The Project Engineer's Guide To

Facility Systems Design & Installation

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Introduction

In most industrial processing companies around the country, project engineers are tasked by upper management to scope the equipment needed for a new build, retrofit, or expansion project. There's a significant challenge with this approach—often, the engineers tasked with scoping don't have experience with the systems they are trying to price.

Find yourself in this exact situation?

Under-scoping a project can have huge implications on the business. An oversight during scoping can result in escalating costs and extended construction schedules once the project is underway. That's a worst-case scenario that you must avoid.

The good news is, we have a guide to help you accurately scope process equipment and impress (in a big way) your upper management.

Over 35+ years, we've worked alongside hundreds of project engineers to install billions of dollars worth of equipment, structures, and systems. Our experience has enabled us to build a proven process that project leaders can follow to predict and manage costs with greater accuracy. And it's given us the credibility to create this guide.

If you've been tasked with scoping new equipment at your facility, follow this guide before you reach out to vendors and gather pricing. It could make all the difference.

SECTION 1

Understanding the Basics of Facility Systems

Today's processing businesses rely on highly complex, well-optimized processes to make, store, and transport their products.

The facilities where this happens are comprised of a complex framework of equipment, structures, and pathways. Whether your business is food & beverage production, oil & gas extraction, or nutritional complex creation—the components of a facility are often similar.

The major systems of a processing facility often include:

Cooling Systems	Power Distribution	Storage Systems	Material Handling	Packaging Systems	Steam Systems	Emission Control

Here's the challenge—every industrial facility is a unique organism, made up of a number of process and/or utility systems. And each system is a collection of equipment, structures, and parts.

You can see, then, how it can be dangerous to scope a project based on only the equipment costs. The equipment cost is *only part of the true cost consideration*.

What is a "System"?

Rarely does a single piece of equipment provide the entire solution to a process unit operation challenge.

A cooling tower, for example, won't cool without properly designed recirculation pumps, a blow down mechanism, properly specified chemical treatment, and coordination with the piping and equipment systems. These aspects that make the cooling tower perform, when combined with the cooling tower, comprise a "cooling tower system." A cooling tower for Minnesota will be much different than a cooling tower for East Texas.

Another example is a wet scrubber. By itself, a scrubber won't do too much without critical ancillary support devices such as a fan, a recirculation pump, often times a pH control loop, sometimes a side arm cooler, blow down, level control, and typically, an exhaust stack. Again, when all these components are assembled, they create a scrubber system.

For this reason, the project engineer must think in terms of the total system when scoping a new capital project. A system is the capital equipment, ancillary components, support structures, and connections to the rest of the plant.

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Identify your System Requirements

The system concept is easy enough to understand, but scoping with this in mind can be a confusing process. This is where many project engineers get into trouble.

The Problem With Process Equipment Estimates

As we've discussed, when scoping process equipment, the piece of equipment is only part of the costs for the project. The challenge is determining what else you need when purchasing equipment.

Manufacturers typically don't make this easy. They will likely only provide the cost of the equipment itself—and leave it up to you to determine the rest.

For example, the piece of equipment could be a wet scrubber for scrubbing vapors, which doesn't make up the entire system. From there, it's up to the purchaser to figure out what else is needed, how to integrate the various components, and engineer, design, and construct the installation.

Further complicating matters, the equipment scopes themselves are confusing. Each manufacturer (or distributor/reseller) offers differing scopes of supply. If, for example, there are 10 suppliers for a scrubber, you could very likely get 10 scope offerings, each with different performance and different component manufacturers (for example Goulds pumps vs. FlowServe vs. Sulzer, and so forth).

It can be extremely challenging to compare apples to apples unless you ask the right questions from vendors. So how do you get to the right solution when buying something like a scrubber, or a cooling tower? What questions need to be asked?

The Solution: The Basic Unit Specification Profile

Before you go visit manufacturer websites and start price-comparing, the first order of business is to clearly define what the piece of equipment is expected to do, and the conditions under which it will operate.

This is called the basic unit specification—a document which you should provide to equipment vendors when asking for bids.

Follow the steps below to build your B.U.S. for the system you're tasked with scoping. The guide below will apply to nearly any type of equipment, but as always, there may be exceptions or additional specifications that apply as well.

Ask: What Will the Unit Service?

This seems fairly obvious, but it is critical. A cooling tower's service, for example, could be to provide cooling for an office HVAC system, a fermentation chiller, or a hydrocarbon distillation system.

