A forward look into the US rare-earth industry; How potential mines can connect to the global REE market

by George Barakos, Helmut Mischo and Jens Gutzmer

The Mountain Pass Mine in California, pictured in 2011.

It has been nearly eight years since rare-earth elements (REE) became the subject of front-page headlines. It was when the controversial Chinese export policy for these critical commodities was epitomized in a maritime border dispute with Japan in September 2010 that resulted in the big REE crisis and price spike of 2011 (Barakos et al., 2016c; Mancheri, 2015).

The world was dismayed, especially in REE-importing countries such as the United States that was, and still is, totally dependent on Chinese production and exports (Barakos et al, 2016c; Kennedy, 2015). The short-lived alarm initiated a treasure hunt by way of exploration for REE deposits all over the world. The continuously growing demand on the one hand, and the Chinese sovereignty of the REE-market on the other, led the rest of the world to explore their own REE resources. In just a few years, more than 400 projects were initiated to explore REE deposits outside of China (ERECON, 2015; Goodenough, 2016).

The prices of REE, however, dropped rapidly in late 2017 and were in six-year lows, before the 2011 crisis (Barakos, 2017). The viability of even major established producers is being challenged, not to mention the development prospects of potential REE-market entrants (Barakos et al., 2016b; Rollat et al., 2016). Production cutbacks and industry consolidation in China have impelled REE market experts to forecast that prices have already reached their lowest point and have nowhere to go but up (Adamas, 2015; Roskill 2015). Yet, expectations for increased REE prices are limited and drastic changes are unlikely to happen in the near future, as there is still excess supply in the overall REE market (Barakos, 2017).

Nevertheless, the low prices of rare earths are not the only reason that potential producers

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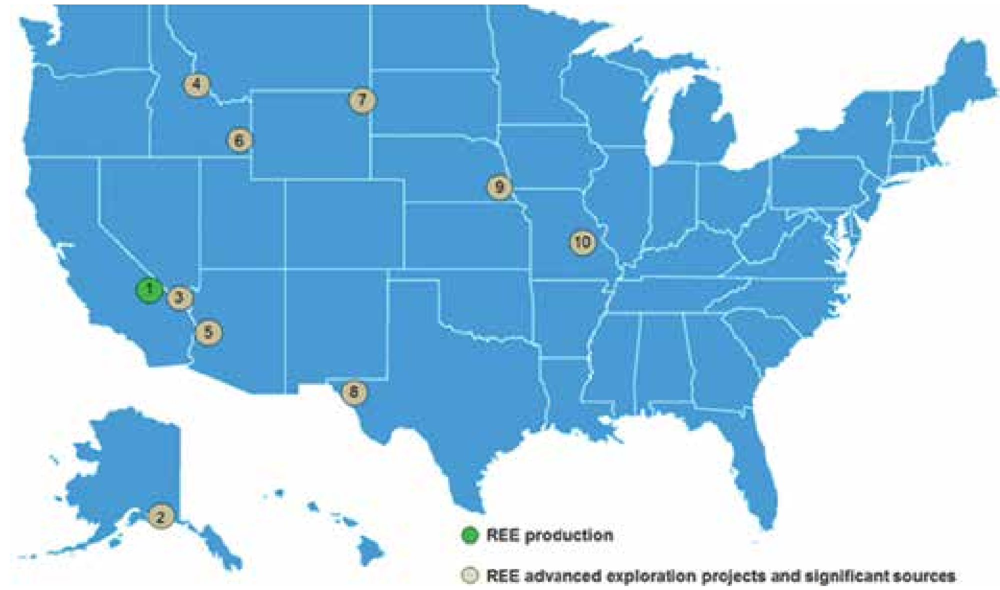
are struggling to enter the global REE market. Among other parameters, the separation process of the individual elements seems to be the most important factor, as it is technically challenging and expensive to build and to operate.

Thus, in this article, an analysis is made to identify the boundary conditions that govern both the global and domestic (U.S.) REE industry in order to determine the factors and establish a market channel that can connect potential U.S. REE projects to the global market.

Figure 1

Map of United States showing the domestic distribution of REE mines and deposits.



A U.S. REE industry retrospective

The REE exploration boom in the United States resulted in finding several REE deposits (Fig. 1); while Molycorp began to re-evaluate the REE project in Mountain Pass, CA with a view to bring the mine back into production.

