Convertible Lump Sum EPS Contracting Model – How to get the plant you need now and still enjoy in 20 years?

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Abstract

In most instances process plants are designed to meet performance objectives that are clearly defined by a detailed technical specification. The contractors and licensors designing and building such process plants are quite proficient at designing a plant to meet those performance values for an economically attractive cost. However the reality for the owner and operator of the plant is that over the 40+ year lifetime of the plant the inlet feeds, production rate and operationally desired set points for each piece of equipment will change. Often times this can result in a non-optimal plant and performance problems or poor reliability. This fact is particularly severe for plants which undergo significant corrosion or fouling like that commonly seen in sulphuric acid plants. Plants are built to make money for their owners. The primary way to make the most money out of a facility is to have the plant operational at as high of a capacity as possible for the maximum number of days in the operational life of the plant. There are numerous ways that the plant designer and builder can place design allowances, safety factors, built in redundancy, optional operational configurations, bypasses and other tricks to allow the facility to operate well for all desired production rates and all desired feed types. The costs of such options are often quite small if dealt with in the initial design phase. Unfortunately, in nearly all instances this optimal facility is not the facility that is built for the client. The reason why is often the inflexibility in the client/designer contractual relationship prevents open discussions on optimization. The Convertible Lump Sum EPS model can be used to get the optimal plant design for the client’s present and future needs as well as providing price surety of a lump sum execution.

This paper will detail the aspects of the Convertible Lump Sum EPS model. It will use an example sulphuric acid plant project to show how the client can be involved in the decision making process to get the best plant design for their site with appropriate design factors and options. Instances will be illustrated where plants have been built that do not have the flexibility required to operate effectively as the plant ages and/or the plant slightly changes operational modes. This lack of flexibility often causes damage to the plant and operational downtime or reduced capacity. Cost/Benefit analyses will be done on each of these cases. This

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paper will show that use of an effective, technically and commercially transparent contracting model with the appropriate partner can allow significant savings in TIC cost as well as for total return on investment.

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1. Introduction

Plants are built to make money for their owners. The primary way to make the most money out of a facility is to have the plant operational at as high of a capacity as possible for the maximum number of days in the 40+ year operational life of the plant. The plant also must meet all of the local environmental rules for the whole time it is operational (ie. to prevent costly regulatory issues, fines or downtime) as well as have a minimum amount of maintenance costs. There are numerous ways that the plant designer and builder can place design allowances, safety factors, built in redundancy, optional operational configurations, bypasses and other tricks to allow the facility to operate well for all desired production rates and all desired feed types. The designer can also select equipment from numerous different sources that have different pros and cons for all of the above desired plant performance parameters. The costs of such options are often quite small if dealt with in the initial design and equipment selection phase. Unfortunately, in nearly all instances this optimal facility in terms of overall Client Value is not the facility that is built for the client. The reason why is often the inflexibility in the client/designer contractual relationship prevents open discussions on plant value optimization. The Convertible Lump Sum EPS model or some derivative of it can be used to get the optimal Value plant for the client’s present and future needs as well as providing price surety of a lump sum execution.

2. Value vs. Risk

What is value? In most cases the value is what each group will get out of the transaction. Value depends on the person or group you are referring to. For the question of a chemical plant like a Sulphuric acid plant the relative value can be looked at as follows:

1) Client and plant owner/operator – What is the total net profits they will make from this plant over 10 years? 20 years? 40 years? What is the total initial investment and payback time of that investment? How will this plant further the image my firm to ensure we are viewed positively by local people, local authorities, clients and shareholders? What is the quality of product produced by this plant relative to international norms?

2) Technology Firm – How much profit was made on this project? Did the project perform to guarantees and was it satisfactory to the Client? Does this installation further the reputation of the Technology Firm? Will this project lead to further work from this Client?

3) EPC, Construction, BE/DE Firms - How much profit was made on this project? Did the project perform to guarantees and was it satisfactory to the Client? Was the project executed on time with suitable quality for the Client to further the reputation of the EPC, C and/or BE/DE firms? Will this project lead to further work from this Client?

Clearly the goals of the various firms are related but the Value they place on each is very different and sometimes conflicting. For example more profit for the Technology/EPC/C/BE/DE firms in reality means less profit for the Client.

What is Risk? Let’s define some types of risk for consistency in the article:

a) Operating Monetary Risk – This is costs associated with reliability and performance of the plant. Maintenance costs, shutdowns, etc…

b) Capital Monetary Risk – This is costs in building the plant for the contractor.

c) Schedule Risk – This is costs associated with a delay in the building of the plant.
d) Process Risk – This is costs associated with the quality of the plant performance and the products that the plant produces.

e) HSE Risk – This is HSE costs associated with building and operating the plant.

f) Environmental Risk – This is costs associated with failing to meet environmental regulations.