Some vendors are more suited to industrial applications than they are commercial or light duty.

Ask: What are the Performance Requirements?

The performance requirement data will be highly variable from one type of equipment to another, but it's important to specify exactly what the facility needs the equipment to do.

These specifications typically consist of the following major criteria:

- **Required Process Rate:** this can be volumetric (GPM), mass rate (#/HR), or another process rate variable.
    - There may be multiple required process rates, or qualifiers. For example, an evaporator may have an evaporation rate specified in #/HR of water evaporated, but may also have a minimum or maximum feed concentration, a minimum or maximum product concentration, and may have temperature limits at both ends.
- **Maximum Process Rate:** this is the maximum rate at which this unit is expected to perform.
- **Up-Time, Duty, or Operation Hours:** it's important to let the supplier know the expectation for runtime, whether it's daily, weekly, yearly, etc. This might trigger discussions such as preventative maintenance, required cleanouts during down times, etc., and could lead to different models being suggested, or vendors declining to quote due to warranty or other issues.

Ask: In What Conditions Will the System Operate?

Operating and location conditions are also very important such as the following:

- **Ambient Temperature**
- **Ambient Humidity**
- **Ambient Pressure:** elevation, inches Hg, etc.
- **Site Specific Wind Load Data**
- **Site Specific Seismic Load Data**
- **Chemical Exposure:** caustic wash downs, salt water, process leaks, etc.

Ask: What Available Utilities Will the System Require?

The specifics of the material that the equipment will be processing must be known to the vendor, whether gas, liquid, bulk solid, 2-phase material, or other. Some such parameters are:

- **pH**
- **Chemical Composition:** particular concerns are chlorides, sulfates, acids, bases, oils, and solvents
- **Viscosity**
- **Specific Gravity**
- **Particle Size Distribution**
- **Temperature Sensitivity**
- **Shear Sensitivity**
- **Boiling Point**
- **Vapor Pressure**
- **Flammability/Combustibility**
- **Abrasiveness**
- **Flowability, Cohesiveness, or Stickiness**
- **Friability**
- **Moisture**

Ask: What is the Required Delivery Date?

It's important to let the vendor know when the equipment is required to arrive at the facility. Some suppliers may be able to meet the date, others may not. This could play a major role in making the final decision.

With your system requirements in place, it's time to approach suppliers and vendors.

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SECTION 3

Getting a Quote from Equipment Suppliers

Getting a quote for a piece of process equipment sounds simple enough – and it is.

Call a sales rep, tell them what you want, and you'll get a price. Call five different reps and you'll get five different prices, all over the place in dollar amount, performance, and scope of supply.

But getting the right price for the right performance and the right scope is a little tougher.

Ultimately, the objective of the pricing, or bidding exercise, is to buy a piece of equipment. Buying the right unit requires pre-planning, basic engineering, asking good questions, and comparing and evaluating the contenders until a clear winner stands out.

The Initial Proposal for Equipment Pricing

The initial proposal consists of information that should be requested from the vendor. The following is a generic overview of what this initial proposal should include.

Confirm Unit Performance Data

Just because performance requirements were given to the vendors via the Business Unit Specification (see previous section), that doesn't mean they can meet those requirements. It's always a good idea to ask them to re-state the performance specifics to confirm the proposed unit meets or exceeds the minimum requirements.

Utility Requirements

The vendor has been told what's available, and now they need to indicate how much of each utility is required. This could lead to changes, increases, or additions to the facility's utility infrastructure to support the equipment operation.

Description of Operation

The vendor should provide a brief description of the equipment operation so the end user better understands the equipment and operator/technician interaction, and to make sure its operation meets the facility's expectation.

Description of Construction

Not all equipment is created equal.

It's imperative to understand the construction of the equipment being proposed, otherwise a meaningful comparison between vendors cannot be made.

The proposal should include specifics such as:

- **Materials of Construction:** carbon steel, stainless steel, alloys, plastics, etc.
- **Coating Systems:** paint, galvanized, etc.
- **Total Shipping Weight:** this can give an indication of robustness
- **Details on Components:** component manufacturers, nozzles, flanges, sensors, limit switches, safety devices, controllers, communication requirements (I/O, protocols such as 4-20, Ethernet, Asi, etc.)
- **Dimensional Information:** ideally this is in the form of a vendor cut sheet or preliminary equipment drawing
- **Motors:** TEFC Premium efficiency, explosion proof

Equipment Scope of Supply

The scope of supply includes only what is inside the suppliers battery limits – or ISBL.

