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THE NEED FOR ENERGY EFFICIENCY IN BAYER REFINING

Lawrie Henrickson[1]
[1]WorleyParsons Minerals & Metals, 2645 Skymark Avenue, Mississauga, Ontario, L4W 4H2

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Abstract

This paper examines the impact of energy efficiency on Alumina refinery operating cost and profitability. The impact of rapid refinery construction during the recent economic boom is reviewed. The various energy sinks in a refinery are examined, with a view to targeting the largest contributors. The perception that the bauxite type contributes significantly to energy efficiency is also examined. The need for ongoing modernization and capitalization of a refinery is discussed, as well as the best time in the market cycle to execute energy improvement initiatives.

Introduction

During the recent economic boom, the high Alumina price encouraged rapid expansion of world Alumina refining capacity. The main objective was speed rather than efficiency, so refineries were constructed faster than ever before, especially in China, taking advantage of lucrative profit margins. In this environment, low operating cost is not always given due priority during design.

However, when the world economy crashed in late 2008, the steep decline in commodities prices caused a severe profit squeeze at many refineries. The lack of built-in efficiency caused many refineries to reduce production or commence full shut-down. One of the more significant operating cost pressures was energy, even with much lower unit energy costs.

This paper examines the key energy efficiency drivers for a refinery, and evaluates the trade-off of capital cost against operating cost, in an environment of rising long-term energy prices. The option of Brownfields retrofits against Greenfields installations is also discussed.

The Recent Economic Boom

The recent economic boom saw a large and rapid expansion in world refining capacity. The focus was on speed of execution, so many refineries were built with sub-standard energy efficiency. This was not a problem for the owners during the boom times, with good profits enjoyed by all.

Similarly, older and less-efficient producers also enjoyed the boom-time profits, maximizing their revenue by maximizing their output.

The Economic Slowdown

The sudden drop in Aluminum and Alumina prices as a result of the economic slowdown towards the end of 2008 suddenly put all the less efficient producers under major pressure. Numerous refineries were idled or even permanently shut-down, including some that were operational for less than 12 months.

However, some refineries continued at full production, remaining competitive due to low operating costs. Many refineries in Brazil and Australia remained at full production, despite vastly different bauxite characteristics and cost structures. Clearly some producers were appropriately set-up to survive the challenging times.

The Industry Cost Curve

The Industry Cost Curve, illustrated in Figure I below, shows the cumulative production of Alumina, by producer, sorted from lowest operating cost to highest.

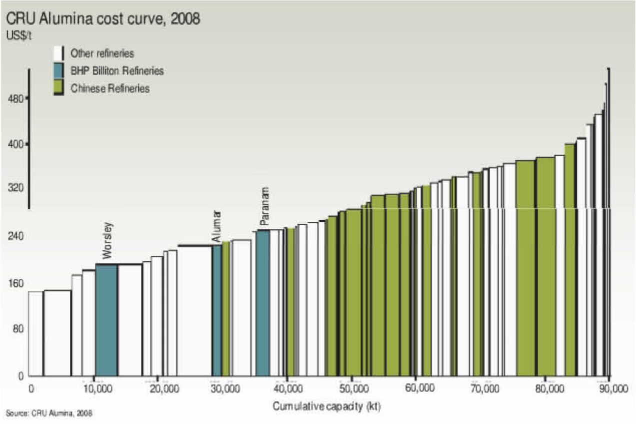

Figure I. Industry Cost Curve [1]

New refineries typically enter near the bottom of the cost curve, where efficient refining measures maximize productivity and minimize OPEX. However, the need for rapid expansion during the recent economic boom often saw refining efficiency sacrificed for execution speed. Many of the new installations did not enter in the ideal position at the bottom of the cost curve, but this was not a concern for their backers until the market slowed.

During the life of a refinery, it will unfortunately tend to move up the cost curve, losing its competitive edge as more advanced technologies and newer, larger refineries enter the market. Eventually, it will be situated in the top quartile, struggling to maintain a profit.

However, ongoing investment by long-sighted owners helps to maintain a refinery's competitive position, securing a long future. There are examples of refineries constructed in the 1970s and early 1980s that still achieve first-quartile operating cost due to increased productivity and ongoing cost reduction initiatives.

