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NEW DEVELOPMENT MODEL FOR BAUXITE DEPOSITS

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1. Abstract

Developing a greenfield bauxite deposit nowadays generally includes constructing an alumina refinery. Economics have resulted in ever-increasing production capacities for recently-built and future planned greenfield refineries. Rationale: economy of scale. As a result the complexity of a greenfield project has significantly increased and its capital cost has grown to several billion USD. Important consequences:

- Project owners aim at risk reduction through project financing and formation of joint ventures, further complicating project implementation.
- Globally only a limited number of (large) companies have the human and financial resources to develop greenfield bauxite & alumina projects.
- Only a limited number of engineering firms have the required skills and experience to successfully implement these mega projects.
- Only large bauxite deposits get developed.

This paper proposes an alternative development model for bauxite deposits resulting in a more efficient use of resources and a lower threshold to develop bauxite & alumina projects.

2. Bauxite Deposit Development

The development of bauxite deposits is sometimes limited to the mining of bauxite for export purposes, which may or may not include drying the bauxite to a certain moisture percentage. Examples are the Boke and Kindia mines (both in Guinea), and the Bintan mine in Indonesia (now closed).

In other cases the mine supplies both a local / in-country refinery, as well as exporting bauxite, e.g. the Trombetas mine (Brazil), and the Gove and Weipa mines (both in Australia).

In most recent cases the projected greenfield development of a bauxite deposit includes directly or indirectly the construction of a captive alumina refinery. Examples: Utkal (India), GAC (Guinea), Aurukun (Australia), CAP (Brasil), Ma'aden (Saudi Arabia).

In some cases the project may be executed in two stages: a first stage of establishing the bauxite mine with (temporary) export of bauxite, and a second stage including the construction of an alumina refinery. A recent example is the Darling Range project of Bauxite Resources Ltd in Australia as stated in press releases.

How have greenfield production capacities and more specifically greenfield alumina refinery design capacities developed over time, and did this have a bearing on project implementation?

3. Alumina Refinery Capacity Evolution

3.1 Overview

An alumina refinery consists of a number of unit operations such as grinding, digestion, evaporation, etc. A unit operation generally comprises a string of equipment which together performs the desired process step, e.g. digestion with feed tank, heat exchangers, pumps, digester vessel(s), flash vessels, etc. Such a string of equipment is often referred to as a "train", "unit" or "circuit" (e.g. digestion unit, precipitation train, mill circuit). Alumina refinery design generally takes the digestion area as plant bottleneck due to its high unit capital cost and its requirement for constant flow for optimum performance.

The design / initial refinery production capacity of greenfield projects has evolved over time from about 0.5-1.0 Mt/y alumina 25-30 years ago (e.g. Worsley, Alumar, Aughinish) to 1.4-3.3 Mt/y alumina for more recently constructed and future planned projects (e.g. Lanjigarh, Yarwun, Utkal, GAC). Figure 1 illustrates this trend.

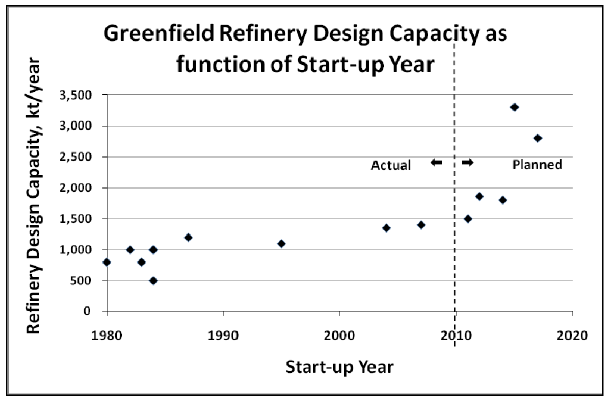

Figure 1 – Refinery Design Capacity vs Start-up Year

Note that actual refinery production capacities increase over time as a result of de-bottlenecking, improved process efficiencies and operations performance, etc. In a paper presented at the ICSOBA 2008 conference [1] R. den Hond even suggests a doubling of design capacity by exploiting overdesign and post start-up installation of novel technology.

What has been the rationale for this trend of ever-increasing design production capacities for recently built and future planned greenfield refineries and what are its consequences?

3.2 Economy of Scale

The rationale offered for this trend is the economy of scale: an increased alumina production capacity improves the economics (NPV, IRR, VIR[1]) of a greenfield bauxite and alumina project[2].

