Economies of scale and alumina refining

The rationale provided for an increase in the production capacity of a greenfield, brownfield or existing (bauxite and) alumina project is often that the increase results in improved project economics [1] as reflected in NPV, IRR, and VIR. In this article, we investigate the effects of economy of scale on operating cost (opex), capital cost (capex) and the overall economics of alumina refinery projects.
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To illustrate the effects of the economy of scale on opex [2], we need to consider its main components:
• **Variable costs**: In $/year, variable costs vary in proportion to plant production, at least within certain plant production rates (typically ± 10-15%), for bauxite, caustic soda, coal, fuel oil, lime, and so on. The overall plant on-line time of an alumina refinery with more than one production unit/train – such as a digestion unit – is higher than a plant with one production unit only due to increased flexibility in equipment operation and maintenance. The effect on plant on-line time is generally limited (indic. 0.2-0.5% abs), however, it may vary widely and in specific cases could be significant (≥1% abs). As a result the plant operates with fewer interruptions, and operating efficiencies (e.g. consumption of bauxite, caustic soda, and energy) 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/year). Good examples here would be labour, maintenance materials and contract services, administration and other fixed costs. This is the area in which the economy of scale may have a significant impact (drop in cost per tonne of alumina – tA – 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 production trains, the positive dilution effect is reduced because not necessarily the size of the equipment involved increases, but (also) its number. In addition, the requirements of complex and large alumina refineries may result in disproportionate increases of overhead costs such as management and technical support, contract services and so on.

Table 1 illustrates the above for a greenfield project which was evaluated at two different production capacities (1.4 and 3.2 Mt/year).

Refinery production capacity, Mt/y*	1.4	3.2
Variable Costs		
Bauxite	14	14
Energy	90	88
Consumables (caustic soda, lime, etc)	32	31
Other variable & transport costs	19	18
Total Variable Costs, $/tA	**155**	**151**
Fixed Costs		
Maintenance Materials & Services	18	18
Labour	12	8
Other Fixed	8	7
Total Fixed Costs, $/tA	**38**	**33**
Total Operating Cost, $/tA	193	184

* Mt/y = million tonne alumina per annum

Table 1. Effect of Economy of Scale on Opex – Increased no. of Operating Units

The larger refinery capacity is based mainly on an increased number of production units in several areas such as digestion, resulting in only a limited improvement of the fixed costs per tA. The decrease in variable costs is the result of improvements in operating efficiencies mainly due to operating two production units instead of one.

In another case, a greenfield project increased its design production capacity from initially 2.8 to 3.3 Mt/year without changing the number of production units. This modification represented an increase of equipment size at very similar process conditions. This has two major consequences: virtually unchanged variable operating costs, while fixed costs are significantly diluted. This is illustrated in **Table 2**, which shows

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a drop in fixed costs (3$/tA at a production increase of 0.5 Mt/y), which, in relative terms, is much larger than the drop in fixed costs of **Table 1** (5$/tA at a production increase of 1.8 Mt/y).

Refinery production capacity, Mt/y*	2.8	3.3
Total Variable Costs	**152**	**151**
Fixed Costs		
Maintenance Materials & Services	20	18
Labour	9	8
Other Fixed	7	7
Total Fixed Costs, $/tA	**36**	**33**
Total Operating Cost, $/tA	188	184
* Mt/y = million tonne alumina per annum		

Table 2. Effect of Economy of Scale on Opex – Increased Equipment Size

In summary, a significant effect of economy of scale on Opex is on fixed operating costs (expressed per tA), and especially if a production capacity increase is the result of an increase in equipment size rather than equipment number. The effect on variable operating costs is generally small, unless the increased production capacity results in an increase in production trains, particularly going from one to two trains.

Economy of scale effect on capex [3]

The main effects of the economy of scale on capex are:

• In general larger equipment, particularly tanks and vessels, are more cost effective per tA produced because larger tanks have a smaller surface area over volume ratio than smaller tanks, hence are lower in material cost per m^3 stored volume. This effect is sometimes referred to as the “0.6 factor rule”, and potentially represents a significant drop in capital cost per tA (note: this factor may differ for different equipment types/unit operations).

