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Yanhai Aluminum Co.: A Question of Costs

It was a cold Thursday afternoon in December 2019, and Min Yang, the CEO of Yanhai Aluminum (延海铝制公司), sat in her office at the top of the company's Binzhou, China headquarters, looking out over the bay. A light snow was falling as Yang pondered whether to expand and update the company's aluminum smelting plant in Yunnan—the only one of its smelters that ran on hydropower, rather than coal. It was a costly idea, but if done well, it could build the company's reputation as a "green" primary aluminum producer and set Yanhai up for the future as the country pushed to move away from coal.

There was a knock at the door. "Please come in," Yang said, and the two visitors sat in the chairs across from her desk: Chief Strategy Officer (CSO) Ailing Zhou, a woman with a bob hairstyle and a gray suit, to the left, and Chief Marketing Officer (CMO) Yichen Liu, a man with close-cropped hair and a blue suit, to her right. Yang had tackled tough questions with Zhou before, and while Liu was new to the aluminum industry, he was a C-suite veteran with years of experience in financial services.

"I've just had a meeting with the board," Yang said. "They proposed that we make a major expansion to the Yunnan plant, nearly doubling its annual capacity. What's more, they suggested that we invest in turning it into a fully 'green' aluminum plant. It already runs on hydropower, unlike our three coal plants, but we could build on that by adding automation to reduce our greenhouse gas emissions, and solar panels and battery storage systems, so that it can better handle any power interruptions. I'm supposed to make a recommendation by next week about whether we should go ahead with the project."

Yang's colleagues looked as surprised as she had felt when first receiving this news. "That's a big proposal," Liu said. "What inspired it?"

"Well, the government has been pushing for smelters to shift to renewable power," Yang said. "They've been shutting down small coal-fired plants, and a lot of smelters are moving capacity to Yunnan because of the region's hydropower. We already have our factory there, so why not build on that advantage? Right now, only about 15 to 17% of the world's primary aluminum production is 'green.'[1] But more and more companies—like European carmakers, for instance—are looking to prove their sustainability to customers, and that includes having a 'green' supply chain.[2] They might even be

Professor Ramon Casadesus-Masanell and Research Associates Johnson Elugbadebo, Jordan Mitchell, and Karen Elterman prepared this case. This case was developed from published sources. Funding for the development of this case was provided by Harvard Business School and not by the company. The protagonists and Yanhai Aluminum Co. are fictional. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

willing to pay more for green aluminum.[3] If we add automated control systems that reduce our greenhouse gas emissions, we could double down on our 'green' reputation. We anticipate commanding a 4% price premium over conventional primary aluminum if our Yunnan smelter achieves full 'green' status."

"Those seem like pretty good reasons," Zhou, the CSO, said. "But I'm guessing you have some concerns, or you wouldn't have called us here."

"You know me well," Yang said. "As you can imagine, building something of that scale isn't cheap. While the automation might lower our operating costs in the long run, it's a big investment up front. All told, the project will probably cost in the range of $7 billion. And the board only wants to go through with it if we can expect a pre-tax return on investment of 15%. I'm just not sure if that's realistic. Right now, aluminum prices are near a 20-year low, at $1,811 per ton."

Yang paused and handed her colleagues each a copy of the report she'd begun to draft, based on her meeting with the board. "So…what do you think we should do?" she asked.

Report Regarding Possible Expansion of the Yunnan Plant (2019)

Proposal: Expand the current hydro powered 1.2-million-ton capacity aluminum smelting facility in Yunnan to 2.3 million tons and further "green" the plant by installing automated control systems, which greatly reduce emissions of potent greenhouse gases known as PFCs (perfluorocarbons).[4]

- **Phase 1:** Upgrade the existing 1.2-million-ton capacity to add automation systems. Additionally, install solar panels and energy storage systems to mitigate the risk of electricity interruption in times of drought. The estimated total cost of this phase is US$1.5 billion.

- **Phase 2:** Add 1.1 million tons of capacity at the Yunnan plant, including the latest automation technology, at a capital cost of approximately US$5.5 billion, bringing its total capacity to 2.3 million tons. This would make Yunnan—our only plant powered with renewable energy—into our largest plant, and cause "green aluminum" to comprise over a third of our output.

Note: *While implementing Phase 1 alone is a possibility, we will only pursue Phase 2 if Phase 1 is also implemented.* That is, the expansion cannot be completed without first upgrading the plant. The backup energy systems added in Phase 1 will serve as protection against hydropower shortages (e.g., drought) and are needed to support the additional capacity in Phase 2. Additionally, installing automation in only the expanded portion of the plant would lead to complications due to inconsistencies (e.g., training workers on multiple conflicting processes).

Background on "Green" Aluminum: Primary aluminum smelting (as distinct from the previous stage, alumina refining)[a] requires 2,600 liters of fresh water and between 13 and 15 megawatts (MW) of energy per ton of aluminum.[5] Globally, the underlying energy source of electricity shifted from gas and oil in the 1970s to hydroelectricity by 2019, especially in the Americas and Europe. However, the Middle East and China continue to rely mostly on natural gas and coal, respectively, while Africa relies on hydroelectricity and coal in nearly equal parts.[6] As of 2019, about 80% of primary aluminum smelting in China uses electricity from coal.[7] [See **Exhibit 1** for energy sources for primary aluminum smelting in 2019.] Each ton of aluminum produced using coal power releases 13 tons of greenhouse gases,[8] about 80% of which are emitted during smelting.[9] In 2019, global primary aluminum consumption was reported to be around 62.3 million tons, though figures vary slightly across sources.

