

ELEMENTS OF MECHANICAL EQUIPMENT LIFE-CYCLE COST ANALYSIS



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ABSTRACT

Mechanical equipment typically comprises 25 to 35 percent of the total capital investment in a new plant project. This percentage usually increases in upgrade, revamp, or debottleneck projects. For lump sum turnkey projects, the contractor's main focus is in plant capital, installation, and commissioning costs, and the "after-startup" costs, such as power consumption, maintenance, on-stream time, spare parts consumption, etc., may not always receive equal consideration in equipment selection. Thus the end user may not be getting the best value over the life of the plant. Contractors, working in alliances with end users and mechanical equipment suppliers, can add long-term value by considering these and other evaluation parameters during the procurement process.

This paper discusses many of the parameters that comprise a complete mechanical equipment life-cycle cost evaluation, including how to determine the most critical parameters for a given project. A few examples of the total process are presented. Emphasis is placed on the less frequently considered elements, such as performance, reliability, and maintenance cost, as well as some subjective elements such as design flexibility, future growth potential, and factors that affect the cost of doing business.

The discussions and examples given in this paper focus on compressors, but the concepts presented can be applied to any capital purchase. Plant owners and contractors will understand that life-cycle cost analysis and lump sum turnkey project costs need to be considered equally in the justification of a capital project. The desired result will be a closer working alliance between the owner, contractor, and capital equipment supplier.

INTRODUCTION

There are many factors that can affect the total life-cycle cost (sometimes referred to as "total cost of ownership") of mechanical

equipment. Each of these factors should be considered when evaluating bids for new or refurbished equipment installations. The process of total life-cycle cost analysis is a team effort, including input from the end user, specifier, and suppliers. The end user and the specifier must determine the most critical evaluation parameters and assign a weight or priority to each, based on the unique circumstances of the affected project. Additionally, the commercial analysis must be discussed and the evaluation criteria agreed upon by the project team and communicated to the suppliers. The role of suppliers in the process is to offer the lowest possible life-cycle cost alternative based on the defined critical parameters and the capabilities of their equipment.

The examples discussed in this paper are based on experiences encountered by the authors during the course of equipment bid evaluations. Although the examples concentrate on compressors, the concepts presented can be applied to any mechanical equipment evaluation. A different set of critical evaluation parameters may be applied to a boiler feed water pump than, for instance, a process gas compressor. A comprehensive list of the parameters is presented in Figure 1, and many of the parameters are discussed in detail in the examples that follow.

EQUIPMENT PURCHASE COST

Obviously, purchase price is the first entry on the bid evaluation. The following factors contribute to the total equipment purchase cost.

Scope of Supply

The specifier defines the scope of supply to be included in the suppliers' proposals. The specifier must perform a thorough review of each supplier's proposal to assure compliance with specifications. This is probably the most difficult task in the

COST TO ACQUIRE	General Labor
Specify	Inspection
Inquiry	COST TO OWN & OPERATE
Evaluate	Utilities
Purchase	Driver power
Inspect (shop)	Heater power
Expedite	Lube pump power
Review documentation	Control power
Packing & Crating for Shipment	Cooling water
Receive	N2/Instrument Air
Storage/care until needed	Steam
Purchase Price	Personnel
Freight	Operator
Taxes	Surveillance/monitoring
Payment terms	Training
COST TO INSTALL	Shared Auxiliaries (e.g., oil clarifier)
Real estate	Consumables
Housing	Lube oil
Handling at site	Inlet air filter panels
Foundation	Disposal of consumables
Design	Availability
Construction	Planned outage
Materials	Unplanned outage
Piping, Valves, Fittings	Upgrades
Design	To recover performance
Construction	To improve performance
Materials	To debottleneck
Electrical	COST TO MAINTAIN
Design	Wear parts
Construction	Consumables
Switchgear	Insurance parts
Bulk materials	Stocked bulks
Power wiring	Storage of parts
Instrument wiring	Records keeping
Paint / Insulation	Labor
Control Room Interface	Rental units
Commissioning	Cleaning/painting
Field checks/testing	Factory Service Reps
Commissioning parts	COST TO DISPOSE
Manpower	Salvage charges
Skilled Labor	Scrap value
Service Representative	Depreciation

Figure 1. Life-Cycle Cost Parameters for Process Equipment.

evaluation process, due to inherent differences among manufacturers' designs, and/or the various types of equipment available for the application. Typical examples include selection of compressor type, auxiliary support systems, instrument and control philosophies, and environmental regulatory requirements. To further complicate the analysis, each supplier typically will provide the specifier with "propaganda" regarding the advantages of their design. The specifier and end user are encouraged to ask questions, check references given by the suppliers, or rely on their own experience. Comments and exceptions to specifications must be reviewed, and any cost additions to comply with mandatory requirements must be addressed. The specifier must assess advantages/disadvantages of the various supplier offerings based on their relative level of compliance.