The Long Term Selling Price of Alumina

Many of the producers blame the current low market prices for Aluminum metal as a result of the economic downturn, claiming the current market situation is unusual. Examination of the long-term price history illustrated in Figure II shows that this claim is unjust, and that the abnormality was actually the preceding economic boom. The current prices are similar to 2004 levels and are consistent with the longer term price history.

Figure II. Aluminum Metal Price History [2]

The refineries currently under cost pressure fall into two groups:

1. Older refineries suffering from a lack of modernization that have been under cost pressure for many years, but experienced brief respite during the economic boom.
2. Modern refineries that were built during the economic boom under the perception that the high Alumina prices were here to stay.

The current profit squeeze afflicting new refineries shows a lack of foresight and appreciation for the typically stable long-term price of both Aluminum and Alumina.

Operating Cost Components

Alumina refineries have a typical operating cost structure, which can be broken down as shown in Table I:

Table I. Typical Alumina Refinery Operating Cost Breakdown

Item	Contribution
Energy	20% - 40%
Bauxite	15% - 30%
Caustic	10% - 20%
Payroll	5% - 10%
Spares & Maintenance	5% - 10%
Sundry Charges	5%
Lime	<5%
Water	<5%
Flocculant and Reagents	<5%

The highest OPEX contributor is usually energy. It is important to note that the long-term cost of energy is rising on average, and some refineries that were built when energy was relatively inexpensive now find it is their greatest operating cost. The refineries in the United States are a classic example, constructed when crude oil was <$5/BBL, with energy barely a concern, and now their greatest expense and threat to their livelihood. Even low cost refineries such as the Western Australian plants attribute up to 40% of their operating cost to energy.

Energy Usage

Energy usages vary widely throughout the Alumina Industry, as evidenced by Table II, with 5 examples of Bayer refineries with energy usages ranging from ~10 to 15+ GJ/t. The Industry range is 7 to 32 GJ/t [3].

Table II. Sample of Alumina Refinery Energy Usages [4]

Corporation Name	Overall Energy Intensity (GJ/t Al_2O_3)
China Pinguo plant	15.1
France Gardanne plant	13.5
Australia Pinjarra plant	11.2
Greece Shennigola plant	14.9
Germany Stade plant	9.6

Energy Pricing Trends

A review of historical median energy prices shows a substantial price shift in modern times, with energy prices increasing far more than the Alumina selling price. Table III below shows the comparative costs of various commodities, with fluctuations acknowledged.

Table III. Commodity Prices

Item	1965	1965, Indexed to 2007 CPI [12, 13]	Present
Crude Oil Price ($/bbl) [5, 6]	2	15	70
Crude Oil Cost ($/GJ) [7, 8]	0.40	2.50	11.50
Aluminum selling price ($/t) [9, 10]	100	700	1900
Alumina selling price ($/t) [11]	13.9(2)	90(2)	250
Energy as % of Selling Price (Oil)(1)	33%	33%	57%
Typical Energy Cost as a fraction of OPEX	5%	5%	30%

[1] Assuming 12.5GJ/t Alumina total energy use

[2] Assuming Alumina price fraction of metal price as per 2007 ratio

Note that energy was barely a concern for Alumina Refinery OPEX in the 1960s, and this is reflected in the approach to refinery design, with typically high energy use in the refineries of that era. However, it is of greatest concern for a modern refinery, and is a major reason for older refineries losing their competitiveness, slipping up the industry cost curve.

The cost of energy is expected to keep rising, and the observed trend of energy cost rising faster than the selling price of Alumina is expected to become more pronounced, with peak oil prices potentially rising to over $200/BBL within the next 10 years. Energy is already typically the greatest contributor to operating cost, and the marginal contribution of this component is only going to become more pronounced. Availability of low-cost local energy will become a more significant driver for locating Greenfield refineries in the future.

Alumina Refinery Energy Sinks

The importance of energy efficiency to minimize operating cost and maximize profit has now been established. To determine how a refinery may minimize its energy use it is important to understand the energy sinks in Alumina refining.

A refinery typically uses energy in the following 3 forms:

1. Steam for Digestion and Evaporation heating, with Digestion typically the larger user. This component is usually the largest energy sink on the refinery, consuming anywhere from 4.0 – 10+GJ/t (GJ energy used per tonne of Alumina product produced).
2. Calcination fuel. This component's contribution varies from 3.0GJ/t to 4.5GJ/t, depending on the technology employed.
3. Electrical power. This is usually the smallest energy sink, typically consuming <1GJ/t.

