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OPERATING COST – ISSUES AND OPPORTUNITIES

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ABSTRACT

The operating cost of a bauxite and alumina project is sometimes regarded as a burden to have to deal with. However the operating cost and its underlying rationale provides tools to assess the "health" of a project and may offer improvement opportunities.

This paper provides an insight in facets and issues related to the operating cost of a bauxite and alumina project and it explores ways for improvement.

INTRODUCTION

Economic evaluations of a project require generating (discounted) cash flows over its lifetime and applying several criteria to ascertain if it meets threshold levels.

Generally the primary economic evaluation criterion of a project is its Net Present Value (NPV), which is calculated as follows:

$$NPV(i)=\sum a_j*(1+i/100)^{-j} \quad (1), \text{ with}$$

i = discount rate, %;
$\sum$ = summation from j=0 to n (project duration, no. of years);
a_j = annual cash flow (after tax) at time (yr) j.

Key inputs to annual cash flows are:

- On the revenue side: the amount of product generated and its sales price.
- On the cost side: capital cost, operating cost and tax payable.

In other words operating cost is an important element in the economics of a project, including bauxite and alumina projects.

Exchangeability of Opex & Capex

Both the project total operating cost ("opex") and initial capital cost ("capex") represent negative cash flows. Therefore a form of exchangeability exists between the two with respect to their effect on NPV and thus project economics.

To illustrate this effect, the following is assumed:

1.5 Mt/yr Alumina capacity expansion project
Alumina Price: 210 $/tA
Evaluation period: construction time + 25 yrs
Construction time: 3 yrs (capex spread equally)
Project construction starting next year
Tax depreciation period on capex: 20 yrs
Corporate tax rate: 30%
Full production from operating year 1 onwards
Numbers in "real terms" (inflation removed)

Table 1 – Main Assumptions

Assuming that project NPV (10%) should remain unchanged the following correlation can be found for a project without tax holiday:

$$Capex = -6.5*Opex + 905 \quad (2), \text{ with}$$

Capex in $/Annual tA expansion capacity, and
Opex in $/tA.

Correlation (2) means that an increase in opex of 10 $/tA for a project without tax holiday would require a drop in capex of 65 $/AnntA if NPV (10%) was to remain unchanged, as illustrated in Figure 1.

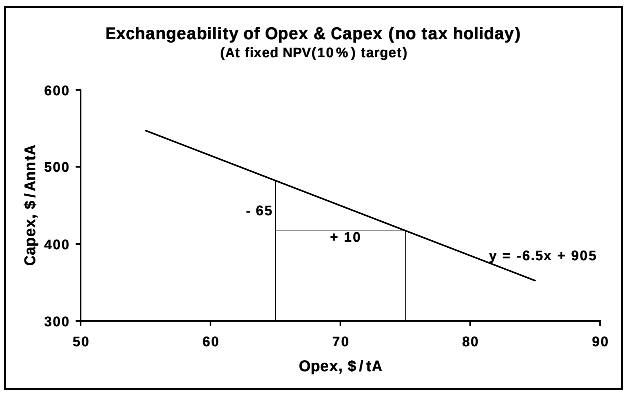

Figure 1 – Exchangeability of Opex & Capex (no tax holiday)

The slope of the line in Figure 1 (-6.5) applies to a fixed NPV (10%) target. At other discount percentages this slope would be different (steeper at lower discount percentages).

A similar approach for a project with a 10 year tax holiday (typical for a greenfield project), with otherwise the same assumptions as Table 1, results in the following correlation for a fixed project NPV (10%):

$$Capex = -7.7*Opex + 1567 \quad (3).$$

In other words an increase in opex of 10 $/tA for a project with a 10 year tax holiday would require a drop in capex of 77 $/AnntA if NPV(10%) was to remain unchanged, as illustrated in Figure 2.