Accessories

The specifier should verify that the quoted accessory items, such as drivers, filters, valves, and instrumentation, etc., meet the defined specifications. Ratings of each component should be compared, and the impact of differences should be included in the evaluation.

Value Engineering

Suppliers may offer alternatives to the specification that may be subjected to the value engineering process. "Value engineering" can be defined as a review of what is actually needed to meet the business objectives of a project, and the elimination of nonvalue added costs. The process tries to systematically differentiate between "wants" and "needs," and removes the "wants." Examples of nonvalue added costs may include the following, depending on project premises:

- Redundancy.
- Excessive margins on capacity or power or design pressures.

- Specification requirements resulting from "once-before" experiences.
- Upgraded materials of construction.
- Customized versus supplier standard designs.
- Nonstandard testing.

Typically, many specification requirements have been incorporated as a result of attempts to avoid a problem that may have arisen on one unit in the past. The history behind the specification requirement should be reviewed to determine if the additional cost is warranted, relative to the potential frequency of the problem that caused the requirement to be implemented.

An example of this process is specification of removable-bundle oil coolers for centrifugal compressors. This requirement may have been specified based on end user experience with oil-flooded rotary compressors, or reciprocating engines, where the oil side can become fouled. In most centrifugal compressor designs, the oil never comes in contact with the process gas, and the oil (shell) side is not subject to fouling. The water (tube) side, however, is subject to fouling, depending on the type of cooling system used and the maintenance practices of the plant. However, a fixed-bundle oil cooler is typically supplied with straight tubes and removable bonnets. The bonnets can be removed, and the tubes can be rod-cleaned in place, without removing the bundle. The cost of a removable bundle cooler can be avoided, resulting in decreased life-cycle cost.

Freight

Various elements affect the total cost to transport the equipment from the suppliers' factories to the job site, and these must be included in the evaluation. These elements include distance to the site, size and weight of equipment (permits and restrictions may be applicable), shipment mode, cost of insurance, and duties. The specifier/purchasing agent can simplify this portion of the evaluation by specifying FOB job site, or the other applicable delivery condition per international shipping standards.

Field Service/Training

For many types of equipment, some supplier technical assistance will be required for erection and/or commissioning. The cost of technical assistance should be included in the evaluation. Factors that affect the total cost of field service include availability of supervision/labor (locally dispatched versus factory-supplied), per diem rates, travel and living expenses, and competence of the service representative(s). Onsite versus factory training can be evaluated. Again, the specifier/purchasing agent can request a lump-sum price for onsite technical assistance. For large projects, the end user may pay for living expenses directly.

Spare Parts

Erection/commissioning parts are those parts that are required/consumed during the normal process of installation and startup of the equipment. Maintenance parts are those that are replaced periodically to maintain the equipment in optimum operating condition, typically every two to three years. Emergency or insurance, also referred to as major capital spares, are those that typically would only require replacement in the event of a major equipment failure and may have a long delivery. The decision whether to include the various categories of parts in the evaluation can be affected by availability (special versus in-stock at supplier), job site location (import issues), operating history of similar units, and, ultimately, the amount of downtime that can be tolerated.

DELIVERY SCHEDULE

The delivery schedule for some projects can become a critical issue. For these situations, cash flow models should be developed

to determine the economic impacts to adjust the delivery schedule to meet the construction need date. Delivery of equipment is usually a milestone for payment of an invoice, so the evaluation team should consider the effect of quoted/required delivery schedule on project cash flow. For short cycle projects, alternatives for shorter lead times, such as used, refurbished, stock, or multiple equipment of smaller size, may be considered.

Delivery commitments apply to more than the equipment. For large, long-term projects, delivery of drawings and documentation to support the contractor's design effort may be a more critical factor than equipment delivery.