Risk again depends on which group you are talking about.

1) Client and plant owner/operator
   a. Operating Monetary Risk - What happens if the Sulphuric acid plant is not operational for a period of time? Hours? Days? Weeks? Months? What costs will I incur?
   b. Schedule Risk - How important is the overall schedule of this contract? What happens if it is late? How will it affect financing and cash flow? What is additional reliability worth to me?
   c. Process Risk – What happens if the plant does not perform adequately or the product is not suitable quality? What happens if capacity cannot be reached?
   d. Environmental Risk – What happens if emissions increase above regulatory limits or if regulatory limits are subsequently reduced below the capability of the plant design?
   e. HSE risk – How do we manage this effectively?

All are important but the biggest risks for the Client are HSE Risk, Process Risk and Operating Monetary Risk. Major HSE failure and you may never get to use your plant again. Process issue and the plant may never operate correctly or produce saleable product. Monetary risk and you will have repetitive failures and downtime in the plant. The costs associated with these three can all be large enough to make any project nor economic for the client. These three risk types need actively monitored throughout the project to ensure they are avoided to the maximum extent. Schedule risk is a one time only type risk, and can be reasonably mitigated and is typically much less in magnitude. Environmental risks under the regulatory regime in place at the time of construction only apply one time only for the Technology and EPC/Construction/BE/DE firms, however this type of risk is special because it can re-apply at a later date due to changes imposed by the regulator. If a plant cannot be economically modified to meet future environmental regulations, it can be forced to shut down prematurely.

2) Technology Firm
   a. Operating Monetary risk – Largely rests in the risk of extra time to correct deficiencies
   b. Capital Monetary Risk – Associated with extra time to perform the contracted work.
   c. Process Risk – Risk associated with performance guarantees
   d. Environmental Risk – Risk associated with performance guarantees

3) EPC, Construction, BE/DE Firms
   a. Capital Monetary risk – Construction, exchange rate, material cost and design changes can lead to significant cost overruns.
   b. Schedule risk – Delays can lead to significant cost overruns and penalties from Client.
   c. Process Risk – Risk associated with performance guarantees
   d. Environmental Risk - Risk associated with performance guarantees
   e. HSE risk – How do we manage this effectively?

The key for a successful project is to ensure that the Risk is minimized to the maximum extent for all parties and maximum possible Value is obtained for all parties. Process, Operating Monetary and HSE Risks must be minimized for the Client to ensure the project will be a successful, high profit and high Client Value facility. Care must be taken to ensure that the vendor firms do not minimize their own Capital Monetary Risks at the expense of Clients Operating Monetary risks.

Note that from a purely monetary perspective the Client has the greatest amount of money and reputation to gain or lose with the project and its overall execution from conception to end of life. The client makes money for 40+ years on this project. The other service firms make money one time – when the plant is being designed and built. As such it makes sense for a client to try to understand the benefits and consequences of key decisions being made in the plant design, equipment selection, layout and construction and be involved in that decision up front to gain maximum long term benefit for themselves. A small amount of money spent optimizing the value of the plant design will lead to orders of magnitude more profit in the next 40+ years of plant operation. As a relative comparison and assuming the fairly commonly used Lump Sum EPC contracting model, a typical EPC firm will make average profits of 6 to 8% on
executing a project. A Technology firm will make 20 to 25% profits but on a much smaller scope. The client will desire to make 25% return on total investment annually. As such on a $100,000,000 TIC cost the EPC firm would make $6 to $8 million once, the Technology Firm would make $1.5 million once and the Client would make $25 million every year. The potential long term reward for the Client is huge yet the Client is setting up a contracting model to allow and in fact encourage the EPC firms to make decisions to cut costs in all theoretically reasonable ways (ie. buy from the lowest cost EPC). These decisions are not necessarily made for the long term value for the Client but for the one time value for the EPC firm. A $1 million dollar savings by minimizing the acid tower design clearly is in the benefit of the LS EPC contractor and has a huge positive effect on their project profitability but this significantly reduces the overall Client Value in the resulting facility. Clearly it is in the Client’s best interest to ensure that the plant they get is the best Value plant for their needs.