While technological improvements have resulted over time in a general increase in equipment size available for most processing equipment (vessels, tanks, pumps, mills, filters), there are physical, technical and/or economic limitations to equipment size. In addition, design considerations may favour, in specific cases, a larger number of small equipment over a smaller number of large equipment.

• Plant infrastructure (both shared and non-shared) costs are diluted (e.g. piperacks, water supply, power distribution), and spare equipment may act as common spares in case a larger production capacity results in the construction of more production units. Both aspects result in a lower capital cost per tA produced. As an illustration: for a refinery with two digestion units shared facilities (such as raw materials handling, general facilities, shared spares, etc) would represent, indicatively, 20-25% of its capital cost. Here again there are limitations: first, with respect to sharing spare equipment; and second, capacity increases in infrastructure will be 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 could look like **Fig 1**.

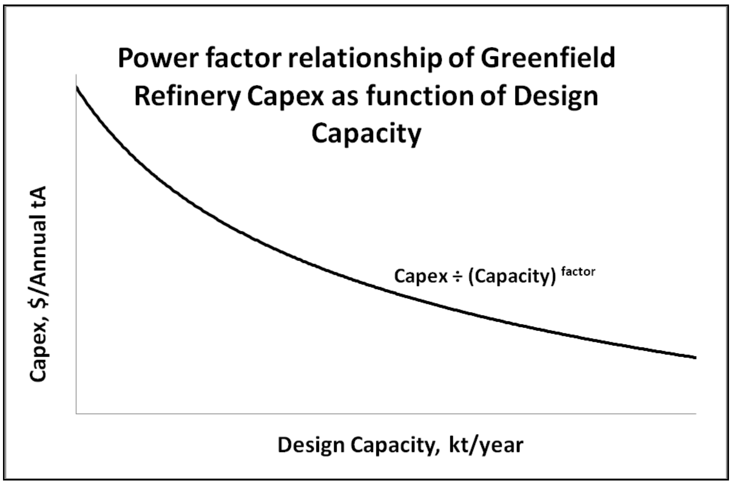

Figure 1. Refinery Capex vs. Design Capacity – General Power Factor

In most cases, however, increases in plant (and thus project) capacity are a combination of increases in equipment size and in equipment numbers (e.g. as a result of an increase in the number of production trains). In addition, an increased project scope also adds (sometimes disproportionally) to complexity.

As a result, actual capital cost per tA produced may deviate from a smooth curve as shown in **Fig 1**. Canbäck and others[4] refer to Bain who found in a study of 20 industries that at the plant level, beyond a minimum optimum scale few additional economies of scale can be exploited.

Available information for the alumina industry suggests that with respect to the relationship between refinery capex and design capacity, a differentiation may be made in two production capacity ranges as illustrated in **Fig 2**:

- Up to about 1.5 Mt/year: a power factor of indicatively 0.7 $\pm$ 0.05.
- Above about 1.5 Mt/year: a power factor of indicatively 0.9 $\pm$ 0.1.