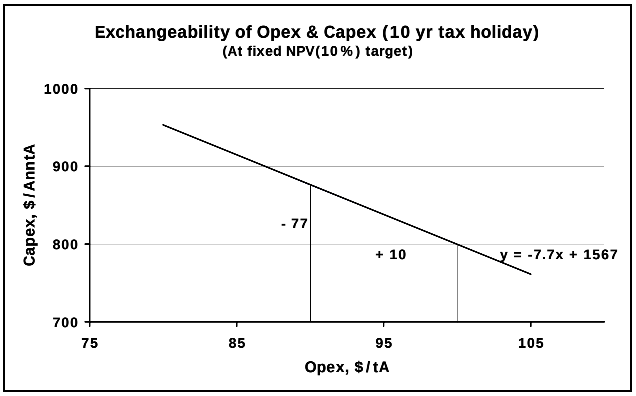

Figure 2 – Exchangeability of Opex & Capex (10 yr tax holiday)

The following conclusion may be drawn from correlations (2) and (3): in order to maintain NPV(10%), an increase in opex for a project with a 10 yr tax holiday would require a significantly larger decrease of capex than a project without tax holiday.

The difference between correlations (2) and (3) (reflected in the different slopes) is the consequence of the 10 year tax holiday.

Another way of putting the conclusion above is that under the assumptions mentioned, a change in opex has a more profound effect on the NPV of a project with a tax holiday than on the NPV of a project without tax holiday.

This may be illustrated as follows: a decrease of 10 $/tA in opex for the above mentioned example of a 1.5 Mt/yr alumina capacity expansion project would result in an NPV (10%) increase of:

- 92 M$ for a project with a 10 yr tax holiday;
- 72 M$ for a project without tax holiday.

Robustness of Low Operating Cost

Projects with low operating cost under otherwise the same conditions, are inherently robust with respect to adverse economic conditions such as a drop in the alumina price.

This is illustrated in Table 2 for a project based on Table 1, with a 10 year tax holiday (typical for greenfield project):

Low Opex Robustness (10 year tax holiday)		Low Opex Project	High Opex Project
BASE CASE	Aa Price, $/tA	210	210
	Opex, $/tA	90	105
	Capex, $/AnntA	800	800
	NPV(10%)	146	7
	IRR	11.8	10.1
Price Sensitivity	*Aa Price -10 $/tA*	200	200
	NPV(10%)	54	-85
	IRR	10.7	8.9

Table 2 – Low Opex Robustness (10 yr tax holiday)

As can be seen from Table 2, the economics of the low opex project remain attractive whereas the economics of the high opex project become unattractive.

Table 3 illustrates the same for a project without tax holiday, comparing a typical low opex, high capex option with a high opex, low capex option having similar base case IRR values.

Low Opex Robustness (no tax holiday)		Low Opex Project	High Opex Project
BASE CASE	Aa Price, $/tA	210	210
	Opex, $/tA	60	100
	Capex, $/AnntA	550	400
	NPV(10%)	469	348
	IRR	17.1	17.2
Price Sensitivity	*Aa Price -30 $/tA*	180	180
	NPV(10%)	255	133
	IRR	14.0	13.0

Table 3 – Low Opex Robustness (no tax holiday)

Again the low opex option proves to be more robust with respect to alumina price fluctuations.

Opex, NPV and IRR

In the paper "Greenfield Dilemma – Innovation Challenges" [1] correlations were discussed between Opex and NPV (linear correlation) and Opex and Internal Rate of Return (IRR) (polynomial of the second order).

Conclusions

Conclusions are that the operating cost of a bauxite/alumina project has a significant effect on project economics (more so on those of a project with a tax holiday), and low opex projects are inherently robust.

OPEX BASICS

Conventionally project operating cost may be split in different ways, e.g. "controllable" and "uncontrollable", fixed and variable. This serves a purpose for an existing bauxite/alumina project. When a greenfield projects is being considered however it makes good economic sense, as outlined above, to focus on identifying projects with inherently low opex. Let us therefore consider the basics of operating cost.

The opex of a bauxite/alumina refinery project is not a stand-alone item but is an integral characteristic of the context of the project because it is influenced by:

I. Resource quality;
II. Country infrastructure;
III. Logistics of raw materials import and alumina export;
IV. Alumina production capacity;
V. Technology/Design.

