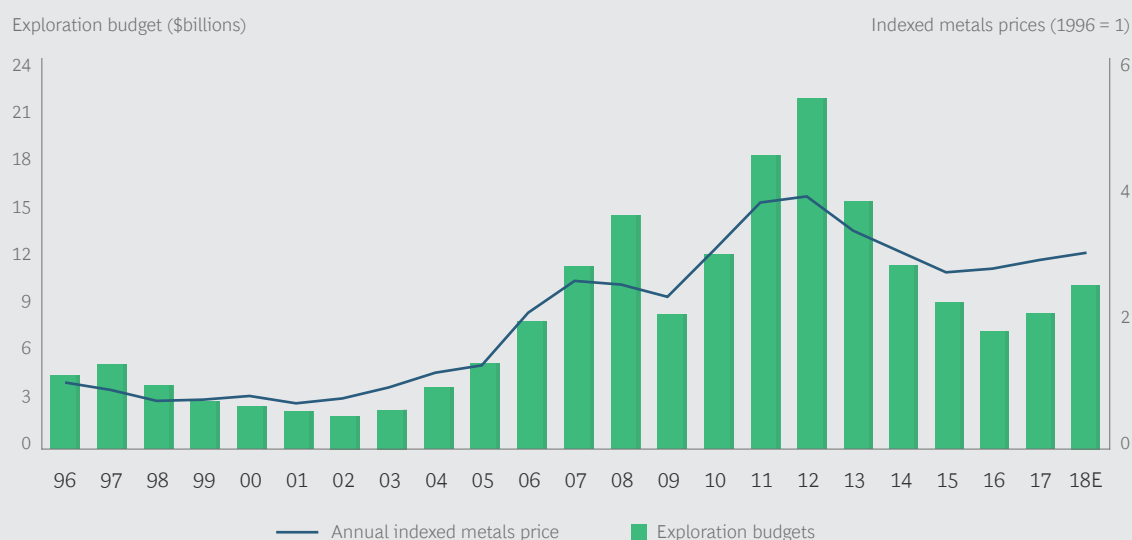
The industry-wide shortage of attractive, high-quality, large-scale projects is a major reason for the limited investment in growth projects. With many potential projects facing expectations of diminished returns, companies must rethink their approach to developing these deposits. Companies will need to identify opportunities to adjust project scopes, apply value engineering principles, and boost execution efficiency and construction productivity. In addition, they should explore how digital tools and methods, which have improved considerably in recent years, can help projects achieve their value expectations.

Exploration Is on the Rebound

The industry's appetite for exploration appears to be growing again. After hitting bottom in 2016, exploration budgets over the past two years have turned around, although they remain well below their 2012 peak. (See Exhibit 10.) The increases are primarily happening in brownfield (mine site) exploration, whose share of total exploration has been increasing steadily over the past several years. Not surprisingly, most of the activity and spending increases are in gold and copper (in line with their historical share of exploration spending). Geographically, the focus is on South America and Australia, and away from Canada and Southeast Asia.

EXHIBIT 10 | Exploration Budgets Are Reviving but Remain Shy of Their 2012 Peak

Exploration budgets versus indexed metals prices (overall industry)



Source: S&P Global Market Intelligence.

The major producers are responsible for the biggest chunk of total exploration expenditure, as well as for roughly half of the increase in spending since 2016. After losing share to the majors for years, junior mining companies revived their spending in 2017 and 2018, and now account for almost one-third of total exploration expenditure. Overall, the uptick in spending activity for majors and juniors indicates that the appetite for riskier ventures is growing. (See Exhibit 11.)

Although the increase in exploration investment is promising, exploration productivity remains the big question. Despite a tenfold increase in spending from 2002 to 2012, for example, the number of discoveries was flat. Moreover, the number of giant and major discoveries fell during this time, and discoveries tended to be lower grade. As a result, the unit cost of discovery increased dramatically, and it is projected to remain above historical long-term averages.

M&A Remains Subdued

Despite expectations, M&A activity has not kept pace with commodity price trends. Many industry observers believed that as prices bottomed out around 2015, M&A would naturally rebound, for all the usual reasons:

consolidation logic, a steady supply of distressed assets, and favorable financing costs. Yet the companies in our sample have, in aggregate, been more focused on divestment than on acquisitions—in sharp contrast to the pre-2012 period.

The industry is seeing fewer mega deals and little activity. Deal making—acquisitions, in particular—has remained subdued relative to historical levels. (See Exhibit 12.) Within our sample, the aggregate value of large deals (those over \$5 billion) has declined sharply from previous peak levels. Midrange deals (\$500 million to \$5 billion) are down, too, and the same is true of smaller deals (those below \$500 million).