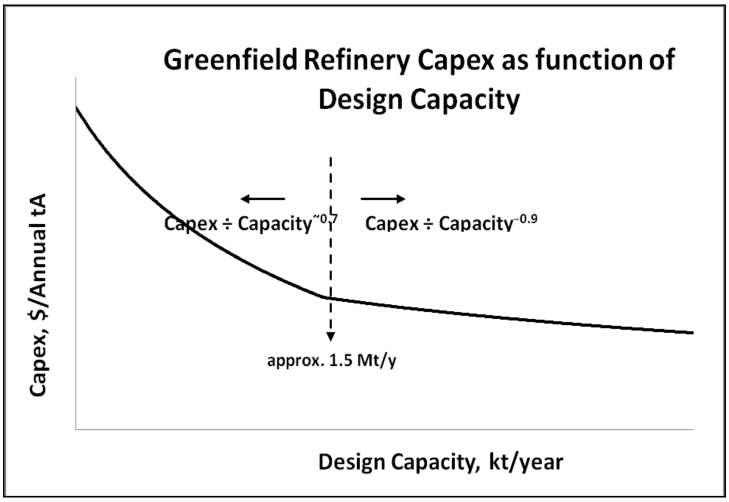

Figure 2. Refinery Capex vs. Design Capacity – Actual Power Factor

The production capacity of about 1.5 Mt/y is consistent with the current maximum production capacity of an alumina refinery with one digestion unit/train, which appears reasonable as this area is generally taken as plant bottleneck due to its high unit capital cost and its requirement for constant flow to achieve optimum performance levels. This capacity, perhaps, represents Canbäck's "minimum optimum scale" [4].

In summary, economy of scale effects on alumina refinery capex appear most pronounced for design production capacities up to ~1.5 Mt/y, with less potential to improve capital cost per tA at larger capacities. Note that 1.5 Mt/y is not a fixed number, but indicative only (range ~1.4 – 1.7 Mt/y), and may increase over time as equipment sizes increase.

What is the reason for several new and future projects with design production capacities well above 1.5 Mt/year?

Project infrastructure costs and overall economics

The answer is that greenfield projects have infrastructural requirements which may include access roads, bridges, a railway line and port facilities. In case of extensive infrastructural requirements, the related capital cost is significant and has a disproportional bearing on the economics of a greenfield project with a relatively small production capacity.

An example may illustrate this point for two greenfield project options at the same location: an option at 1.5 Mt/year alumina production design capacity, and an option at 3 Mt/year. The following infrastructural requirements have been assumed: 100 km railway line, railway wagons and locs, port jetty and wharf, and port ship loading/unloading, storage and handling facilities. **Table 3** provides indicative numbers for capital, operating and sustaining capital costs for these two options, and their indicative economics.

Refinery capacity	1.5Mt/y	3Mt/y
Capital Cost, M$		
Mine	115	200
Refinery	1,800	3,200
Infrastructure (railway, port)	430	500
Total Capital Cost, M$	**2,345**	**3,900**
$/AnntA	1,563	1,300
Operating Cost, $/tA	**193**	**186**
(incl. Infrastructure opex)		
Sustaining Capital, $/tA	**8**	**8**
Economics* (indicative)		
NPV (8%), M$	-248	221
IRR, %	6.7	8.6
Payback period[≠], y	11.5	10
VIR^, %	-11	6

*Alumina price at 360$/tA; 30 years operation
[≠] After start of operations
^ Capital efficiency ratio, expressed as NPV (8%) as percentage of Capex

Table 3. Effect of Economy of Scale on Capex & Overall Economics (indic.)

Table 3 shows that, despite the refinery capex per annual tA for the two options more or less following the trend illustrated in **Fig 2**, the overall project economics flip from a significant positive NPV(8%), an IRR of 8.6%, a payback period of 10 years and a VIR of 6% for the 3 Mt/year case to a significant negative NPV(8%), an IRR of 6.7%, a payback period of 11.5 years and a VIR of -11% for the 1.5 Mt/year case.

A major contributor is the disproportional increase in $/tA of the infrastructure capex for the smaller project. To underpin that: had the same capacity factor applied to the overall case as for the refinery capital cost, the economics of the 1.5 Mt/year project (in that case at a total capex of ~1,463 $/AnntA) would have been: NPV(8%) = -137 M$; IRR = 7.3%; Payback period = 11 years; VIR = -6%.

The reasoning could also be turned around: a significant increase in project scale is required to achieve acceptable overall project economics.

Conclusion

Economy of scale and infrastructural requirements are two key selection criteria to consider when deciding on the production capacity of a greenfield (bauxite and) alumina project. Other criteria include bauxite deposit size, market economics and logistics.

References

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