GREENFIELD BAUXITE / ALUMINA PROJECTS: ECONOMICS, TECHNOLOGY, RESEARCH & DESIGN CENTER

Peter-Hans ter Weer, MSc Chem Eng
TWS Services and Advice, Imkerweg 5, 1272 EB Huizen, The Netherlands
Phone +31.6.46143965, Email twsservices@tiscali.nl

ABSTRACT

Several Bauxite / Alumina greenfield projects are being considered worldwide. However many of these potential projects have difficulty to meet economic threshold criteria.

This paper considers economics of greenfield projects, selection criteria to differentiate between potential project options, technology and innovation challenges and key points of a research and design center.

PROJECT EVALUATION CRITERIA

Project proposals in the bauxite / alumina industry are economically evaluated applying several criteria to ascertain if they meet company threshold levels and for ranking purposes in case a choice has to be made between a number of projects.

These evaluation criteria include:

- Net Present Value (NPV), the sum of a project's annual cash flows at a chosen discount percentage per year. In the bauxite / alumina industry the discount rate may range from about 6-16%. In this paper 10% has been used (indicated as NPV(10%)). NPV measures how much value is added or lost and is often used as prime criterion to assess the attractiveness of an investment.
- Value over Investment (VIR) or capital efficiency ratio, the ratio of NPV and the investment (e.g. as discounted capex). VIR may be considered a measure of the "quality" of an investment.
- Internal Rate of Return (IRR), the discount percentage at which NPV equals zero. Another "quality" measure.
- Payback period. The period for the cumulative cash flow to become zero from a defined point in time. The cash flow may be expressed in different ways.

Of course several other criteria are also taken into consideration when a project is evaluated, such as availability of resources, strategic reasons, country risk, marketing and financing aspects, cost leadership with respect to position on the cash cost curve, risks, etc. However these are not included in this paper.

This paper focuses on greenfield bauxite/alumina projects and assumes an alumina production capacity of 1.5 Mt/yr ("greenfield" referring to projects based on undeveloped – greenfield – sites).

Before considering the economics of greenfield bauxite/alumina projects, we will first review some effects of changes in alumina price, project operating cost ("opex"), initial capital cost ("capex") and tax holiday on NPV and IRR.

For simplicity's sake, the following has been assumed:

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: 35%
Full production from operating year 1 onwards
Numbers in "real terms" (no inflation considered)
Cost of studies etc not considered

Table 1 – Project Assumptions

NPV and IRR have been calculated using an Excel spreadsheet.

ALUMINA PRICE

The alumina price, although outside the control of a project, plays an important role in project economics.

Figure 1 illustrates the relationship between NPV(10%) and Alumina Price for a bauxite/alumina project with 100 \$/tA opex, 800 \$/Annual tA capex and no tax holiday.

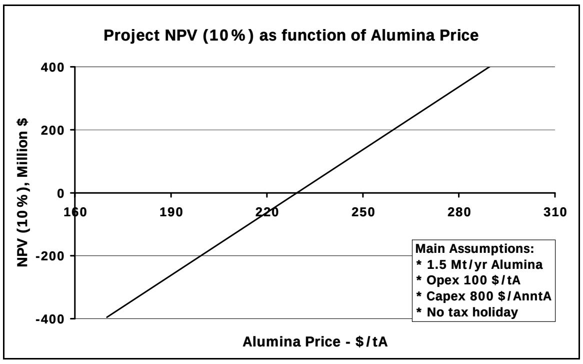

Figure 1 – NPV(10%) as function of Alumina Price

A linear relationship exists as a result of the way the NPV is calculated. The angle of this line is the same for different sets of values for opex and capex, however the intercept with the y-axis changes.

Figure 2 illustrates the relationship between IRR and Alumina Price for the same project.

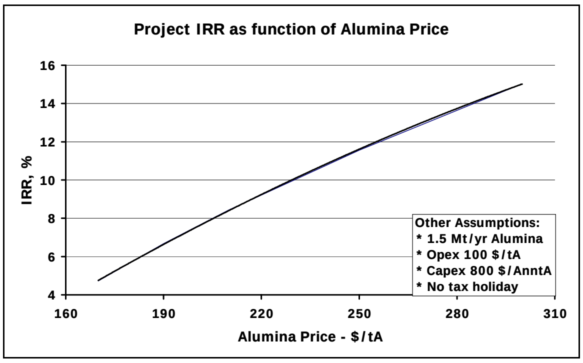

Figure 2 – IRR as function of Alumina Price

Figure 2 shows a good fit for a polynomial relationship of the second order. At different sets of values for opex and capex, polynomials of the second order show a good fit, however the coefficients differ. This is caused by the shape of the curve describing NPV as function of discount percentage (see Figure 3).