In the context of alumina refinery projects, economy of scale aspects may be applied to Operating Cost and Capital Cost.

[1] NPV=Net Present Value; IRR=Internal Rate of Return; VIR=Value over Investment (capital efficiency) ratio.
[2] Reference [2] provides an overview of bauxite & alumina project economics.

3.2.1 **Effect on Operating Cost**[3]

To better assess the effects of the economy of scale on Operating Cost, we should consider its major components:

- *Variable costs: In $/year these costs vary with plant production, at least within certain plant production rates (typically ± 10-15%), examples: bauxite, caustic soda, coal, fuel oil, lime.* The overall plant on-line time of an alumina refinery with more than one train / unit / circuit, e.g. a digestion train, is higher than a plant with one train only, as a result of more flexibility in equipment operation and maintenance. The effect on plant on-line time is generally limited (indic. 0.2-0.5% abs), however may vary widely and in a specific case could be significant (≥1% abs). As a result the plant operates with less interruptions and operating efficiencies (e.g. bauxite, caustic soda, energy consumption) improve, albeit generally to a limited extent (indic. 0.5-3%).
- *Fixed costs: In $/year these costs do not vary with plant production, at least within certain plant production rates (typically ± 100,000 t/yr), examples: labour, maintenance materials, administration, other fixed costs.* This is the area on which the economy of scale potentially has the largest effect, i.e. a drop in cost per tonne of alumina produced, due to the "dilution" of "fixed" annual expenses by a larger production volume. This applies particularly to labour and other fixed costs. If the increase in production capacity includes an increase in the number of trains, this positive effect is dampened because not just the size of the equipment involved increases, but also its number. In addition, the requirements of complex and large alumina refineries may result in disproportional increases of overhead costs.

The example provided in Table 1 may illustrate the above. In this example the larger refinery capacity is based on an increase in the number of operating units in several areas, resulting in a limited improvement only of the fixed costs per tA.

Table 1 – Effect of Economy of Scale on Opex – 1

Refinery Production Capacity, Mt/y*	**1.4**	**3.2**
Variable Costs, $/tA	85	83
Fixed Costs, $/tA	40	34
Total Operating Cost, $/tA	**125**	**117**

* Mt/y = million tonne alumina per annum

Table 2 provides an example in which the capacity increase involved an increase in equipment size rather than the number of operating units, illustrating in that case a more pronounced effect on fixed costs per tA.

Table 2 – Effect of Economy of Scale on Opex – 2

Refinery Production Capacity, Mt/y*	**2.8**	**3.3**
Variable Costs, $/tA	84	84
Fixed Costs, $/tA	50	42
Total Operating Cost, $/tA	**134**	**126**

* Mt/y = million tonne alumina per annum

[3] Reference [3] provides an overview of Operating Cost

The conclusion from the above is that the primary effect of economy of scale on Operating Cost is on fixed costs (expressed per tA), and particularly if a capacity increase is the result of an increase in equipment size rather than equipment number.

3.2.2 **Effect on Capital Cost**[4]

Economy of scale has the following main effects[5] on Capital Cost:

- In general larger size equipment, particularly tanks and vessels, is more cost effective per tonne alumina (tA) produced because larger tanks have a smaller surface area over volume ratio than smaller tanks, hence are cheaper in material cost per m^3 stored volume. This effect is sometimes known as the "0.6 factor rule"[6], and potentially represents a significant drop in capital cost per tA (note: this factor may be different for different equipment types and unit operations). Although technological improvements have resulted over time in a general increase in equipment size available for most processing equipment (vessels, tanks, pumps, mills, filters, etc), there are physical, technical and/or economic limitations to the size of all equipment. In addition, design considerations may favor in specific cases a large number of small equipment over a small number of large equipment.
- Infrastructure (both shared and non-shared) costs are diluted (e.g. piperacks, water supply, power distribution), and spare equipment may be shared in case of a larger production capacity resulting in the construction of more units. Both of these result in a lower capital cost per tA produced. As an illustration: for a refinery with two digestion trains, shared facilities represent indicatively 20-25% of its capital cost (includes raw materials handling, general facilities, shared spares, etc). Here too there are limitations: both with respect to sharing of spare equipment and because capacity increases in infrastructure are required at some stage.

The overall effect is a drop in capital cost per tA produced at higher production capacities. A straightforward power factor relationship between these would look like Figure 2.

