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Best Practices in Refinery Front-End Design at Alcoa World Alumina

With a formidable lineup of capital projects projected for the next 10 years, a method to "templatize" best practices and design of alumina refineries offers many advantages to this global aluminum producer

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Despite recent volatility in all global markets, it is still widely held that in the long term global aluminum demand will continue to increase. The challenges presented by high input costs will, however, reward those companies that can deliver operations that combine high efficiency and low operating costs.

Alcoa continues to evaluate and design refining and smelting operations on a global basis, and intends to deliver these when market conditions are appropriate. Alcoa will leverage its ability to develop these facilities at the bottom of the cost curve.

Several projects which Alcoa World Alumina has under consideration can be classed as mega projects—those with multibillion dollar capital costs. The challenges of implementing such projects are multiple, and include:

- Because of their size, mega-projects are particularly challenging to execute. Research has found that these are typically prone to cost growth and schedule slip, and due to the large labor requirements, any schedule slip burns more money.[1]
- Due to their sheer size, these projects can overwhelm local institutions, labor resources, infrastructure and regulatory bodies.
- Each of these factors is exacerbated by the heated industrial sector and pressure on skilled resources and labor alike.

Having a highly specified and well-developed front end on a project is a critical enabler in improving the return on capital and certainty of outcome.

Independent Project Analysis (IPA) research has also shown that, for projects in general:

- Projects that are highly schedule- and cost-driven tend to suffer the worst from cost and schedule blowouts against the authorization expectations.[1]
- Projects which have high levels of owners' input and engineering competency in the key project definition phase will be better matched to the business objectives.[2]
- Projects which integrate a strong owner's team into the project organization tend to achieve the best performance in cost and schedule, and almost equal in plant operability classes of assessment.[2]
- Projects with high levels of front-end-loading (FEL) and significant use of Value Improving Practices (VIPs) will tend to outperform those that do not.*

But how is a company to improve on these areas? Schedule and cost drivers are always going to play heavily on project goals and objectives. How do you successfully resource owners' teams and implementation of VIPs in an environment where experienced resources are scarce?

For Alcoa, part of the solution is recognizing and finding solutions that:

- Capture existing knowledge and expertise, document it and retain it.
- Rapidly train young engineers in operating plants to gain experience to seed owner's groups.
- Leverage the knowledge that Alcoa has accumulated at its nine operating refineries, its research facilities and centers of excellence.

*VIPs, or Value Improving Practices are a list of practices that are applied mostly in early project development stages that are statistically linked to better project outcomes for the same front end loading index.[2] The Alcoa GPDG has been keen to establish how to better implement particular VIPs:

- Technology selection
- Process simplification
- Class of plant quality
- Waste minimization
- Design to capacity
- Energy optimization.

- Use standard designs to include owner's input and successes, and to minimize cost and schedule damage during design iteration—get it right the first time.
- Improve the workflow at the front end by re-using successful designs and implementing automation.
- Take in-house control of front-end project definition and deliverables so that the output to contracted engineering houses is highly defined and can be implemented without rework.

The development of concepts and ideas in large or geographically dispersed groups has traditionally required a long cycle time. Today, the level of detail required to evaluate concepts to the required level of accuracy in an environment of "design to capacity," modular construction, tight timelines and more stringent standards and regulations, is increasingly difficult using the design techniques and methods of the past.

In the end, the goal is to achieve a FEL2-level scope that is complete, consistent with the projects objectives, and flexible enough so that as the design develops and progresses through the design phases, minor issues do not become fatal flaws that require major rework.

For Alcoa World Alumina's Global Process Design Group (GPDG), the challenge has been to:

- Quickly develop the rapid high quality concept, FEL1- and FEL2-level scopes to facilitate project feasibility assess-ments and prioritization.
- Facilitate the application of VIPs.
- Assess and develop alternate technology solutions.
- Increase productivity and efficiency of the limited resource of experienced process engineers.

This is done through:

- Automating as much of the front-end design work as possible and integrat ing the various design tools used.
- Storing and re-using of knowledge from previous projects and proven designs.
- Storing design knowledge from existing projects for future use.
- Streamlining the workflow of engineers and minimizing points of error generation and propagation.