(Note that commodity prices – e.g. caustic soda, coal, fuel oil, lime – are not included because FOB prices are basically the same for all projects)

Simply put, opex reflects the efforts required to deal with the "imperfections" of the bauxite resource when converting it to smelter grade alumina with the selected technology, at the desired quality, in a responsible way with respect to safety and environment.

[1] Refer "Greenfield Dilemma - Innovation Challenges", paper by P.J.C. ter Weer, Light Metals 2005, San Francisco, pp 17-22

I. Resource Quality

Resource quality includes:

- **Location** and accessibility of the resource with respect to the port from which the alumina is exported (distance, height, mountain and river crossings).

  This is reflected in a transportation cost (either of the raw materials and alumina to the refinery site at the resource or of the bauxite to the refinery at the exporting port). Depending on resource particulars this transportation cost may range from 3-8^{+} $/tA.

- **Deposit characteristics** (uniform versus pockets, overburden thickness, bauxite horizon thickness, beneficiation requirement). These affect cost of mining, crushing, storage, beneficiation, rehabilitation, etc.

  This aspect is reflected in the overall $/tBx cost CIF refinery (bauxite transportation may either be included – e.g. if the mine is close to the refinery, or be covered by a separate transportation cost referred to above), and may range from 6-40^{+} $/tA.

- **Bauxite** refinery feed **characteristics** (hardness, available alumina – level and % gibbsite/boehmite, reactive silica, impurities).

  These aspects are mainly reflected in caustic soda cost (partly) and energy cost (partly), and may range from 8-50^{+} $/tA.

Note that if an alumina refinery project does not participate on an equity basis in a bauxite mine, the first two aspects mentioned above do not apply. In that case a market price will have to be paid for the bauxite, which is usually more than the sum of the costs mentioned above for these two elements. For reasons of economics it is unlikely that new greenfield alumina refinery projects would be based on export bauxite.

II. Country Infrastructure

In the context of this paper, country infrastructure includes:

- **A "hardware" aspect.** This covers items such as the presence and state of repair of a port (via which raw materials are imported and alumina exported), rail road (if the resource is a significant distance from the port), a town site (incl. hospital), roads, and water availability.

  This aspect is reflected in infrastructure operating and maintenance costs.

- **A "software" aspect.** This refers to elements such as royalty (on bauxite or alumina), levies, duty on raw materials, and the effect of legislation (e.g. with respect to environmental requirements).

  Taxes (and tax holidays) are very important, but more so from an overall economics perspective than from the point of view of the opex.

Total infrastructure related costs may range from 0-11^{+} $/tA.

III. Logistics

Accessibility of and logistics to the port via which raw materials are imported (e.g. caustic soda, coal, fuel oil, lime) and alumina (or bauxite) is exported.

This item is affected by location of the port (e.g. industrial area), ship size (water depth) and the proximity to frequently used sea lanes, and it is reflected in the cost of raw materials CIF the importing port and/or in freight charges for export alumina (or bauxite). In other words it is affected by refinery location in case the refinery is built in the same country as the bauxite resource.

Total logistics costs cover a wide range from 2-35^{+} $/tA.

IV. Alumina production capacity.

Refinery production capacity has an impact on opex because it "dilutes" fixed operating and maintenance costs and may also result in efficiency improvements. It also has a positive "economy of scale" effect on capital cost (outside the scope of this paper).

A larger production capacity therefore generally results in (significantly) more attractive overall project economics.

Resource size is an important aspect in this context. In order to capture the opex (and capex) advantage of a large production facility, a bauxite resource should be able to support an alumina refinery for its lifetime (typically 50^{+} years).

However, a project's initial and final production capacities are also the result of a company's view on alumina demand and supply developments and access to capital, and to a lesser extent the selected process technology.