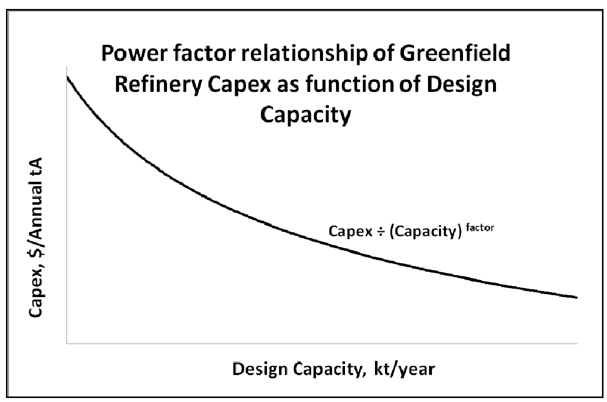

Figure 2 – Refinery Capex vs Design Capacity – Power Factor

In many cases however plant (and thus project) capacity increases are a combination of increases in equipment size and in equipment numbers (e.g. as a result of an increase in operational

[4] Reference [4] provides an overview of Capital Cost.
[5] A second-order effect is an increased plant on-line time as a result of a plant consisting of more than one train resulting in a slightly lower capex per annual tA.
[6] Theoretically the factor is 0.67.

units / trains). In addition, an increased project scope also adds (at some stage disproportionally) to its complexity.

As a result, actual capital cost per tA produced may deviate from a smooth curve as shown in Figure 2. In fact Canbäck and others [5] refer to Bain who found in a study of twenty industries that at the plant level, beyond a minimum optimum scale few additional economies of scale can be exploited.

Available information suggests for the alumina industry that with respect to the relationship of refinery capital cost and design capacity, a differentiation can be made in two design capacity ranges as illustrated in Figure 3:

- Up to about 1.5 Mt/y: a power factor of ~0.7.
- Above about 1.5 Mt/y: a power factor of ~0.9.

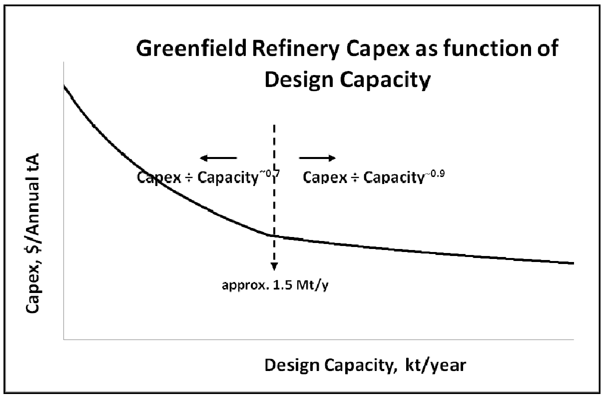

Figure 3 – Refinery Capex vs Design Capacity

From Figure 3 it would appear that although further gains in capital cost per tA are possible at design capacities above ~1.5 Mt/y, these will be limited. A design capacity of about 1.5 Mt/y for an alumina refinery might perhaps be the "minimum optimum scale" referred to by Canbäck . Note that 1.5 Mt/y is meant to be indicative only.

This raises the question how this result can be reconciled with the design capacity of some future planned projects which are well above 1.5 Mt/y (refer Figure 1).

3.2.3 Infrastructure Costs & Overall Economics

The explanation for the above result is that greenfield projects have infrastructural requirements which may include access roads and bridges, a railway line, port facilities, and employee living facilities. In case of extensive infrastructural requirements, the related capital cost is significant and has a disproportional bearing on the economics of a smaller capacity greenfield project.

An example may illustrate the above for two greenfield project options at the same location: option 1 at 1.5 Mt/year alumina production design capacity, and option 2 at 3 Mt/year. Assumed infrastructural requirements for this location:

- 100 km railway line.
- Jetty and wharf, and ship loading/unloading facilities at the alumina export port.
- Employee housing and living facilities.

Table 3 provides indicative numbers for capital, operating and sustaining capital costs for the two options considered in this example and their economics.

