Consider Modular Plant Design

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Modular plants offer many benefits over a conventional stick-built facility. Read about the pros and cons of the modular approach to help you decide if it makes sense for your project.

Manufacturing plants based on modular equipment are emerging as a viable and beneficial alternative to conventional stick-built processing plants. Modular equipment offers several benefits, including flexibility in plant siting, fewer safety concerns during construction, and ease of equipment modification. These benefits, however, must be considered in the context of your project and the limitations and costs associated with modular design.

This article discusses modular equipment for the chemical process industries (CPI) and identifies the benefits and drawbacks of this type of plant. It provides guidance on determining whether modular construction makes sense for your project and how to approach developing a modular plant. Finally, the article discusses several situations in which modular plants offer significant benefits.

▲ **Figure 1.** Modular plants consist of steel frameworks (skids) on which process equipment, instrumentation, valves, piping components, and electrical wiring are mounted. The skids are transported to the construction site, where they are erected and connected to form the larger process system.

What is a modular plant?

In a modular plant, the process equipment, instrumentation, valves, piping components, and electrical wiring are mounted within a structural steel framework (*i.e.*, skid or module). Heat tracing, thermal insulation, and an integrated control system are often included in the mounted structure. Each skid is a self-contained process unit that is typically constructed offsite. A modular plant can be comprised of many unit operations contained on a single skid or on multiple skids that are connected at the production site to form a large process system. The modules are shipped to the manufacturing site, where they are erected and integrated in the final orientation. Once at the end-user's facility, the units can be connected to the site utilities and tested in place for startup and commissioning (Figure 1).

Module construction requires more steel than traditional construction, because each module needs to be designed and built to stand independently and to withstand the stresses of being transported, lifted, and erected. The units are therefore structurally stronger than conventional units constructed onsite. The drivers of modular construction are more complex than simply the strength of the structure, and careful consideration is required when evaluating the pros and cons of modularization.

The pros of going modular

Modular construction does not make sense for all processing plants. However, it does offer many benefits.

Worksite safety. The construction of a CPI plant has fundamental risks and hazards associated with working at heights, the use of heavy machinery, electrical work, and so on. These risks and hazards are compounded by the conditions found at a typical construction site, which is often outdoors and amidst workers and existing infrastructure. In such an environment, equipment is susceptible to damage during installation and weather-related damage. Modular plants, on the other hand, are fabricated in a safer, controlled environment at an offsite, indoor location.

Quality. Modular equipment is often designed and built at the same location, which enables better communication between the design and build teams. With improved communication, equipment is often of a higher quality than traditional, onsite-constructed equipment.

Schedule efficiency. A quick turnaround period from concept to the finished product can be critical for companies operating in emerging markets or that face time-to-market pressures. Modular plants can be constructed much faster than conventional plants for several reasons. The most significant is that the site and foundation work can be completed at the same time as the equipment fabrication. In addition, weather conditions will not delay or interfere with the construction schedule because the modules are built indoors.

Flexibility. A plant consisting of several small-scale production units offers flexibility that is not available to its large-scale counterpart. Small, skid-mounted production units can be operated at one centralized location or at several geographically dispersed locations, for instance near the source of raw materials or at the point where the product will be used. When all of the units are centrally located at the same site, output can be easily scaled to meet changing demand by adjusting the number of parallel units running. Distributed plants can be built with slight variations among them to account for the varying characteristics of feedstock or end-product requirements.

Minimal site work. Modular plants arrive at the final site pre-assembled, tested, and electrically wired, so they require minimal labor for equipment connection and troubleshooting during startup and commissioning.

As discussed, modular plants are operated as several process units in parallel at one location, or as separate units at geographically disperse locations. This might seem like it would necessitate additional labor. However, automation and control technology enables facilities to be controlled from a central location, so modular plants do not require significantly more labor than one large plant, as was the case before the technical advancements.

The cons of going modular

While modular plants offer many benefits, those must be weighed against the drawbacks of modular construction.

Transportation. The limitations and costs associated with transporting equipment to the construction site must be considered when deciding whether it is a good idea to take the modular approach (Figure 2). In some situations, single pieces of equipment must be transported directly from the equipment manufacturer to the construction site; in such cases, mounting the equipment within a steel framework offers no additional benefits.

Transportation costs may still be an issue for equipment that does not need to be transported directly to the construction site. For example, the larger the equipment, the higher the complexity and costs of transporting that equipment. Roads often have restrictions on the height, width, and/or weight of trucks, which could either prevent modules from being transported by road or restrict the route that can be taken. Other transportation concerns include harsh weather and bad road conditions.

Upfront engineering. Another disadvantage of modular fabrication is the level of upfront engineering and planning required. Often a fully detailed and engineered package must be provided to the module fabricators before the equipment can be made. This also poses additional requirements for planning, communication, coordination, and project management among multiple parties, including the end-user, site contractor, and offsite module fabricators. Using a module fabricator with an experienced engineering design team reduces the scope of the required upfront engineering.

Labor availability. The availability of local, cost-effective labor should be considered before deciding to take the modular approach. When the module fabrication is not very complex, limited engineering and supervision can direct onsite labor to complete work in a timely fashion.

▲ **Figure 2.** Careful consideration is required when deciding whether to take the modular approach. For example, road transportation may be subject to width, height, and/or weight limits, which may direct the route available for transporting modules to the manufacturing site or prevent the use of trucks.