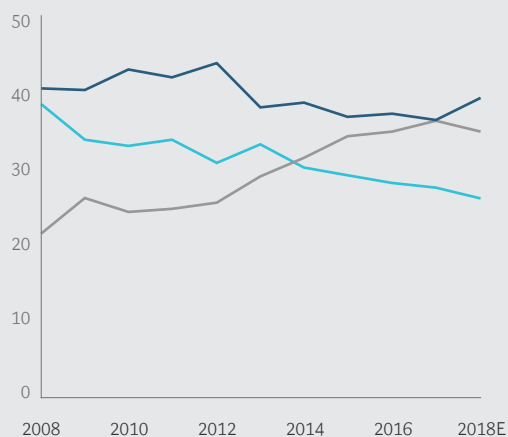
Constraints hold sway. With cash flows already committed to existing capital projects and debt reduction, and with no immediate shortages in reserves or production, companies have little impetus to jump into acquisitions. In addition, poor outcomes from many peak-era deals seem to have dampened investor sentiment, adding to mining executives' reticence to actively pursue deals.

Nevertheless, some M&A-based growth strategies in mining have produced spectacular successes. Northern Star Resources, an Austra-

EXHIBIT 11 | Exploration Spending Is on the Rise

Brownfield accounts for an increasing share

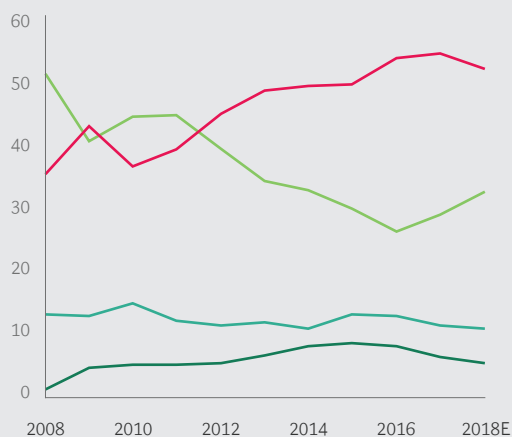
Percentage of total spending



— Late-stage greenfield — Early-stage greenfield
— Brownfield

Majors rule, but juniors' share has rebounded

Percentage of total spending

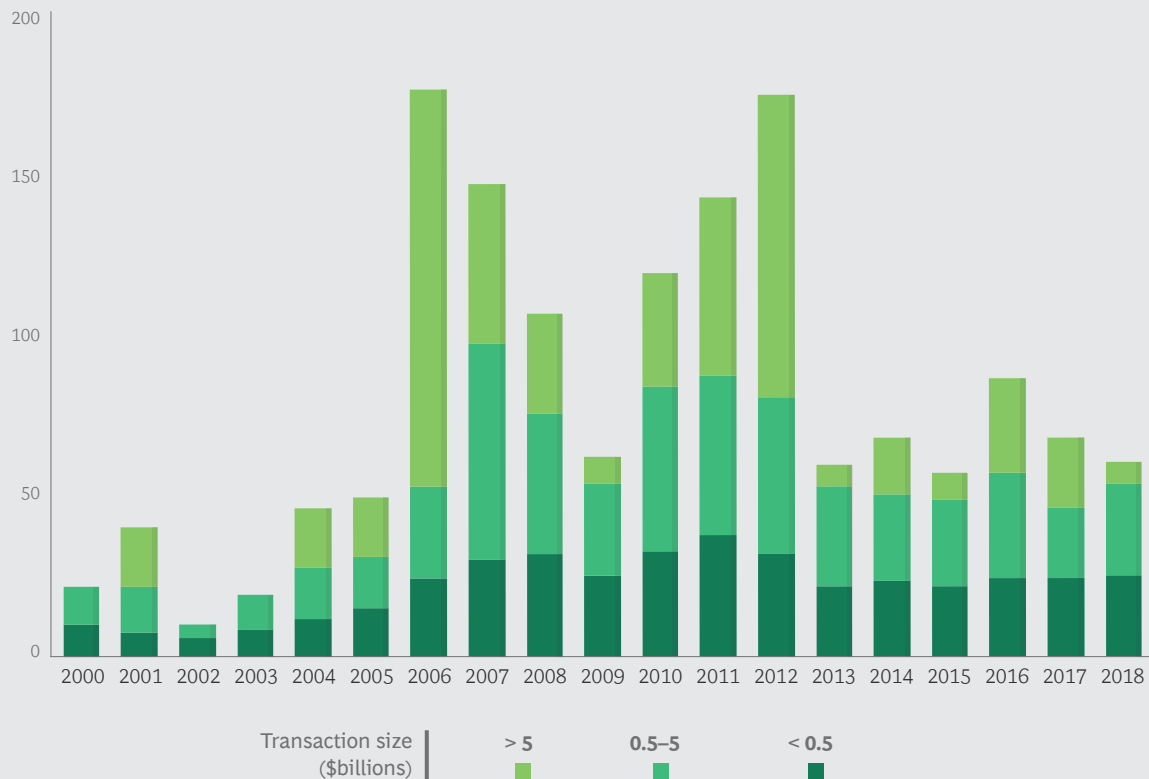


— Majors — Juniors — Intermediates — Government/other

Source: S&P Global Market Intelligence.

