Application of Life Cycle Analysis in the Capital Assets Industry[1, 2]

Bob Prieto

Chairman & CEO
Strategic Program Management LLC

Life Cycle Analysis (LCA) is the assessment of the total cost or benefit of an asset over its lifetime. Also referred to as Whole Life Costing (WLC), LCA systematically considers all relevant costs and revenues associated with the acquisition, ownership and disposal of an asset. LCA supports a comprehensive assessment of sustainability by considering all benefits and impacts within a Triple Bottom Line Framework.

In this paper we will look at the components that comprise a comprehensive LCA and some of the factors to be considered in evaluating the life cycle cost or benefit of an asset. These costs or impacts as well as accrued benefits will also be considered from the perspective of the Environmental and Social Bottom Lines.

Subsequently, we will consider how to apply LCA in a program or business setting, where multiple projects or assets may be employed.

The intent of this paper is several fold.

First, to broaden the perspectives of program managers who increasingly are being tasked to consider more than initial delivery of a program. Rather they are increasingly focused on helping the facility's owner meet broader and deeper strategic business objectives and as such factors such as availability, operability and maintainability are increasingly important.

The second intent of this paper is to provide insights to individual project managers as they consider project life cycle costs to ensure false tradeoffs are not made impacting reliable facility operation. In addition many projects are beginning to consider life cycle aspects other than cost and thus the triple bottom line focus embedded in this paper.

Finally, this paper is focused on facility owners and attempts to provide an initial roadmap with a triple bottom line focus, to help them plan and make the right kinds of cost vs. value tradeoffs as they implement their capital asset programs.

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The LCA construct described in this paper also allows for the consideration of risk and uncertainty both with respect to revenues (benefits) and costs (impacts). The time value of money is also reflected but there has been no such consideration included along the environment and social bottom lines.

Why Life Cycle Analysis is Important to the Capital Asset Industry

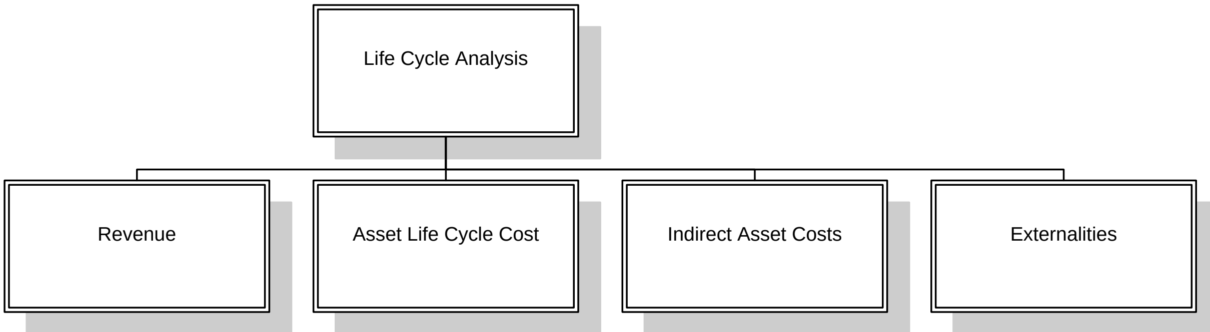
Competitive pressures, shortages of capital and increased emphasis on sustainability all combine to shine a spotlight on the full life cycle impacts of the acquisition and operation of today's capital assets. Whether it is an industrial facility with high levels of energy and water intensity, a facility with potential greenhouse gas or wastewater discharges, or a public infrastructure asset that must be operated and maintained over many decades, full life cycle analysis is essential to making better decisions.

Life Cycle Analysis vs. Life Cycle Cost Analysis

Life Cycle Analysis (LCA) employs a broader perspective than that traditionally encountered in an asset based Life Cycle Cost (LCC) analysis. This is illustrated in the figure below. LCA looks beyond just the life cycle cost of an asset, considering how revenues are influenced (both positively and negatively) by life-cycle performance characteristics, capturing the benefits of shorter design and construction schedules, longer service life-times and higher availability or flexibility of the asset. LCA also considers a range of indirect asset costs which may include factors such as land usage, applicable tax regime or financing structures available under different asset configurations. Other externalities are also considered in LCA which may include intangibles such as brand value, susceptibility to "Black Swan" type risks, and "strategic speed".