V. Technology/Design

In terms of operating cost, "technology" relates to plant design and layout, process and equipment technologies and operating and maintenance philosophies. These aspects are reflected in:

- **Energy and raw materials** costs (caustic soda, lime, etc) – albeit partly in some cases. These are affected by technology choices such as co-generation of steam and power (when possible), choice of energy carrier (coal/fuel oil/gas), residue circuit thickener/washer, precipitation, residue disposal, heat recovery, return of disposal run-off water etc.
- **Other variable** costs (crystal growth modifier, filter cloth, acids, etc);
- **Maintenance materials** and contract services costs, affected by the complexity of the refining plant, choice of layout, etc;
- **Labour** and other fixed costs: as maintenance materials affected by technology and layout choices.

The costs related to capacity and technology may range from 55-105^{+} $/tA.

Summary

Table 4 summarises the above with typical ranges of these five elements.

Element	**Range** (typ) ($/tA)
I. Resource Quality	25 – 95+
II. Infrastructure	0 – 11+
III. Logistics	2 – 35+
IV&V. Capacity and Technology/Design	50 – 105+
Total Opex incl. sustaining capex	**95 – 230+**

Table 4 – Typical ranges of opex elements

In other words, if aspects of the infrastructure of the country of the bauxite resource and the location of the exporting port are also considered as part of resource quality in its widest sense, the typical ranges of "Resource Quality" and Capacity and Technology costs (incl. sustaining capex) are as shown in Table 5.

Element	**Range** (typ) ($/tA)
"Resource Quality"	35 – 130+
Capacity and Technology/Design	50 – 105+

Table 5 – Typical opex ranges of Resource Quality & Capacity and Technology

Table 5 shows that the cost range of "resource quality" is even wider than that of "capacity and technology". Taking the capacity effect out (which may range from 2-15 $/tA) would narrow the latter range may be to 60 – 100+ $/tA.

In other words "bauxite (resource) quality" in its widest sense has a more profound effect on operating cost than technology. Or to put it differently, for a greenfield project it makes good economic sense to primarily focus on identifying the "right" bauxite resource.

This may be done by ranking bauxite resources on the basis of a set of selection criteria taking the above elements into account.

Bauxite Resource Selection Criteria

A set of bauxite resource selection criteria should focus on main criteria and provide target threshold values. Such a set is not meant to be applied rigidly. In other words a bauxite resource not meeting one (or possible more) of the threshold values should not necessarily be discarded. The overall result of the ranking of available bauxite resources should be considered.

Criteria relating to the strategic importance of a resource to a company, which could result in a different outcome of a resource ranking exercise, have not been included because those fall outside the scope of this paper.

Table 6 presents a set of bauxite resource selection criteria addressing the resource quality elements I-III and the alumina production capacity element IV discussed above. These criteria address both opex as well as capex related aspects as the two are linked.

This set of selection criteria may be used as ranking tool for bauxite resource evaluation purposes.

Criterion	Target
1. Distance Resource to Alumina Export Port	200 km max
2. Average Bauxite Horizon Thickness	5 m min
3. Total Material Handled	4 t/tA max
4. Bauxite Beneficiation	Not required
5. Alumina in Boehmite	3 % max
6. Ratio Extractable Organic Carbon / Available Al2O3	0.008 max
7. Residue to Disposal Factor	1.2 t/tA max
8. Total Caustic Soda Consumption (100% NaOH basis)	70 kg/tA max
9. Country Infrastructure	Mostly in place
10. Resource Contained Alumina	200 Mt* min

* M=million

Table 6 – Bauxite Resource Selection Criteria

As mentioned above these criteria and their targets should not be looked at in isolation but as part of an overall analysis of a bauxite resource.

The rationale behind these criteria is as follows:

1. **Distance bauxite resource to alumina export port maximum 200 km.** This criterion addresses the resource location aspect of element I above. If the transportation distance increases much above 200 km, raw materials and alumina or bauxite transportation costs increase prohibitively. If bauxite slurry pumping as planned by CVRD for the Paragominas mine in Brasil proves to be successful the maximum distance may increase (costs of bauxite de-watering and additional evaporation should be included).