EXHIBIT 12 | M&A Activity Remains Near Cyclical Lows

Transaction value (\$billions)



Sources: S&P Capital IQ; BCG ValueScience Center.

Note: Transactions with no total transaction value available are excluded; closed and announced deals are included.

lian gold producer, grew successfully through acquisitions, first of junior companies and later of mines divested by Newmont and Barrick Gold. Most recently, it ventured outside Australia to purchase the Pogo mine in Alaska from Sumitomo. By strategically timing its purchase of a string of smaller holdings over the course of several years, Northern Star increased its enterprise value 16-fold during the period from 2013 to 2018, delivering a TSR of almost 70% annually.

Albemarle is another noteworthy example. Banking on the projected demand for electric vehicles, which rely on lithium batteries, Al-

bemarle bought Rockwood Holdings' lithium unit in 2015. Interest in lithium has since risen sharply, contributing to a doubling of Albemarle's enterprise value from 2013 to 2018, and to an average annual TSR of 17% during that period.

Even so, however, M&A is not without risk—particularly in sectors as volatile as mining. Numerous companies have found themselves in difficult positions after large or ill-timed deals. To guard against this, companies need to consider M&A in tandem with other strategic options and avenues.

MOVING FORWARD

THE CRITICAL DECISIONS

INDUSTRY circumstances have improved greatly since 2016. The prices of many commodities have risen substantially. Margins and cash flows have returned to levels they had not reached since 2013 and 2014. Companies have exercised restraint in their capital investments, and they have paid down debt and returned cash to shareholders via buybacks and dividends. After an extended slump, exploration investment by both juniors and major companies has revived.

Value creation strategies must deliver attractive returns throughout the cycle.

These positive signs do not warrant complacency, however. In the second half of 2018, prices for several commodities retreated, and operating costs are once again rising. Exploration discovery rates remain subdued. Opportunities available during the downturn, such as buying low, have generally vanished. Although attractive capital projects are in short supply, companies that are not actively pursuing them risk being unable to meet future demand. Macroeconomic headwinds, such as slowing Chinese growth, are exerting pressure on prices, leading to uncertainty in future pricing. Meanwhile, resurgent resource na-

tionalism, particularly in Africa, has added new complexity and uncertainty to strategic decision making for some companies. Management teams face pressure to “do something” while ensuring that they heed the lessons of the past cycle with regard to capital discipline, rigorous project evaluation, and lean project design and execution.

Craft a Plan to Create Long-Term Value Through the Cycle

The outlook for commodity prices remains uncertain. Several major trends, such as the shifting mix of global energy sources and the emergence of electric vehicles, have profoundly affected current and expected demand for a number of commodities. At the same time, while supply deficits have arisen in some minerals (such as high-quality iron ore), supply shortages anticipated elsewhere have not materialized. These and other forces have weakened correlations among commodity prices for both niche and major minerals.

For all of these reasons, mining companies need to develop value creation strategies that will deliver attractive returns throughout the cycle, independent of commodity prices. BCG research has consistently shown that TSR performance varies widely within every industry, including mining. Clearly, some companies systematically and consistently outperform their peers in creating value.

Many factors affect stock prices in the short term, although few of them are meaningful over the long term. But this does not at all mean that TSR is irrelevant. Although it can be comforting to use notionally simpler measures of value creation (such as production, cash cost, or earnings per share), those measures are inherently incomplete—and therefore potentially misleading—representations of value creation. To successfully create long-term value, companies must understand the key drivers of TSR, including fundamental performance, market valuation of current and future performance, and associated cash flows to investors in the form of dividends and buybacks. Above all, they must figure out how to activate these drivers in a holistic way.

Profitable growth often plays an outsize role in creating long-term value. The prerequisite for delivering such growth is to start from a robust position.

Take Productivity to the Next Level Through Technology

Continuing the productivity journey is one way to maintain robustness. Among the many lessons of the last cycle is the importance of bolstering the sustainability of current cash flows. Costs will inevitably go up; in fact, they already have, as economic activity has heated up. And although successive rounds of implementing cost reductions can be wearying, the task is never done. Already it's time to renew efforts to improve margins and productivity, which remain key levers for value creation regardless of commodity prices.