[a] In alumina refining, raw materials including bauxite, fresh water, caustic soda, and calcined lime were used to produce alumina, a key input to primary aluminum production.

While there is no single, universally accepted definition of "green aluminum," there are two main ways[b] to green the primary aluminum smelting process.[10] The first is to shift to renewable energy sources, such as hydropower.[11] Doing so can cut total production emissions by 85%.[12] In China, firms are increasingly moving their capacity to the Yunnan province, where hydropower is abundant.[13]

A second method is to address emissions that occur during the production process. Relatively simple automation can make a major impact in cutting these emissions.[14] For example, our factories currently use a manual method of stopping "anode effects," a chemical reaction that emits PFCs. Currently, workers use a stick to stir molten aluminum, causing the liquid metal to touch the anode (a block of material that conducts electricity into the pot),[c] which disrupts the reaction by short circuiting it.[15] However, automation systems can cut down significantly on the duration of the anode effect (and therefore its emissions), while also reducing manual labor.[16]

Motivation: First, China, though well established as a primary aluminum producer, is just beginning a major transition toward green aluminum. Earlier this decade, primary aluminum production in China surged, driven by lower labor costs and fewer environmental restrictions, even as it fell in North America.[17] As of 2019, China accounts for about 56% of global aluminum production.[18] [See **Exhibit 2** for global end use of aluminum by sector, and **Exhibit 3** for primary aluminum production volume by region.] However, as climate change poses an increasing threat, our country has set a goal of reaching carbon neutrality by 2060[19] and getting 20% of its primary energy from renewable sources by 2030.[20] As a result, the government is pushing aluminum smelters to transition away from coal power.[21] From 2018 to 2019, production volumes shrank by 3.8% due to "supply-side" reforms which shuttered small-capacity plants that were powered by coal.[22] By expanding, we could take advantage of this market.

Second, our Yunnan plant is uniquely well positioned for upgrade and expansion. While our other three plants are coal powered, the Yunnan plant takes advantage of the region's geography and already runs on hydropower. Adding automation there is a natural fit, since we will then be able to market our aluminum as being "green" throughout the production process.

Third, Yanhai is well established in our industry, with significant know-how in smelting technology and a positive reputation with alumina suppliers and energy providers due to prompt payments.

Table A Estimated Operating Costs at the Yunnan Plant Under Different Scenarios ($/Ton)

Category	Current	Phase 1	Both Phases
Electricity cost	679.7	635.2	635.2
Alumina cost	728.4	688.7	605.3
Plant fuel	18.5	10.2	5.2
Consumables	194.7	194.7	194.7
Maintenance and other	132.8	112.2	92.1
Labor (salaried) – long-term contracts	22.3	22.3	13.3
Labor (hourly) – short-term contracts	44.6	44.6	32.6
Freight	28.3	28.3	28.3
Rent & other G&A	6.2	6.2	5.2
Financing	6.3	6.3	6.3
Marketing	24.1	24.1	12.8
TOTAL	1,885.9	1,772.8	1,631.0

Source: Casewriters; CRU, "Aluminum Smelter Cost Data – 2019," Prepared for Harvard Business School, June 2024.

[b] This discussion excludes the capture and storage of carbon emissions (difficult in aluminum smelting because of the low concentrations of CO2 released) and the purchase of carbon offsets to 'cancel out' emissions.

[c] A pot was a large, carbon-lined container where alumina (aluminum oxide) was converted into molten aluminum.

Phase 1 will result in cost savings for electricity and alumina due to renegotiated contracts. We will also see savings on plant fuel due to new energy management systems and on maintenance due to automation (damage to machinery is less likely when processes are automated).

If both phases are implemented, we will see additional cost savings due to increased bargaining power derived from larger purchase volumes of alumina and fuel, and due to economies of scale (maintenance, salaried labor, rent, and marketing).

Risks: The main source of risk from the project, aside from its capital costs, is fluctuations in hydropower availability. Hydropower is seasonal and, in the event of a drought, may become scarce.[23] Aluminum production requires a continuous supply of electricity, any interruption of which could cause severe disruption to the smelting process.[24] For example, if electricity stops due to an outage, there is a risk that the metal in the pots could solidify, which would require repairs and a relining of all the pots, leading to additional costs and a loss of materials.[25] Furthermore, specialist crews are required for three to four months after an emergency shutdown to restart three to five pots per day until the entire potline stabilizes.[26] This risk can be mitigated by investing in solar power and energy storage systems that would allow us to save excess power created during peak periods for times when availability is low.[27]

There are also other firms working on reducing carbon emissions by developing "inert anodes," which are made of different materials and release only pure oxygen rather than carbon.[28] Rio Tinto and Alcoa are currently developing inert anode technology through a joint venture with funding from Apple, and they plan to eventually license the technology,[29] though it has not yet been deployed at an industrial scale.[30] It is possible that these more experimental technologies will outshine the benefits we gain from automation and that we would be better off investing in them when they become available.