Table 3 – Effect of Capacity on Overall Project Economics

Refinery Capacity	**1.5 Mt/y**	**3 Mt/y**
Capital Cost*, M$		
Mine	115	200
Refinery	1,635	3,000
Infrastructure (railway, port, town)	500	680
Total Capital Cost*, M$	**2,250**	**3,880**
$/AnntA	1,500	1,293
Operating Cost, $/tA (incl. Infrastructure opex)	**137**	**125**
Sustaining Capital, $/tA	**8**	**8**
Economics# (indic.)		
NPV(8%), M$	- 139	369
IRR, %	7	9
Payback period, y	10.5	9

* Basis W Europe, Mid 2010 US$
# Alumina price at 325 $/tA

Table 3 shows that, despite the Refinery capex per annual tA for the two options following the trend illustrated in Figure 3, the overall project economics flip from a significant negative NPV (with IRR 7% and payback period 10.5 years) to a significant positive NPV (with IRR 9% and payback period 8.5 years).

A major contributor is the disproportional increase in $/tA of the Infrastructure capex. To underpin that: had the delta in capital cost between the two project options expressed in $/Annual tA remained unchanged from the delta between the two refineries, the economics of the 1.5 Mt/year project (in that case at a total capex of 1,383 $/AnntA) would have looked as follows: NPV(8%) = -12 M$; IRR = 8%; Payback period = 9.5 years.

On re-considering the trend shown in Figure 1, the reasoning could be turned around: a disproportionate increase in project scale is required to result in acceptable economics.

In a similar context, A. Kjar in his paper presented at the TMS 2010 Annual Meeting [6] discusses in general terms the uncompetitive capital cost of recent Western-developed greenfield alumina projects as a result of (among other reasons) large project size and increased project complexity.

3.3 Consequences

The indicated increase in the design / initial capacity of greenfield (bauxite mine and) alumina refinery projects over the past decades has had the following major consequences:

- The complexity of these mega projects[7] has increased significantly, especially in terms of project planning and management. Significant infrastructural works are often required, involving extensive government involvement, adding to project complexity.
- Project capital cost has grown to several billion USD, and project owners reduce risk through project financing and the formation of multi-party joint ventures. This is perfectly reasonable, however it complicates project implementation (e.g. with respect to decision making processes).
- Due to the financial commitments involved, globally only a limited number of (very) large companies have the financial and human resources to develop greenfield bauxite & alumina projects.

[7] Typically projects over 1 billion US$.

- For the same reasons (project scope, complexity), only a limited number of engineering firms have the required engineering, construction and project management skills and experience to successfully implement these projects.
- Typically a project life of 30^+ years is (implicitly) applied to justify the significant investment of a greenfield bauxite & alumina project. Reason: an alumina refinery can operate effectively for decades (refer e.g. Paranam, Gove, Kwinana, QAL). For greenfield bauxite & alumina projects with a captive refinery this means that the bauxite deposit on which a project is based should be able to sustain refining operations for such a period. Therefore only (very) large bauxite deposits are developed, indicatively 200-300 Mt and more.

In summary, worldwide only a small number of companies develop mostly very large greenfield bauxite and alumina projects, which often take a decade and more to develop.

3.4 Where from here?

With an objective to lower the threshold for the development of bauxite and alumina projects, the question may be asked if the underlying trend, viz. ever-increasing alumina refinery design capacities, is inevitable, or if viable alternatives exists. The basic reason for the trend being economics (refer section 3.2), the question could be reformulated as follows: is it possible to develop smaller greenfield bauxite and alumina projects at acceptable economics?

A. Kjar addresses this question and some of the issues discussed above, albeit from a different perspective, in his earlier mentioned paper. He indicates that as a means to overcome some of these issues, attempts were made by others: 1. To gain improved control over the project execution process; and 2. To increase the level of pre-assembly to reduce total costs of on-site construction labor and low productivity – refer also a paper by R. Valenti and P. Ho [7]. A. Kjar proposes the use of replication of a modern plant design, and small increments of capacity (without quantifying a capacity), in order to quickly and more cost-effectively build a large plant / project.

Although A. Kjar's paper has a different angle (viz. building a large plant at lower capital cost), there are overlaps with the subject of the current paper (investigating the possibility to lower the threshold for the development of – smaller – bauxite and alumina projects).

To further explore the subject, a more in-depth look at the make-up of a greenfield project's capital cost is required.

4. Capital Cost Make-up

4.1 Refinery Capital Cost

4.1.1 Overview

The capital cost of a greenfield alumina refinery may be split up as shown in Table 4. In this table typical numbers are shown for a low-temperature digestion alumina refinery with a 1.5 Mt/y production capacity. Note that actual numbers may deviate significantly as a result of bauxite quality, technology choices, plant location, etc.