Productivity efforts should target new levels of ambition, and technology can go a long way toward helping companies achieve these new levels. New technologies—in particular, data analytics and digital technologies—offer an excellent way to improve the economics of mining operations. These new technologies span a vast spectrum, from exploration to logistics. At one end, radical emergent technologies (such as robotic swarms) promise previously unimagined improvements in access and safety, as well as reduced environmental impact. At the other end, upgrades in processing equipment (such as the new generation of high-pressure grinding rolls) are delivering

dramatic gains in both energy efficiency and throughput.

Autonomous equipment offers a prime example. Although Western Australia is the global hub for autonomous equipment, operations elsewhere in the world are adopting the technology, too. Beyond performing work efficiently, autonomous equipment minimizes downtime, thanks to embedded sensors that permit condition monitoring and predictive maintenance. Drones are proving to be highly versatile and effective at monitoring inaccessible locations, for environmental, maintenance, and even exploratory purposes.

Integrated operations centers can help cut unit operating costs by 25% or more.

Some of these technologies are already commercially available; others are still in the experimental or field-testing stages. But all of them promise powerful new ways to unlock value, whether by optimizing existing operations or by spurring productivity in more transformative ways. (See the sidebar.) Virtually all of them involve digital applications that support data collection for monitoring, tracking, analytics, and modeling. Integrated operations centers (which are becoming increasingly easy to implement) bring real-time operational data to one location. Companies can now make better decisions along the end-to-end path from resource to market, and as a result can cut their unit operating costs by 25% or more.

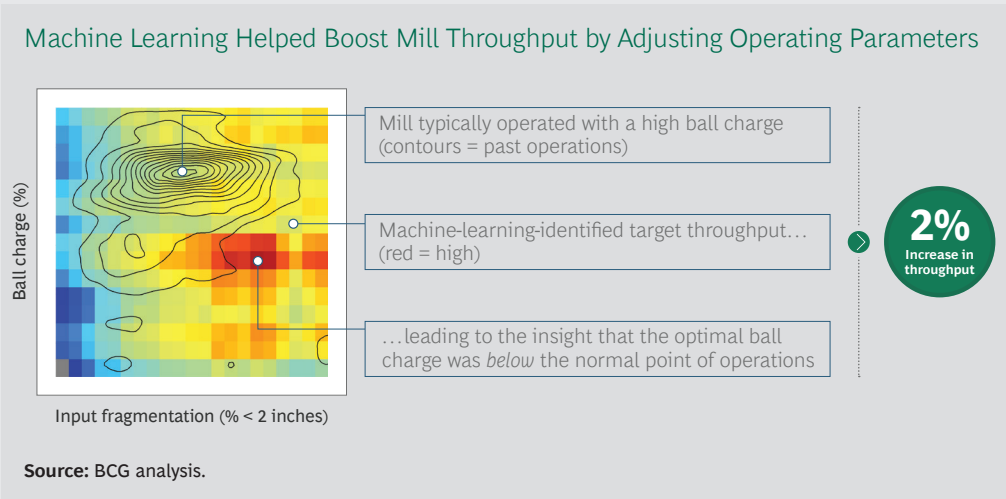
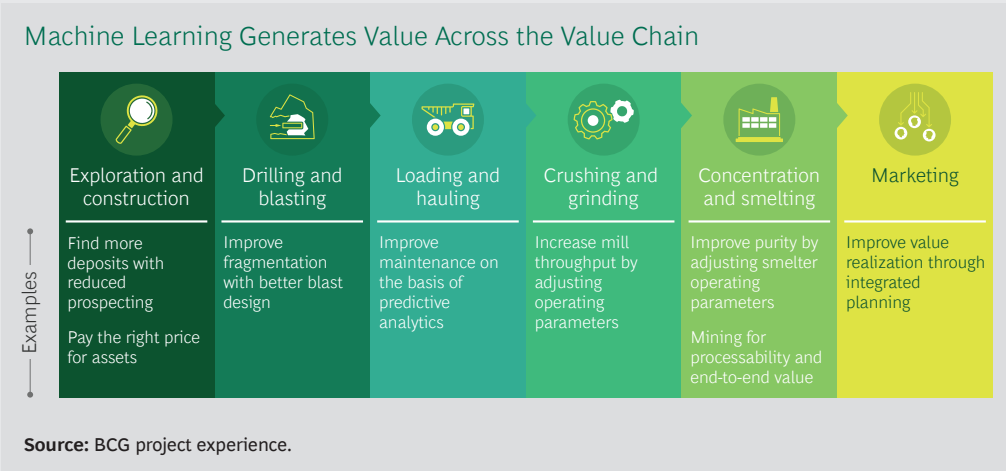
As exciting as these new technologies are, developing a coherent strategy for using them can be difficult, for reasons ranging from the newness of the technology to the challenge of finding the right talent to successfully embed the technology. The best approach is to start with a clear view of the problems that need to be solved and the potential value of solving them. It is also advisable to take a user-centric view of the mining value chain—one that considers the pain points experienced by people within the organization. This will help

MACHINE LEARNING’S GAME-CHANGING BENEFITS

Companies frequently use computer models to test options and make better decisions in a low-cost way. Traditional models rely heavily on empirical, physics-based equations, which are often incomplete when applied to real-world situations. Machine learning is a powerful way of modeling that relies directly on observed data, thus allowing quantification of complex, nonlinear relationships. Many applications for machine-learning models exist all along the mining value chain, from exploration and construction to marketing. (See the first exhibit below.)