Conclusion: We feel that it is an opportune time to consider an aluminum smelter expansion at Yunnan given projected long-term demand for green aluminum and the existing plant's use of hydropower, a renewable energy source. However, a more detailed financial analysis will be necessary to guarantee that the plant can expect a pre-tax return on investment (ROI) of 15% in line with investor desires. [See **Appendix A** for an explanation of ROI and its relationship to the Internal Rate of Return (IRR).]

When Yang's colleagues had read the report, she handed them an information packet containing, among other things, the cost structure of Yanhai's four aluminum smelting plants. (See **Exhibit 4**.) Liu took out his laptop, Zhou a pencil and calculator, and they each did a series of calculations.

After several minutes, Liu, the CMO, said, "If you look at the margin, three of our four smelters are currently losing money on every ton[d] of aluminum sold. The local Binzhou plant is losing $74 per ton of aluminum produced, while the Huimin plant is losing $92 per ton. The Zouping plant is making money on each ton—but only $2.80! And the Yunnan plant is the worst of all, losing $336 per ton. Honestly, given this information, a costly expansion seems out of the question. Instead, we should probably shut down the unprofitable plants, at least for a while. Later, we can reopen the plants, and *maybe* begin to consider the expansion." (See **Exhibit 5** for cost structures among active and inactive smelters.)

"I strongly disagree with the proposal to close the plants," Zhou said. "For one thing, an orderly closure of our smelters would cost between $250 per ton—at Yunnan—and $322 per ton, at Binzhou. Restarting a plant is complicated, too: it requires additional labor and materials and costs at least $200

[d]All mentions of "tons" in this case refer to metric tons, which are 1,000 kilograms or ~2,200 pounds.

per ton.[31] Secondly, while it's true that we're losing money now, if we shut the plants down, we might be losing *even more*."

"Are you out of your mind?" Liu challenged her. "If we shut those plants down, we'd stop bleeding money—no electricity costs, no alumina, no maintenance. How could we possibly lose more by closing them than by running them at a loss?"

"It's true we'd avoid some costs," Zhou replied calmly. "But not all. We'd still be stuck with fixed costs we can't escape in the short run, like capital charges from past investments, long-term rent agreements, and salaried staff we've already committed to, including the new management team in Yunnan."

"But those aren't permanent," Liu countered. "Over time, we could renegotiate or let those contracts expire. Doesn't that make shutdown the better call?"

"Eventually, yes," Zhou said. "But not today. Right now, those costs are sunk. We're locked in for years. Shutting down just means we lose revenue while still paying a big chunk of the bill."

Yang looked puzzled. "Wait! So, Zhou, are you saying you support the expansion?"

Zhou looked thoughtful. "I think the expansion is worth considering," she said. "But to really answer this question, we need more information. The profitability of these plants greatly depends on the price of aluminum. So we need to better understand what future prices will be."

"That's something I've been thinking about, too," Yang said. "I'm cautiously optimistic: In the past, prices have been substantially above the current price of $1,811." (See **Exhibit 6** for primary aluminum prices over time.) "Just a year ago, they were $2,138 per ton. So it's possible that they'll soon rebound. For example, future demand might outstrip current supply, which would push prices up. In fact, in one research report, the analysts estimate a 50% probability that demand for primary aluminum[e] will have grown by 3% two years from now. They also give a low estimate, with 25% probability, of demand decreasing by 4%, and a high estimate, also with 25% probability, of demand increasing by 6%."

"That's encouraging," Zhou said. (Liu had been quiet since the argument about closing the plants.) "But I want to remind us that unexpected events can always throw off the forecast. Recently, there's been news of a number of cases of pneumonia in the Hubei province, caused by an unknown virus. I don't mean to be negative, but if something like that spreads, many of the businesses we supply to might have to shut down, which would seriously curtail demand."

It was now 4:30 in the afternoon. Yang swiveled her chair to glance out once again through the large windows behind her desk. The snow had stopped, but gray clouds still filled the sky. She turned back toward her colleagues.

"That's true," Yang said, "and thank you for pointing it out." Normally, demand for primary aluminum was inelastic, particularly in the short run, since it was a vital input in industries like aerospace, automotive, and construction, where substitutes were often limited or impractical. But Zhou was right that if even *those* industries shut down, it could have a major impact on their business.