3. **Examples of Costs of Errors**

In a Sulphuric acid plant a design firm is contracted to provide equipment or a plant that meets a certain performance guarantee. This assumes a provided input and a desired output. We have never seen any plant where the input is precisely what was provided in the specification nor was the output actually desired by the operating plant precisely that of the specification. The reality is that plants are living beasts and they change over time, from night to day, from winter to summer, from year to year. In fact in many cases the plants are modified and retrofitted with new technologies multiple times over their 40+ year life. However, clients in many cases write very precise technical performance specifications and ask the technology firms to precisely comply with them. The Technology firms are very good at predicting performance and can very accurately design a piece of equipment or plant that will perform precisely as requested. Unfortunately economics also comes into play and in order to win the project, the technology firm needs to be cost competitive so they minimize the design so it will meet the guarantee requested in the specification yet the design has little or no flexibility for changes in plant operation or design, let alone normal winter/summer variations (unless specified in the technical specification). This applies from simple Technology Package all the way through to full Lump Sum Engineer Procurement Construction (LS EPC) contracts including all contracting models in between. It also applies for retrofit projects all the way to full new facilities. For LS EPC the plant received will be cost minimized and will precisely meet what the technical specification requested – and no more.

Clearly the group with the most to gain and the most to lose – the Client – will likely not receive a maximum Client Value facility via contracting models that inherently encourage this behavior.

Examples of errors that are commonly seen in Sulphuric acid plants:

3.1 **Sulphur Furnace**

- Too small
  - Over time sulphur nozzles will wear out, droplets will get bigger, impact and burn on baffle walls/refractory, or leave furnace not fully combusted. Refractory damage, baffle wall failure, sulphur build up on boiler tubes, reduced heat transfer, carryover to converter bed 1, overheating of bed 1 and damage to catalyst, inability to achieve acid plant design capacity will occur.
- Too thin shell on furnace
  - Needs more than 2 supports, these multiple supports move relative to each other and will distort the shell, leads to cracking in refractory, eventual sag/oval shape of shell leading to refractory collapse.
- Shell design temperature not in acceptable range
  - Too hot will overheat shell and cause high temperature sulphur corrosion, too cold will condense sulphuric and sulphurous acid leading to accelerated corrosion
- Poor quality and/or too few sulphur nozzles
  - Poor atomization leading to baffle wall damage and carryover as above. Also true for too high of capacity of nozzles
  - Poor turndown leading to sputtering
- Too big a furnace
Only issue is too much money spent. Layout / ducting / thermal expansion will be more costly. Cost to make furnace somewhat conservative in design is less than 0.5% of plant TIC. The method to fix a furnace if any of the above issues is present is extremely difficult and costly and may result in a new furnace, new boiler, new refractory and/or new bed 1 catalyst.

![Figure 1: Refractory Failure due to impingement of droplets](image)

### 3.2 Dry Tower – Brick lined

- Too little packing height
  - Can lead to poor absorption of water, sulphuric acid formation and damage to downstream equipment (blower, boiler, ducting, gas heat exchangers, catalyst, etc…)
- Too small a gas inlet
  - High velocities lead to maldistribution in tower and reduced water absorption. Higher operating cost due to high pressure drop
- Poor construction quality, shell ovality
  - Brick installation very difficult, dome loses a lot of structural strength. Collapse of dome. Locations where brick separates from backing and leads to failure of PTFE lining and/or other layers
- Single layer of brick, lack of PTFE multilayer lining, no mitred elbow inlet
  - Leaks in tower shell prematurely. Large maintenance cost and replacement in 5 to 10 years
- Too small in diameter
  - Poor absorption – water carryover and damage to downstream blower and other equipment, higher operating cost due to high pressure drop, higher risk of flooding tower / surging blower
- Too large in diameter
  - Poor absorption due to gas channeling, needs a lot more acid flow to work, costs more money to build and operate.
- Poor packing support design
  - Packing fell through and can block gas channels, higher pressure drop, more difficult to maintain
- Flat tower bottoms
  - Bricks not under compression. Acid will get behind bricks through heaving and buckling and corrode shell
- Mist Pad Design and selection inadequate
  - Mist carryover and damage to the downstream equipment, poor catalyst efficiency
3.3 Inter and Final Tower – Brick Lined

- Same issues as above but replace “water” with “SO₃”
- Mist eliminators not adequate
  o Carryover of acid droplets and damage to downstream equipment. High operating cost due to high pressure drop. Higher risk of mist eliminator elements blown open due to high pressure difference over the elements.
  o In final tower can lead to direct acid mist emissions to the environment and problems with local regulations.