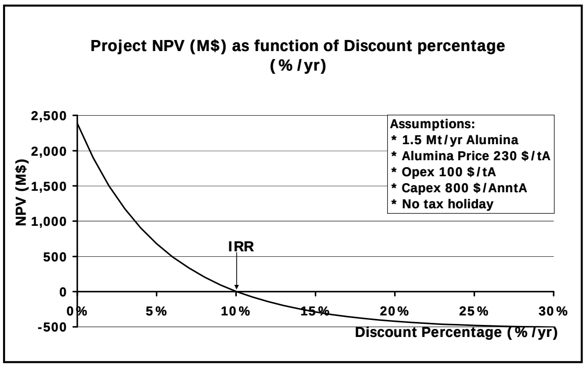

Figure 3 – Project NPV as function of Discount %

Figures 1 and 2 above illustrate the effect of alumina price in the range 150-310 \$/tA. During an economic cycle, prices may range from 90 to 400^{+} \$/tA. As can be seen from these figures, the timing of a capacity expansion project in the economic cycle may have a big impact on its economics.

OPEX & CAPEX

Both Opex and Capex of a project influence project economics. To illustrate their effect the alumina price has been kept constant at 230 \$/tA in the examples below.

Figure 4 below provides an example of the relationship between NPV(10%) and Opex for a project at 230 \$/tA alumina price, 800 \$/Annual tA capex, without tax holiday.

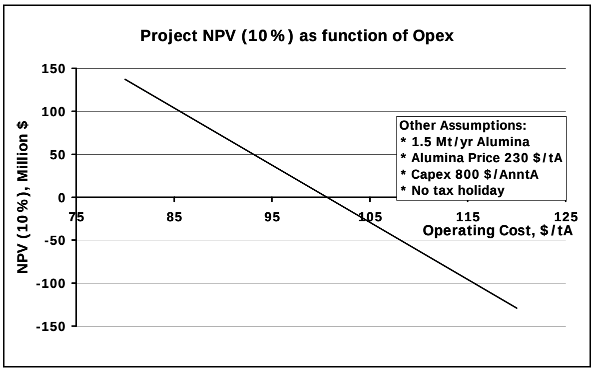

Figure 4 – NPV(10%) as function of Opex

The relationship is again linear, with a negative angle. As above for the NPV-Price relationship, the angle of this line is the same for different sets of values for operating cost and capex, however the intercept with the y-axis changes.

Note that opex for greenfield bauxite/alumina projects may typically range from 80-130 \$/tA.

The relationship between NPV and Capex is also linear, with the same characteristics as those between NPV and Opex above.

Polynomials of the second order show a good fit for the relationship between IRR and Opex and IRR and Capex, similar as above between IRR and Price, however with different coefficients.

Note that the capex range for greenfield projects may typically range from 850-1100 $/AnntA.

EFFECT OF TAX HOLIDAY

A tax holiday may be granted by governments to provide an incentive for the implementation of a project in their country. It is therefore often granted to greenfield projects, as such projects represent sometimes the first or a very significant investment of a company in that country.

Depending on project scale, country and existing agreements between government and investing company, a 10 year tax holiday on a greenfield project may be negotiable.

Although not further detailed in this paper, the effect of a tax holiday on project economics are generally significant (compare e.g. Figure 4 with Figure 5).

Table 2 summarizes the effects of alumina price, opex and capex on NPV and IRR for a typical greenfield project.

Plant Capacity: 1.5 Mt/yr Alumina Price: 230 $/tA		GREENFIELD 800 $/AnntA Capex; 100 $/tA Opex	
		NPV(10%)	IRR
Base Case	No tax holiday	+ 4 M$	10.0%
Alumina Price	+20 $/tA	+ 133 M$	+1.6%
Opex	- 10 $/tA	+ 66 M$	+ 0.8%
Capex	+ 50 $/AnntA	- 45 M$	- 0.6%

Table 2 – Effect of price, opex and capex changes on economics of a Greenfield project

Note that the numbers in this table do not represent a specific project. However they are illustrative of the effects of the changes in price, opex and capex on NPV and IRR.