Consideration of the environmental and social bottom lines must also be made from this broader perspective. ISO 14044, "Environmental management – Life cycle assessment – Requirements and guidelines" provides a good roadmap for considerations around the environmental bottom line. ISO 26000, "Guidance for social responsibility" outlines some of the core subjects and issues to be considered as part of LCA.

At each level in the LCA, risk and uncertainty need to be considered and careful attention paid to appropriate treatment of combined risk and risks which may reside in the "white space" between various LCA elements.



It Starts With Revenue

All too often the basic revenue model associated with an asset's performance is overly simplified in the definition of the required asset. This decoupling between the revenue model and the asset specification may lead to sub-optimization of overall life cycle performance. For example, in specifying the "required" asset, assumptions will typically be made with respect to:

- Output quality levels
- Asset availability
- Asset lifetime or time to obsolescence
- Time to revenue service
- Product and by-product value (by-products are often treated with zero or even negative value)

Comprehensive LCA will consider the interaction between these revenue assumptions and other LCA factors allowing improved optimization of the asset's whole life business model. For example, does a market exist for higher or lower quality product outputs (or intermediate products)? If so how would revenues and associated asset LCC change under different scenarios? What would the optimum output/revenue profile look like?

Similarly, would changed design or equipment selection improve overall asset availability and if so what would the new LCA look like when both higher revenues (from improved availability) and first costs are considered. Accelerated project delivery would result in earlier first revenue and depending on the asset may result not only in an acceleration of revenue streams but also an increase in total output over the assets life.

It is in these later examples where decisions we make as part of more traditional LCC may have the greatest impact, going beyond just reducing life-cycle maintenance costs.

For public infrastructure projects which may be provided as a "public good", non financial benefits can be similarly quantified arriving at metrics such as reduced hours of congestion per dollar or unit of service rendered per dollar such as in the case of schools or recreational facilities. Alternately, broader economic benefits can be considered such as in the case where a publicly financed asset such as a new stadium or expanded airport capacity is put into service significantly earlier. In the case of certain asset revenue streams, such as the stadium example, seasonality needs to be considered, so that one has not incurred additional cost only to have the asset sit unused for a longer period of time.

As in any such analysis, one ends up with an "efficient frontier" of potential optimizing scenarios, which may be constrained by the availability of capital, time or any other resource.

Revenue forecasts can be considered with different overall confidence levels using techniques such as Monte Carlo analysis where multivariate analysis allows the different confidence levels around different revenue factors to be combined.

Subsequently, when combined with LCC and other LCA factors, a better representation of optimal LCA profiles will emerge.

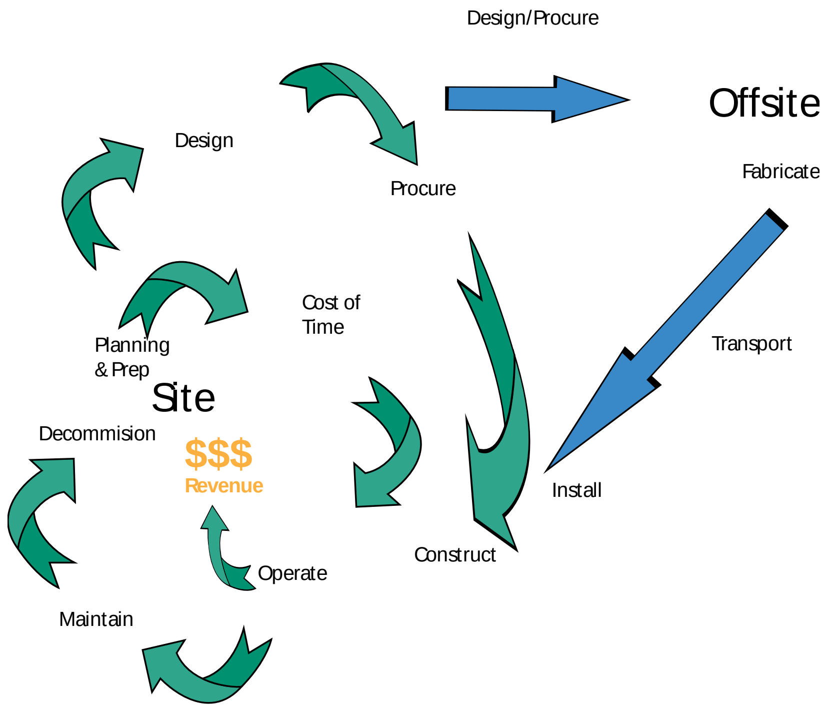
Finally, although treated as a cost elsewhere in the LCA, tax credits may be generated in select instances through decisions related to asset acquisition and operations, in effect representing added sources of revenue.