3.4 Silicon Stainless Steel Alloy Towers (Dry, Inter or Final)

- Too little packing height
  o Can lead to poor absorption of water/SO₃. Sulphuric Acid formation and damage to downstream equipment (blower, boiler, ducting, gas heat exchangers, catalyst, etc…)
- Too small a gas inlet
  o High velocities lead to maldistribution in tower and reduced water absorption, higher operating cost due to high pressure drop
  o Can lead to dry spots on shell and oleum corrosion of shell.
- Too small in diameter
  o Poor absorption – water carryover and damage to downstream blower and other equipment, higher operating cost due to high pressure drop, higher risk of flooding tower / surging blower
- Too large in diameter
  o Poor absorption due to gas channeling, needs a lot more acid flow to work, costs more money to build and operate.
- Poor packing support design
  o Packing can fall through and can block gas channels, higher pressure drop, more difficult to maintain
  o Localized oleum or weak acid formation leading to local corrosion and packing support collapse
- Mist Pad Design and selection inadequate
  o Mist carryover and damage to the downstream equipment, poor catalyst efficiency
- Inadequate HAZOP done
  o Metal towers not as “forgiving” compared to brick lined towers with respect to deviations in acid conditions during normal operation, start up and shutdown conditions (towers must be properly isolated from weak acid corrosion during shutdown). Control systems and instruments need to be appropriate for the equipment design in the plant.
Figure 3: a) Packing support design disrupted flow of acid on the walls leading to localized weak acid or oleum corrosion. b) Dry spots created on shell leading to localized oleum corrosion – zero corrosion can be seen in photo where wet.

Additional cost to make the acid towers (either brick lined or alloy) have features that will allow long life and be conservatively designed to ensure adequate operation in all future foreseen operating modes is in total less than 2% of plant TIC. Example adders would be 20-30% more packing depth, slightly larger diameter tower, larger gas inlet, additional blank spaces for candle filters, multilayer PTFE liner, multilayer bricks, etc… Fix if any of above issues is present is extremely difficult and costly and will likely result in premature or forced replacement of the towers, new blower, new boiler, new ducting, new economizers/superheaters, new gas heat exchangers and perhaps not meeting environmental regulations.

3.5 Ducting

- Too small in diameter
  - Increased plant pressure drop, increased energy consumption, reduced operating campaign time – too small ducting can impact performance of equipment (gas distribution in towers and gas exchangers).
- Not engineered correctly
  - Excessive stress and strain on ducts and equipment leading to gas leaks and shut downs.
  - If bellow expansion joints used there is the ability to offset in multiple dimensions. Costly, premature repetitive failure and leaks. Hinged joints should be used.
- Insulation and cladding incorrectly done
  - Does not deal with thermal expansion of duct versus cladding. Failure of cladding means more water ingress to the metal, boiling off water with chlorides in it and more duct leaks.

Figure 4: a) Deformation and cracking of ducting expansion joint due to water ingress through insulation and cladding. b) Stress Corrosion Cracking of stainless steel due to water ingress, boiling and localized chloride concentration.
Additional cost to design and supply good quality ducting, cladding and insulation is no more expensive than doing it incorrectly. Only if the ducting is larger in diameter to reduce pressure loss does the price climb slightly. The key to ensuring good ducting design is to have a person experienced in ducting design for Sulphuric acid plants do the design and ensure the ducting is designed to provide low stress and strain on all the attached equipment. Doing it correctly and conservatively sized would add less than 0.3% to the TIC cost over the poorly designed ducting. Failure to do so will lead to repetitive ducting leaks or equipment nozzle leaks, higher strain on neighbouring equipment and perhaps premature failure of that equipment. Each shut down caused by a duct leak creates stresses and strains on the whole plant and this can lead to premature plant aging/replacement.

3.6 Gas Exchangers

- Using carbon steel in the wrong places
  - Acid corrosion / sulphates will form leading to high pressure drop. Internal leaks lead to poor SO2 conversion and high stack emissions. External leaks lead to fugitive emissions and HSE risks.

- Using 304 or 304L Stainless Steel or Carbon Steel for high temperature applications like Hot Heat Exchanger
  - Leads to oxidation and material failure

- Hot SO3 gas flowing up on the shell side or up on the tube side
  - Not able to drain the acid down leading to acid build up and fouling, difficult to clean

- No means to remove acid drainage from bottom vestibule
  - Acid pooling at bottom of exchanger

- Too small tube diameter
  - Not able to drain acid leading to tube blockage, higher pressure drop, higher energy requirement

- Too large tube diameter
  - Lower heat transfer rate, bigger exchanger

- Cold Exchanger not designed for acid mist removal
  - Sulphate build up and corrosion leading to higher pressure drop and premature failure.

- Expansion joint not selected appropriately
  - Failure of exchangers from cracking of tube to tubesheet joints

![Figure 5](image_url)

Additional cost to design and supply good Client Value gas heat exchangers would be less than 1% adder in plant TIC over the simplest theoretically acceptable gas heat exchanger.
3.7 Other equipment

Acid tanks, economizers, superheaters, converters, boilers, etc... all have similar design choices that need to be made in the final plant design. There are potential ripple effect issues with each choice.

Each of these choices is in essence a value and risk decision that is largely being made for the client by the contractor. The question is how to find a contracting method that allows the client to get the best value plant while the contractors also receive appropriate value for their services? This all has to be done in a manner that appropriately manages risk for all.