As discussed previously, a piece of equipment generally does not work by itself; it typically needs a pump, or an agitator, or supply/discharge conveyor, etc.

Some vendors will include these ancillary components in their proposals even if not requested, so it's extremely important for the vendor to describe the battery limits of their proposal and detail each component so an accurate comparison can be made.

Another factor that can vary from vendor to vendor that could affect the installation cost is the degree of shop assembly vs. field labor required to assemble the unit. Although not a physical ISBL item, it certainly can make a difference in cost.

An example is with chain-type drag conveyors. Some vendors will install paddles on the chains prior to shipment, some will pre-install the drive on the head section, some might even pre-install chain with paddles in the casing sections—all reducing the amount of field labor, but likely increasing the delivered price.

Non-Equipment Scope of Supply

Some equipment is straightforward – for example, a pump – but others can be complex, like an evaporator system or an ion exchange system. With complex systems it's sometimes wise to ask the vendor for support in addition to the actual equipment supply.

This support can come in the form of start-up assistance, user training, engineering assistance, and many others. This will be a case by case decision based on the nature of the equipment being considered.

Pricing

Obviously, the overall purpose of the proposal is to get pricing. But, the way the pricing is presented in the proposal is also important.

One vendor may lump the main piece of equipment and all options into one price, while others may not even provide options.

This can make proposal comparisons nearly impossible. To avoid this scenario, the pricing format should be made very clear in the early stages. The following detail should be requested as separate line items:

- **Base Price:** Price of the main component or components FOB manufacturer's location
- **Itemized Pricing for Ancillary Items**
- **Itemized Pricing for Options**
- **Freight Cost:** Freight can get complicated for large equipment that does not fit over the road
- **Spare Parts:** Recommended list and itemized pricing
- **Taxes**

Delivery

The delivery date is obviously important, but there are other dates and timelines that are equally important, such as:

- **Approval Drawing Delivery:** typically referenced ARO (after receipt of order)
- **Fabrication/Assembly Time**
- **Ship Date**
- **Transit Time**
- **Arrival on Site Date**

Terms and Conditions

The supplier’s terms and conditions of sale are very important to understand, and can have legal consequences. The following are some items that require some attention:

- **Down Payment**
- **Progress Payments**
- **Final Payment**
- **Warranty**
- **Confidentiality**
- **Dispute Resolution**

SECTION 4

Comparing Bids & Choosing a Proposal

Once proposals are received from the various suppliers, a comparison must be made to identify strengths and weaknesses in each vendor's offering.

Vendor comparison can be a tedious process, but it's the key to making the correct technical and financial decision.

Technical Evaluation (Technical Bid Tabulation)

In order to make a true "apples to apples" comparison, it's necessary to evaluate each pertinent variable between the various suppliers. Some pertinent variables are those related to size, capacity, material of construction, shipping weight, etc.

Different types of equipment will require the evaluation of different specifics relative to their type, but in general should capture each of the specifics that we included in the basic unit specification discussed previously. Any new specifics featured in the various proposals should also be included.

The following is an example of a bid tabulation for plate and frame heat exchangers:

PLATE AND FRAME HEAT EXCHANGER BID TABULATION						
COMMENT				UPDATED 3/17/09		ADJUSTED TO 304SS
MANUFACTURER		MFG 1	MFG 2	MFG 3	MFG 4	MFG 5
QUOTE ID		543.1	NA	NA	NA	70-0
EQ TAG NUMBER		E-408	E-408	E-408	E-408	E-408
MODEL NUMBER		FP 60-109-1 E	P47	GP237-10000L-82	GX-042***	NT150S H BY-150
AREA (SQ FT)		691.04	392.88	187.23	393.1	447.78
NUMBER OF PLATES		109 ???	75	82	85	82
MAX NUMBER OF PLATES		130	144	103	154	????
REQUIRED HEAT TRANSFER COEEFICIENT (BTU/FT^{2}HR°F)		279.74	488.65	769.9073		433
ACTUAL HEAT TRANSFER COEEFICIENT (BTU/FT^{2}HR°F)		499.8	944.43	1033.734	493	493
HOT SIDE	PASSES	1	1	2	1	1
	CHANNELS	108	37	41		41
	PRESSURE DROP	2.074	4.78	4.95	4.57	2.88
	INLET SIZE	6"	4	4"	4"	6"
	OUTLET SIZE	6"	4	4"	4"	6"
COLD SIDE	PASSES	1	1	2	1	1
	CHANNELS	108	37	40		40
	PRESSURE DROP	1.074	2.45	2.53	2.79	1.56
	INLET SIZE	6"	4	4"	4"	6"
	OUTLET SIZE	6"	4	4"	4"	6"
PLATE MATERIAL		NOT STATED	304 ss	304	316 SS	304 SS
GASKET MATERIAL		EPDM	EPDM	EPDM	EPDM	EPDM
GASKET RETAINER		NOT STATED	LOCK STYLE	CLIP-ON	glueless	glueless
PRESSURE RATING (PSI)		150	150	150	150	150
QUOTED PRICE (IDIVIDUAL) BASE		NA	$5,720	$6,379	$ 7,915.00	$ 7,995.00
PRICE PER SQ FT (INDIVIDUAL) BASE		NA	$ 14.56	$ 34.07	$ 20.13	$ 17.85
QUOTED PRICE (TOTAL)		$ 78,900.00	$ 40,630.00	$39,669	$55,047	$39,165
PRICE PER SQ FT (TOTAL)		$ 33.43	$ 19.52	$ 39.11	$ 24.84	$ 15.60
OPTIONS						
316 PLATE MATERIAL		NOT STATED				
total plate area						
FREIGHT		???	$ 2,025.00	FOB Batavia, NY	Freight SC - Plant add $4,800	

Once the initial bid tabulation is prepared, there will invariably be pieces of data missing from one or more of the vendor proposals. In addition, it's common for one of the bidders to provide more information than requested, giving you additional insight into the quality of the unit proposed.

Run a True Technical Comparison

Don't skip the crucial step of evaluating various suppliers and their variables.

Commercial Evaluation (Commercial Bid Tabulation)

In addition to the Technical Bid Tabulation, it's also necessary to prepare a Commercial Bid Tabulation (price and terms).

These are frequently combined into one spreadsheet, depending on the buyer's preference. The same principle applies, however; be as detailed as possible so the proper information is available to make the best-informed decision.

Between the Technical Bid Tabulation and the Commercial Bid Tabulation, it's a good idea to identify "value indicators." These indicators will vary across different types of equipment, but they are generally metrics such as *cost per square foot $/sq ft* (as in the above example).

For tanks it may be *cost per gallon $/gal*, for an evaporator it may be *cost per unit of evaporation rate $/# per hour*, for heavy rotating equipment it might be *cost per pounds of shipping weight $/#*. Also unit cost of Horsepower/lb processed.

These value indicators can demonstrate that although a vendor's price might not be the lowest, they may have more capacity or better "value," which can be purchased for a slightly incremental cost.

In the example **Plate and Frame Heat Exchanger Bid Tabulation** above this, the concept of value indicator can be seen in the *Price per Square Foot* rows near the bottom.

Run a True Technical Comparison

Don't skip the crucial step of evaluating various suppliers and their variables.

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Request Clarifications (Second Round of Proposals)

Once the first-round of Bid Tabulations are complete, a trend will generally appear where one bidder has better metrics and often a better price than the others. If there are many bidders (typically 4 or more), there might be some drastically high prices and drastically low prices.

It's best to ignore the prices until it's confirmed that the minimum performance requirements are met.

You're likely to request clarification from each bidder to fill in gaps in the tabulation, and/or to have certain vendors adjust their proposal so they meet the minimum requirements.

Make the Decision

Once the clarifications are received and the tabulations are updated, a winner typically emerges on its own. The winner may not be the vendor with the lowest price, depending on the performance data, but should be the best performer with good value indicators, and a reasonable price.

SECTION 5

Assembling a Complete System & Installation Plan

Now that a vendor has been selected and the scope (ISBL) of that vendor's supply is known, the balance of the system can be assembled.