For example, BCG worked with the operations team at the Collahuasi copper mine in Chile to explore the use of machine learning to help improve throughput. Team

members built a machine-learning model of the grinding plant, focusing on the SAG mills. They used almost three years of historical data (for 400-plus variables at one-minute intervals) to create and train the model. The model helped the team quantify the impact on throughput of varying key operating parameters. For one mill, the model revealed that the optimal ball charge was 18%, significantly different from the 19.5% at which the SAG typically operated. (See the second exhibit below.) By changing this single operating parameter, Collahuasi increased throughput by up to 2% and unlocked considerable value in the process. The same model uncovered several additional opportunities to increase throughput and improve efficiency.



ensure that the business drives technological change, and not the other way around.

From there, companies should develop a portfolio of digital solutions to address these problems. Ideally the portfolio will contain a mix of higher- and lower-risk bets, reflecting the maturity of the technology at hand. Mining company leaders should adopt a venture capital mindset and actively manage the portfolio, focusing on efforts that promise asymmetric returns, and culling those that are unlikely to deliver an attractive minimum viable product (MVP).

To succeed, digital transformations obviously require data and robust enterprise data systems. But data is useful only if it serves the business. To enable a digital transformation to take flight quickly, companies would do well to focus on establishing a digital culture, adopting digital ways of working, and acquiring and developing the necessary talent and skills to succeed.

In managing their digital portfolio, leaders should have a venture capital mindset.

Instill a digital culture. Culture cannot be imposed. Therefore, companies must have in place the appropriate organizational processes, people management policies, and incentives to foster desired behaviors and values, such as an innovation mindset and a value-first orientation. (See *It's Not a Digital Transformation Without a Digital Culture*, BCG Focus, April 2018.)

Adapt digital ways of working. Companies need to combine established ways of working with newer digital ways—not just for digital projects per se, but more broadly to prepare for mining in the future. This includes shifting toward an environment in which managers and even workers have more autonomy to innovate. It calls for applying agile development approaches, where appropriate, and emphasizing pilot projects that will quickly yield a workable initial solution or MVP that

the company can subsequently improve. (See “Taking Agile Way Beyond Software,” BCG article, July 2017.)

Acquire and develop the necessary talent and skills. In the mining industry, the talent needed to deliver on a digital strategy is in short supply. Mining companies must compete with a host of other industries and companies to attract and retain individuals who can deliver real benefits by successfully matching technology opportunities with business needs. We have repeatedly observed the challenges involved; a clear talent strategy is therefore essential. (For more details, see “The New Technology Frontier in Mining,” BCG article, January 2018.)

Secure Future Growth Options

In the long term, success depends on growth, whether organic, inorganic, or a combination of the two.

Make the most of exploration. Now that exploration activity is resuming, it's important for companies to craft a clear exploration strategy grounded in value, the volume of ore needed to fulfill long-term goals, and the financial attractiveness of in-house exploration compared to acquisition of more advanced deposits and projects. Companies can use various approaches to improve their odds of discovering new reserves. For example, they can pursue a balanced portfolio of mineralized districts, view frequent drilling as an essential activity, and balance the proportions of greenfield and brownfield exploration to hedge against risk.

Companies should evaluate exploration management for efficiency and effectiveness, at both the managerial level and the in-field level. They should also consider applying innovative technologies, such as machine learning, that have shown considerable promise in improving targeting and discovery rates. Finally, companies need to recognize that, more than ever, they are competing for talent with other industries, not just with other mining companies. They must therefore make every effort to attract, incentivize, develop, and retain the best talent, particularly individuals who combine an understanding of geology, technology,

and business. (See *Tackling the Crisis in Mineral Exploration*, BCG report, June 2015.)

With M&A, measure twice, cut once. M&A can be an attractive means of replenishing resources, reserves, and the project pipeline; it can also be a powerful value generator. BCG research has shown that deals made in a downturn create more value. Serial acquirers are particularly successful in downturns. Companies have often acquired juniors for less than the internal cost of discovery and development. And as Albemarle's acquisition of Rockwood Holdings demonstrates, main-stream ores aren't the only place to find deals.

M&A is a legitimate pathway to growth, but companies need to approach it with care. To manage the associated risks, companies should identify comfortable deal sizes and evaluate potential deals with a broad set of price and demand scenarios. Companies should explicitly define and assess the full strategic benefit of any deal. Unpacking the various sources of value and risk in a transparent and comprehensive way supports better-informed decision making.