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The nature of the site and process need to be investigated prior to choosing the modular method of construction. Some projects, such as modifications or additions to an existing plant, may not lend themselves logistically to a modular system. In these cases, onsite field activities are often a better choice if site disturbances can be tolerated.

When to go modular

When deciding whether to take the modular approach or construct your plant onsite, consider the pros and cons discussed in the previous sections of this article. Key questions to answer during this evaluation include:

- Is local labor limited and/or expensive?
- Are there risks associated with the production, storage, and transportation of your product?
- Do you want to minimize disruptions or congestion at your site?
- Do you require a high level of quality?
- Are scheduling benefits associated with parallel site and module construction important for your project?
- Will you need to perform extensive factory acceptance testing?
- Do you expect to need more process equipment for future facilities or to meet increasing demand?
- Is the technology and market for that technology immature?

▲ **Figure 3.** To reduce the risk of transporting hazardous chemical products, modular plants can be located at their point of use. This modular plant produces a hazardous chemical that is used at the site, and it can be relocated with ease and at minimal cost.

How to go modular

A shift in approach is needed when you are building a modular plant. Modular plants are manufactured offsite and then connected onsite, which necessitates more upfront planning and design work. During the initial planning stages, the work must be divided into onsite and offsite activities. Documents needed during the initial stages of design include a detailed conceptual layout of the plant to determine site constraints and perimeter access, and energy and mass balances to determine the size and scope of the project. The initial planning phase of modularization should consider the end stages of the project, such as transportation and erection of the modules, to determine and address challenges early. Modules should be designed to allow for ease of transportation and reassembly.

Once you have decided to take the modular approach, it is a good idea to choose a module fabricator as soon as possible. Often, the key design parameters and hazard assessments are still being finalized in the initial stages of the project, so it is good to choose a module fabricator with engineering expertise so they can adjust to changes.

Effective communication among those involved in the design, construction, and final erection of a modularized plant is critical. Three-dimensional models of the modules and final plant can be used as communication tools.

The modular plant should be tested to the maximum extent possible in a remote fabrication shop to limit the time needed for reassembly, testing, and startup at the site. Therefore, the modules should be connected to the fullest extent possible at the fabricator's shop. Completing the factory acceptance testing (FAT) at the module fabricator's facility reduces the amount of onsite startup time and is an excellent opportunity for operator training.

Point-of-use production

Modular plants can be located at the point of use, which makes sense for several applications, including processes that involve hazardous chemicals (Figure 3). The production,

▲ **Figure 4.** A commercial-scale pyrolysis facility was constructed with modular equipment. Biomass-based pyrolysis is an example of the type of process that could benefit from locating small production facilities at geographically disperse locations, such as where there is abundant biomass.

transportation, and storage of hazardous chemicals have safety risks. To reduce these risks, companies can consider using a modular plant to produce the hazardous chemicals at their point of use.

Much of the world's supply of valuable energy resources have remained untouched because of the economic and environmental challenges associated with processing and transporting material to the point of use. It is estimated, for example, that 30–60% of the world's natural gas reserves are stranded — *i.e.*, they are located away from processing infrastructure or remote from market demand. However, as low-cost gas reserves produced by conventional methods become depleted, these smaller reserves have become of greater interest. Small-scale production plants installed at the source (Figure 4) can economically convert stranded gas into synthetic crude. Once liquefied, this high-value product can be transported via existing pipelines and infrastructure, eliminating the high costs associated with the transportation of gas. Since stranded gas reserves are generally available in small quantities at various sites, a small-scale modular plant can be relocated to another site once a reserve is depleted.

Similarly, associated gas, a byproduct of oil production, can benefit from flexible, dedicated, small-scale modular plants. Associated gas is typically flared, vented, or injected back into the gas reserve at a high cost and with significant impact on the environment. A modular plant located at the oil production site could convert this associated gas into valuable chemicals. London-based CompactGTL developed a two-stage Fischer-Tropsch demonstration process that is low-cost, small-scale, and modular. The technology features a compact, modular plant that incorporates multiple reactors connected in parallel, providing a flexible and robust process for converting associated gas into liquid synthetic crude.

▲ **Figure 5.** This oil production facility consists of multiple operating trains. The producer was able to increase capacity by adding additional units instead of initially building one large unit.

Going small to grow big

When considering how to increase capacity, does it make sense to increase the size of production equipment or operate multiple smaller units (Figure 5)? In the-bigger-the-better business case, unit costs of production usually decrease with increasing facility size. While this may be true for the production of widgets, it is not always true for chemical production plants. If the technology is not mature, the process will need ongoing modifications and advancements.

Small production plants have several advantages over large facilities in new or developing markets. Building small plants is less economically risky than building a large plant. Although the cost per unit output of the first small-scale plant may be high, the initial investment is much lower than it would be for a large-scale plant. In addition, the time between initial investment and revenue generation is shorter for a small-scale plant. This strategy may be advantageous when the overall market volume is uncertain. Additional operating units can be deployed gradually over time to meet increasing demand. Similarly, small-scale production units permit easy turndown to accommodate products with a short lifecycle.

A path forward

Many CPI companies are finding that the environmental and economic advantages of modular plant design outweigh the benefits of a large centralized stick-built plant. To reap maximum benefits of modularization, you must integrate the modularization considerations from the beginning. It is important to look to a module fabricator with strong engineering capabilities and depth of experience in design/build applications. This allows for more-effective communication, which is especially important in offsite process module fabrication. The case for small-scale modular plants can be a powerful one when you consider the potential benefits of reduced risk, shortened schedule, lower capital investment, and overall operational flexibility. CEP

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