This table illustrates how significant price changes are on project economics. It is also clear that opex and capex changes may have a significant effect, however the opex and capex changes used in the table are quite substantial (-10 $/tA and -50 $/Annual tA).

In the examples above the NPV numbers were calculated at a discount rate of 10%. As mentioned on page 1, this discount percentage may be different for different projects. That would change the absolute NPV numbers (not IRR), but wouldn't change the above trends.

IMPORTANCE OF LOW OPEX

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 may be illustrated in Table 3 for a project based on Table 1, with a 10 year tax holiday:

Low Opex Robustness (10 year tax holiday)		Low Opex Project	High Opex Project
BASE CASE	Aa Price, $/tA	230	230
	Opex, $/tA	90	105
	Capex, $/AnntA	900	900
	NPV(10%)	193	57
	IRR	12.1	10.6
Price Sensitivity	*Aa Price -20 $/tA*	210	210
	NPV(10%)	12	-124
	IRR	10.1	8.6

Table 3 – Low Opex Robustness (10 yr tax holiday)

As may be seen from Table 3, the economics of the low opex project remain attractive whereas the economics of the high opex project become unattractive.

ECONOMICS OF GREENFIELD BX/AA PROJECTS

The greenfield projects constructed in the early 80's had huge brownfield expansion capacity inherently built in. In addition many of these projects were constructed in the same period. The result has been that for a long period of time little incentive existed to develop greenfield projects and to actively pursue significant improvements in project design and layout.

Although the global alumina consumption may not yet have fully caught up with the remaining brownfield capacity expansion potential, several companies seem interested to expand their alumina production capacity, including companies that do not have the option of brownfield expansions.

Alumina prices through economic cycles have shown not to stay at a high level forever. In fact the long term cycle average alumina price was declining consistently until about 4 years ago. The most robust long term approach to improve the economics of greenfield bauxite/alumina projects therefore is to assume that alumina prices will not remain at a certain (high) level. Let us now consider the economics of greenfield bauxite/alumina projects.

The following illustrates the combined effect of capex and opex on the economics of a typical greenfield project of 1.5 Mt/yr capacity, an alumina price of 230 $/tA and otherwise the same assumptions as in Table 1.

A 10 year tax holiday is assumed for a greenfield project. Figures 5 and 6 show the NPV(10%) and IRR of this project for typical opex and capex ranges.

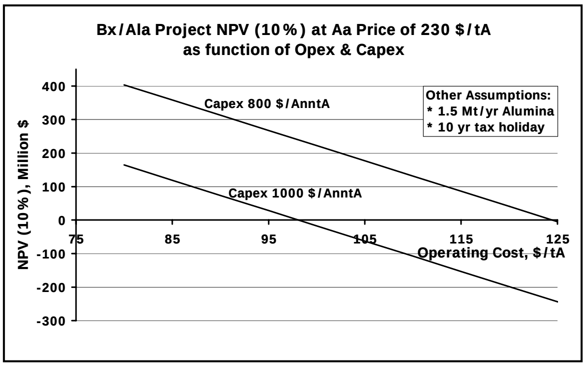

Figure 5 – NPV(10%) for a greenfield Bx/Ala project as function of typical Opex & Capex ranges

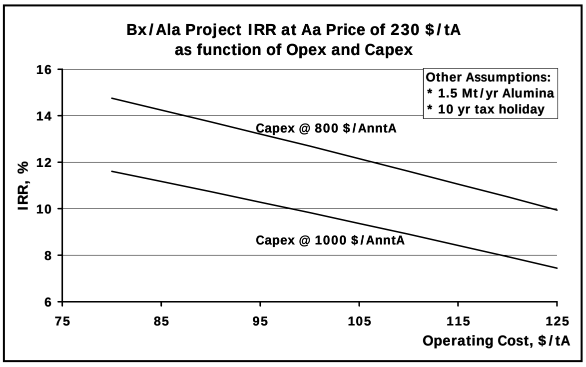

Figure 6 – IRR for a greenfield Bx/Ala project as function of typical Opex & Capex ranges

Observations from Figures 5 and 6:

- In order to have a positive NPV(10%), a project with a capex of 1000 $/Annual tA should have an opex of less than 97 $/tA, while a project with a capex of 800 $/Annual tA may have an opex of up to 125 $/tA;
- Absolute values of the economics of a greenfield project are attractive only for a limited set of opex and capex values;
- A higher than planned opex or capex may well result in unacceptable economics for a greenfield project, i.e. economics are robust only for a limited set of opex and capex values.