Total energy use is anywhere from 8GJ/t – 20+GJ/t, with ~12GJ/t being typical. The small contribution from electrical power shows there is little incentive to look for major efficiency gains from this item. Calcination energy tends to be somewhat quantized, with older kiln technology achieving typically 4.5GJ/t, while the more modern fluid-bed and gas-suspension Calciners achieve 3.0 – 3.2GJ/t. Retrofitting Calciners can enable an older refinery to reliably and consistently achieve ~1.5GJ/t energy reduction, although the capital cost can be prohibitive to smaller installations. However, the rising unit cost of energy should make this retrofit more attractive with time, and should be appropriately factored into calculations of NPV (i.e. do not use a fixed or falling energy price). Calciner retrofits have been successfully installed at various refineries, such as Queensland Alumina (QAL) in Australia.

The obvious place to invest in energy reduction initiatives is in Digestion and Evaporation. However, there are other more subtle methods that may be employed that not only boost refinery production, but also improve energy efficiency, which will be discussed shortly.

The Impact of Production Creep

Steadily increasing production by continuous debottlenecking of refinery flow is standard business for any refinery. Increased revenue from the additional output is attractive for all owners. However, this is typically done without any additional capital to boost heat exchange area, with the result that heat recovery efficiency falls. Initially there is often excess capacity in the heat recovery systems, so there is no observed adverse impact on energy use, and the incremental production actually reduces unit energy consumption.

As the refinery becomes more stretched and all excess capacity in the heat recovery systems is absorbed, energy use begins to increase, as evidenced by higher steam addition to Digestion to maintain target temperature. However, the push for more production continues, with the philosophy that increased production will offset increased energy use, thereby minimizing efficiency losses. Obviously this cannot continue indefinitely, and when the trim heating systems become overloaded, auxiliary heating systems are often installed, such as contact heating in Digestion, with little or no heat recovery. Energy use rises dramatically, sacrificing efficiency to boost production. This effect is particularly problematic during boom times, when owners push for maximum production. Unfortunately the behaviour becomes set, and there is rarely any initiative to restore balance when the push for additional production eases, as evidenced by the recent market downturn. Many high energy use producers remain in the energy trap, with no funding to increase heat recovery area.

It has been suggested that production creep by increased yield rather than by flow debottlenecking can avoid this effect. This definitely has merit, and will be subsequently examined. However, producers should be mindful that any increase in production dictates an increase in Bauxite use, thereby increasing the heat duty in Digestion due to the endothermic reaction, and also increasing the hydraulic load through Digestion. Both of these effects increase the load on the Digestion heat recovery systems, partially offsetting any potential gains, and also potentially creating new flow bottlenecks.

The best approach is to ensure that refinery heat recovery area is maintained and expanded as required. Some refineries have shown this foresight, installing additional Digestion heat recovery and indirect trim heating area during major upgrades to maintain efficiency, which ensures their longevity in the market.

The Influence of Bauxite Type

Various refineries processing Gibbsitic Bauxites at the relatively modest temperature of ~150ºC achieve low energy usages of typically <10GJ/t, leading many to believe that the low digestion temperature drives the low energy use.

However, there are refineries that digest Boehmitic bauxites at high temperature that also achieve low energy use, such as Rio Tinto Alcan – Yarwun's <10GJ/t despite 270+ºC digestion temperature using Weipa bauxite.

The above suggests that although the digestion of Gibbsitic bauxites at low temperature appears to favour low energy use, there is no barrier to achieving low energy use simply due to high digestion temperature. It should also be noted that some Gibbsitic bauxites are of very poor grade by world standards, dictating larger energy consumption in Milling and Bauxite Slurry Heating. Further to this, the high impurities of some of these low-grade Gibbsitic bauxites result in much lower yields than the higher grade bauxites, yet the refineries still achieve high energy efficiency. This suggests that there are other more significant factors than bauxite type that determine energy efficiency.