Prior to the rise of REE mining in China, the United States dominated the global market. Mountain Pass initiated operations in 1965 and was the leading producer worldwide for decades, with the next-largest producer, Australia, producing only a fraction of the U.S. output (Barakos, 2017). However, mining activities stopped in 1998, mainly due to the competition from China as well as in response to environmental issues in the surrounding area of Mountain Pass (Ali, 2014; Mancheri, 2015).

Molycorp re-activated the mine in 2010 and committed to an expansion, that cost US$1.6 billion in order to upgrade its processing and separation facilities (Roskill, 2015). Pressed by declining prices for its products, however, Molycorp was forced to share capital increases, and several investors entered the joint venture. Despite the recapitalizations, Molycorp could not avoid filing for bankruptcy in 2015, loaded with $1.7 billion in debt (Barakos et al., 2016b; Machacek & Kalvig, 2016). On its way out of bankruptcy, Molycorp decided in early 2016 to abandon its Mountain Pass mining facility. The company tried to rebuild itself around the Neo Material line of businesses that process rare earths, while the Mountain Pass Mine was separately purchased by MP Mine Operations LLC in July 2017 (Roskill, 2017).

Apart from Mountain Pass, significant exploration projects in the United States include the Bear Lodge, the Bokan-Dotson Ridge, the Round Top and the La Paz projects. The aforementioned projects are listed in the TMR Index (www.techmetalsresearch.com) as being in an advanced exploration and/or evaluation stage.

Additionally, some other deposits have attracted interest. A list of the most important REE sources in the United States is illustrated in Table 1. The numbering of projects is not related to their significance; it starts from west to east and from north to south.

The Bokan-Dotson Ridge REE project

Table 1

REE mining and exploration projects in the United States.

REE project	Ownership
1. Mountain Pass	MP Mine Operations
2. Bokan Dotson Ridge	UCORE Rare Metals
3. Thor	Elissa Resources
4. Lemhi Pass	U.S. Rare Earths
5. La Paz	AusAmerican Mining
6. Diamond Creek	U.S. Rare Earths
7. Bear Lodge	Rare Element Resources
8. Round Top Mountain	Texas Mineral Resources
9. Elk Creek	NioCorp Developments
10. Pea Ridge	Wings Enterprises

in Alaska deals with the largest heavy rare-earth element (HREE) deposit in the United States and is currently in the evaluation stage. UCORE Rare Metals owns the project and intends to produce separated and purified rare earth oxides (REO) using molecular recognition technology (MRT) (Izatt et al., 2016).

The Bear Lodge light rare-earth element (LREE) deposit in Wyoming is being explored by Rare Element Resources. The mineralization is LREE dominated, like Mountain Pass (Roskill, 2015). The project is at an advanced stage; an updated prefeasibility study was published in 2014.

The Round Top Mountain REE deposit is another very large, yet low-grade resource worth mentioning. The project is located at Round Top Mountain, TX and is enriched in both LREE and HREE as well as in other elements, such as lithium, beryllium, thorium, uranium, niobium, tantalum and hafnium (Roskill, 2015).

The La Paz REE deposit is a low-grade LREE source located in Arizona. AusAmerican Mining Corp. owns and runs the La Paz REE exploration project that is still under preliminary evaluation.

Other remarkable REE sources that have not been translated yet into advanced exploration projects include the Thor REE deposit in New York Mountains, NV; the Lemhi Pass and Diamond Creek sources in Idaho; the Elk Creek project in Nebraska and the Pea Ridge REE project in St. Louis, MO (Roskill, 2015).

According to the U.S. Geological Survey (USGS) the global estimated reserves of rare earths are approximately at 120 Mt (132 million st), while the domestic reserves in the United States are calculated at 1.4 Mt (1.5 million st) (USGS, 2017). It should be mentioned here that the reserves estimate for 2015 was 4.1 Mt (4.5 million st), whereas the estimate for 2010 was 13 Mt (14.3 million st) (Paulick & Machacek, 2017). This reduction is attributed to the reclassification of historic resources at Mountain Pass using the more stringent requirement of NI 43-101 reporting.