Revenue Factors Typically Considered in a Capital Asset Life Cycle Analysis
First Revenue Date
Plant Availability Factor
Asset Life (Duration from First Revenue during analysis period)
Capacity or Throughput
Byproduct Value Captured
Tax Credits Realized

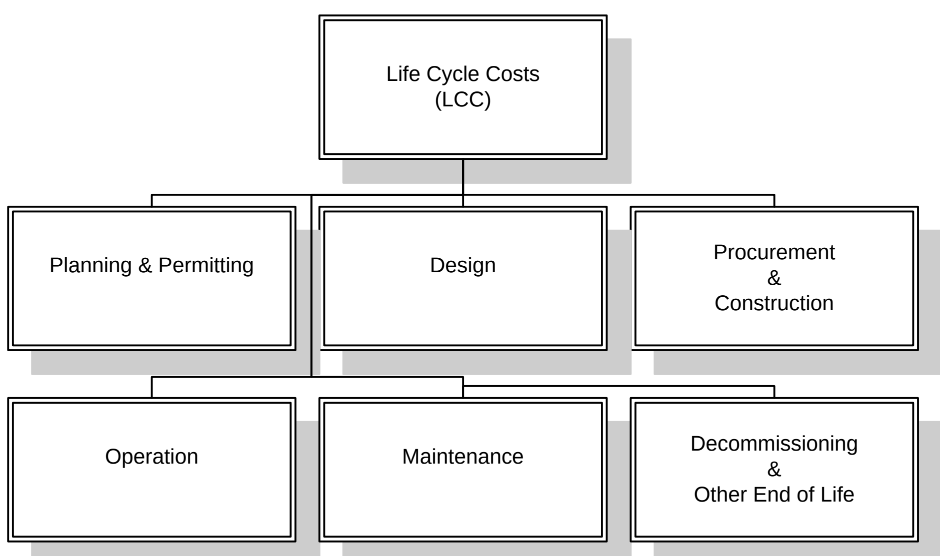
Assessing All Life Cycle Costs

Life Cycle Costing (LCC) is the typical area of focus in most capital asset project tradeoff efforts. LCC encompasses asset acquisition, operation, maintenance and decommissioning and other end of life costs. Asset acquisition costs can include planning and permitting costs as well as more traditional design and construction costs, whether the later are accomplished at the final site or at an offsite location such as a prefabrication facility or mod yard. Land costs are not included in LCC and will be treated later in this LCA discussion.

The figure below illustrates the various steps in the assets life cycle and recognizes the importance of time in the first delivery of the asset. Revenue from the facility as discussed in the previous section is also reflected, recognizing that revenue will be impacted by the myriad of asset factors.



Similar to our view on LCA, LCC can be seen as consisting of an organized set of activities which must be accounted for in our optimization of LCA. Each LCC related activity is discussed below and key factors to be considered in the LCA are described.