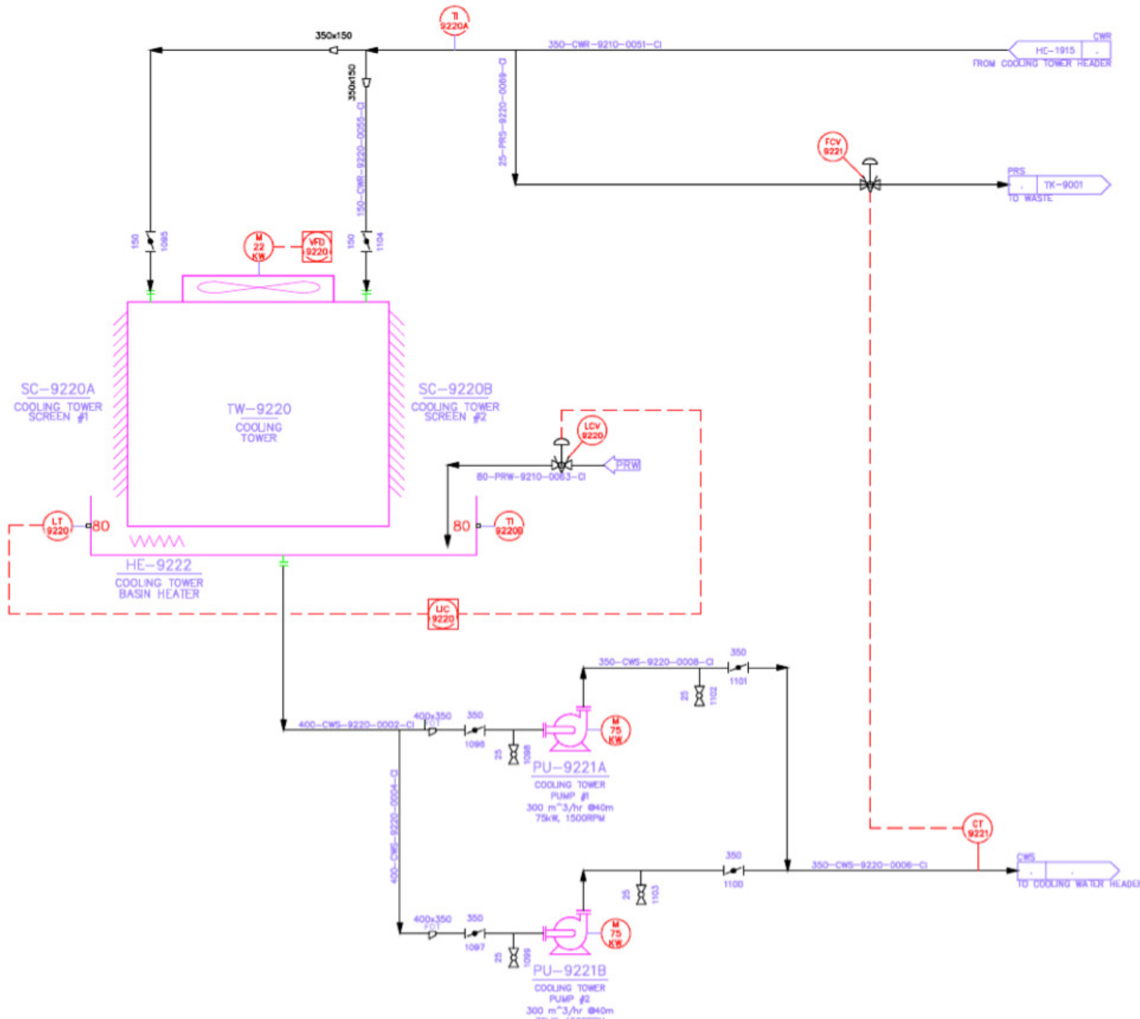
The P&ID: Understanding Ancillary Components & Devices

The first step in designing the system is to understand what ancillary components or devices are required. Purchasing one piece of equipment is likely just the first step in building out a complete operating system – there's a lot more to it.

The best tool to guide this process is Process and Instrumentation Diagram (P&ID), sometimes referred to as a Piping and Instrumentation Diagram.

The P&ID is where the connection of the main piece of equipment to the facility begins. This is where the need for pumps, instruments, utilities, piping, etc. become obvious, and where these decisions are documented.

Please refer to the following sample P&ID for the upcoming discussion:



Let's assume that the procurement process detailed above resulted in the purchase of the cooling tower TW-9220 in the sample P&ID. The typical scope of supply (ISBL) for such a tower would include only the tower TW-9220, the basin heater HE-9222, and the motor that is shown as 22 KW.