Take a Value-Driven Approach to Project Evaluation, Selection, and Execution

There is no pressing need today for added supply of most mineral commodities. Nevertheless, aging mines must be replaced, and existing mines expanded, as economic realities allow. Last cycle's hard lessons with regard to large capital projects—notably the lessons pertaining to cost and schedule overruns—remain highly relevant.

Given the short supply of landmark projects, companies should apply the principles of lean design to their projects. In our experience, accurately framing the project, selecting the right scope, and striving for the minimum technical solution can reduce the capital intensity (capital required per unit of productive capacity) by from 8% to 17%.

By improving construction planning, properly aligning incentives, and boosting construction productivity, companies can reduce capital intensity by from 9% to 23%. The more so-

phisticated digital methods now available—including building information modeling (BIM) and dynamic schedule optimization and forecasting tools—are proving their worth in these areas.

Last cycle's hard lessons about large capital projects remain highly relevant.

New mine construction provides a good opportunity to prudently implement forward-looking technologies. But this effort entails looking into the future, an inherently uncertain exercise that conflicts with the way companies have traditionally evaluated and approved mining projects. It is tempting to choose established technologies during the design stage, but these technologies may be a decade out of date by the time production begins. Mining executives must, of course, balance certainty of delivery against the uncertainty of building for the future, but they should resist the urge to embrace the ostensibly lowest-risk option without fully evaluating the impact of doing so.

Consider New Approaches to Social and Policy Challenges

Relationships between governments and the industry, which have often been strained, are complicated by shifting political and economic dynamics. These dynamics may change more rapidly than leaders on both sides realize.

In the near term, nationalistic measures complicate operations and planning. In the medium to long term, advances in automation and digital will reduce the need for human labor. Meanwhile, some emergent technologies promise to significantly lessen mining's environmental impact, potentially tilting public opinion in its favor.

As companies consider their exploration and operational strategies, in both the near term and the long term, they need to recognize the shifting priorities and politics that are likely to weaken what were once effective incen-

tives to governments. For their part, governments need to consider not just the value of foreign investment but also the fact that the costs of the new technologies to mining companies are significant and may influence mining companies to reach different decisions than they might have in the past.

Navigating fragile political and social landscapes is difficult but crucial. Going forward, economic, social, and political sustainability will be as much a matter of good relationships as of self-preservation—for both sides.

A Path to Long-Term Value Creation

The past decade has been a volatile one for the mining industry. After quickly recovering from the 2008–2009 financial crisis, the industry flourished. Around 2012, a painful downturn set in, persisting for three years and putting great stress on producers' profitability and balance sheets. The downturn eventually gave way to a rebound; but after two promising years, the industry now appears to have reached another pivotal point, as commodity prices once again come under pressure.

Whether the stall that began in mid-2018 is a temporary pause or augurs something worse is of course uncertain. Indeed, uncertainty is a defining characteristic of the current global economy.

The lessons of the downturn—chief among them, that banking on rising commodity prices is not a strategy—mean that it's time for a return to strategy, in the fullest sense.

Companies must keep expanding their profit margins to build resilience in their businesses. Continuing their productivity journey is

one clear path to this goal. Productivity, in fact, is best seen as an ongoing pursuit, an essential way of doing things—one that continually evolves as new methods, tools, and technologies arise. Investing in and attracting the right talent has become more critical to success as new technologies and approaches begin to revolutionize operations and the ways of working throughout the value chain.

Over the long term, however, profitable growth matters. BCG research has established that profitable growth drives most long-term value creation. Although there is no imminent need to add capacity, mining companies must think ahead and build options for the future through exploration and development, as well as through M&A. Timing is always critical, whether in pursuing organic or inorganic growth strategies, which is why a value-driven, portfolio mindset is all the more important as a way to balance strategic gains against risks—and, once decisions are taken, as a way to mitigate calculated risks and exposure.