Challenges for the U.S. REE industry

Without doubt, the United States is home to a significant amount of REE resources and, theoretically, there could be a supply of rare earths for several years. Nevertheless, the country is 100 percent import-reliant on REE and the exploitation of U.S. domestic resources seems to be offering no real solution to the problem. The emphatic failure of Molycorp to run Mountain Pass in a successful manner is the most typical example (Barakos et al., 2016b; Kennedy, 2015).

The REE industry is not a simple explore-extract-merchandise business; it is governed by a set of special boundary conditions that can determine the feasibility of any potential REE mining project. These conditions are discussed in order to evaluate the connection potential of future U.S. REE mines to the global rare earths market.

REE prices. A major challenge for the U.S. REE industry are the low prices of the elements. The REE prices soared in response to the implementation of strict export quotas from the Chinese government and from the fear that there would be a supply chain disruption (Barakos, 2017). However, when buyers realized that the actual supply to consumers was not that tight, prices plunged. The disruption in supply was also short-lived, and the demand for rare earths barely exceeded supply in 2010 and 2011 (Roskill, 2015).

Despite lasting for only a short period of time, the high prices of REE enticed investments in small exploration companies in the United States and around the world, which in turn promised to develop new sources of rare earths. Nonetheless, mining does not react as quickly to market demands; in fact, it takes a few years to advance from the exploration stage to the actual initiation of mining operations. Surprisingly, this was to the benefit of many potential REE producers, since the drop in prices led to second thoughts and a re-evaluation of the prospects of their projects. This situation, however, had a profound impact on the potential of junior companies to secure investments for capital costs required to work toward mine development (Paulick & Machacek, 2017)

The steady low prices of REE in the last two years, until the moment of writing this paper, indicate that price developments are not necessarily linked exclusively to changes in supply and demand. Through its monopolistic control over the small and opaque REE market, China has managed to reduce the prices to a level that is low enough to prevent other potential producers from commencing mining operations. However, there are also indications that the potential of China to influence REE prices is now also limited; the prices have dropped so low that even the viability of Chinese REE projects is at risk. Illegal mining and processing of rare earths inside China and their smuggling out of the country is destroying the Chinese REE industry, while only the downstream industries are profitable at the expense of the environment (Packey & Kingsnorth, 2016).

In an effort to reduce illegal depletion of domestic resources at the expense of the environment, Chinese authorities have been consolidating the domestic REE industry into big government-controlled enterprise groups (Roskill, 2015). Nonetheless, as long as illegal production of REE finds customers both inside and out of China, the prices of the elements will stay at alarmingly low levels.

The balance problem. But even if the REE prices were high enough to allow potential producers to initiate operations, there would still be important issues that would jeopardize the long-term viability of their projects.

An obvious reason for possible failure is the oversupply of REE in their relatively small market. The global consumption is of the order of 150 kt/a (165,000 stpy) (USGS, 2017) and any additional production of rare earths would cause a glut in the marketplace. A reasonable argument could arise at this point. Since new sources of REE are now available outside of China, it would be a good opportunity to change the current situation so that worldwide consumers stop buying from China, thus allowing new producers to obtain that significant share of the market. Nevertheless, the rationale behind this argument is not that simple.

The group of REEs consists of 15 different elements with interesting similarities but extremely different characteristics and behaviors. Their diversity in physical and chemical properties defines their individual demand in different applications and, in turn, their criticality. In addition to this, REE are not present in equal amounts in their host minerals. REE-bearing minerals generally contain most of the rare earths in varying concentrations but tend to be biased toward either LREE or HREE. In general terms, light REE are substantially more abundant in REE deposits than the heavy REE.

It is not possible to selectively target just one specific element of the REE group for mining. All REE have to be mined together and get separated through various metallurgical procedures. Hence, if the elements in higher demand have a lower abundance within these geological formations, the minimum quantity that needs to be mined, processed and separated must be at least the amount required for these critical applications (Binnermans & Jones, 2015). As a consequence, elements of higher abundance and lower criticality will be produced in larger than required quantities, and due to these surpluses, they will have to be stockpiled, thus increasing the costs of mining, processing and storing. This is the reason why, for the time being, cerium and lanthanum sell below cost (Kennedy, 2015).

