

ALUMINA PLANT COSTS AND ECONOMY OF SCALE

Economic evaluations of an alumina refinery project require generating (discounted) annual cash flows over its lifetime and applying several criteria to ascertain if it meets threshold levels (net present value [NPV], internal rate of return [IRR], etc.).

Key Inputs to Project Economics

Key inputs to annual cash flows are as follows (Ter Weer 2006):

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

The quality of the bauxite deposit and the design of the refinery also significantly affect an alumina refinery project's capital and operating costs.

Bauxite Deposit Quality Criteria

The main bauxite deposit quality criteria affecting alumina project economics are (ter Weer 2014)

- Country infrastructure capital cost;
- Distance from the bauxite resource to the export port (bauxite, alumina);
- Disturbed acreage per metric ton of alumina produced;
- Material handled per metric ton of alumina, consisting of
 - Material mined
 - Residue to disposal;
- Alumina in boehmite;
- Total caustic consumption per metric ton of alumina;
- Ratio of the extractable organic carbon-to-available Al_2O_3 ; and
- Resource-contained alumina.

Alumina Refinery Design Criteria

The main plant design criteria affecting economics are as follows (Ter Weer 2015):

- Liquor productivity/yield
- Digestion temperature
- Digestion technology
- Bauxite residue settling and washing technology
- Heat interchange technology
- Precipitation technology
- Power- and steam-generation technology
- Calcination technology
- Bauxite residue disposal technology
- Overall plant
 - Design and layout
 - Production capacity
 - Equipment and additives
 - Control equipment

Economy of Scale

Increasing plant production capacity is achieved by debottlenecking the area that limits plant capacity (this is often, but not always, the digestion area). This may be accomplished by adding another *train/unit* with commoning up in some areas, but also through higher flows of the liquor circuit, additional tank volume, pumps, piping, and so forth, and through increased liquor productivity/yield (approximately twofold over the past 40 years).

The design of alumina refinery production capacities of greenfield projects outside China have evolved from approximately 0.5–1.0 Mt/yr alumina 25–30 years ago to 1.4–3.3 Mt/yr alumina for more recently constructed and future planned projects. A refinery project represents a major investment with an expected operating life of 30–50 years.

Actual production capacities of existing projects have significantly increased as a result of brownfield expansions, debottlenecking, and improved process efficiencies and operations performance. Rationale for this

trend is the economy of scale: An increased production capacity is required to improve the economics of greenfield projects to meet corporate economic criteria.

Economy of Scale and Operating Cost

Economy of scale affects operating costs (P.J.C. ter Weer 2006), which include variable and fixed costs.

Variable Costs

Variable costs include bauxite, caustic soda, coal, and so forth. Overall plant online time of an alumina refinery with more than one production unit/train (e.g., a digestion unit) is generally slightly higher than a plant with only one unit (indicatively 0.2%–0.5% absolute) because of increased flexibility in equipment operation and maintenance. As a result of an increase in production units, the plant operates with fewer interruptions, and operating efficiencies improve (e.g., consumption of bauxite, caustic soda, and energy; indicatively by 0.5%–3%).

Fixed Costs

Fixed costs include labor, maintenance materials, contract services, administration, and so forth. Economy of scale may have a significant impact because of the dilution of fixed annual expenses by a larger production volume (drop in cost per metric ton of alumina produced). If the increase in production capacity includes an increase in the number of production units, the dilution effect is reduced. In addition, the requirements of complex and large alumina refineries may result in disproportionate increases of overhead costs.

Table 10 illustrates this concept for a greenfield project evaluated at different production capacities. The larger refinery capacity shown in Example 1 in Table 10 is mainly the result of more production units in several areas (e.g., digestion) causing a limited improvement of fixed costs per metric ton of alumina. The decrease of variable costs is mainly caused by improvements in efficiencies from operating two production units instead of one.