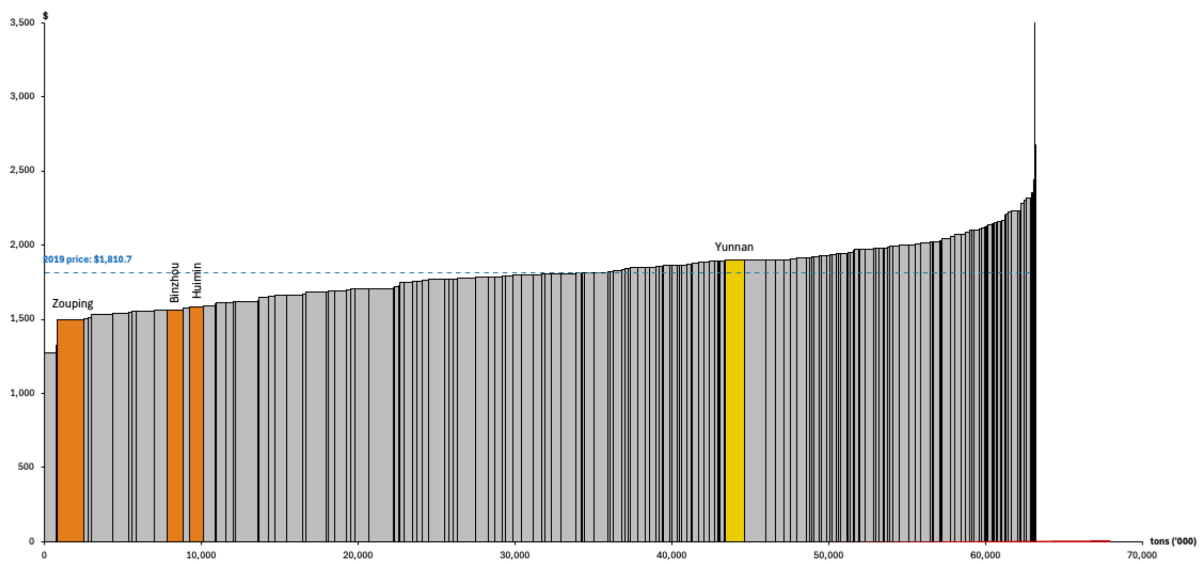
[e] Primary aluminum was produced by taking mined bauxite rock and separating out the aluminum through two main stages: aluminum refining and aluminum smelting. In addition to primary aluminum, there existed a secondary (recycled) aluminum market with a different production process, which used scrap aluminum as its main raw material and required 90% to 95% less energy to make. Primary and secondary aluminum were different products with different applications and demand functions; Yanhai was only equipped to make primary aluminum.

"Regardless," Yang continued, "to actually predict prices with any accuracy, we need to consider not just demand, but supply. That's what I'd like to ask of you next. A new CRU[f] report just came out with data on cost structures throughout the industry.[32] Why don't you each develop a supply curve based on that data, and bring them to me next week?"

To Build or Not to Build?

The next Thursday, the three executives again convened in Yang's top-floor office. According to the data they'd received, there were currently 181 active primary aluminum smelters in the world.[33] The data included estimated cost structures for each plant in 2019. These costs were expected to stay relatively stable over the coming years, and no new supply was expected to come online for the foreseeable future, given the current low price of aluminum. Liu, the CMO, presented his analysis first:

Figure A Liu's Supply Curve



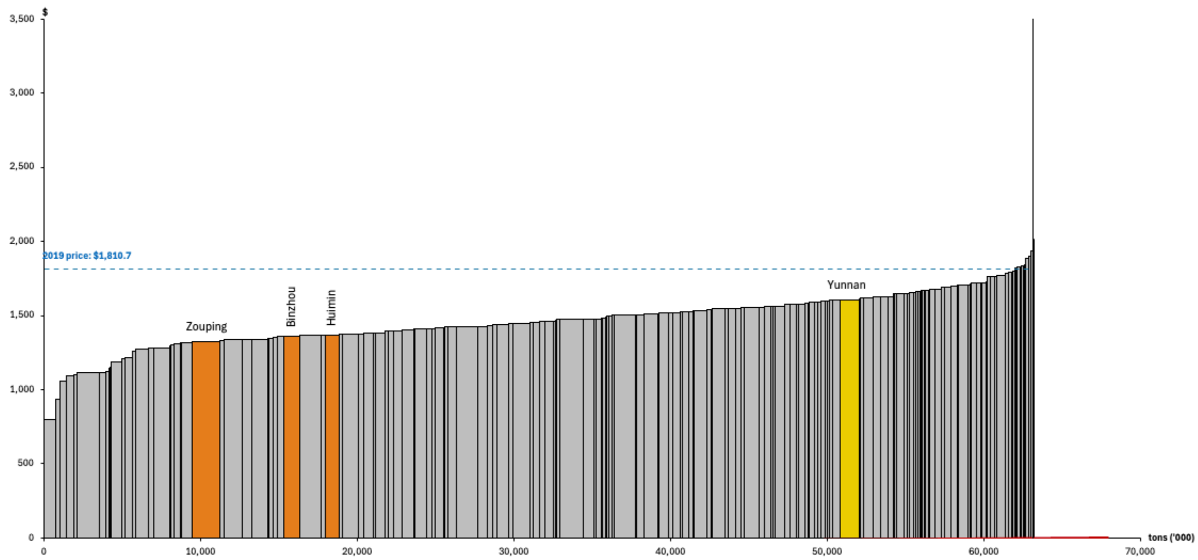
Costs included: Electricity, alumina, plant fuel, consumables, maintenance, labor (salaried), labor (hourly), freight, rent + G&A, financing, marketing, capital costs, closing costs

Source: CRU, "Aluminum Smelter Cost Data – 2019," Prepared for Harvard Business School, June 2024.

"According to my calculations," Liu said, "over the long run, I expect the price of aluminum to rise above $2,200/ton, compared to $1,811 now." Next, Yang asked Zhou, the CSO, to present her findings:

[f] CRU was a business intelligence company (originally known as the Commodities Research Unit) that focused on the metals, mining, and fertilizer industries.