The evaluation team should validate that the documentation and equipment delivery schedules proposed by the suppliers are realistic and attainable. The quoted deliveries should be compared, and supplier performance histories should be investigated. Most suppliers will provide references, in the event that the specifier/end user has no recent history. Other factors that can be included in the evaluation are delivery incentives (i.e., bonus for early delivery or penalties/liquidated damages for late delivery), air freight, overtime, and exclusive use of truck.

When equipment is ready for delivery well in advance of project requirements, costs for storage and long-term preservation may be incurred. The evaluation team may consider the commercial impact of delaying fabrication of equipment as an alternative to storage. Suppliers may offer low-cost storage with acceptance of "bill-and-hold," or payment prior to delivery.

PERFORMANCE CRITERIA

There are many factors that affect the equipment evaluation based upon the complete performance profile. The evaluation process should include valued input from the end user, specifier, and supplier. It is important as a first step to understand the "complete" performance profile, such as guaranteed operating point, turn down points, varying gas or liquid properties, ambient conditions, startup and shutdown conditions, etc. After all the various process parameters are determined, the proper equipment selection can be made. The following factors should be considered in the performance evaluation.

Flow Rate

For rotating equipment, the basis for specified flow rate is an important factor in the evaluation process. The evaluator should ensure that all suppliers are quoting flow rates that match the specifications. As an example, for air compressors, the flow rate delivered to the process is specified using a standard delivered flow rate, such as scfm or the metric equivalent of Nm³/h. In this case, the specifier must define the basis for delivered flow rate. The basis most universally accepted for English units is 14.7 psia, 60°F, and dry. For metric units, the value is based on 1 atmosphere, 0°C, and dry. Other bases can be used, as long as the basis is defined.

Evaluated Power Cost

For rotating equipment, shaft power, typically expressed in brake horsepower (bhp) or shaft kilowatts (skW), equals the sum of gas or liquid horsepower, mechanical losses, and convection losses. For cases where power is an evaluation criterion, then the parameters defining the cost of energy and the operating points to be evaluated should be defined in the inquiry documents so the suppliers can optimize their equipment selection.

The evaluation of power is a function of the unit power cost, the expected operating mode (continuous versus intermittent), and the end user's desired payback period (usually determined by project goals). The sample evaluations in this paper include typical methods of calculating evaluated power cost. The evaluation team should be sure to evaluate all offers on the same basis.

The power evaluation is typically based on measured values, which include driver effects, such as electric motor efficiency and

power factor. For steam turbine drivers, the cost of producing the steam should be evaluated, relative to the driver efficiency/steam flow rate.

The evaluation team should be aware that there are several types of performance guarantees. The specifier typically should define the guarantee basis in the inquiry. The guarantee basis usually includes a tolerance on the performance parameters. For example, centrifugal compressors can include tolerances defined by ISO (no negative tolerance on discharge pressure, ± 4 percent on flow, and ± 5 percent on specific power. (Specific power is defined as power per unit of flow rate.) A typical absolute guarantee, as defined in API specifications, is no negative tolerance on flow and pressure, and a +4 percent tolerance on quoted power. The performance curve in Figure 2 illustrates an ISO tolerance. Figure 3 illustrates the same compressor with API tolerance.

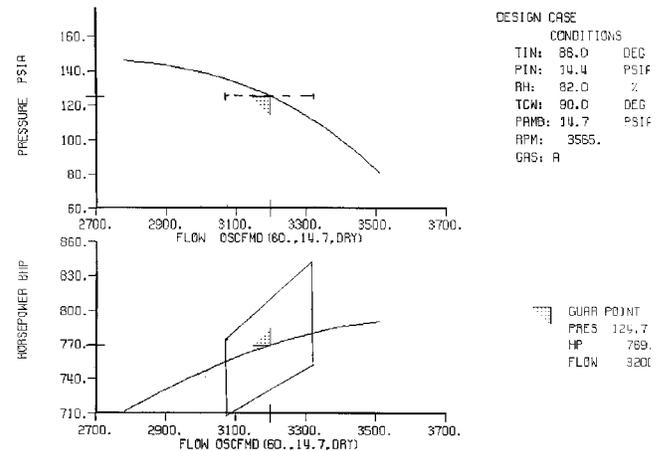


Figure 2. Compressor Performance Curve Showing ISO Tolerance Box.