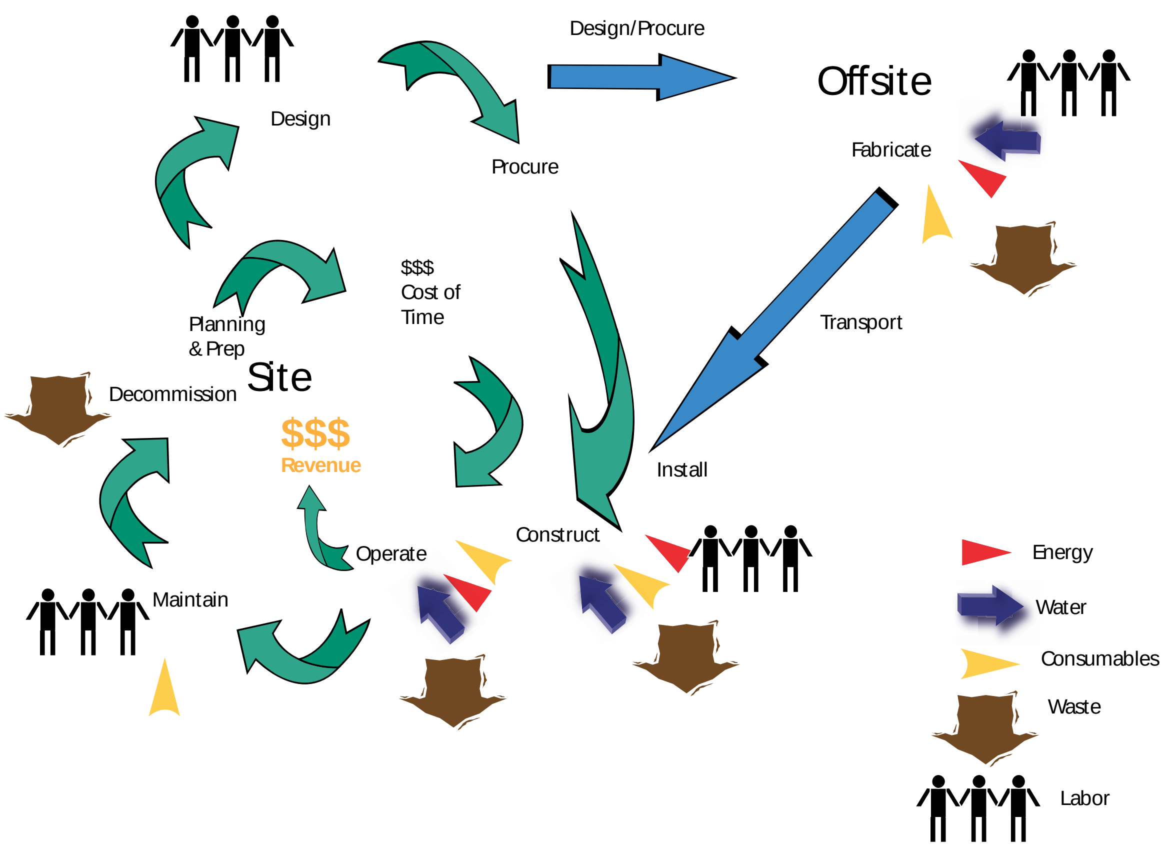
Major Categories to be Considered in Each LCC Activity

The discussion that follows looks deeper at each of the LCC activity areas. Cutting across each of these areas are several broad factors which will require serious consideration. They represent not only major potential cost categories but more importantly significant opportunity areas. In each instance constraints may exist around any or all of these factors which will act to constrain the "efficient frontier" of optimizing solutions. Asset decisions which avoid these constraints will tend to open the door to a wider set of optimizing solutions and thus a better opportunity to maximize the results of the LCA.

These broad cross cutting factors include:

- Energy
- Water
- Consumables
- Waste
- Labor

Other factors may exist but these typically represent the potential for most significant impact on the LCA. The influence of these factors in each of the LCC activities can be seen in the following figure.



Planning & Permitting

The influence of planning and permitting related costs on life cycle costs typically manifests itself in its contribution to overall asset acquisition schedules. More difficult and controversial permitting activities carry with them the risk of longer and perhaps more uncertain project schedules as well as potentially greater risk of being denied use of the selected site or the necessary construction or operating permits. LCA carried out at the earliest planning stages where different sites (the center of a city versus in the middle of nowhere) or core technologies (potentially susceptible to catastrophic failure or inherently benign) are being considered need to reflect not only the cost of the actual planning and permitting activities, but also the value of time and the value of risk associated with delay or absolute failure to move ahead.

In addition, various permitting regimes may drive the need for social or environmental enhancements beyond those otherwise integral to basic asset acquisition and operation. These may range from a provision of a range of community facilities or programs to environmental enhancements intended to improve the overall environmental setting and not just mitigate the direct effects of the delivered asset.

Planning & Permitting Factors Typically Considered in a Capital Asset Life Cycle Analysis
Labor Costs associated with planning & permitting activities
Permit Fees
Potential Litigation Cost
Cost of Time (related to activity length including potential litigation duration)
Value of Risk (delay or failure)
Stakeholder Engagement Costs
Enhancement Costs (social and environmental)

Design

While design is a major driver in ultimate LCA assessments, its contribution to alternative LCC evaluations is typically not a principal driver. But this is not always the case and several factors can come into play which can change its significance in overall LCA assessments. Among these factors is the degree of standardization or design reuse. This has the potential to not only reduce design costs but also accelerate the overall design schedule allowing for earlier start of construction and operation.