In another case (Table 10, Example 2), a greenfield project increased its design capacity from 2.8 to 3.3 Mt/yr maintaining the number of production units. This change represented an increase in equipment size at similar process conditions. This had two major consequences: virtually unchanged variable operating costs and significantly diluted fixed costs. Example 2 shows a drop in fixed costs (\$3/tA [metric ton of alumina] at a production increase of 0.5 Mt/yr), which in relative terms is much larger than the drop in fixed costs of Example 1 (\$5/tA at a production increase of 1.8 Mt/yr).

In summary, economy of scale has a significant effect on fixed operating costs, especially for plant capacity increases resulting from 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, because of an improved online time.

Economy of Scale and Capital Cost

The overall impact of the economy of scale is a drop in capital cost per metric ton of alumina produced at higher production capacities, although its impact on equipment and plant infrastructure differ (Ter Weer 2007, 2013). In most cases, increases in plant/project capacity are a combination of increases in equipment size and equipment number (e.g., increased number of production trains).

In addition, an increased project scope adds (sometimes disproportionately) to project complexity. As a result, actual capital cost per metric ton of alumina produced as function of plant capacity will not show a smooth curve. Canbäck and others (2006) refer to a study of 20 industries showing 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 the refinery capital expenditure (CAPEX) and design capacity, a differentiation may be made in two ranges as illustrated in Figure 13:

1. Up to ~1.5 Mt/yr with a power factor of $\sim 0.7 \pm 0.05$
2. Above ~1.5 Mt/yr with a power factor of $\sim 0.9 \pm 0.1$

The production capacity of ~1.5 Mt/yr is consistent with the current maximum production capacity of a refinery with one digestion unit/train. This appears reasonable as this area is generally taken as a plant design

Table 10 Economy of scale effect on operating expenditures (OPEX)

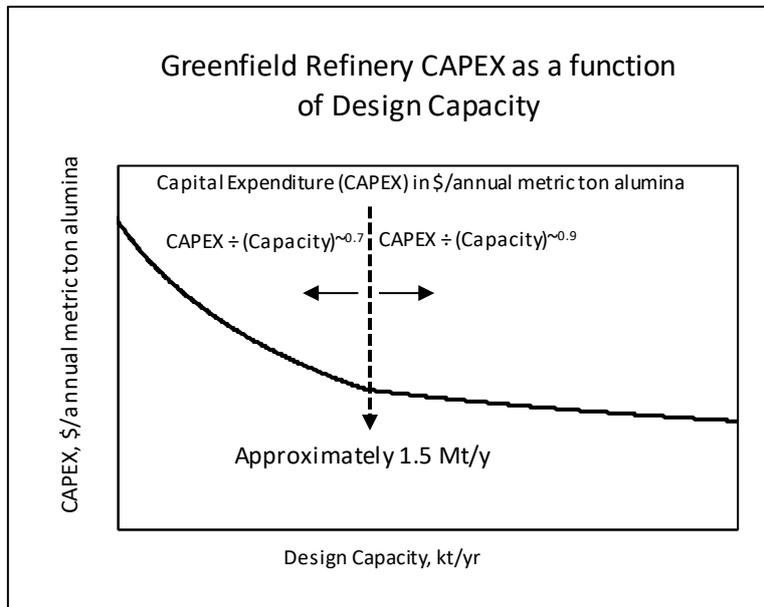
Example 1: Increased Number of Operating Units		
Plant Capacity, Mt/yr	1.4	3.2
Variable Costs		
Bauxite	14	14
Energy	90	88
Consumables*	32	31
Other variable costs†	<u>19</u>	<u>18</u>
Total Variable Costs, \$/tA‡	155	151
Fixed Costs		
Maintenance (materials and contract services)	18	18
Labor	12	8
Other fixed costs	<u>8</u>	<u>7</u>
Total Fixed Costs, \$/tA	38	33
Total OPEX, \$/tA	193	184
Example 2: Increased Equipment Size		
Plant Capacity, Mt/yr	2.8	3.3
Total Variable Costs, \$/tA	152	151
Fixed Costs		
Maintenance (materials and contract services)	20	18
Labor	9	8
Other fixed costs	<u>7</u>	<u>7</u>
Total Fixed Costs, \$/tA	36	33
Total OPEX, \$/tA	188	184

Source: P.J.C. ter Weer 2013

* Caustic soda, lime, etc.