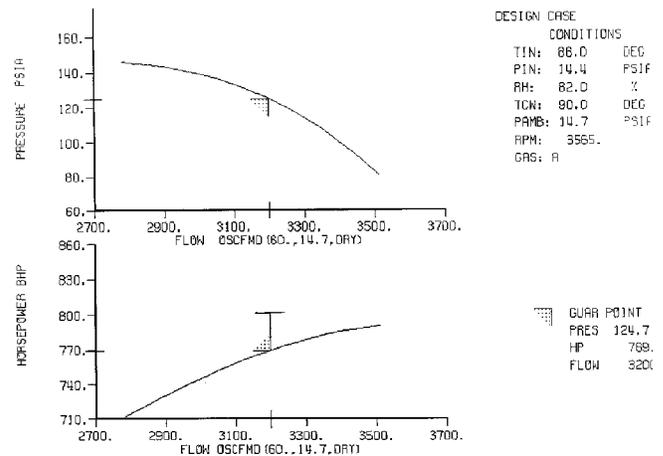


Figure 3. Compressor Performance Curve Showing API Tolerance Box.

It should be noted that specifying an unnecessarily tight tolerance may add to the equipment cost for extra machining, inspection, and/or testing.

Other Utility Costs

The evaluation team should consider other factors in the performance evaluation. These may include cost to supply external seal gas, instrument air, coolant, and power consumed by auxiliary systems.

Flexibility/Future Growth

If the end user has defined future operating requirements for the equipment, these requirements should be included in the project specifications. The cost impact to modify and/or replace the equipment to meet the future conditions can be included in the evaluation. Conversely, the impact to predesign for possible future conditions should be defined in the suppliers' proposals, and included in the evaluation. This impact is usually poorer efficiency at the initial conditions with associated higher operating costs.

INSTALLATION COSTS

The impact of installation costs should receive due consideration. For equipment of similar design, the cost differences of the various options may be minimal. The evaluation team may choose to use "delta-costs," as opposed to total actual costs. The parameters are listed in the examples and discussed as follows.

Complexity of Installation

The size, type, configuration, and extent of packaging of the equipment all affect the installation cost. Additional field assembly may be required for larger units, including installation of maintenance accessibility platforms, foundations, and grouting. Large equipment components may require mounting on a concrete pedestal, using soleplates, rather than on a baseplate. Other factors that can affect installation cost include field assembly of main equipment, separately installed accessories, interconnecting piping and wiring, crane capacity, and supplier supervision.

The cost of a building to house equipment, including building permits, internal maintenance crane costs, heating, cooling, insulation, etc., must be included, if applicable. The location of the project may dictate the use of a building. There may be extra costs involved to supply equipment for outdoor installation. Noise levels, and costs to provide noise abatement, may affect the decision to provide a building.

RELIABILITY/MAINTENANCE

When continuous operation of equipment is critical to the process, end users will generally require the equipment to operate for long periods of time (three years or more) without being shut down for maintenance. Objective reliability and maintenance data are often not readily available, thus more research and discussion among team members are required to assure that subjective data included in the evaluation are reasonable. It is important that the historical data used to evaluate operating costs, maintenance frequencies, and overhaul/repair frequencies are provided by the end user in order to define an overall "reliability cost" factor for each equipment type. When evaluating reliability, the evaluation team can include (when applicable) the additional cost of lost production, rental units, and other costs that may be incurred when the primary equipment is out of service.

Additional support data should be obtained in the form of the suppliers' recommended routine and major maintenance programs, along with recommended maintenance and capital spare parts prices.

COST OF DOING BUSINESS

The total life-cycle cost evaluation should include the relative cost of doing business. Factors that may affect this include the following:

- Design coordination.
- Timeliness and accuracy of supplier documentation.
- Quality assurance/inspection.
- Expediting.
- Travel costs.
- Prenegotiated commercial terms.

Alliances, partnering, development of standard designs/specifications, and well-established working relationships can all minimize the relative cost of doing business.