Alcoa had successfully modeled their alumina refinery processes, on a plantwise basis, using a simulation tool, Aspen Custom Modeler (ACM). Over many projects, this has been used to develop highly detailed full-plant models carrying thousands of streams and hundreds of unit operations and performing full mass and energy balances and chemical reaction calculations. The key attraction of this package is that the programming language allows customizable calculations, rather than other packages which are more constrained to an "out of the box" calculation methodology.

Alcoa's use of ACM has generated a library of models able to be selected and incorporated into any design to suit the bauxite feedstock of the location being investigated and the technology options being evaluated. These model blocks are often also generally able to both model and size equipment. ACM is, however, an analytical tool, and more traditional manual methods have previously been used for developing PFDs, managing data on equipment types and developing datasheets.

As an advance in leveraging this knowledge and experience assembled in ACM and manual tools, Alcoa-GPDG examined the possibility of applying an integrated front end design tool, Aspen Basic Engineering (Zyqad). Zyqad acts as a central data repository, interface and integration tool during front-end design, collecting data from simulation model runs and equipment calculation programs. As a central, multidisciplinary shared database, it provides "one version of the truth" for all engineers and contractors engaged in a project. In its usual application in the oil and gas and chemicals industries, the Zyqad integrated database benefits from integration to chemical process simulators and to process industry datasheet templates. To apply this tool to the alumina refining domain, Alcoa-GPDG and Aspen Technology worked together to achieve the necessary integration and to develop the specific custom calculations, datasheets and equipment lists as used commonly in the minerals industry.

An overview of the Alcoa front end design solution is shown in Figure 1.

Alcoa-GPDG began implementation of the Zyqad solution in the fall of 2006 on the front-end design on one of its mega projects. After two years of use, this solution has already demonstrated strong value. In particular:

- Integration with the ACM simulation modeler, which moves data accurately into the Basic Engineering database such that a design template can be created.
- Integration with Alcoa's proprietary Excel-based design calculation tools and other simulation packages (e.g. Aspen HTFS+, Aspen APLE [now Plate+] and JKSimMet), and storing the results of those calculations in the Zyqad database.
- Capture of Alcoa design criteria in the system, ensuring best practices and standardized engineering, and
- Rapidly producing front-end design deliverables, including equipment lists and equipment data sheets, which greatly assists project estimating and business decision-making.

The test project on which this tool has been used received a rating of "Best Practical" rating from IPA for the current FEL phase and is now ready to move into the next phase. A potential next step and enhancement to productivity will be sharing of the design database with the EPCM contractor. Additionally, with a project database now populated, the design template exists which can be expected to yield significant benefit in the assessment, costing and engineering of subsequent refinery projects or upgrades.

Adapting Aspen Basic Engineering to the Metals Industry

Aspen Basic Engineering (Zyqad) is a comprehensive, integrated software system for improving workflow and efficiency in the front-end design process. The software was designed for the chemical and oil process industries and so the first step in Alcoa's implementation was to adapt the solution for the specific engineering design requirements of aluminum refining. The key tasks involved in adapting the solution to minerals processing have been:

- Mapping the refining unit models developed in Aspen Custom Modeler to the Zyqad database.
- Creating mineral processing-specific datasheets such as rakes, filters (disc, drum, belt, pan), bag house, mills (ball, rod, sag), ESPs, lime slakers and cyclones.
- Implementation of design rules to support Alcoa's engineering work flows and best practices.

Front-End Design Workflow—The front-end engineering workflow in use at Alcoa, prior to adoption of the Zyqad software, involved separate drafting of

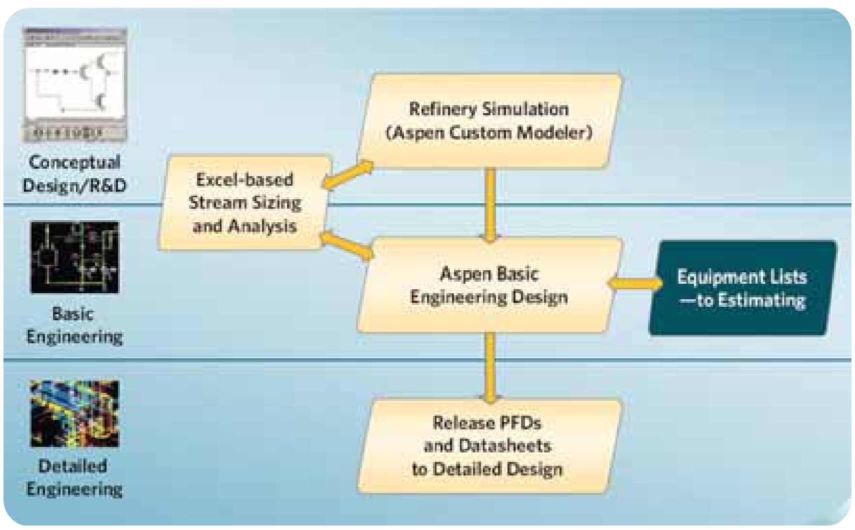

Figure 1: Alcoa front end design approach with ACM, Excel and Aspen Basic Engineering.