2. **Average bauxite horizon thickness minimum 5 m.** This criterion addresses the deposit characteristics aspect of element I above and has economics and environmental angles: if the bauxite horizon thickness is much below 5m, the mining opex increases significantly and the acreage of land mined (and rehabilitated afterwards) per tonne alumina becomes environmentally prohibitive.

3. **Total material handled maximum 4 t/tA.** This criterion also addresses the deposit characteristics aspect of element I above and includes the bauxite proper (affected by available alumina and alumina recovery in the refining plant), the overburden (affected by the overburden/bauxite ratio) and tailings from the beneficiation plant if applicable (affected by beneficiation recovery – see below).

4. **Bauxite beneficiation not required.** This criterion also addresses the deposit characteristics aspect of element I above. Bauxite beneficiation has several drawbacks: additional installations are required involving extra capex, extra opex and environmental issues (water usage, tailings disposal). In addition if the beneficiation recovery is low (may be as low as 25%) these aspects quickly become

prohibitive. When the overall economics of a bauxite/alumina project improve, applying bauxite beneficiation may be appropriate.

5. **Alumina in boehmite maximum 3%.** This criterion addresses the bauxite refinery feed characteristics aspect of element I above. There are several aspects to this point, the most important one being that below this maximum the large majority of the available alumina is gibbsitic requiring a low digestion temperature. This has two advantages, i.e.

   1. Required temperature and pressure for steam to digestion are at a relatively low level, providing the opportunity to first use high pressure boiler steam for co-generation of steam and power, which has a positive impact on overall energy cost and thus opex, and
   2. Capex of digestion and power & steam generation equipment is lower than would be required for high digestion temperatures.

   Another aspect is that below this maximum boehmite in bauxite feed level, processing technology and operating conditions can be chosen such that boehmite does not dissolve in digestion and should not give rise to boehmite reversion (which would otherwise negatively affect efficiencies and operational conditions). Higher boehmite levels would require high temperature digestion with consequential higher opex (energy and maintenance costs) and capex (high pressure refinery and powerhouse equipment).

6. **Ratio of extractable organic carbon to available alumina maximum 0.008.** This criterion also addresses the bauxite refinery feed characteristics aspect of element I above. Below this level impurity removal may either take place sufficiently by natural balances (e.g. with residue) or by relatively simple removal methods (e.g. concentrating plant spent liquor in a salting out evaporator). At higher ratios extensive facilities may be required (oxalate removal, organics removal) at significant opex and capex. In addition precipitation yield may be affected negatively impacting on overall energy efficiency and capex.

7. **Residue to disposal factor maximum 1.2 t/tA.** This criterion also addresses the bauxite refinery feed characteristics aspect of element I above and impacts on residue handling and disposal facilities, i.e. has both economics and environmental angles. It is affected by the available alumina and reactive silica in bauxite refinery feed and alumina recovery in the refining plant.

8. **Total caustic soda consumption maximum 70 kg (100% NaOH basis)/tA.** This criterion also addresses the bauxite refinery feed characteristics aspect of element I above because caustic soda is one of the main operating cost components, mainly influenced by the ratio of reactive silica to available alumina in bauxite refinery feed, physical soda losses with bauxite residue (affected both by available alumina and alumina recovery in the refining plant and by the technology chosen in the residue wash circuit) and soda losses with removed impurities (oxalate, organics).

9. **Country infrastructure mostly in place.** This criterion addresses elements II and III above, i.e. refers both to physical installations and a country's legal framework. Its effect on opex may range from quite low (e.g. with limited royalty requirements and no physical infrastructure to run) to significant (with bauxite levies and extensive infrastructure opex). Its effect on capex may also be significant.

   Some of these elements may be negotiable and therefore more difficult to quantify at an early stage of a potential project. In addition a country's government and/or other third parties may be willing to assume responsibility for (some of) the physical infrastructure requirements.