EXAMPLES

Table 1 presents an evaluation summary for three combinations of compressors to be used as the main (or base load) air compressor and booster air compressor in a large oxygen generation plant. Supplier "A" offered a combined service single casing single shaft centrifugal unit. Supplier "B" offered a single casing, single shaft unit for the main air compressor, with a separate integrally geared unit for the booster compressor. Supplier "C" offered a combined service three pinion, six stage integrally geared centrifugal unit. The critical evaluation parameters are defined in the lefthand column. Table 2 includes a set of clarifying notes for the evaluation.

Table 1. Equipment Bid Evaluation, Main Air Plus Booster Air Compressor.

	Air Flow (CFH-NTP)	Suction Pressure (psia)	Discharge Pressure (psia)	Suction Temperature (Deg F)	Cooling Water Temperature (Deg F)	Compression Ratio	Relative Humidity (%)
BLAC (4 Stg)	10,000,000	14.5	120	60	70	8.3	75
BAC (2 Stg)	2,500,000	115	330	60	70	2.9	0

Value of Power = 3500 \$/kW

NOTES (SEE ATTACHED)	SUPPLIER	"A"	"B"	"C"
		(BLAC / BAC) BEAM TYPE Single Casing, Single Shaft	(BLAC + BAC) BLAC - BEAM - SCSS, BAC - Integral Gear	(BLAC / BAC) Three Pinion Integral Gear
	NUMBER OF COMPRESSORS	1	2	1
A	NUMBER OF BLAC STAGES	4	1	4
B	BLAC SHAFT POWER, BHP	34,348	30,396	34,027
C	BLAC MOTOR HP	40,000	35,000	40,000
D	BLAC MOTOR SPEED, RPM	1,200	1,200	1,200
	BAC SHAFT POWER, BHP	N/A	3,891	N/A
	BAC MOTOR HP	Included	5,000	Included
	BAC MOTOR SPEED, RPM	n/a	1,800	n/a
E	STARTING MOMENT OF INERTIA, LB	225,000	225,000	160,000
	CAPITAL COSTS			
F	BLAC capital COST, \$	2,960,000	2,430,000	3,300,000
G	BAC capital COST, \$	Included	1,000,000	Included
H	BLAC MOTOR capital COST, \$	680,000	595,000	680,000
	BAC MOTOR capital COST, \$	Included	215,000	Included
I	BLAC SPARES (Startup + insurance), \$	100,000	71,000	97,714
	BAC SPARES (Startup + insurance), \$	Included	30,000	Included
J	NOISE RECTIFICATION (lagging/hood)	75,000	110,000	75,000
	TOTAL CAPITAL COSTS	3,815,000	4,451,000	4,152,714
	SHIPPING / STORAGE COSTS			
K	SHIPPING COST/DUTY, \$	40,000	10,000	30,000
L	SITE STORAGE	15,000	15,000	12,000
	TOTAL SHIPPING/STORAGE COSTS	55,000	25,000	42,000
	OPERATING COSTS			
	BLAC POWER, kW	25,618	22,666	25,374
	BAC POWER, kW	incl	2,902	incl
	TOTAL POWER - kW	25,618	25,568	25,374
	delta POWER, kW	244	194	BASE
M	EQUIV. delta CAP OF POWER, \$\$3500	854,000	679,000	0
	DELTA POWER COST	854,000	679,000	0
	INSTALLATION COSTS			
N	delta FOUNDATION/CIVIL) COST, \$	35,000	50,000	0
O	delta LABOR/EQUIP (MECHANICAL) \$	0	60,000	30,000
P	delta ELECTRICAL COSTS	215,000	0	215,000
Q	delta PAINT/INSULATION	20000	30000	0
R	MAINTAINABILITY EXTRAS	10000	15000	5000
	TOTAL delta INSTALLATION COSTS	280,000	155,000	250,000
	MISCELL COSTS			
S	delta TESTING, \$	0	25,000	50,000
T	Delta EXECUTION COSTS	25,000	35,000	base
U	FIELD SERVICE/TRAINING	10,000	25,000	included
	TOTAL MISCL COSTS	35,000	85,000	50,000
	TOTAL EVALUATED COSTS	5,038,000	5,398,000	4,494,714

The APPENDIX presents an evaluation summary in narrative form for three different types of compressors proposed for a low molecular weight process gas in a recycle application. The narrative discusses the selection process, and identifies the critical evaluation parameters for the project. A comprehensive spreadsheet evaluation was done for this project, including an analysis of utility, chemical and catalyst, maintenance, and overall cost of downtime over a 20 year plant life. Space does not permit publication of the spreadsheet in this paper. However, Table 3 includes a list of the cost parameters included in each portion of the evaluation, and Figure 4 presents a summary of the results in graph form.