3.8 Cost Summary

Assuming a plant TIC cost of $100 million USD, the additional cost of adding in design features to get to an optimized high Client Value plant would add 5 to 10% to the TIC cost for a fertilizer plant sulphuric acid plant. This is $5 to 10 million USD additional. Looking at the typical issues that arise by minimizing the plant design to thus minimize the TIC cost, let is look at the cost of a few common errors in detail with the client.

a) Too little packing height in acid towers – leads to water (dry tower) or SO$_3$ (Final and Inter) carryover to downstream equipment.
   - Additional cost to have conservative design = 30% more packing, 30% more tower height, 5% more tower diameter. Approximately $200,000 US per tower = $600,000 USD.
   - Operating Monetary Risks – Water absorption in dry tower not sufficient so acid formation and damage to blower, ducting, boiler, bed 1 catalyst, etc… Premature replacement of all items listed. Shut down time for replacement. Assuming 10 day shutdown to replace blower and $150 USD/MT of 98% sulphuric acid, product value loss is $6.3 million USD for 4200 MTPD plant. Blower cost plus installation will easily cost another $3 million USD. Add in catalyst, ducting, boiler damage.
   - Environmental Risks – Final tower does not absorb sufficient SO$_3$ leading to stack emissions issues. Costs could include fines or plant shutdown or large scale modification of multiple equipment and even the final acid tower replacement.
   - Total Risk to Client = $10 to $30 million USD or even higher. Cost to design in flexibility $600,000 USD.
   - To fix the long term repetitive issue may require a tower top replacement or a complete tower replacement costing $5 to $8 million USD for each tower.

b) Ducting design not done to minimize stress and strain on equipment
   - Additional cost to have conservative design = 500 more engineering hours by qualified and experienced sulphuric acid ducting designer. 5% more material for larger diameter low pressure drop ducting Approximately $200,000 US additional cost.
   - Operating Monetary Risks – Ducting cracks due to excessive stress and strain. Leads to 10+ “hot” shutdowns of 8 hours each per year. $2.1 million USD lost production. Higher stresses and strains on neighbouring equipment leading to premature replacement/repair of towers, gas heat exchangers, converters, economizers and superheaters.
   - Environmental Risks – Leaks of SO$_2$ and SO$_3$ to environment.
   - HSE Risks – Leaks are an HSE hazard and make local work difficult. Can delay other shutdowns.

Total Risk to Client = $10+ million USD plus Environmental and HSE issues. Cost to design in flexibility $600,000 USD. Cost to fix ducting design to reduce strains and stresses and solve the issue permanently after poor design would be $2 to 4 million USD.

The costs to design and build in plant flexibility are relatively small if done from the beginning. The costs to fix once the plant is built are huge and the reduction in Client Value for their plant can be millions of dollars per year which could be avoided by paying a one time fee of approximately 10% of that annual loss. Capital Risk Benefit gained by Vendor is trivial compared to Operating Risk Cost accepted by Client with these decisions.
4. Contracting Models

There are many different contracting models and each has its different pros and cons. A summary and a brief description with relative risk for the client is as per below.

1) Process Design Package (PDP) + License
   - Technology vendor provides details of their process design, very basic proprietary equipment design details and a license to use their technology. All basic and detailed engineering and equipment supply by others. Very high risk for buyer. Almost akin to going to a high end restaurant and being given the recipe and told to go home and make it yourself. In terms of performance guarantees the norm is to provide a free engineering study for work within scope to recommend a strategy to fix the problem. Usually no schedule related guarantees.

2) Basic Engineering (BE) package + critical supply
   - Technology vendors provides basic engineering, license and critical components. This is better for the Client, but the Client is still relying on other typically generic engineering firms to figure out the rest of the plant design. Not all the critical details of the design can be spelled out in a BE package and best practices / designs are not passed on. High Process and Operating Monetary risk for buyer still. This is akin to buying the main and critical ingredients for the meal and an instructional video on how to make it. Can be mitigated if client hires a skilled and knowledgeable EPCM contractor. In terms of performance guarantees the norm is to provide a free engineering study for work within scope to recommend a strategy to fix the problem plus some form of monetary liquidated damages if performance not met. Usually no schedule related guarantees except for engineering timing.

3) Core Detailed Engineering (DE)
   - Technology vendor only does detailed engineering on their critical items and plant processes. Civil and general Electrical and Instrumentation outside of the core process plant can be done reasonably well by most competent engineering firms. This scope has moderate Process risk for buyer. However this is not always the most efficient model as there are many interfaces, extra work / communication between multiple parties and the owner’s engineer may not buy the right equipment in their scope because they do not fully follow the detailed engineering specifications. Significant Schedule risk for the client due to so many interfaces between the firms. In terms of performance guarantees the norm is to provide a free engineering study and redo of engineering within scope to fix the problem plus some form of monetary liquidated damages if performance not met. Usually no schedule related guarantees except for engineering timing.