The Influence of Digestion Temperature

As explained above, there are refineries that achieve high energy efficiency despite a high digestion temperature. This may seem counter-intuitive, since it stands to reason that a hotter digestion temperature should require more steam and therefore higher energy consumption would be expected. However, from first principles it is apparent that energy consumption in Digestion is not driven by the final temperature, but instead by the temperature differential between the last regenerative heating stage and the target digestion temperature. This shows the need for adequate heat exchange area in the regenerative (flash) heaters, to ensure the maximum available heat in the digester product slurry is recovered to the feed, minimizing the demand from trim heating.

Table IV below shows SysCAD modelling data from a hypothetical Digestion circuit (as shown in Figure III), with three different operating cases, all producing 1.5Mt/a Alumina. The first case utilizes heaters that are obviously undersized, resulting in an excess of blow-off vapour, and a large input of trim heating steam via contact heaters. The second cases utilizes much larger heat recovery area, with a considerable reduction in wasted blow-off vapour, and similar large reduction in trim heating steam input. The final case shows the result of switching Case 2 from contact steam to indirect steam, and returning the resultant live steam condensate to the power station for a condensate credit. Note the vast improvement in energy efficiency from Case 1 to Case 2 by appropriate capitalization of the heat recovery system. The Case 3 result of 2.2 GJ/t shows that high energy efficiency in Digestion is definitely achievable even at 260ºC digestion temperature, dispelling any myth that high temperatures dictate high steam consumption.

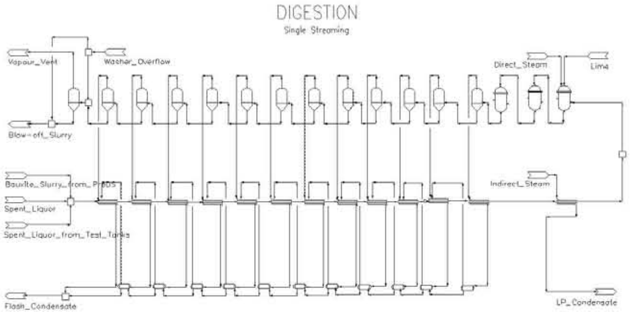

Figure III. Digestion Model Schematic

Table IV. Digestion Modelling Results

Case	Trim Heating method	Individual Flash Heater Area	Steam Use	Blow-off Vapour	Energy Use
		m^2	t/h	t/h	GJ/t
1	Contact	400	410	223	6.09
2	Contact	2000	199	41	2.95
3	Indirect	2000	291	18	2.21

Cogeneration and Its Interplay with Digestion Temperature

A major downside of a high digest temperature is the required temperature of the trim steam. The following fundamental heat transfer equation shows the need for temperature driving force between the heating media and the digestion slurry:

$$Q = U.A.LMTD \tag{1}$$

Where:

Q = steam [trim] heater duty (W)

U = overall heat transfer coefficient ($W/m^2.K$)

A = heat exchange area (m^2)

LMTD = log mean temperature difference between the heat source and the heat sink (K)

When using contact steam for trim heating, the direct mixing of the steam and slurry ensures maximum heat transfer coefficient and maximum heat exchange "area", thereby minimizing the required temperature differential between the steam and slurry outlet temperature. This explains why refineries that use contact steam in digestion require very little temperature differential between the steam and the digester feed slurry, typically 5 – 15ºC. Conversely, refineries that utilize non-contact (indirect) steam are limited by the achievable heat transfer coefficient and installed heater area, dictating the need for a much higher temperature differential of typically 30 – 40ºC. When targeting a Digestion temperature of 270ºC using indirect heating, this dictates a steam temperature in excess of 300ºC!

Whether using contact steam or indirect heating, a high-temperature refinery will require considerably hotter steam than a low-temperature refinery. This limits the let-down potential of the steam supply. There are existing low-temp refineries that take advantage of the associated low steam temperature requirement to cogenerate considerable electrical power, with the heat recovery steam generators letting down high temperature steam to a much lower temperature [and pressure] through steam turbines. This effect is so pronounced that the power generating system often generates more power than the refinery requires, enabling the power contractor to supply the refinery with the resultant low pressure steam and a fraction of the electrical power, but supply the considerable surplus power to the domestic power grid. This is a win-win situation for all involved, with the captive Alumina refinery receiving low-cost steam and power, the power generating contractor achieving high thermal efficiency, and the domestic power consumers seeing reduced power costs. Conversely, a high-temperature facility and its associated cogenerating power supplier do not see the same advantages, resulting from the refinery's need for higher temperature steam to achieve the higher digestion temperature for a Boehmitic bauxite digest, which results in less available pressure drop between the turbine inlet and outlet. This effect becomes more pronounced as the digestion temperature increases, with virtually no cogeneration achievable when refineries require steam temperatures in excess of 310ºC.