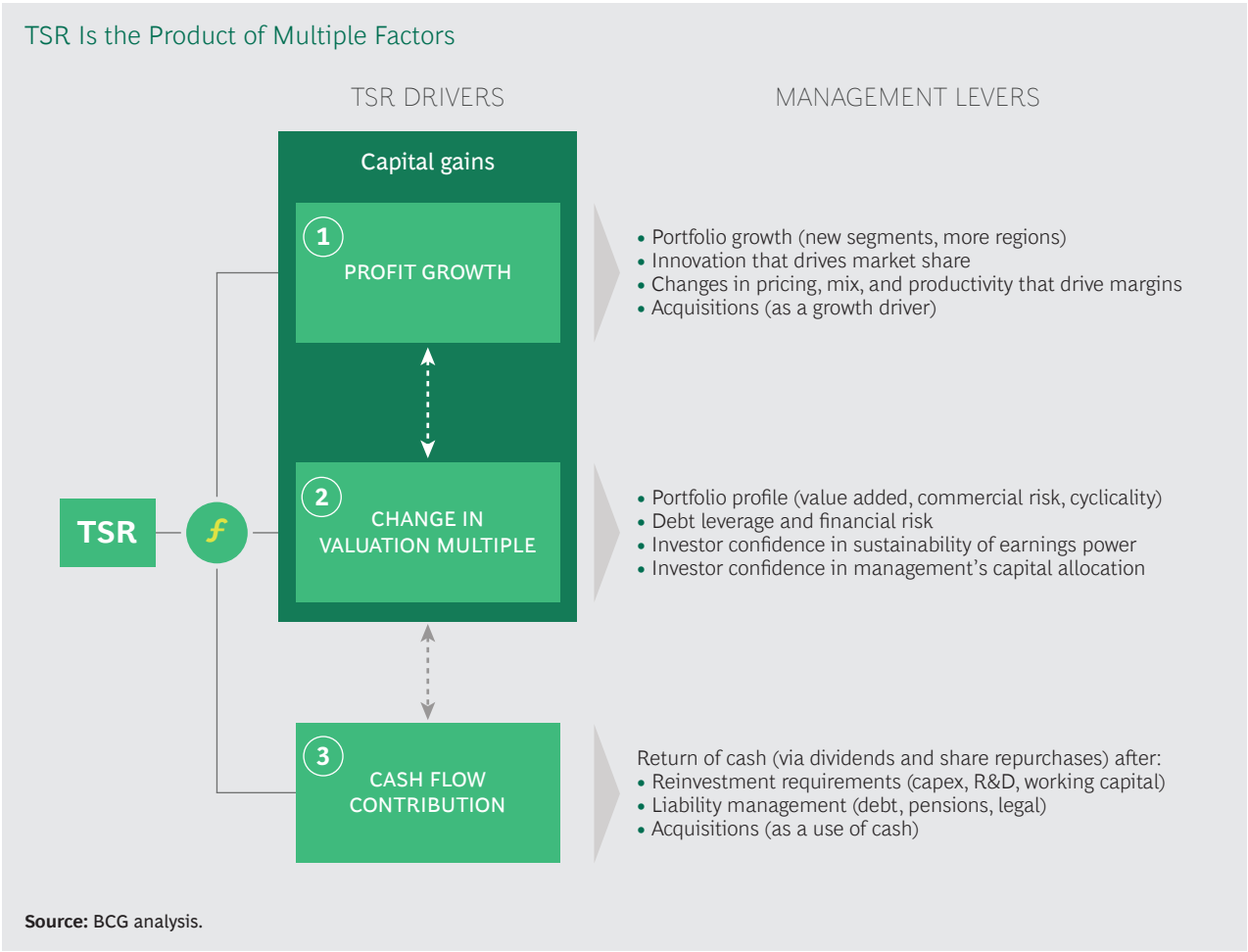
The history of mining is a history of bold (and often countercyclical) moves. Such moves are still necessary. But they need to be made following a dispassionate and rigorous assessment—and not only because this is the most reliable path to long term-value creation. In a growing, increasingly interconnected world, stakeholders have a bigger say in value creation than ever before.

APPENDIX

This appendix consists of two parts: a description of the components of total shareholder return, and a presentation of data on the 63 mining companies analyzed for this report.

The Components of TSR

As illustrated in the exhibit below, total shareholder return is the product of multiple factors. BCG’s methodology for quantifying the



relative contribution of the various sources of TSR uses the combination of revenue growth and change in margins as an indicator of a company's improvement in fundamental value. It then uses the change in the company's valuation multiple to determine the impact of investor expectations on TSR. Together, these two factors determine the change in a company's enterprise value. Finally, to determine the contribution of free-cash-flow payouts to a company's TSR, the model also tracks the distribution of free cash flow to investors and debt holders in the form of dividends, share repurchases, or repayments of debt.

Companies Analyzed

The exhibits that follow provide information on the 63 mining companies analyzed for this report. The first exhibit lists the names of the companies; the second shows the locations of their primary listings around the world and the primary minerals that they produce.

The Study Sample Consisted of 63 Mining Companies...