4) Select Engineer, Procure + Services (EPS)
   - Technology firm does full detailed engineering (E), supply (P) of key imported or performance elements and select field services (S) such as erection, training and commissioning advisors. Good low risk option for the Client Process wise. Less interfaces with engineering contractor and key equipment is specified and purchased by the technology firm leading to less errors in critical parts. Schedule risk less than for DE. Usually done a Lump Sum (LS) basis. This is akin to providing a cooking class. You are guided through all the steps with interaction and feedback each step of way. In terms of performance guarantees the norm is to provide guarantees on all critical performance parameters including product quality, pressure drop and emissions that are either make good, redo work within scope and/or liquidated damages if performance not met. Schedule related liquidated damages for all work within scope.

5) Full EPS
   - Technology vendor supplies all items except erection contractor supplied bulks items (structural steel, concrete, rebar, wiring, electrical, etc…). All detailed engineering and supply of plant except bulks is by Technology Vendor. Site services provided to allow local construction firms selected by client to have access to technical expertise for specific sulphuric acid related equipment or plant requirements. Very low Process risk for client. Low Schedule risk due to minimum of interfaces. Low Capital Monetary risk due to local installers being used supported by technology vendor
expertise. The Clients are typically more knowledgeable about local suppliers (steel, fabricators, suppliers, vendors) in their own region / country and local contractors. The Client already has a relationship with them and as such the Client is often better positioned to economically supply good quality local goods and services with EPS contractor’s service support. Usually executed on a LS sum basis by the technology firm. In terms of performance guarantees the norm is to provide guarantees on all critical performance parameters including product quality, pressure drop and emissions that are either make good, redo work within scope and/or liquidated damages if performance not met. Schedule related liquidated damages for all work within scope.

6) Engineer, Procurement and Construction (EPC)
   - The EPC vendor takes on the scope of designing and constructing the entire process plant for the client often on a LS basis. Very few technology firms will execute EPC contracts by themselves but will usually work via a partner. Usually the EPC partner will want to take on additional scope from the technology company usually leading to a PDP or BE scope for the technology vendor. This could mean that a non-specialized EPC firm is doing a large portion of the detailed engineering and supply for the process plant. Low schedule risk for client. Low Capital Monetary cost escalation risk if LS. Significant cost premium is paid to EPC firm by Client to have them accept LS EPC supply. The majority of this cost premium is associated with locally sourced bulk items and local construction risk. The further the technology provider is away from the end user the more costly it gets to execute an EPC contract. Difficulties arise if there are multiple EPC firms working on the same site for different process plants. They tend to compete for local resources. A single C type construction firm for all projects may be a lower risk and lower cost option for the client. This model is akin to buying a fast food meal. You know what you will pay and you know what you will get. It will be fast but not exotic. In terms of performance guarantees the norm is to provide guarantees on all critical performance parameters including product quality, pressure drop and emissions that are either make good, redo work within scope and/or liquidated damages if performance not met. Schedule related liquidated damages for all work within scope.

7) Lump Sum Turn Key (LSTK)
   - Essentially the same as LS EPC except the vendor takes responsibility for starting up the chemical plant and running it until it reaches stated performance. This is becoming a less common model. Lots of Capital Monetary and Schedule risk for the vendor and as such a high premium price paid for by the Client.

8) Build, Own, Operate and Transfer (BOO or BOOT)
   - Not commonly done but is a viable contract model. Difficult to find firms willing to execute BOO type contracts.

9) Engineering, Procurement and Construction Management (EPCM)
   - The EPCM vendor takes on the scope of designing and managing the construction of the entire process plant for the client often on a reimbursable basis. This is a good choice for a client requiring maximum vendor, client contact and especially where the precise site technical requirements are not clear at the beginning of the project. EPC should only be used when the technical specifications are very certain and largely cast in stone. Selecting an EPCM firm with intimate knowledge and skill on the particular process plants being executed is an effective way of reducing risk. Guarantees are normally provided by the Technology vendor and are proportional to the scope and risk that the technology vendor is responsible for.

10) Convertible contract
    - Essentially this is a contract type where the client hires the Technology firm to do a simplified PDP or BE type contact initially. The client works with the vendor during this simplified PDP/BE study to develop a plant design that specifically suits their current and future needs. Client preferred vendors can be considered and incorporated where appropriate. Optional design decisions to add Client Value to the plant can be added or removed as desired or required. At the end of the PDP/BE study, an open book estimate of cost is created for a defined scope (usually Select EPS or full EPS...
but could also be used for DE or EPC). This open book estimate is used to make clear to the Client the costs of each option. The client can make an educated decision for what is appropriate for their site’s optimal Value plant. Once the design and price is agreed, the vendor is hired (if desired) by the client to execute the contract on a LS basis for the defined price. This model has maximum Value addition for the client, lowest Process, Operating Monetary and Capital Monetary risk plus low Schedule risk (depending on scope of vendor). Note that by doing the PDP/BE portion first the vendor has much less design and engineering uncertainty so a lower contingency on the project can be provided. This method often ends up saving the client more than the cost of the PDP/BE study package. Adding this model is like hiring a nutritionist to help with menu planning.