That being the case, the deposit in Mountain Pass is rich in noncritical LREE (mainly lanthanum and cerium) and this has factually played a major role in its current economic status. Reportedly, there is already a surplus in the global market of the LREE that Molycorp had been producing. As if this is not enough, expanding the production of these specific elements may gradually affect market prices for all the other noncritical rare earths. For instance, an increase in supply by REE-separating companies in mid-2014 resulted in prices descending further, especially for dysprosium, praseodymium and neodymium oxides (Barakos, 2017; Mancheri, 2015).

But even if the production in Mountain Pass would have included large volumes of high-valued REE, the only way for Molycorp and for any other potential REE producer to sell the total amount of its planned production would be by marketing into China, which is the main global consumer of rare earths. This would place the companies in direct competition with a mature Chinese mining and processing sector with significantly lower costs and thus far lower prices (ERECON, 2015).

The broken REE supply chain. But neither the overall costs nor the low prices are the real problem facing the United States among other non-Chinese industrial nations. The actual problem is the absence of a robust and fully integrated value chain with sufficient capacity to translate the ore coming out of a REE mine into valuable end-products such as smart phones, wind turbines and electronic components for defense systems.

This vertical integration consists not only the mining and primary beneficiation of REE — which are likely the easy steps to take — but also the separation and purification of the individual REO and their refining to meet specific downstream technology applications (Fig. 2). Eight years after the REE crisis, it is now common ground that the separation of the individual elements is the most fundamental part of the overall supply chain, since it is both technically challenging and expensive to build and operate.

Rare-Earth Elements

Figure 2

The rare-earth element supply chain.

China is currently the only country that has developed this complete value adding chain — comprising of numerous independent companies dedicated to REE research and production, each providing highly differentiated technologies, processing, formulation, or component-specific applications.

On the other hand, the processing potentials of rare earths outside of China are limited with respect to the separation of LREE and none concerning the separation of HREE (Barakos, 2017; Machacek & Fold, 2014). The Lynas Advanced Materials Plant (LAMP) in Malaysia is currently the most advanced facility in the world for producing a mixed rare earth oxide concentrate that is free of any impurities and hazardous elements (e.g. naturally occurring radioactive materials — NORMs).

When it comes to the chemical separation of the individual REO, it can be accomplished by only a handful of companies outside of China. There are three European-based firms, namely Rhodia in France (also known as Rhône-Poulenc, and which is now part of Belgian Solvay and supplying technology to Lynas), Silmet in Estonia (which is owned by Molycorp) and the British company Less Common Metals. Additionally, there are a few Japanese companies such as Hitachi Metals, Santoku, Showa Denko K. K., Shin-Etsu Chemical and Nippon Yttrium (Barakos, 2017; Roskill, 2015).

In the United States there are no active REE processing facilities. Following the failure of Molycorp to establish a processing plant in Mountain Pass, UCORE is the only company that has entered into an agreement with IBC Advanced Technologies Inc. to develop a metallurgical processing method for the separation and purification of the REE coming out of the Bokan Dotson Ridge potential mine in Alaska. Through a customized SuperLig hydrometallurgical process at bench scale with the use of Molecular Recognition Technology, IBC successfully separated the entire suite of individual REE at high purity >99 percent (Izatt et al., 2016). The application of MRT is presented by Ucore as a revolutionary clean chemistry alternative to the more costly, slower and environmentally invasive solvent extraction-based methods of REE separation. So far, however, the company has provided no information regarding either the costs or the potential environmental impacts associated with the use of MRT. Hence, at the time of writing this paper, no safe conclusions can be drawn for the efficiency of this processing method.

By taking these facts into account, it is easily understandable why consumers prefer to be supplied by China and not from standalone mining companies who cannot replicate a complex REE value chain. To further highlight the significance of this issue, it must be pointed out that before its bankruptcy Molycorp was shipping all of its noncerium and lanthanum oxides to China for refining into high-value metals, alloys and then into valuable end-products with all that this situation implies (Kennedy, 2015).

Environmental impacts and legislation issues

The REE industry is characterized by another drawback, namely environmental impacts. Gaining the necessary permits to run a mine including the social licence to operate is a challenge for all mining operations but is a particular difficulty for REE producers if ores contain NORMs and if they will produce radioactive waste. Waste disposal areas are exposed to weathering conditions and have the potential to pollute the air, soil and water if adequate monitoring and protection measures are not utilized (Barakos et al., 2015). In addition to the presence of radioactivity, the use of dangerous chemicals and toxic compounds during the processing of REE can also result in negative environmental effects.