<ul style="list-style-type: none">• Agnico Eagle Mines• Agrium¹• Anglo American• Anglo American Platinum• AngloGold Ashanti• Antofagasta• Barrick Gold• BHP• Boliden• Cameco• China Coal Energy Co.• China Molybdenum Co.• China Shenhua Energy• Compañía de Minas Buenaventura• CONSOL Energy• Eramet• Exxaro Resources• First Quantum Minerals• Fortescue Metals Group• Franco-Nevada• Freeport-McMoRan	<ul style="list-style-type: none">• Goldcorp²• Gold Fields• Grupo México• Imerys• Impala Platinum• Industrias Peñoles• Inner Mongolia Yitai Coal• Israel Chemicals• Jiangxi Copper• K+S• KAZ Minerals• KGHM Polska Miedź• Kinross Gold• Lonmin• The Mosaic Company• Newcrest Mining• Newmont Mining• NMDC• Norilsk Nickel• Pingdingshan Tianan Coal• Potash Corporation of Saskatchewan¹	<ul style="list-style-type: none">• Qinghai Salt Lake Industry• Randgold Resources• Rio Tinto• Royal Gold• Shandong Gold Mining Co.• Shanxi Lu'an Environmental Energy• Shanxi Xishan Coal and Electricity Power• SQM• Teck Resources• Turquoise Hill Resources• Vale• Vedanta• Western Mining Co.• Wheaton Precious Metals• Wintime Energy• Yamana Gold• Yanzhou Coal Mining• Yara International• Yunnan Copper• Zhongjin Gold• Zijin Mining Group
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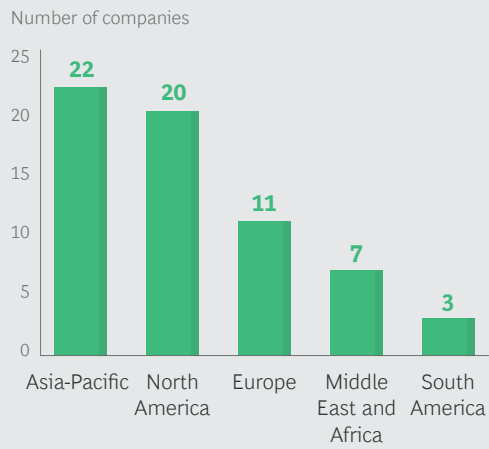
Sources: S&P Capital IQ; BCG analysis.

¹Agrium and Potash Corporation of Saskatchewan merged to form Nutrien as of January 1, 2018.

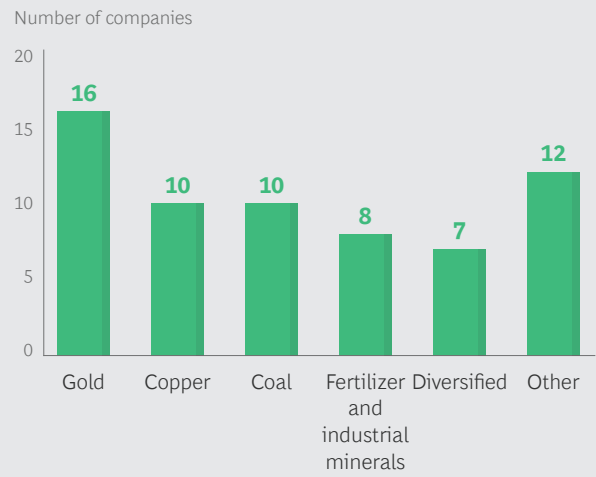
²Included prior to proposed acquisition by Newmont, announced in January 2019.

...and Covered All Major Regions and Commodities

Location of primary listing



Primary mineral produced



Sources: S&P Capital IQ; BCG analysis.

FOR FURTHER READING

Boston Consulting Group publishes many reports and articles that may be of interest to mining management teams. Recent examples include the publications listed here.

Ten Lessons from 20 Years of Value Creation Insights

An article by Boston Consulting Group, November 2018

It's Time for New Mindsets and New Ways of Working in Mining

An article by Boston Consulting Group in *Mining Journal*, October 26, 2018

The Electric Car Tipping Point

A Focus report by Boston Consulting Group, January 2018

Mining Value in AI

An article by Boston Consulting Group, October 2017

Three Ways to Beat the Odds with Capex Investments

An article by Boston Consulting Group, September 2017

Data-Driven Transformation: Accelerate at Scale Now

A Focus report by Boston Consulting Group, May 2017

Digital Technology: Hype or Ripe?

An article by Boston Consulting Group in *Mining Journal*, February 24–March 9, 2017

Value Creation in Mining 2016: Restoring Investor Confidence

A report by Boston Consulting Group, December 2016

Mining and Metals in a Sustainable World 2050

An article by Boston Consulting Group, September 2015

Mining's Productivity Imperative: Burning Fat, Building Muscle, and Thinking Straight

An article by Boston Consulting Group, June 2015

Getting the Most from Mining Technology

An article by Boston Consulting Group, November 2014

NOTE TO THE READER

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This report was sponsored by BCG's Industrial Goods practice, which works with clients to deliver solutions to the challenges discussed in this report. These clients include some of the world's largest and most successful mining companies in both developed and emerging economies.

If you would like to discuss the insights in this report or learn more about the firm's capabilities in the mining industry, please contact the authors.

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