From the above discussion it would appear that contact steam is a better option than indirect steam heating, with its lower required supply temperature maximizing the cogeneration potential. However, it should be noted that indirect heating recovers *all* of the condensate from the heating operation, whereas contact heating only recovers the flash condensate. The resultant increased condensate generation from indirect heating not only improves the refinery water balance, maximizing the available wash-water input, but also increases the energy recovered in the condensate. Whereas a contact steam generation system must heat the required steam from an ambient water supply, the condensate return from an indirect system is already at elevated temperature, reducing the boiler heat load. Furthermore, the difference in temperature requirement between contact steam and indirect steam is not substantial – the major driver for the steam temperature is the target digestion temperature, so the loss in cogeneration potential from selecting indirect heating is not significant. This explains why modern Greenfields designs tend to favour indirect heating, sacrificing the minor amount of cogeneration potential for a larger credit in condensate return.

Influence of Yield

Yield and energy efficiency are often viewed as mutually exclusive. Producers tend to view yield as an enabler to increased production, while energy efficiency is viewed as a separate entity. Given energy use is typically indexed to production, and the accepted influence of yield on production, it is apparent that energy use must have a strong dependence on yield.

The precedent in industry is evident. As explained above, some refineries operating on high grade, low impurity bauxites achieve excellent energy efficiency. The same refineries also achieve 90+g/l precipitation yield.

The relationship between yield and energy can be readily established by examining the production equation:

$$\text{Production} = \text{Flow} \times \text{Yield} \qquad (2)$$

The higher a refinery's yield, the lower its associated flow to achieve target production. While the production rate partially dictates the energy sink in digestion associated with the endothermic dissolution of Alumina, the greater influencer of energy use in Digestion is the refinery flow that must be heated. A refinery with high yield is at an obvious advantage in its heat requirements for Digestion.

Table V below shows two cases for a 1.5Mt/a hypothetical refinery, with vastly different yields. The high-yield refinery requires only 66% of the flow of the low-yield refinery to achieve the same production, and therefore has 1000m^3/h less recirculating liquor. The obvious gain is the reduction in pumping power, but this is a small contributor to the energy demand as previously explained. The larger benefit is the substantial reduction in heat load for Digestion. The simulations shown in Table V were with fixed heat-exchange area, where the low-yield refinery is not only suffering from heating the additional recirculating liquor, but also has to use additional steam to off-set the lack of heat recovery area. For a Greenfield refinery the effect could be less dramatic, with the low-yield refinery instead requiring higher CAPEX for proportionately larger heat recovery area.

Table V. Hypothetical Example – Two refineries, one with high yield and one with low yield

Refinery Yield:	Low	High
Production (Mt/a)	1.5	1.5
Yield (g/L)	60	90
Flow (m^3/h)	3000	2000
Parasitic Flow (m^3/h)	1000	-
Digestion Energy Use (GJ/t)	6.80	2.98

It is therefore paramount for a refinery's yield to be maximized wherever possible, subject to capital constraints and operator know-how.

The low energy use associated with high yield refineries was discussed above, but there are cases of refineries with relatively low yield also achieving low energy use. This is achieved by the installation of good heat recovery systems, the key driver behind energy use. It is important to note that such refineries would achieve even lower energy use with an incremental yield increase.

Greenfields Refinery Design

During the recent economic boom, refineries were built in as little as one year, compared with the typical western approach of 3+ years, usually with only minor regard for efficiency. This was acceptable in the good times, but with the onset of the economic downturn, the inefficient producers, were forced to reduce or idle production or even shut-down. Conversely, recently built or modernized western refineries remained at full production, taking full advantage of efficient design.

Alumina refineries are designed with typically a 30+ year lifespan, and are often on-line for 50+ years. Designing a refinery based on short-term market upswing conditions is obviously short-sighted. Capital expenditure on the initial Greenfield is most efficient, when productivity factors are highest, and installation complexity is lowest. Conversely, attempts to rectify a serious efficiency shortfall by subsequent capitalization incur a much greater cost, and are not always practical.