Lax compliance with the regulations has resulted in environmental consequences and illegal mining in China (Ali, 2014), while overly strict environmental regulations forced REE mining operations in Mountain Pass to stop in the first place (Barakos, 2017). The Chinese legacy of environmental damage due to REE mining and processing activities has raised social concerns and caused hesitation against any REE production activities elsewhere.

Nevertheless, the pressure to take action on REE had quickly swelled in Congress, the U.S. Department of Defense, the U.S. Department of Energy and elsewhere across the U.S. government. In the recent years, a series of bills were introduced to the Congress. Among the most important legislation enactments were the H.R. 4883 and S. 2006 bills that introduced the establishment of a National Rare Earth Refinery Cooperative to provide for the domestic processing of thorium-bearing REE concentrates (Barakos et al., 2016a).

Connecting potential mines to the REE market

Based on the above, the status quo of the REE market and industry does not allow for potential producers to initiate their projects in the foreseen future. Nevertheless, these discussions are deemed necessary not only for preventing potential projects from failure but also for determining which, if any, are the connection perspectives of U.S. potential REE projects to the domestic and global market.

Policies and strategies. To begin with, a change of policy is necessary now more than ever. China can hardly be blamed for its clever use of global mineral resources. Prior to the rise of REE mining in China, the United States dominated the world scene for decades, but the unsustainable U.S. mineral resource policies during the last 30 years have contributed to the present state of dependence.

Relying on export streams from China became easier and economically more feasible. However, stakeholders should think about short-term versus long-term. The decision to sit on the sidelines may work in a nearsighted scenario, but when a single entity has a near monopoly such a move will no doubt become less than desirable as time passes.

China is no longer mining REE for a source of income and political clout but first and foremost for its own benefit; its growing population is consuming REE at an astonishing rate. This is why China is trying not only to control the depletion of its own resources, but also seeks to invest in foreign exploration REE projects. In the recent past, China has been close enough to take control of some of the most significant REE sources in the rest of the world, including Mount Weld in Australia and the Mountain Pass Mine in California.

The latter was eventually sold in July 2017 to a Chinese-led consortium and it is likely that Beijing will have an influence over the development and direction of the Mountain Pass Mine. Similarly to other REE projects in the United States and around the world, the restart of production at the Mountain Pass Mine in the short-term remains unlikely.

A suggestion could be that the United States should play a waiting game and simply allow for reserves in China to be exhausted (Paulick & Machacek, 2017). Such a mindset, however, is troubling, since it would place an additional delay on the time it would take to ready a potential REE mine site or build a processing plant for the full separation of rare earths. In addition to this, the Chinese expansionary policy will keep on luring junior projects from all over the world to ship their products to China for further processing and fabrication.

China was able to establish an integrated value-adding chain of REE, but it has taken decades to achieve current capacities and capabilities and Chinese producers have been careful to keep this technology secret. Hence, such a technology cannot be duplicated in the short-term and that is something that the Western world has to realize and act accordingly.

It will take time and a lot of effort to catch up with China, let alone the fact that the cost of creating a large-scale, fully integrated value chain exceeds the financial capacity of any one company, industry or even nation. In such cases, the United States has historically used cooperatives to overcome market failures by spreading financial risk, gaining access to low-cost capital, and expanding market access, thus ensuring the production and lowering the cost for critical resources (Kennedy, 2015).

A cooperative would enable end users to act together and procure finished REE products that currently are available only from China. This value chain could provide a market for the U.S. REE resources, without being undercut by the Chinese monopoly.

Initially, however, the low REE prices and the elevated costs will still be a deterrent factor for new REE projects even in a cooperative. Thus, projects that can start with a low capital expenditure, and then run at low cost, may have a distinct advantage. Furthermore, the extraction of REE as co- or byproducts from existing mines is potentially an attractive way to bring new supplies rapidly on stream, possibly even "switch-on, switch-off" supplies that could react quickly to changes in demand and to the fluctuation of REE prices.

Stakeholders from the U.S. coal industry hope to repurpose old mines to produce REE, while recent research in the United States points out that the size and concentration of HREE as byproducts in some unmined U.S. phosphorites predominate over the world's richest REE deposits (Barakos et al., 2016b).