Table 4 – Greenfield 1.5 Mt/y Aa Refinery Capital Cost (typ.)

Cost Item	1.5 Mt/y
Direct Costs	
Equipment*	231
Commodities[#]	539
Total Direct Costs, M$	**770**
Indirect Costs	
Freight	78
EPCM	256
Temp. Construction, start-up, Commissioning, etc	180
Owner's Engineering & Other Costs	190
Total Indirect Costs, M$	**704**
Contingency, M$	**161**
Total Refinery Capital Cost[&], M$	**1,635**

* Incl. steam & power generation, sub stations, residue disposal, water supply, communication & info systems
# Incl. concrete, steel, mechanical bulks, piping, wire and cable, etc
& Basis W Europe, Mid 2010 US$

4.1.2 Commodities and Plant Layout Aspects

Table 4 illustrates that the Commodities represent a very significant element in the refinery capital cost. Commodity amounts and their related capital costs reflect plant design including plant layout.

Current alumina refinery layouts are designed to accommodate additional (future) digestion units (and all of the other required process units – e.g. precipitation, evaporation). The consequence is that plant design is not optimized for its initial production capacity. Plant layout is characterized by an "open architecture", at best compromising between on the one hand the limited layout requirements for the initial / design capacity and on the other hand the more extensive requirements to accommodate future additional process units. And in the worst case consisting of a layout of a large-capacity plant of which part is built, resulting in an inefficient plant layout for the design / initial capacity. In addition, in some cases plant design includes equipment which at some future stage might be used to its full capacity, but operates (well) below design for a considerable part of its lifetime.

4.1.3 Alternative Approach – Dedicated Plant Capacity

A. Kjar's proposal to use replication means that a design is developed for a dedicated production capacity. Or putting it differently, this alternative design approach aims at designing an alumina refinery for a dedicated production capacity, i.e. without provisions for future expansions. This approach enables optimizing plant layout for the targeted production capacity, e.g. with respect to positioning similar equipment close to each other, use of common spares, etc.

This more "closed" layout architecture results in a more efficient plant layout, reflected for example in the design of main plant piperacks. This is illustrated in Figure 4 which shows the main piperack layout for a typical (current design) 1.5 Mt/year capacity refinery (i.e. in the expectation that additional production lines in the various areas will be added in the future), and the layout for a dedicated 1.5 Mt/y capacity alumina refinery (same scale).

The alternative approach with its more closed layout design impacts positively on commodity volumes: for the same production capacity, commodity volumes for a greenfield plant designed along this alternative approach are similar to that of a brownfield expansion of an existing refinery. This is illustrated in Figure 5 which shows the total length of piping of greenfield and brownfield projects as function of plant production capacity, and the requirement of a dedicated plant of 1.5 Mt/y capacity.

This approach also stimulates focusing on a "lean" design and exploit any potential overdesign right from start-up (refer the comment made in section 3.1).