Above all, sacrificing OPEX to save CAPEX is often not in the best long term interest of the refinery and its owners.

Brownfields Refinery Approach

When reviewing the payback of an energy improvement initiative, the cost of energy should account for significant escalation in the future which is more realistic, rather than a flat-rate energy cost. Secondly, fast payback is of little relevance if a particular refinery is not even making a profit. Many refineries in the Americas are currently borderline for profit, so there is little sense in dictating a 2-year payback, when the alternative "do nothing" option is losing money, and has the potential to get significantly worse.

The situation is well illustrated in Jamaica, with 3 of the 4 refineries idled, while one facility remains on-line, benefiting from ongoing capitalization and modernization. Alpart Refinery's former Managing Director Alberto Fabrini was quoted on his departure, stating "The most important factor is the market recovery, but also the market is only one side of the equation; there is also internal efficiency and energy. We have to find ways to lower our energy consumption because, otherwise, it's going to be difficult." [14]

An almost guaranteed energy improvement can be achieved by installing Calciners in place of rotary kilns, for an energy efficiency gain of ~1.5GJ/t. At a reasonable $10/GJ long-term energy price this saves $15/t OPEX, and is clearly a major step forward. This retrofit is also fairly low risk, as calciner design is mature, off-the-shelf technology.

As explained above, there is usually a greater opportunity in enhancing Digestion efficiency, but this is often more complex and is not simply a matter of retrofitting an off-the-shelf vendor package. Each refinery is unique, and upgrades to Digestion need to be carefully tailored, with strong consideration for future production requirements.

Finally, any Brownfield improvement justification should consider the energy efficiency benefits from increased yield. In the current market there is little demand for additional production, but at steady production a yield enhancing project would enable the refinery flow to be reduced, reversing the adverse impact of long term production creep. Refinery flow is a KPI for most refinery managers, so this approach would require a paradigm shift, but the livelihood of the business would be improved.

Carbon Footprint

So far, the argument for improving energy efficiency has all been straight economics, but there is a new potential player in the economic evaluation, especially in western refineries: carbon footprint. Energy nearly always comes at the cost of carbon footprint, and government regulations are only becoming tighter in this regard. Many governments have proposed carbon tax schemes, and when these come into effect, the marginal producers' situation will only worsen. Energy efficiency is therefore not only a cost improvement initiative for today; it is likely to be make-or-break once carbon tax schemes come into effect. Unfortunately, since the schemes are not in place yet, their potential cost is difficult to quantify. Estimates should be made where possible to factor these into project justifications, to properly quantify the long term potential cost of energy inefficiency.

Project Timing

Project execution costs peaked during the market boom, and have similarly dropped off in the down-turn. Engineering fees and commodity prices are low, so project costs should be far more competitive than in recent years. The anticipated rise in energy cost before the metal price suggests it is worthwhile executing energy improvement projects now, taking advantage of the lower project costs, and improved justification from the rising energy price. Access to the plant to instigate modifications should be easier for plants with idled capacity.

It must also be remembered that engineering projects take considerable time to execute. Major modifications that are planned now will take at least 12 months to implement, and by that time the market could look quite different. Companies that move on improvement projects now have the advantage of being ahead of the game, enjoying low-cost projects but being ready for warmer market conditions.

Conclusions

- Alumina refineries typically have a lifespan of many decades, and should be designed to handle all market cycles.
- The recent push for speedy construction with little regard for operating efficiency rendered many new facilities uneconomic to operate in the economic downturn.
- Energy is typically the largest OPEX component for Alumina refineries, and with energy prices rising faster than Alumina prices, this expense is expected to increase.
- Refineries with low-cost local energy suppliers should consider the longevity of the supply before committing to a low efficiency - low CAPEX installation.
- Each bauxite type has its advantages and disadvantages, and the key is to respond to the challenges.
- Yield enhancing projects can dramatically improve energy efficiency, especially at a given refinery production rate.
- Alumina refineries inevitably lose competitiveness on the market if they are not continually updated and modernized. Owners need a long-sighted view when assessing efficiency projects, to ensure the longevity and profitability of the asset is preserved.
- Efficiency improvement projects are best executed during a market downturn, with low project costs, acknowledgement of execution lag, anticipation of rising energy costs ahead of rising sales prices, and with better access to the plant when it is not under pressure to maximize production.

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