† Including transport costs.

‡ tA = metric ton of alumina.



Source: P.J.C. ter Weer 2013

Figure 13 Capital expenditure (CAPEX) versus design capacity

bottleneck because of its high unit CAPEX and its requirement for constant flow to achieve optimum performance levels.

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

Infrastructure Costs and Overall Economics

Several new and future projects have been designed with production capacities well above 1.5 Mt/yr. The reason for this is that greenfield projects have infrastructure requirements that may include access roads, bridges, railway lines, port facilities, and so forth. When requirements are extensive, the related CAPEX is significant and has a disproportional impact on the economics of greenfield projects with relatively small production capacities.

An example illustrates this point for two greenfield project options at the same location: 1.5 and 3 Mt/yr alumina design capacity. The following infrastructure requirements have been assumed: 100-km railway line, railway wagons and locomotives, port jetty and wharf, port ship loading/unloading, and storage and handling facilities. Table 11 provides indicative numbers for capital, operating, and sustaining capital costs for these two options, as well as their indicative economics.

Table 11 Economy of scale effect on capital expenses and overall economics (indicative)

Plant Capacity, Mt/yr*	1.5	3
Capital Cost		
Mine	115	200
Refinery	1,800	3,200
Infrastructure	<u>430</u>	<u>500</u>
Total Capital Cost, M\$	2,345	3,900
\$/Annual tA [†]	1,563	1,300
Operating Cost, \$/tA		
	193	186
Sustaining Capital, \$/tA		
	8	8
Economics (indicative) [‡]		
Net present value (8%), M\$	–248	221
Internal rate of return, %	6.7	8.6
Payback period, yr [§]	11.5	10
Value over investment ratio, %**	–10.5	5.7

Source: Ter Weer 2013.

* tA = metric tons of alumina.

† Including infrastructure operating expenditures.

‡ Alumina price at \$360/tA; 30 years operation.

§ After start of operations.

** Capital efficiency ratio: NPV (8%) as percentage of capital expenditure.

Table 11 shows that despite the refinery CAPEX per annual metric ton of alumina for the two options essentially following the trend illustrated in Figure 13, overall project economics flip from a significant positive NPV (8%), with an IRR of 8.6%, payback period of 10 years, and a value over investment ratio (VIR) of 5.7% for the 3-Mt/yr case to a significant negative NPV (8%), with an IRR of 6.7%, payback period of 11.5 years, and a VIR of –10.5% for the 1.5-Mt/yr case. The major contributor to this is the disproportional increase in cost per metric ton of alumina of the infrastructure CAPEX for the smaller project.

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

Summarizing, economy of scale and infrastructure requirements are two key design criteria to consider when deciding on the production capacity of a greenfield (bauxite and) alumina project.

Alternative Project Approaches

Economy of scale and infrastructure requirements have resulted in ever-increasing production capacities for recently built and future planned greenfield refinery projects. As a consequence, the complexity of greenfield projects has significantly increased and capital cost in many cases has grown to several billion dollars, with vital consequences:

- Project owners aim at risk reduction through project financing and formation of joint ventures, further complicating project implementation (Kjar 2015).
- Globally, only a limited number of (large) companies have the human and financial resources to develop greenfield bauxite and alumina projects.
- Only a limited number of engineering firms have the skills and experience required to successfully implement these mega projects.
- Only (very) large bauxite deposits get developed.

The uncompetitive capital cost of recent Western-developed greenfield alumina projects is a result of (among other reasons) large project size and increased project complexity (Kjar 2010). To quickly and more cost-effectively build a large plant/project, increasing capacity in small increments and replicating modern plant design is recommended (Kjar 2010).

A new approach from a slightly different angle aims at designing an alumina refinery for a dedicated production capacity without provisions for future expansions (P.J.C. ter Weer 2011). This enables optimizing plant layout for the targeted production capacity, for example, with respect to positioning similar equipment close to each other, use of common spare equipment, and so forth. Possible future (brownfield) capacity expansions should justify themselves on their own economic merits.

Both of these alternative approaches result in improved project economics.

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