The documentation methods of the two examples differ, but each example illustrates that the keys to the process are defining the critical evaluation parameters and assigning appropriate costs to those parameters.

CONCLUSION

From the points and examples presented, the following conclusions are evident:

- The engineering/construction contractor, in concert with the end user, may be able to justify increased capital cost (and an increase in their contract price, if applicable), if overall life-cycle cost savings can be demonstrated.
- “Low price” is not always “low cost.”
- The primary focus of a successful project team or organization is to add value for their customer.
- For the evaluation process to be successful, communication between the end user, specifier, and supplier is of prime importance.
- Ask questions—all questions are considered important when evaluating capital expenditures to support project economic goals.

Table 2. Notes for Table 1.

A	NUMBER OF STAGES	Stages are intercooled single impeller or groups of impellers
B	SHAFT POWER	Power as measured at the coupling between the driver and driven equipment
C	MOTOR HP	Rated horsepower of the motor, minimum of 115% of maximum compressor HP
D	MOTOR SPEED	Motor speed as provided by the compressor supplier
E	MOMENT OF INERTIA	Moment of inertia of the compressor, which can effect the cost of the driver
F	BLAC CAPITAL COST	Complete first cost of the compressor, documentation and auxiliaries from the compressor supplier, less spares and service
G	BAC CAPITAL COST	For two compressor options, complete first cost of the booster compressor, including documentation and auxiliaries from the compressor supplier, less spares and service.
H	MOTOR CAPITAL COST	Projected cost of the motor for the corresponding compressor.
I	SPARES	Spares include commissioning, or start-up spares, and any major capital spares defined by project definition due to cost projected life and availability
J	NOISE REDUCTION	Cost of supply and installation of sound abatement, may include birms. Lagging or hoods.
K	SHIPPING/DUTY	Cost of shipping the equipment provided by the supplier. Includes import duty when applicable. This may also be from multiple locations.
L	SITE STORAGE	Cost of preservation and handling on site for equipment before and after installation, before plant commissioning.
M	POWER DELTA COST	The cost of power evaluated over the commercial life of the installation.
N	FOUNDATION	Cost of the civil contract for the foundation of the compressor(s) and motor
O	LABOR EQUIPMENT	Cost of site labor and heavy equipment for setting, assembling, and installing the equipment.
P	ELECTRICAL DELTA	Cost of additional electrical equipment. This would include transformers, motor control centers.
Q	PAINT / INSULATION	Extra cost of painting and insulation that is required in the field.
R	MAINTAINABILITY EXTRAS	Additional scope required to increase maintainability. May include platforms, cranes, cooler bundle pullers, etc.
S	DELTA TESTING	Cost extras for testing, includes extra costs for set-up and/or major testing of sub-components.
T	EXECUTION COSTS	Cost for additional qualification efforts, travel costs for testing, documentation reviews, etc.
U	FIELD SERVICE TRAINING	Projected cost for field service and training of operators.

Table 3. Total Cost of Ownership Economic Model, Hydrogen Recycle Compressor Breakdown of Cost Categories.

Owner's Cost	EPC Costs	Commissioning & Start Up Costs	Operating Costs	Maintenance Costs	Lost Production Costs	Disposal Costs
• Development	• Contractor Engineering	• Labor	• Labor	• Labor	• Unscheduled Downtime	• Waste Disposal
• Licensor Fee	• Contractor Procurement	• Supervision	• Supervision	• Supervision	• Reduced Capacity	• Demolition
• Permits	• Equipment	• Management & Engineering	• Management & Engineering	• Management & Engineering	• Off-Spec Product	• Restoration
• Financing	• Bulk Materials	• Subcontractors	• Subcontractors	• Subcontractors		
• Management & Administration	• Contractor Construction	• Consumables	• Utilities	• Building & Shops		
• Internal Consultants		• Replacement Parts	• Chemical & Catalyst	• Inventory (Parts & Materials)		
• External Consultants		• Hydrocarbon Inventories	• Waste Disposal	• Monitoring		
			• Administration	• Repair		
			• Taxes	• Preventative Maintenance		
			• Royalties	• Turnaround		
			• Infrastructure			
			• Risk Management			