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PFDs and development of datasheets, both of which were dependent on manual transmittal of heat and material balance information from the simulation model, as well as the results of Excel-based manipulation of thermal and chemical data of the process streams. This left Alcoa's GPDG with the time-consuming task of preparing, communicating, checking and rechecking PFDs and datasheets to ensure accuracy and consistency. The engineering change process also was lengthy and expensive due to double handling of data and repeated check cycles both on the owner's side and the E&C's side for every revision of a deliverable. The process also was prone to errors due to manual reentry of data and other manual steps.

The engineering workflow has evolved with the progressive implementation of the Zyqad software. A key difference is the integration of the datasheet, PFD and equipment list deliverables within the software, kept consistent through a common database. A second key difference is the integration between the simulation model and the Zyqad database, making the database the repository of the process simulation results. These results can then be manipulated and analyzed with proprietary calculation programs. Datasheet, equipment lists and PFDs are all issued by the Zyqad software with complete design consistency. These deliverables are still checked by the Alcoa engineering team and issued after checking, but the necessity of cross-checking between the design deliverables is greatly diminished.

Issued PFDs are effectively snapshots of a live refinery system design and are published en masse. Using traditional methods, PFDs were manually generated from particular revisions of process models, and maintaining consistency was problematic particularly when more than one model is used.

With Zyqad, the PFD data is live throughout all PFDs in the database, until the point of issue—ensuring all PFDs are consistent with each other and also completely consistent with equipment lists and datasheets. Other supporting models or software are typically linked into Zyqad, such as equipment-sizing software, which can be run with data from the database, and outputs returned to the database.

Several industry studies[3] have identified that up to 2.5% of the installed cost of an asset can be tied up in these information-transfer inefficiencies.

Figure 2 shows this new FEL workflow at Alcoa.

Capturing Design Rules—In addition to providing a shared database, the Zyqad system also incorporates the capability to capture design rules. Incorporating company-specific or project-specific design rules ensure that design best practices or standards are applied in a common way to a given type of equipment, process unit, stream or other engineering entity. With the alumina refining process involving a number of unique and proprietary engineering principals, this ability is a fundamental advantage of the system for Alcoa.

The rules-based programming tools within Zyqad provide an experienced Alcoa engineer the ability to program-in customizations based on the user's own engineering practices or insights, and then to cause those best practices to be applied by all engineers on this or similar projects. As an example, this provides the ability to automate updating of particular attributes with any level of granularity—for example, all pumps to have particular gland sealing arrangement or VFD is to be installed on all systems that meets certain criteria X, or attaching or applying certain specifications or standards across multiple equipment items. In the past, data were written into a separate standard and referred to in the datasheet, or required manual transposition, but now it can now be linked directly to "global" attributes for a project which can be revised at any point and automatically deployed across one or multiple projects, enterprise wide. Alcoa has written rules to automate equipment naming, generate equipment descriptions, manipulate equipment in lists, track equipment datasheet completion status and so forth.

Streamlining Engineering Time and Effort—Implementation of Zyqad in Alcoa GPDG has been gradual with progressive setup and development occurring in parallel with the ongoing project and other activities. Some benefits have been subtle and become a routine part of the workflow, while others were immediately apparent and exceeded expectations.

For example, a team of three Alcoa engineers implementing the Zyqad package was able to develop and generate from scratch a set of PFDs for an entire refinery (approximately 50 equipment lists) with preliminary equipment sizing (over 1,000 pieces of equipment) in the space of three months—while in parallel establishing the system and being involved in other projects.