Figure B Zhou's Supply Curve



Costs included: Electricity, alumina, plant fuel, consumables, labor (hourly), freight, marketing, closing costs

Source: CRU, "Aluminum Smelter Cost Data – 2019," Prepared for Harvard Business School, June 2024.

"In my analysis," Zhou said, "aluminum prices could exceed $2,200 in the mid-term, but only if the optimistic demand forecasts from industry experts materialize."

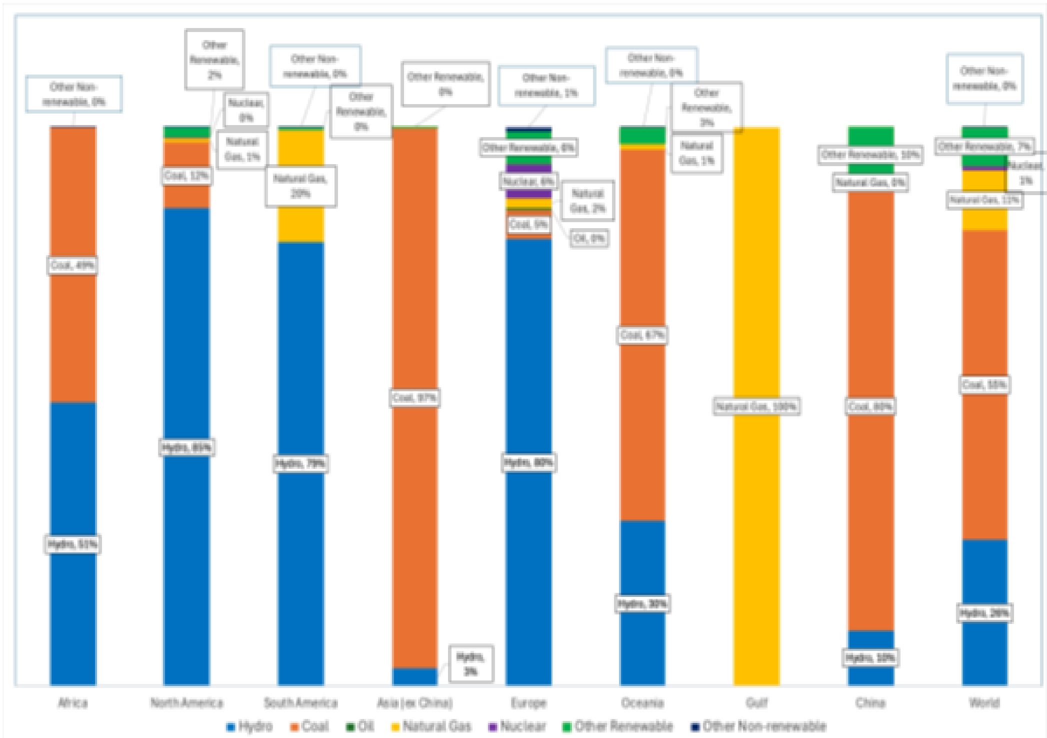
Yang thanked her colleagues and dismissed them before turning her attention back to the supply curves laid out in front of her. The two graphs told very different stories. Still, one thing now seemed clear: Even at the current low aluminum prices, both supply curves indicated that Binzhou and Huimin should remain operating.

The real question was what to recommend regarding the Yunnan smelter. Should Yanhai double down, expanding the plant and investing heavily in both capacity and environmental upgrades? Or should it take the opposite path, shutting down the Yunnan facility entirely?

Global aluminum prices were at a historic low. But when would they rebound, and by how much? And what moves would competitors make? Would they close older plants or build new capacity?

With so many unknowns still in play, Yang faced significant uncertainty as she weighed Yanhai's strategic options. What should she propose at next month's board meeting? And was there any critical information that might help tip the scales?

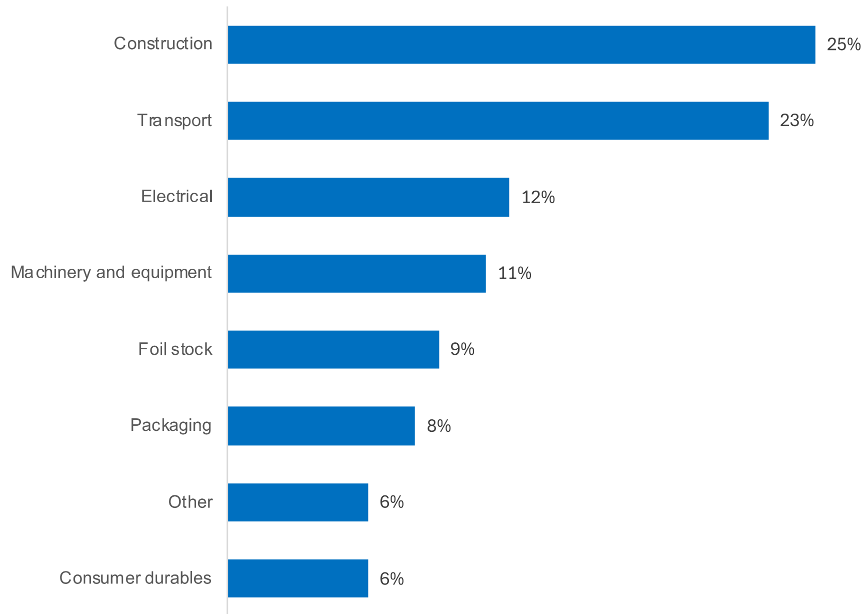
Exhibit 1 Energy Sources for Primary Aluminum Smelting in 2019