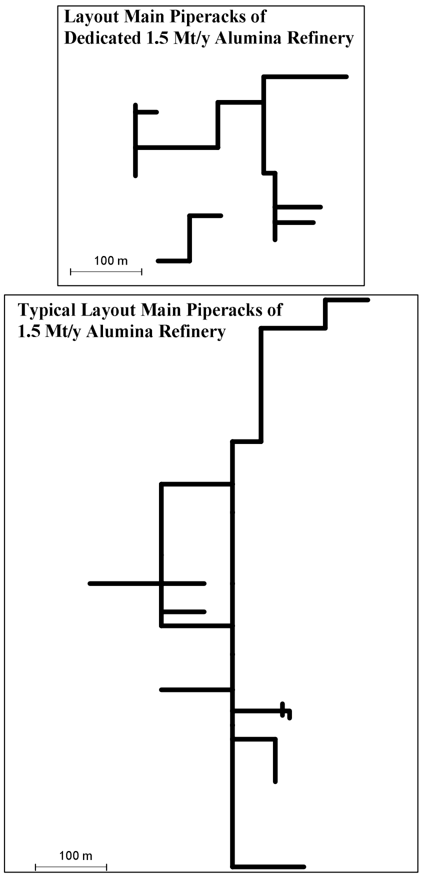

Figure 4 – Main Piperack Layout Comparison

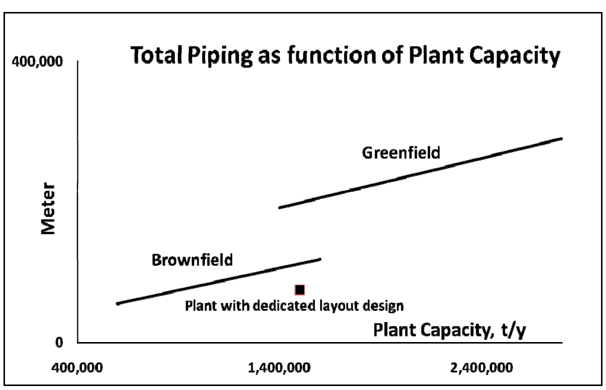

Figure 5 – Total Piping as function of Plant Capacity

4.1.4 Effect Alternative Approach on Commodities Cost

A dedicated greenfield plant design results in lower amounts (in some cases significantly lower amounts) per annual tA produced of commodities such as steel, concrete and piping. This is reflected in lower Commodities costs, resulting in lower Direct Capital Costs, in turn lowering Indirect Capital Costs. The overall effect on the capital cost of a greenfield dedicated low-temperature digestion alumina refinery of 1.5 Mt/y is illustrated in Table 5 (indicative numbers).

As can be seen in this table, the alternative approach improves the total refinery capital cost indicatively by over 10%. In fact the capital cost expressed per annual tonne of alumina capacity is lower than that of the current-design refinery at 3 Mt/y capacity (976 vs 1,000 $/Ann tA – refer Table 3).

Table 5 – Comparison of Refinery Capital Costs (indic.)

Cost Item	**1.5 Mt/y Refinery Capacity**	
	Current-design	**Dedicated**
Direct Costs		
Equipment*	231	224*
Commodities	539	459
Total Direct Costs, M$	**770**	**682**
Indirect Costs		
Freight	78	69
EPCM	256	227
Temp. Constr., start-up, Comm.	180	175
Owner's Eng. & Other Costs	190	168
Total Indirect Costs, M$	**704**	**640**
Contingency, M$	**161**	**142**
Total Capital Cost#, M$	**1,635**	**1,464**
$/AnntA	1,090	976

* The more efficient plant layout enables slightly lower equipment cost as a result of a more efficient use of common spare equipment
# Basis W Europe, Mid 2010 US$

4.1.5 Compact Refinery – Simple & Limited Scope

Along the lines of A. Kjar's paper (although he does not quantify "small increments of capacity"), applying the proposed dedicated-capacity approach to a compact alumina refinery capacity of 0.4 Mt/y results in a project with a simple and much more limited scope. Available data suggest that as a result some Indirect capital cost items decrease more than proportionately, particularly costs related to temporary construction and start-up support, camp and other construction related items, and owner's costs.

Table 6 illustrates the capital cost for a 0.4 Mt/y alumina refinery based on a dedicated design (indicative numbers). The table shows that the capital cost per annual tonne alumina (1,295 $/AnntA) is higher than that of the much larger 1.5 Mt/y dedicated plant (976 $/AnntA – refer Table 5), however is at a level which could result in a project with acceptable economics, provided Infrastructure capital cost is limited (compare with the 1,293 $/AnntA for the overall project capital cost of a 3 Mt/y refinery – see Table 3). Table 6 also shows that the total capital cost is at a level which would enable many more (relatively small) companies to develop such a project without necessarily requiring the formation of multi-party joint ventures, simplifying overall project management and thus enabling to lower costs (effect not included in Table 6).

Note that the 0.4 Mt/y refinery production capacity used here is not fixed but is meant to typify a capacity range of ~ 0.3-0.6 Mt/y. The higher end of this range is limited by the objective to end up with a total project capital cost well below 1 billion US$, the lower end is determined by logistical limitations (e.g. with respect to caustic soda and fuel oil shipments) and may vary for different locations.

Table 6 – 0.4 Mt/y Refinery Capital Cost (indic.)