The last two points are also illustrated by Figure 7, which shows the VIR ratio (NPV(10%)/Discounted Capex) for the capex and opex ranges used above.

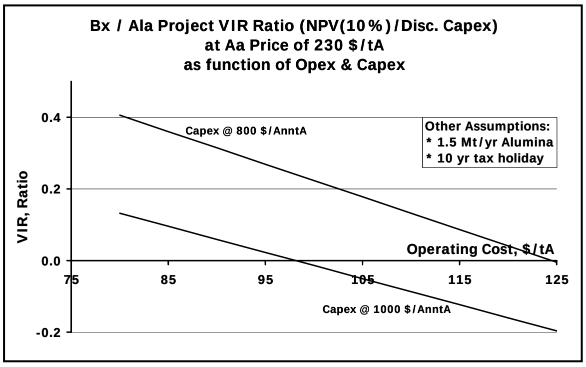

Figure 7 – VIR for a greenfield Bx/Ala project as function of typical Opex & Capex ranges

This ratio, as mentioned on page 1, may be used as indicator of the “quality” of an investment. VIR ratios above about 0.25-0.3 are typically considered attractive for greenfield projects. And as Figure 7 shows, under the assumptions used this would only apply to a relatively small set of combinations of opex and capex.

Final NPV and IRR values for a project depend on actual alumina price, capex, opex, tax rate etc as discussed earlier. In addition NPV and VIR values also vary with the selected discount percentage.

However the three observations mentioned above do not significantly change. Only high alumina price levels, such as the industry has been experiencing over the last three years or so, sustained over a long period of time would affect these conclusions.

This is the issue facing companies that are deciding on bauxite / alumina capacity expansion projects: a greenfield project is often difficult to justify purely based on economics.

BASICS OF LOW CAPEX AND OPEX

The capex and opex of a greenfield bauxite/alumina refinery project are not stand-alone items, but are integral characteristics of the context of the project because they are 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 in principle the same for all projects).

Simply put, capex and opex reflect 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.

I. Resource Quality

Resource quality includes:

- **Location** and accessibility of the resource with respect to the port from which the alumina is exported.
- **Deposit characteristics** (uniform versus pockets, overburden thickness, bauxite horizon thickness, beneficiation requirement).
- **Bauxite** refinery feed **characteristics** (hardness, available alumina – level and % boehmite, reactive silica, impurities).

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. For economic reasons it is unlikely that new greenfield alumina refinery projects would be based on purchased bauxite.

II. Infrastructure

In the context of this paper, country infrastructure includes:

- **A "hardware" aspect**: 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.
- **A "software" aspect**: items 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.

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. In other words it is affected by refinery location in case the refinery is built in the same country as the bauxite resource.

IV. Alumina production capacity.

Refinery production capacity has an impact because it "dilutes" fixed operating and maintenance costs in opex and may also result in efficiency improvements. And it also has a positive "economies of scale" effect on capital cost.

A larger production capacity therefore generally results in 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 supply and demand developments and access to capital.

V. Technology/Design
"Technology" relates to plant design and layout, process and equipment technologies and operating and maintenance philosophies. These aspects are reflected in:

- **Capex related**: plant layout, design and operational concepts, equipment sparing philosophy, etc.
- **Opex related**: Energy and raw materials costs, other variable costs, maintenance materials and contract services costs and labour and other fixed costs.

Resource quality in widest sense

The above mentioned elements of the infrastructure of the country of the bauxite resource and the location of the exporting port may also be considered to be part of the "Resource Quality" in its widest sense.

It has been shown[1] that the "bauxite resource quality" in its widest sense has a more profound effect on capex and opex 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 mentioned 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 possibly more) of the targets should not necessarily be discarded. The overall result of the ranking should be considered.

Criteria relating to the strategic importance of a resource to a company that 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 4 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.

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

Criterion	Target
1. Distance Resource - Ala 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 Al_2O_3	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. Infrastructure	Mostly in place
10. Resource Contained Alumina	200 Mt* min

* M=million

Table 4 – Bauxite Resource Selection Criteria

The rationale behind these criteria can be found elsewhere [1].