APPENDIX A—
TOTAL COST OF OWNERSHIP ECONOMIC
MODEL HYDROGEN RECYCLE COMPRESSOR

Introduction

A compressor study was performed for a recycle hydrogen compressor application to determine the most economical solution

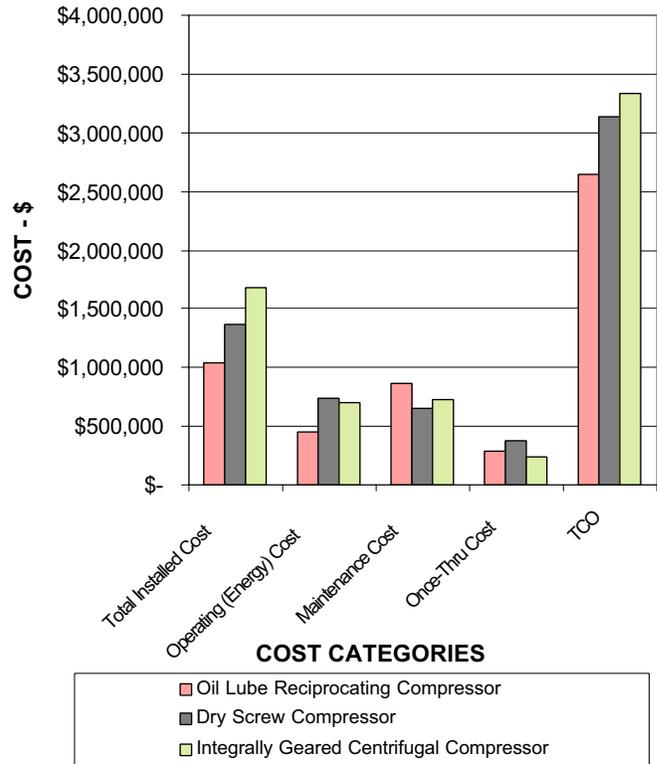


Figure 4. Total Cost of Ownership Economic Model, Hydrogen Recycle Compressor Summary Graph.

based upon a total cost of ownership (TCO) economic model. The TCO model is defined as the sum costs for the development, financing, procurement, installation, startup, operation, maintenance, repair, modification, and disposal of a facility over the period of a 20 year plant operating life. These costs have been categorized in Table 3.

In the TCO evaluation for the compressor study, the analysis was focused on the following criteria:

- Capital equipment cost
- Operating (energy) cost
- Maintenance cost
- Downtime cost

This study excluded the costs of cooling water consumption, costs for bulk materials, etc., because it was determined that these costs would not affect the decision as to what type of compressor is best suited for this application.

The equation used for evaluating present and future costs is:

- TCO = Total installed cost
- + Present worth (maintenance costs over life of plant)
- + Present worth (net utility costs over life of plant)
- + Present worth (catalyst and chemical costs over life of plant)
- + Present worth (cost of onstream factor)

Key economic factors established are as follows:

- Economic life— 20 years
- Escalation cost—3 percent
- Discount rate—11 percent
- Present worth—Mechanical completion date

Operating Conditions

The design conditions for the hydrogen recycle compressor application is shown in Table A-1. In this study, the compressor

types that were evaluated included centrifugal compressors, lubricated and nonlubricated reciprocating compressors, and screw compressors.

Table A-1. Design Conditions for Hydrogen Recycle Compressor Application.

Rated Capacity	4,148 LB / HR
Inlet Pressure	225.7 PSIA
Suction Temperature	110° F
Discharge Pressure	326.9 PSIA
Molecular Weight	2.6 to 4.9

Installation Cost Analysis

The installation cost includes materials and manhours to properly install the compressor equipment at the job site. Installation procedures were requested from each compressor supplier and costs to comply with these procedures have been incorporated into the analysis.

The installed cost analysis includes the installation of the lube oil console and labor costs to interface piping, control system, and electric wiring to the junction boxes and electric motor drivers. The analysis also includes cost estimates to chemically clean and flush all lube oil piping prior to startup. The installed cost does not include bulk piping and electrical material costs, which were judged to be comparable for all cases.