The items not included are:

- **All Piping**
- **Pumps PU-9221A&B**
- **Level Control Loop LT, LIC, and LCV9220**
- **Temperature Indicators TI-9220A&B**
- **Blow Down Control Loop CT-9221 & FCV-9221**
- **Variable Speed Drive VFD-9220/li>**
- **Cooling Tower Screens SC-9220A&B**
- **All Manual Valves (10 in the case of this sample)**
- **Motor Starts for Pumps PU-9221A&B**

For each of the items not in the tower supplier's scope, many decisions must be made, and likely, a procurement process similar to the process outlined previously must be followed. To support that process, each component must be engineered and specified prior to approaching vendors for these items.

In addition to the components that must be purchased, many other decisions must be made and a certain level of engineering tasks performed, such as:

- **Mechanical Layout Preparation:** general arrangement, maintenance access
- **Foundation/Support Steel Engineering & Drawing Preparation**
- **Electrical System Evaluation:** confirm the current electrical system has the necessary capacity
- **Electrical System Specification & Design:** motor starters, cabling, arc-flash study, etc.
- **Pipe Line Sizing:** flow rates, pressure drop, etc.
- **Pipe Routing:** support design, tie-in location, low point drains, high point vents, etc.
- **Process Water Supply Evaluation:** available water capacity, water quality, etc.
- **Blow Down System Capacity:** process waste, sanitary sewer, etc.
- **Control System Evaluation:** is there enough I/O space for the added devices
- **Control System, SCADA Configuration**

The main point of this exercise is to further illustrate the fact that purchasing a piece of equipment, in this case a cooling tower, is just the beginning of developing an operating cooling tower system.

What Constitutes a Complete System?

In the previous cooling tower example, many of the decisions, engineering functions, and procurement functions were addressed. There are many more considerations that must be evaluated before a safe, reliable, and efficient system can be expected.

It's crucial to take the time to ensure these precautionary measures are met, in order for your system to be as successful as possible—as well as ensuring your environment remains safe.

We've put together the following checklist of topics, considerations, and tools that can help assure a successful system installation:

Are there any safety concerns?

- **Chemicals**
  - OSHA PSM regulated chemicals
  - Eye Wash/Shower stations
  - Double block & bleeds
  - Personal Protective gear/hardware
  - Exposure prevention/PEL sniffers/alarms
- **Elevated Temperatures**
- **Flammability/Combustibility Concerns**
- **Noise Levels**
- **Mechanical Concerns**
  - Belt chain guards
  - Pinch Point identification
  - Safety Interlocks
  - Lock-Out – Tag-Out
  - Confined Space Entry
  - Fall Protection
  - HAZOP

How are required ancillary components identified?

- **P&ID**
- **Mass/Energy Balance**
- **Motor List**
- **Instrument List**
- **Piping Line List**
- **Maintenance Requirements (hoist, manways, etc.)**

What utilities are required for all the components of the system to function properly?

- **Electricity for Motors** (110v, 480v,4160v, etc.)
- **Electricity of Other** (electric heaters, heat trace, control panels, etc.)
- **Cooling Water**
- **Process Water**
- **Plant Air**
- **Instrument Air**
- **Natural Gas**
- **Steam** (other heat sources)
- **Chemicals**
- **Control System I/O space** (DI, DO, AI, AO, other protocols)

How will physical support and access for the major and minor equipment be determined?

- **Mechanical Layout** (general arrangement)
- **Foundation/Steel Drawings**
- **Deflection Concerns**
- **Wind Loads**
- **Seismic Loads**
- **Vibration Concerns**
- **Personnel access**
- **Live Loads/Dead Loads**

What is required to make the system operate as expected?

- **Process Operation Narrative**
- **Process Control Narrative**
- **SCADA Programming**
- **Interlocks & Setpoints**

SECTION 6

From Price Ambiguity to Cost Accuracy

In this guide, we've shown the process you should leverage when you're tasked by upper management to scope a piece of equipment for a CAPEX project.

We've discussed specifying and buying a piece of equipment to solve a process challenge, and identifying the parts and pieces required to make that piece of equipment perform at its ideal level. And we've shared many of the engineering and design functions that must take place to ensure the installation and operation is safe, reliable, and efficient.

It's not a guide written without context. Over 35 years, we've refined and implemented this model to save companies from ill-quoted and poorly planned projects—saving millions of dollars for our clients.

Follow this guide, and you'll be well positioned to lead your company through its next project.