5. Who has the Knowledge?

There are different ways to mitigate different types of risk. For process risk for both short and long term the key item is ensuring that the group doing the specific task is the group with required knowledge. Note that this knowledge is also related to overall cost risk. The more knowledge a group has on the task, the more common it is to them and the less time it will take them to do it, with less uncertainty of how long it will take. Additionally they will often know the tricks of the trade and the best vendors to use for the various equipment or fabrication or whatever the task may be. This leads to lower time consumed, lower cost equipment, better fabrication and installation and lower contingency required. Table 1 identifies the typical types of knowledge present in firms involved in the work of building a sulphuric acid plant. A similar table could be made for any type of process plant. The assumption in the table is that the EPS firm is in fact a specialist technology firm taking on greater scope for this project. The DE or Construction firm is an independent DE firm hired by the Client. The EPC firm is a specialist EPC firm who has teamed up with a PDP technology partner with the EPC column only reflecting the EPC firm knowledge. This table is intended to be indicative and not comprehensive. There will be certain instances or vendors where these generalities are not completely correct.

Thinking about the different project execution models once again and comparing with the table you can see clear trends:

1) PDP Package + License
   o There is a lot of missing knowledge present that needs to be filled by others. These gaps are outside of the scope of the Technology Firm so Client is taking on this risk. Big issues are Process and Operating Monetary Risk which can be somewhat mitigated by selecting an EPCM or EPC partner who is very familiar with the plant process.

2) Basic Engineering (BE) package + critical supply
   o Still a lot of missing knowledge but the Client has more to work with. Adds some of the DE column and fabrication column to the knowledge base at least on the critical items. This becomes an effective model if the EPCM or EPC firm selected has intimate knowledge of the process and assigns these key people to this specific project.

3) Core Detailed Engineering (DE)
   o Technology vendor adds in the DE column to their scope. A lot more knowledge is present but there are still significant gaps that the client is taking on as risk. In particular some Operating Monetary risk remains due to all items being purchased by those without intimate knowledge of the differences.

4) Select Engineer, Procure + Services (EPS)
   o Here the knowledge is complete except for construction. The people with the intimate knowledge are doing the work or are responsible for the work. Extra Operating Monetary risk still exists as the non core items are being purchased by others. This should be a small risk if the core items are selected appropriately and fabrication advisory help is used from the EPS firm.
<table>
<thead>
<tr>
<th>Technology/BE Firm</th>
<th>DE Firm</th>
<th>Construction Firm</th>
<th>Fabricators</th>
<th>EPS Firm</th>
<th>EPC Firm</th>
<th>Client</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process design</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Sometimes (if commonly working with PDP technology partner)</td>
<td>Sometimes (but usually from an operations perspective)</td>
<td></td>
</tr>
<tr>
<td>Proprietary Equipment basic design</td>
<td>Yes</td>
<td>Not usually</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Proprietary Equipment fabrication design</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes (if they own their own shop)</td>
<td>No</td>
</tr>
<tr>
<td>Non-proprietary equipment sourcing</td>
<td>Sometimes</td>
<td>Sometimes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Civil/structural design</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Sometimes</td>
<td>No</td>
</tr>
<tr>
<td>Civil/structural supply</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Electrical and Instrumentation Design</td>
<td>Partially</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Electrical and Instrumentation Supply</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>International sourcing</td>
<td>For key items only</td>
<td>Sometimes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Local to Client sourcing, fabrication and/or construction</td>
<td>No</td>
<td>Only if local firm</td>
<td>Yes, if local</td>
<td>Sometimes (if they have executed prior projects in area of client)</td>
<td>Sometimes (if they have executed prior projects in area of client)</td>
<td>Yes</td>
</tr>
<tr>
<td>International Shipping</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Sometimes</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Local Shipping</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Overall project scheduling</td>
<td>No (basic concept only)</td>
<td>Sometimes</td>
<td>Construction part only</td>
<td>Fabrication part only</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Site Construction</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Sometimes but on their equipment only</td>
<td>Usually no</td>
<td>Yes but via subcontractors</td>
</tr>
<tr>
<td>Construction Management</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Commissioning</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Troubleshooting or debottlenecking</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
</tbody>
</table>

5) Full EPS
   - Here the knowledge is complete except for construction. Construction advisory services provided to provide specific technology expertise to the Client selected Construction firm to fill all gaps in knowledge.