Source: International Aluminium, "Primary Aluminium Smelting Power Consumption," https://international-aluminium.org/statistics/primary-aluminium-smelting-power-consumption/?publication=primary-aluminium-smelting-power-consumption&filter=%7B%22row%22%3Anull%2C%22group%22%3A1%2C%22multiGroup%22%3A%5B%5D%2C%22dateRange%22%3A%22annually%22%2C%22monthFrom%22%3Anull%2C%22monthTo%22%3Anull%2C%22quarterFrom%22%3A1%2C%22quarterTo%22%3A4%2C%22yearFrom%22%3A2019%2C%22yearTo%22%3A2019%2C%22multiRow%22%3A%5B7%2C15%2C16%2C8%2C9%2C10%2C11%5D%2C%22columns%22%3A%5B39%2C40%2C41%2C42%2C43%2C44%2C45%2C46%2C47%5D%2C%22activeChartIndex%22%3A0%2C%22activeChartType%22%3A%22pie%22%7D, accessed June 2025.

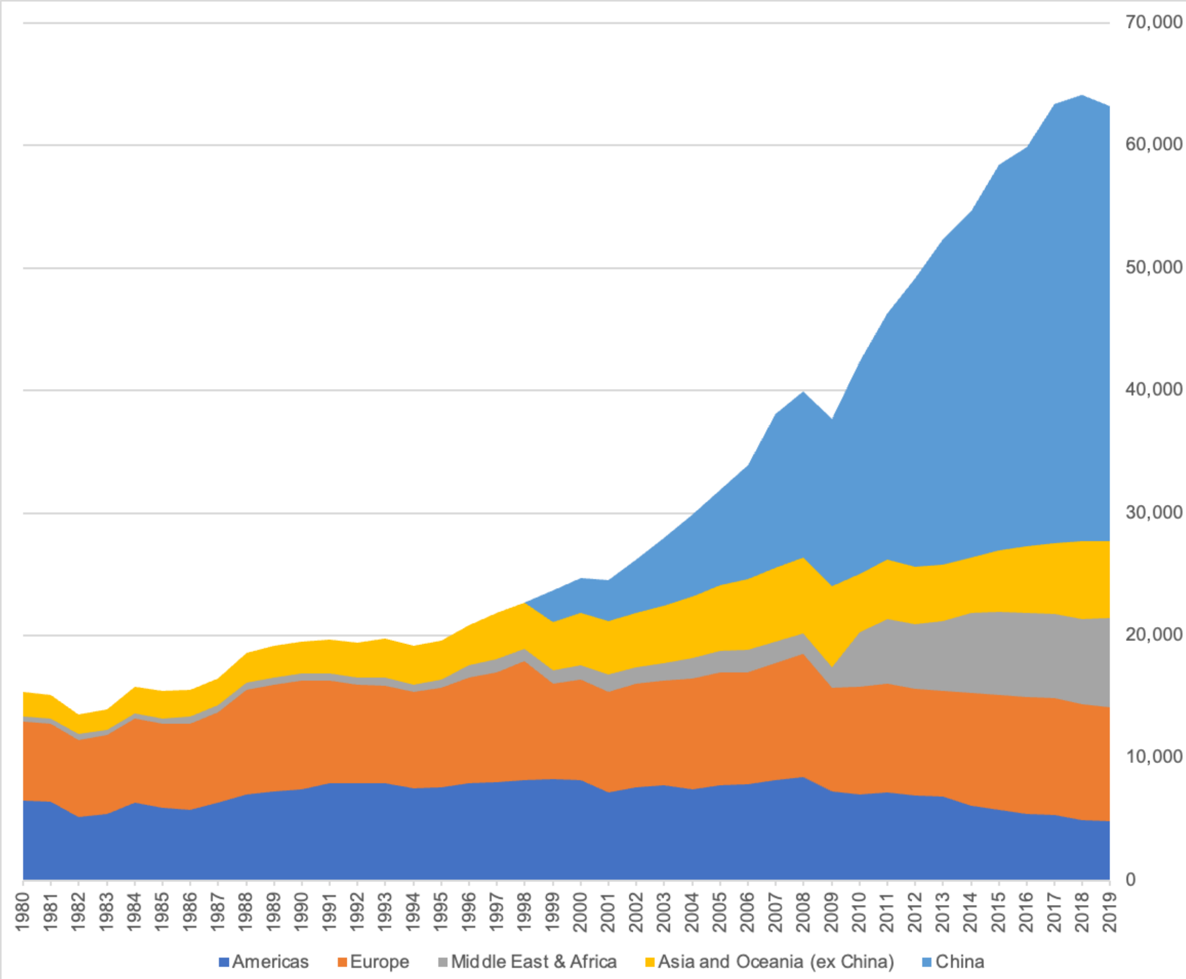
Note: Figures are rounded. Energy sources labeled "0%" made up more than 0.0% but less than 0.5% of a region's energy usage for primary aluminum smelting.

Exhibit 2 Global End Use of Aluminum Products by Sector (2020)



Source: "Global end use of aluminum products in 2020, by sector," Statista, accessed July 21, 2024.