All the compressor solutions will ship with the equipment mounted on a baseplate. The cost for the baseplates is included in the TCO economic model. The baseplate will be leveled and grouted to the sub-support concrete foundation pad.

Maintenance and Repair Model Costs

The maintenance and repair economic models were developed using estimated maintenance and major overhaul schedules from historical data. Although each compressor option will have a unique maintenance and repair schedule, the time cycles to perform these repairs are predicated on the end user's maintenance program. The maintenance and repair cycle for this study was derived upon a specific plant site and may not be adequate for all applications.

The economic model includes current market value spare parts pricing data received from each compressor supplier.

The analysis is based upon a 20 year plant life.

Operating Cost Analysis (Cost of Energy)

The cost of energy analysis was based on an actual present value energy cost including an escalation cost of 3 percent and a discount factor of per year over a 20 year plant life (Table A-2).

Table A-2. Utility Rates.

2004 Fuel Cost \$/MMBTU	2004 Power Cost \$/MWH	2004 Steam Cost \$/MLB
\$3.18	\$31.80	\$3.98

Once-Through Hydrogen Cost Analysis

During periods when the recycle compressor is not available due to scheduled maintenance or outage, process plant operations will continue using the once-through hydrogen mode. The once-through hydrogen mode is based on the value of the fresh hydrogen stream being converted to fuel gas. The present worth value derived for this study is \$645.00/hour. The model does account for the fact that the compressor motor is not consuming power while in this operating mode.

Discussions of Findings

Each compressor supplier submitted their best compressor selection to meet the rated design operating conditions as specified on the process data sheets provided by the process licensor. Based upon the compressor performance received, only the lubricated reciprocating compressor and integrally geared high speed compressors met the rated performance duties without having to add natural gas into the recycle gas stream. The dry screw compressor option required adding natural gas into the recycle gas stream in order to raise the molecular weight. This was required so the compressor would be able to increase the volumetric efficiency at the rated flow condition.

The process licensor confirmed that there would be no detriment to the process by adding a small amount of pipeline quality natural gas into the recycle hydrogen stream to increase its molecular weight to 6. It is predicted that the column pressure may be increased slightly (if at all), and the vent rate will increase due to the addition of natural gas. It is expected that the purity of the recycle gas stream hydrogen will be higher during unit startup. It will be necessary to use the natural gas injection system for startup of all centrifugal and rotary screw compressors to ensure that the compressor develops sufficient differential pressure. The TCO economic model includes additional costs for an analyzer and control valve station necessary to control natural gas injection into the recycle gas stream for the integrally geared centrifugal and rotary screw compressor solutions.

One area of concern involved with use of lubricated reciprocating compressors was the amount of oil carryover into the process. The process licensor reviewed the oil carryover values supplied by the reciprocating compressor supplier and confirmed that this will not adversely affect the process, so long as the lube oil does not contain significant amounts of compounds that may poison the catalysts. To ensure protection to the process, the TCO model included the total installed cost (TIC) for a discharge drum to recover the lube oil, as well as to serve as an acoustical device to dampen pulsation prior to the discharge gas entering into the downstream piping network.

In addition, due to the high rotor speed of the integrally geared centrifugal compressor, an inlet coalescing filter was included in the TIC estimate to increase the operating reliability of the compressor over the plant life.

Summary

The TCO economic model shows that the oil lubricated reciprocating compressor has the lowest total cost for this application and project evaluation criteria. Refer to Figure 4 for a summary analysis of the cost categories. Although normal process industry practice would require two reciprocating compressors to ensure plant reliability, the subject plant will achieve the same result using one compressor backed up by the once-through operating mode of the plant. Low flow and low (and varying) molecular weight process conditions did not favor a good selection for the integrally geared compressor. Extremely high shaft speeds were required to cope with the low molecular weight of the recycle gas. The compressor efficiency of the selections was generally low, and the resultant power consumption was costly in the TCO model. Similarly, the dry screw compressor selection had low volumetric efficiency; natural gas was required to add into the process stream, which increased the mass flow and in turn increased the compression horsepower.

In conclusion, it should be noted that the economic analysis varies depending on the economic criteria required to meet the project objectives. Economic factors beyond the initial capital cost of the equipment may determine the final recommendations when taking into account the total portfolio of the plant economic baselines of profitability.