6) Engineer, Procurement and Construction (EPC)
   - The EPC vendor has knowledge of all the aspects except the details of the process and equipment design/fabrication. Supported by a PDP/BE from the Technology firm with select proprietary equipment supply this package will ensure that all the knowledge gaps are filled. The more work that the Technology firm can do as part of the team, the less the Process and Operating Monetary risk for the Client.

7) Convertible contract
   - Making EPS or EPC or DE contracts Convertible will reduce Schedule, Process, Monetary and Environmental, and HSE risks. It encourages having a well organized technical plan completely together before the project moves forward. The interesting thing is that the supposed time lost in the basic PDP/BE study phase of a Convertible contract is usually recovered in project execution time. Essentially the Client is doing the first 3 months of the full EPS or EPC contract in the study phase, with the opportunity to adjust plans at the end of this period.

8) EPCM
   - The EPCM vendor if appropriately selected has all the required knowledge to bridge the gap between the client and the BE/PDP Technology vendor. The EPCM vendor will be supported by local construction firms to fill the knowledge gap in local construction and fabrication firms. Operating Monetary and Process risk can be present the less the scope of the Technology vendor.
Schedule risk can be significant if the scope division and responsibility division between the Client and the EPCM contractor have too many hold points and interfaces.

Table 2 summarizes the risk types and risk levels accepted by the client is each of the aforementioned contracting models.

<table>
<thead>
<tr>
<th>Risk Type</th>
<th>PDP</th>
<th>BE+ (critical supply)</th>
<th>DE</th>
<th>Select EPS</th>
<th>Full EPS</th>
<th>EPC¹</th>
<th>EPCM²</th>
<th>Convertible Benefit (DE, EPS or EPC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Decreased Risk</td>
<td></td>
</tr>
<tr>
<td>Operating</td>
<td>Very High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Decreased Risk</td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Decreased Risk</td>
<td></td>
</tr>
<tr>
<td>HSE</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Decreased Risk</td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Decreased Risk</td>
<td></td>
</tr>
<tr>
<td>Schedule</td>
<td>Very High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Very Low</td>
<td>Medium</td>
<td>Decreased Risk</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: EPC column assuming PDP/BE package from Technology firm. If EPC firm experienced in specific process plant design then Operating Monetary and Process risk will be reduced one step from indicated.
Note 2: BE+ critical supply column can have risk significantly mitigated if client uses an EPCM firm with extensive knowledge of the particular process. Ideally the Technology firm would take on up to DE scope for further risk mitigation. Schedule, Process, Operating Monetary, HSE, Environmental risk can all be reduced by one step each for this instance.

6. Summary

To achieve the goal of trying to get the highest Value plant for the Client it is apparent that there are significant differences in risks and results with the various contracting models. The following contracting models appear to have the greatest chances of success for the client:

1) EPC – Good for a client who has high demands for TIC cost surety and is willing to potentially pay extra to have this surety. Care must be taken to ensure the EPC is experienced in the type of process plant, or the technology vendor is closely involved in the project and is providing adequate supply to ensure mitigation of Process, Environmental and Capital Monetary Risk types.

2) EPS (Select or Full) – A good value proposition for the client. Provides minimum risk in all the types as well as allows an effective way of removing the premium associated with EPC work. Good for a client that understands their local contractors and fabricators and is willing to take on some scope to get an improved Value final product.

3) EPCM – An effective way in managing a project. It has maximum client contact and input through the project. Can provide good risk reduction on all items provided that the EPCM firm has reasonable control over the schedule related elements of the project. This model should be used in a reimbursable manner if the client requires assistance in developing their overall site business plan and plant specifications.

Each of the above has its pros and cons and the client should decide which model is best for them. If an EPC or EPS model is to be selected it is highly recommended that the project be executed on a Convertible contract basis. This method is the key item in allowing the client to be involved in the key design decisions on the project which will allow the best Client Value plant to be built. This method also allows clarity of scope up front and ensures that there will be minimal interfaces and hold points in the contract between the Client and contractor thus allowing a short project schedule to be maintained. The relative cost of making a design change in the various phases of a project is as follows:

a) PDP/BE phase – Tens of engineering hours - Thousands of USD
b) DE phase – Hundreds of Engineering hours – Tens of Thousands of USD
c) Sourcing – Thousands of Engineering Hours – Hundreds of Thousands of USD
d) Construction – Engineering, Construction time, Equipment – Millions of USD
e) Post Start up – Engineering, Equipment, Installation – Millions to Tens of Millions of USD

Getting it right earlier on in the project is key to reducing risk for both the cost of the initial plant as well as operational savings for the lifetime of the plant.