Regulations and legislation instruments. The enactment of direct and effective legislation in the United States has been an optimistic step toward a more robust and efficient REE supply chain. Yet, there is more that needs to be done. In the context of establishing a cooperative for the domestic REE industry, further regulations must be issued.

No mining or processing licence should be granted if there is an insufficient mining site remediation plan followed by a waste disposal and management project as well. The Chinese pollution problem, which is due to lax legislation that is now costing China billions of dollars to correct is to be avoided at any cost.

However, due to the current regulations on extracting and storing NORMs, many mines dump material containing REE with the rest of their waste products, despite the high value of such material (Kennedy, 2015). Thus the foundation of a corporation with the express purpose of extracting and storing radioactive materials like thorium could result in having additional REE sources without the cost of mining them.

It should be noted that REE do not harm the environment, bad practices do. Under modern technologies the mining and processing of REE might be just as good or bad as in any other mining industry sector (Barakos, 2017). Hence, local societies also need to be informed about the significance of REE production in order for the REE mining companies to obtain the social license to operate.

Marketability of REE mine products. The entire above are steps to be taken in the right direction, but they are not the most determinant factors that will connect a potential U.S. REE mine to the market. Given the size of the market, only a few of the exploration projects will actually become REE mines over the next decade; which ones will go into production is also difficult to predict. The only sure thing is that the different demands for the individual REE will play an important role.

The demand pattern for REE has changed in recent years with a tilt toward higher use of HREE (Paulick & Machacek, 2017). Demand is driven by the expansive interest in renewable and more efficient energy technologies, which rely, among others, on the magnetic and fluorescent properties of HREE.

Consequently, the development prospects of LREE suppliers, like Mountain Pass, seem to be low; only a few of the mines that can produce high-demand and commercially recoverable HREE may start operations.

Nevertheless, the Chinese involvement in the Mountain Pass Mine may be a positive. Shenghe Resources, which is leading the consortium, can bring processing experties as well as its experience of marketing rare earth products. On the other hand, among the HREE-oriented U.S. REE potential projects, Bokan Mountain seems to have some potential. However, until the MRT proves to be a feasible REE separation method the perspectives of this project will remain uncertain.

And if this is not enough, potential REE producers must carefully assess which of their products can be sold entirely and which will be stockpiled. For instance, elements such as holmium, erbium, thulium, ytterbium and lutetium, despite being classified as HREE, have limited to no marketability and should not be considered in the REE basket price calculations. The marketability of REE included in the deposit is, therefore, significant.

The existence of negotiations and/or agreements with potential customers is critical and can determine the REE basket price and marketing policy of the mining company. Having a fixed, long-term pricing deck on customer-specified products (either oxides or mix concentrates) will define the feasibility prospects of the REE project in a more secure manner.

Rational evaluation of potential REE projects. Despite the significance of marketability, no relevant study is included in the majority of published technical reports and prefeasibility studies conducted for potential REE projects in the United States and around the world (Barakos, 2017). Additionally, it is expected in all reports that all products will be sold at unreasonably high REE prices.

Such controversial reporting practices have infused the U.S. REE industry and are widely adopted despite being in disagreement with regulated reporting standards.

Thus, a more careful assessment is needed, where all the erroneous practices are eliminated and the boundary conditions defined in this paper are considered. A proper evaluation will not necessarily mean that any examined REE project will have a positive economic result, but at least it can give more robust indications on whether to further invest in the project or not.

Conclusions

In this effort to determine the connecting factors between potential U.S. REE projects and the marketing of rare earths some interesting conclusions were found.

First and foremost, China still holds the monopoly power and despite all efforts nothing has really changed; as China goes, so goes the global REE market. Many attribute the issue of Chinese monopoly power to the low REE prices, but this is not the only reason. Even if the prices were higher, the U.S. potential market entrants would have to merchandise part of their production into China, in order to sustain themselves.

In order to be competitive, future REE producers should then not only concentrate on the mining side but also try to offer the entire supply chain from mining to end-products in high demand and reach agreements with potential buyers inside and out side of China before proceeding to production.

The United States, along with the rest of the western world, will have to accept the fact that either they will eventually become only the REE end-product customers of China or, that, they will have to cooperate and re-establish the raw materials value chain from the very beginning — having to take a steep and risky road to re-industrialisation, in order to compete with China. ■

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