Traditionally this would have required drafting resources, sketches, mark-ups, reviews, data transposition,

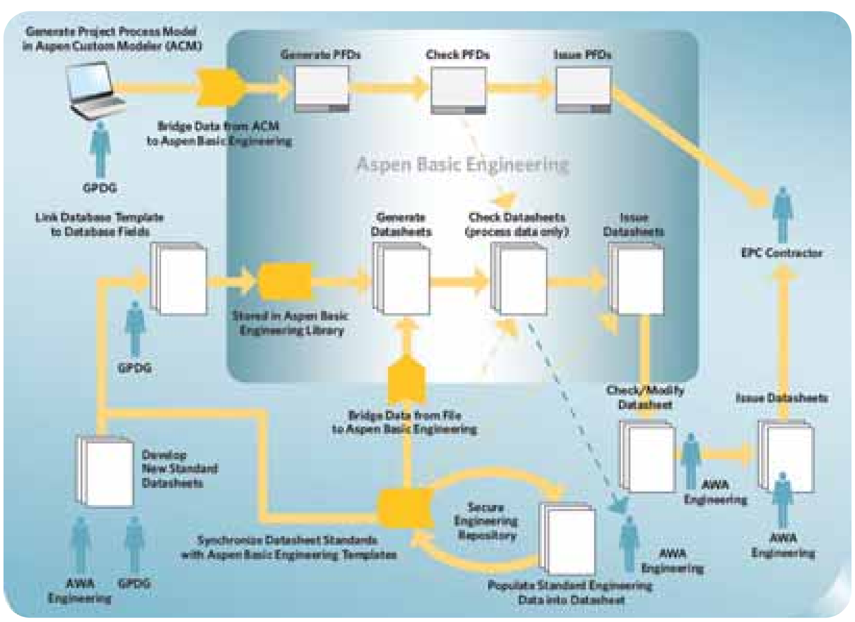

Figure 2: Alcoa GPDG design workflow.

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involving supporting-discipline engineers to develop and manage the equipments lists and start datasheets. In the new model, the process engineers "own" the drawings, the equipment and its preliminary specs, the equipment lists and data sheets, thus reducing the opportunity for error and the need for review/checking and nearly eliminating the mark-up and revision cycle. In this new approach,

- Sketches are done live in the PFD using drag and drop library graphics.
- Data import from model is direct and associated with all streams in the PFD.
- Data manipulation is done live using stream conversion bridges and sizing programs.
- Equipment lists are generated automatically on request.

The typical man-hour requirement for a similar previous effort was on the order of 8,000 man hours, and this was reduced to less than 1,000 man hours.

Perform Proprietary Stream Calculations—Alcoa employs MS Excel-based calculation and analysis programs to define process streams more completely than is provided in the simulation model. The simulation model carries mass and energy balance information, while in a design environment other information such as viscosity, vapor pressure and density are required.

Once the stream topology and stream data has been captured from the simulation model by Zyqad, Alcoa uses the powerful integration between the Zyqad database and Excel to achieve this aspect of the design. Stream information is manipulated and processed within the proprietary Excel tools and then returned to the database for use in developing PFDs, datasheets and equipment lists.

Scenario Analysis, Reusable Design And Best Practices: Templating The Design—Once the refinery process has been modeled in Aspen Custom Modeler, the data are transferred to a Zyqad project database and stream calculations or other equipment design tasks are performed. The database then serves as the design basis for a current refinery project as well as the basis and template for future design efforts, sensitivities or alternate solution evaluations.

Employing a capability within Zyqad known as "packages," the template is easily copied into a new project database, shortcutting the next design project by up to 30% (as measured by other users of this software[4] (See Figure 3).

This feature is also particularly useful in investigating particular scenarios or options, a large element of VIP practice. The use of packages allows equipment lists and scopes to be quickly developed for technology or configuration alternatives. These can be costed in parallel or separately from the main project and incorporated when appropriate, either individually as approved or on a consolidated revision where multiple optimizations are brought together.

Alternate technology options have different benefits depending on flow sheet configuration and bauxite feed type and quality. Those technology options not selected in the current project are now part of the library of options that can be quickly incorporated into other projects—essentially "plug in" unit operations.

Documentation can be stored as native files rather than as database values. This means that design criteria (e.g. as text documents), vendor information, and cost information from spreadsheets and other sources can be stored with and linked to a particular piece of equipment, building or project, and included in the packages generated.

As every project design is completed, the library of transportable design packages grows, and is available immediately for implementation in any project, in whole or in part.