Exhibit 3 Primary Aluminum Production Volume by Region, 1980–2019 ('000 tons)



Volume in tons (000s)	**Americas**	**Europe**	**Middle East & Africa**	**Asia and Oceania (ex China)**	**China**
2019	4,855	9,303	7,248	6,269	35,554
2009	7,267	8,463	1,681	6,611	13,684

Source: International Aluminium, "Primary Aluminum Production," https://international-aluminium.org/statistics/primary-aluminium-production/, accessed May 14, 2024. 2019 total figures are from CRU, "Aluminum Smelter Cost Data – 2019," Prepared for Harvard Business School, June 2024. The relative percentages by region from the International Aluminium Association were applied to CRU's total for 2019 only.

Exhibit 4 Cost Structure of Yanhai's Four Aluminum Plants, 2019 ($/Ton Except Where Noted)

	Yunnan	Binzhou	Huimin	Zouping	Factors Affecting Cost at the Yunnan Plant
Capacity (000 tpy)	1,200.0	1,270.0	880.0	1,850.0	
Electricity usage (MWh/t)	13.4	13.7	13.7	13.2	
Electricity price ($/MWh)	50.8	45.3	45.3	44.1	
Total electricity cost ($/ton):	679.7	621.8	621.8	582.7	The Yunnan province experienced a record drought in spring and early summer of 2019, with the rainy season arriving later than usual.
Alumina usage (t Alumina oxide/t)	1.9	1.9	1.9	1.9	
Alumina price ($/t Alumina oxide)	380.2	318.8	318.8	308.6	
Total alumina cost: ($/ton)	728.4	610.5	609.9	594.3	The Yunnan smelter paid more due to sourcing from more distant suppliers and to contract terms. Still, these were some of the lowest costs per ton of alumina among Chinese smelters. Only 6 plants in China had lower per-ton alumina costs, and 3 of those belonged to Yanhai.
Plant fuel	18.5	5.2	5.3	4.9	Yunnan used more fuel due to different process heat sources and less efficient fuel systems.
Consumables	194.7	280.8	280.8	280.8	Yunnan used significantly fewer consumables due to tech and operational differences.
Maintenance and other	132.8	80.3	83.7	97.7	Yunnan incurred more maintenance-related costs due to older infrastructure and more intensive upkeep.
Labor (salaried) - long-term contracts	22.3	12.2	12.4	9.1	Yunnan had more long-term staff.
Labor (hourly) - short-term contracts	44.6	63.2	63.3	51.3	Suggests lower wage rates due to local labor market advantages.
Freight	28.3	9.7	9.7	9.7	Yunnan was a mountainous region, and its fast-moving rivers, while ideal for hydropower, were not suited to shipping. Although there were highway and railroad networks, navigating this terrain could still be costly. Yunnan was farther from downstream customers and port access was worse.
Rent and other G&A	6.2	6.9	7.5	4.9	(Comparable to rent elsewhere)
Financing	6.3	3.9	3.9	3.8	Financing costs were higher at the Yunnan smelter because aluminum produced there took longer to reach paying customers (due to factors such as greater distance to market, less efficient logistics, longer storage times, and extended payment terms), resulting in a longer and more costly cash conversion cycle.
Marketing	24.1	9.4	9.4	9.4	Because the region's hydropower had attracted numerous other manufacturers, Yanhai had increased its marketing efforts in Yunnan in order to stand out. Specifically, Yunnan engaged in more downstream sales/branding efforts and operated in more competitive markets.
Capital Costs	260.7	181.5	196.0	159.6	Difference due to recent investments and asset upgrades.

Source: CRU, "Aluminum Smelter Cost Data – 2019," Prepared for Harvard Business School, June 2024; see endnote for additional sources.[34]

Notes: t = ton; MWh = megawatt hours; tpy = tons per year; G&A = general and administrative; ANSC = average non-sunk costs

Exhibit 5 Average 2019 Cost Structures Among Active and Inactive Smelters

($ / metric ton except where noted)	**Active Smelters**	**Inactive Smelters**
Capacity (000 ton per year)	349.3	206.1
Electricity usage (MWh/t)	14.4	14.9
Electricity price ($/Mwh)	37.6	50.0
Total electricity cost:	541.9	742.5
Alumina usage (t Alumina oxide/t)	1.9	1.9
Alumina price ($/t Alumina oxide)	371.7	369.3
Total alumina cost:	716.2	713.3
Plant fuel	14.7	13.3
Consumables	262.6	295.5
Maintenance and other	166.9	192.1
Labor	123.3	183.1
Freight	26.5	19.9
Rent and other G&A	25.3	33.6
Financing	8.0	14.8
Marketing	17.1	19.9
Capital Costs	310.9	254.1
Total Costs	2,213.2	2,482.2

Notes: The economic decision for an active smelter was whether to continue production, while for an inactive smelter, it was whether to restart production.