10. **Resource contained alumina minimum 200 Mt.** This criterion addresses element IV above. In order to capture the opex (and capex) advantage of a large production facility, a bauxite resource should be able to support a typical "mature" alumina refinery production capacity of 4 Mt/yr. Alumina refineries are long lifetime facilities (50^+ years). These two combined form the rationale for 200 Mt contained alumina in resource. At a bauxite factor of typically 3 tBx (in situ)/tA, this would convert to a bauxite resource of about 600 Mt.

Conclusion

Conclusion is that for greenfield bauxite/alumina projects the focus should primarily be on identifying the "right" bauxite resource using a limited set of appropriate selection criteria.

OPEX OF EXISTING PLANTS

For existing plants and brownfield expansion projects it may be more appropriate to use a more conventional approach to opex. Let us therefore consider the opex build-up.

Opex Build-up

Project opex may be broken down in the following main components: variable costs, fixed costs and sustaining capital.

Variable Costs

In $/year these costs vary with plant production, at least within certain plant production rates (typically $\pm$ 10-15%).

Variable costs comprise bauxite, energy, caustic soda, other raw materials (e.g. lime, flocculants) and process & operating supplies (e.g. crystal growth modifier, grinding media, and filter cloth). They cover a wide range from typically 60-160 $/tA.

Transportation and handling costs of raw materials and product are sometimes accounted for in the raw materials costs (i.e. raw materials costs CIF plant site), but sometimes presented by a separate variable cost item "materials transportation and handling cost".

A significant part of the variable costs are directly or indirectly the result of "bauxite quality" in its widest sense (see above). They are therefore difficult to improve once the bauxite quality is fixed and technology choices have been made for the various processing steps of the alumina refinery.

In other words structurally improving the variable cost in an existing alumina refinery processing a given bauxite type requires an adaptation to or change of technology of one of the processing steps (e.g. deep thickening technology in stead of conventional thickeners, seed recycle in stead of solids retention in precipitation, etc).

This also means that the scope to improve variable costs significantly in an existing refinery without spending significant capex is limited. A good opportunity is sometimes presented when a brownfield capacity expansion project of a refinery is considered. In some cases it is possible to apply new technology of the brownfield project also to existing units, thus more than proportionally improving economics.

Fixed Costs

In $/year these costs do not vary with plant production, at least within certain plant production rates (typically $\pm$ 100,000 t/yr). They typically range from 20-70 $/tA.

Fixed costs comprise labour, plant maintenance materials, contract services, infrastructure operating and maintenance costs, overheads and other fixed costs.

Plant design and layout affect fixed costs to some extent through simplicity of design, distance to get to facilities, central control room, etc. At the same time plant management controls fixed costs by their choice of operations management systems, number of shifts, maintenance procedures, outsourcing etc.

As mentioned earlier, another way of improving fixed costs (in $/tA) is "dilution" through increased plant production. In fact the "phenomenon" of a long term decrease of plant opex is to a large extent the result of plant production "creep" (the small but steady increase of plant production on a long term basis).

Sustaining Capex

Sustaining capital expenditure comprises items required to maintain the project at target production level, the product at target quality and HSE on target. Although it may be treated differently for tax reasons than variable and fixed operating costs, it represents an annual cost to a project and should be included in the operating cost.

It ranges typically from 8-12 $/annual t capacity and includes:

- Mine sustaining capex;
- Plant (including powerhouse) sustaining capex, and
- Infrastructure sustaining capex.

Sustaining capex is a consequence of equipment installed, i.e. of design and technology choices. In other words to structurally lower sustaining capex generally requires spending significant capex. In addition the scope for improvement is relatively limited.

CONCLUSIONS

The conclusions from the above may be summarised as follows:

- The operating cost of a bauxite/alumina project has a significant effect on project economics (more so on those of a greenfield project than those of a brownfield project);
- Low opex projects have inherently robust economics;
- Greenfield bauxite/alumina projects should focus primarily on identifying the "right" bauxite resource using a limited set of selection criteria;
- The scope to improve variable cost significantly in an existing refinery without spending significant capex is limited;
- Plant management controls to some extent fixed costs. "Dilution" of fixed costs by production increase is a tool to lower opex.