Cost Item	0.4 Mt/y Refinery Capacity (dedicated design)	
Direct Costs		
Equipment	95	
Commodities	177	
Total Direct Costs, M$		**272**
Indirect Costs		
Freight	28	
EPCM	91	
Temp. Constr., start-up, Comm.	37	
Owner's Eng. & Other Costs	33	
Total Indirect Costs, M$		**189**
Contingency, M$		**57**
Total Capital Cost*, M$		**518**
$/AnntA	1,295	

* Basis W Europe, Mid 2010 US$

4.2 Infrastructure Capital Cost

As mentioned above, in order to realise acceptable economics for a project based on a compact dedicated production capacity, Infrastructure capital cost should be limited. Conversely a project based on a compact plant capacity has very limited infrastructural requirements and has several advantages over a large plant, particularly if the project is located close to an existing port, e.g. it may be allowed closer to residential areas (i.e. is closer to existing infrastructure); the existing infrastructure may be sufficient for a small plant, but not for a big plant; a suitable location for a small residue disposal area is easier to find than for a large one, etc. As outlined in section 5.3 several such locations exist worldwide.

4.3 Refinery Technologies

Note that the alternative approach proposed above is independent of the selected refinery technologies, while at the same time stimulating to focus on improvements, e.g. positioning similar equipment close to each other, the use of common spares, etc.

4.4 Replication and Indirect Costs

A. Kjar indicates in his paper that the use of replication of a modern design at small capacity increments has as one of its main advantages far lower indirect capital costs, comprising Project management; Procurement; and Technology & EPCM fees.

Although no direct quantification is mentioned in the paper, this appears consistent with the results discussed above for a dedicated plant design at a compact production capacity. Some of the replication-related cost savings mentioned by A. Kjar may come on top of the cost improvements indicated in this paper.

5. New Bauxite Deposit Development Model

5.1 New Development Model

The bauxite deposit development model proposed in this paper as detailed above is based on the development of a dedicated compact alumina refinery in the range ~ 0.3-0.6 Mt/year.

The dedicated refinery design has no provisions for future expansions, enabling optimizing plant layout and resulting in lower capital cost per tonne of alumina (tA) produced compared with current plant design. The compact capacity results in a project with a simple and limited scope, further improving capital cost per tA produced.

To ensure acceptable economics, Infrastructure capital cost should be limited. At the same time such a project has few infrastructural requirements , especially if located close to an existing port.

5.2 Main Advantages

The main advantages of the new development model are:

- Due to the significantly smaller project capital expenditure involved (lower risk), this approach enables the development of bauxite & alumina projects by smaller companies without a need to form multi-party joint ventures, i.e. it increases the number of companies potentially interested in developing bauxite deposits. In other words competition increases, which should result in more efficient use of resources, both in terms of capital resources and in terms of global bauxite deposits.
- Due to the decreased complexity of compact alumina refining projects, the number of engineering companies potentially able to develop these projects increases, again resulting in more competition and the potential for a more efficient use of resources.
- Small and simple projects carry less risks and require less time to develop, implement and start-up, all of which has a positive impact on economics.
- A long term alumina refining project based on the new model requires only a relatively small bauxite deposit (a deposit of ~40 Mt could support a 0.4 Mt/y project for 30 years). This means that worldwide the number of bauxite deposits that lend themselves to development increases.
- The new development model may be applied also to the development of part(s) of a large deposit.
- This approach may in some cases lower the threshold to increase value creation through alumina refining rather than being limited to bauxite export sales. This is attractive both to host countries and to companies developing potential bauxite & alumina projects.
- In some cases, an adapted version of this new development model may enable bauxite deposit development even in locations with little existing infrastructure, albeit at a larger than compact scale (refer e.g. to Table 5 for a dedicated 1.5 Mt/year capacity project).

5.3 Possible Locations

Following are some examples of bauxite deposits that may lend themselves to development via the proposed alternative approach (between brackets the potential alumina export port):

- Haden, Queensland, Australia (Brisbane).
- Bindoon, Western Australia (Fremantle).
- El Palmar, Venezuela (Ciudad Guayana).
- Trelawny, Jamaica (Discovery Bay).
- Kibi, Ghana (Tema).

The above list is not exhaustive and meant to be illustrative only.

In addition some bauxite deposits which in view of their size could support the current development approach with large-capacity alumina refining projects, may also lend themselves to stage-wise development through the proposed alternative approach. In this case these deposits would be able to support several (smaller) greenfield bauxite and alumina projects as outlined in the last bullet point of section 5.2 above. Example: some of the Eastern Ghats deposits in Orissa and Andhra Pradesh, India, e.g. the Kutrumali deposit (with Visakhapatnam as potential alumina export port).

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