Conclusion

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

TECHNOLOGY AND INNOVATION CHALLENGES

Identifying the "right" bauxite deposit as outlined above ensures that the basics of a bauxite/alumina project are sound. To enhance the economic success of such a project, technology and innovation resources should be focused on supporting that objective.

As mentioned earlier, the brownfield expansion potential of the projects

[1] Refer "Operating Cost – Issues and Opportunities", paper by P.J.C. ter Weer, Light Metals 2006, San Antonio, pp 109-114

constructed in the early 80's resulted in little incentive to actively pursue significant improvements in project design and layout. This may also be reflected by the limited resources that the industry has been dedicating to research and development efforts in innovations and technological improvements.

The issues covered earlier provide some clues for focus items of research and development efforts:

- "Design a project requiring no infrastructure". This shouldn't necessarily be interpreted literally, but innovative thinking could assist in coming some way. Another approach might be not to "take the plant to the bauxite", but taking bauxite to a site with existing infrastructure (refer CVRD's plans to take Paragominas bauxite by slurry pipeline to Alunorte plant).

  In the context of opex this could mean designing a plant requiring "no organisation", e.g. by applying automation and "maintenance-less" equipment, and using a simple straight forward plant design.
- "Don't build costly provisions for future expansions into a project / plant design". Again this statement shouldn't necessarily be taken literally. However if that were the mindset, plant design may look different, as the focus would be on maximising the advantage of building a dedicated plant.
- "Do not over design a project / plant". One approach could be to critically review factors ("fat") built into a design (e.g. with respect to plant operating factor, design allowances and sparing philosophy). Another could be to make a conscious dedicated effort to "achieve maximum production capacity" right from start-up.
- "Do not re-invent the wheel". If others can do something better than you, use your limited resources on the issues that represent your strengths.

  This also includes "Looking over the fence" (e.g. of other industries) to assess / review if technologies / practices that are "proven technology" elsewhere could be applicable and economically attractive to bauxite / alumina projects. This may apply both to process related as to project related aspects.
- Stimulate focused technology development and R&D efforts which cannot be acquired in the market and with significant economic potential.

KEY POINTS OF A RESEARCH AND DESIGN CENTER (RDC)

Based on the above let us consider in outline some of the key points of a corporate bauxite & alumina research and design center (RDC).

Mission ("What do we want to achieve")
The mission should be put in the context of the company's mission and should be specific and clear, e.g. "Improve return on shareholders' funds and contribute to targets for growth and competitive advantage in alumina".

Specify the focus areas by which the mission will be achieved, e.g.: "Through the application of innovations in Process Chemistry, Process Engineering and Process Design".

It is essential to realise that an RDC is supporting the business and not a stand-alone activity. Or to put it differently it needs to earn its keep.

Customers ("For whom")
A key element is to define clearly who the "customers" are of the RDC. In the longer term an RDC will only survive if its customers wish it to. This will avoid the RDC to operate in isolation and loose touch with the needs of the company. Examples of customers could be:

- Operating Companies / Refineries;
- Corporate Center;
- Business Development Division;
- Marketing Division.

Strategies ("How")
These should be quite specific in order to establish focus. Examples are:

- Generate initiatives and provide support to enhance plant cost performance;
- Initiate options and techno-economic proposals to expand plant production rates;
- Provide techno-economic inputs to the corporate alumina business strategy and evaluations of capital and development proposals;
- Develop an alumina technology base as enabler for optimum economic benefit to the company.

Program of Activities ("Implementation")
The overall focus of the activities of the RDC is the result of the above strategies and customer requirements and may be summarised as follows:

- Plant Initiatives & Support;
- Technology Development;
- Corporate Support;
- Marketing Support and
- Project Support.

They may include expert advice, technology development and implementation, business development, independent plant performance and major project reviews, due diligence, best practice evaluation, etc.

The program of activities should cover activities in several categories, e.g.:

- Research (2-4 year time span): red side / white side / other;
- Development (1-3 year time span): modeling / analytical / flow sheet;
- Sustaining (3 months - 1 year time span);
- Third party sponsored activities.

Important is to assess which of these activities should be done at the RDC itself and which could be executed by the plants.

Organisation
The organisation should be kept small and focused on the mission and strategies in order not to loose management time and resources on non-essential issues. This could mean outsourcing several of the RDC's support activities (e.g. HR, IT, some analytical activities). Or even using third party facilities to perform some of the RDC's activities.