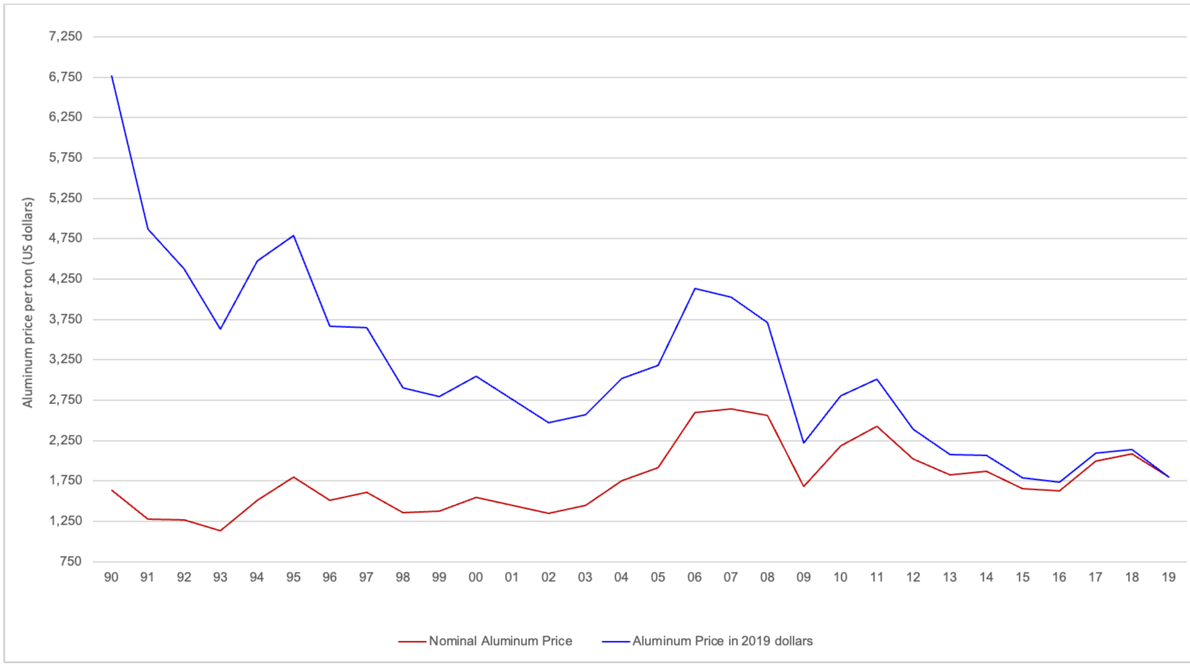
For active smelters, around 71% of labor costs were for hourly (direct) labor, with contracts that could be easily terminated if the smelter shut down.

Financing costs represented the costs associated with financing the metal produced between the moment it came out of the aluminum smelter casthouse and the receipt of payment by the client.

Generally, rental contracts were long-term, multi-year agreements that were difficult to terminate early.

Source: CRU, "Aluminum Smelter Cost Data – 2019," Prepared for Harvard Business School, June 2024.

Exhibit 6 Primary Aluminum Prices: Nominal and Inflation-Adjusted Prices (constant 2019 dollars)



Source: Nominal Aluminum Prices based on London Metal Exchange (LME), Refinitiv Workspace, accessed via Harvard Business School, May 1, 2024. Annual average prices were calculated based on monthly averages within each year. Inflation-adjusted values were calculated by applying annual inflation from world inflation rates, Federal Reserve Bank St. Louis, https://fred.stlouisfed.org/series/FPCPITOTLZGWLD, accessed August 8, 2024.

Appendix A: ROI with Infinite Time Horizon (Perpetuity) and Its Relationship to IRR

In capital budgeting and investment analysis, Return on Investment (*ROI*) and Internal Rate of Return (*IRR*) are both widely used metrics. When evaluating investments that generate perpetual cash flows — that is, constant annual returns that continue indefinitely — *ROI* and *IRR* converge to the same value. This note explains *ROI* in the context of a perpetuity and its direct relationship to *IRR*.

ROI with Infinite Time Horizon (Perpetuity)

Return on Investment (*ROI*) typically measures the gain or return from an investment relative to its cost. When an investment generates a fixed annual profit forever, the *ROI* can be expressed as:

$$ROI = \frac{Annual\ Cash\ Flow}{Initial\ Investment}$$

For example, if a machine costs $1,000,000 and produces $100,000 in profit every year in perpetuity, then:

$$ROI = \frac{100{,}000}{1{,}000{,}000} = 10\%\ per\ year$$

This result is equivalent to the yield on a perpetual asset.

Relationship to IRR

The Internal Rate of Return (*IRR*) is the discount rate (*r*) that sets the Net Present Value (*NPV*) of future cash flows equal to zero. For a perpetuity, the *NPV* of future cash flows is:

$$NPV = \sum_{t=1}^{\infty} \frac{C}{(1+r)^t} = \frac{C}{r}$$

where *C* stands for the annual cash flow (or profit) generated by the investment.

Setting *NPV* equal to the initial investment and solving for *r* gives:

$$\frac{C}{r} = Initial\ Investment \rightarrow r = \frac{C}{Initial\ Investment}$$

This implies that:

$$IRR = ROI$$

when the cash flows continue forever and are constant. In our example:

$$IRR = \frac{100{,}000}{1{,}000{,}000} = 10\%$$

Conclusion

When analyzing perpetual investments, the *ROI* and *IRR* are numerically identical and equal to the annual cash flow divided by the initial investment. This equivalence simplifies analysis and provides a straightforward way to interpret the return characteristics of perpetual assets.

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