Implementation Strategy

Adoption of a powerful, integrated design system, as described in this article, requires an evolutionary approach to ensure that the engineering disciplines can effectively assimilate and adopt the solution and employ it in a way which best takes advantage of its collaborative and interdisciplinary elements. Alcoa-GPDG decided to apply a stage-wise approach to implementation, primarily to:

- Familiarize the engineers with the software.
- Set up the software to deliver a particular set of deliverables.
- Ensure that the modifications and learning are done thoroughly and effectively.

The group needed to learn the new workflow and new skill sets and in the early phases existing deliverables were mimicked, capability of the team and the tool's functionality increased incrementally. The stages have been tied to the key aspects of a project's deliverables that are gradually migrated to the software system as follows:

- Stage 1: Adapt the system to alumina refinery design and embed design rules.

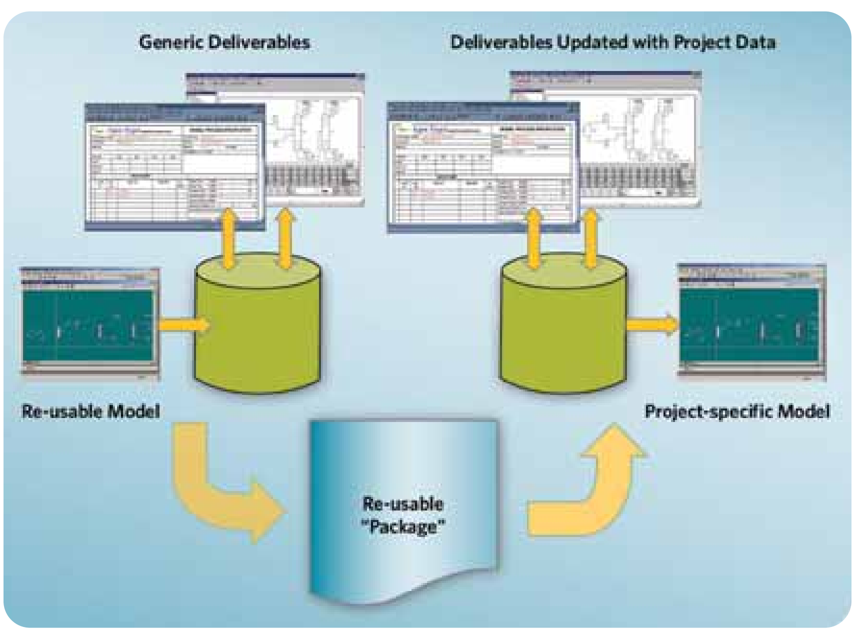

Figure 3: "Templatized" design for best practices and efficiency in repeatable refinery designs.

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- Stage 2: Develop PFD and equip ment Lists.
- Stage 3: Use the system for data-sheets development and release.
- Stage 4: Alcoa Engineering collaborates with E&C and gets back as-built data (D/S) in the Zyqad database for project oversight and asset lifecycle management.
- Stage 5: Integrate Aspen Zyqad with Intergraph SmartPlant. (Note: This and the preceding stage are sched uled for future implementation.)

Alcoa faces many of the same issues as other process industries related to streamlining and improving the front-end design phases of a project, and associated workflow, with the goal of enabling earlier and better business decision-making and better designs and an increased certainty of outcome.

Mega projects in particular can suffer from failures in early in design definition with multiply consequences as the project moves on. Being able to reuse proven component designs and concepts in the process design and quickly screen options is a significant advantage in scope development and risk reduction.

With a formidable lineup of capital projects projected for the next 10 years, it was clear that a method to "templatize" best practices and design of alumina refineries would offer many advantages to Alcoa. Such an approach will both improve project execution in an era of shortage of skilled engineers as well as improve speed and efficiency of front-end design despite the additional learning and skills required to effectively utilize the tool, such as databases and VBA programming the Zyqad language.

The results so far, after two years of use of the Aspen Basic Engineering (Zyqad) software system, have been impressive. Design standards have been captured for reuse and significant engineering man-hours have already been eliminated along with many of the manual and rework/recycle loops incumbent in traditional design methods.

The net result has been a leap forward in project front-end design and engineering for Alcoa's continuing capital program, with the full potential of Zyqad yet untapped.

As Alcoa moves forward whether to detailed design or other evaluations with the new workflow the initial investment of effort will be repaid in a significant reduction in design cycle time and engineering expenditure.

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