Other factors which can impact design costs may include work sharing, degree of subcontracting and what stage design will be taken to (100% or less when design-build delivery is to be used). New technologies or other first of a kind design risks may impact both design cost and schedule but as a minimum will change the design related risk assessment.

As alternatives are considered variations in design uncertainties, such as quantity based uncertainties need to be considered.

In this category other professional services should be included such as surveyors, archaeologists, wildlife specialists, geophysical specialists and the like.

Design & Professional Services Factors Typically Considered in a Capital Asset Life Cycle Analysis
Labor Costs associated with design and other professional services
Benefits realizable through standardization and design reuse
Premium labor costs likely to be incurred because of schedule or availability
Cost of Time (related to design duration and phasing)
Value of Risk (technology or other first of a kind risks; labor availability risk)
Design estimate uncertainties (estimating based; management model driven; rework based on late inputs or owner driven changes)

Procurement & Construction

Procurement and construction costs are major cost components in a life cycle analysis and together make up the largest portion of initial project costs. Procurement and construction costs will be heavily influenced by project location, contract form, existing infrastructure, owner's and regulatory requirements in addition to the performance characteristics of the facility.

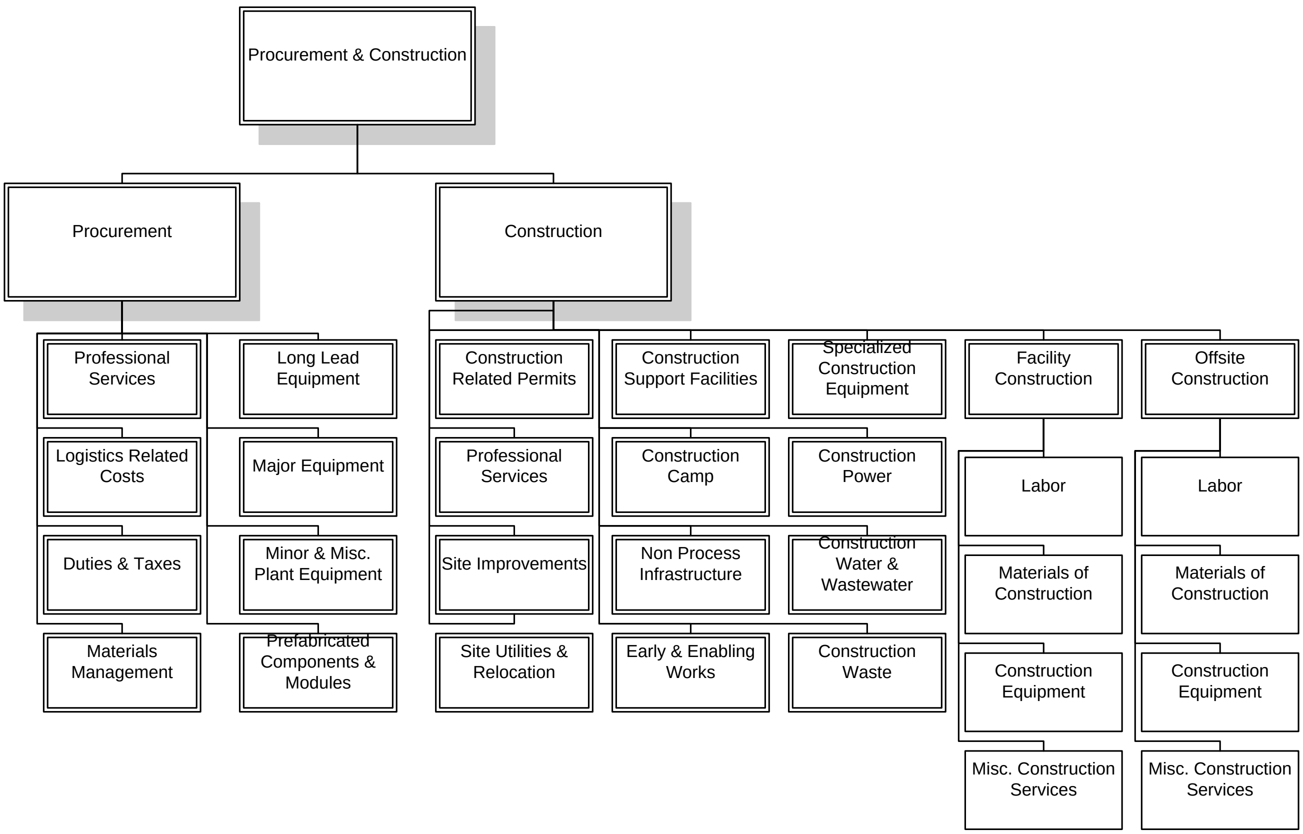
The broad cross cutting factors of:

- Energy
- Water
- Consumables

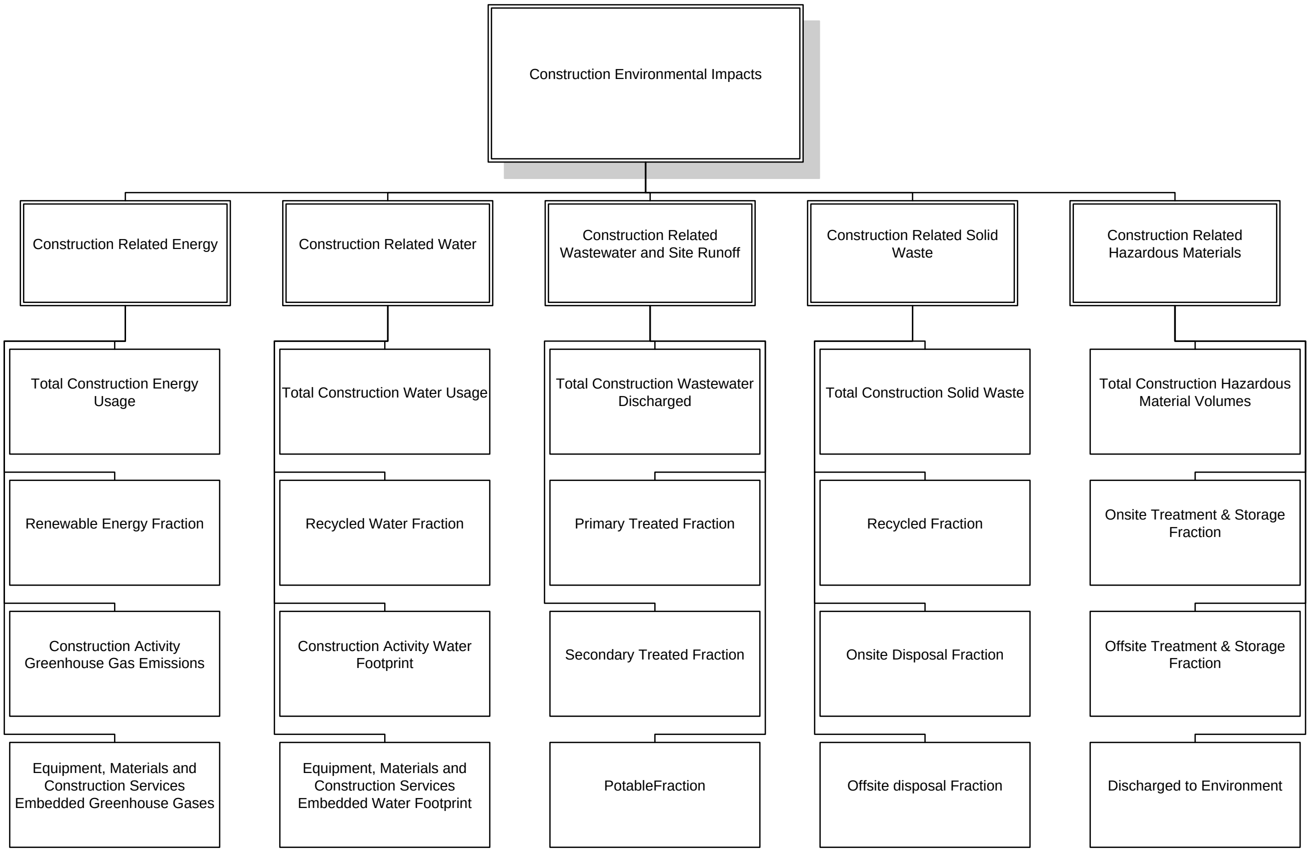
- Waste
- Labor

all come into play during the procurement and construction phase.

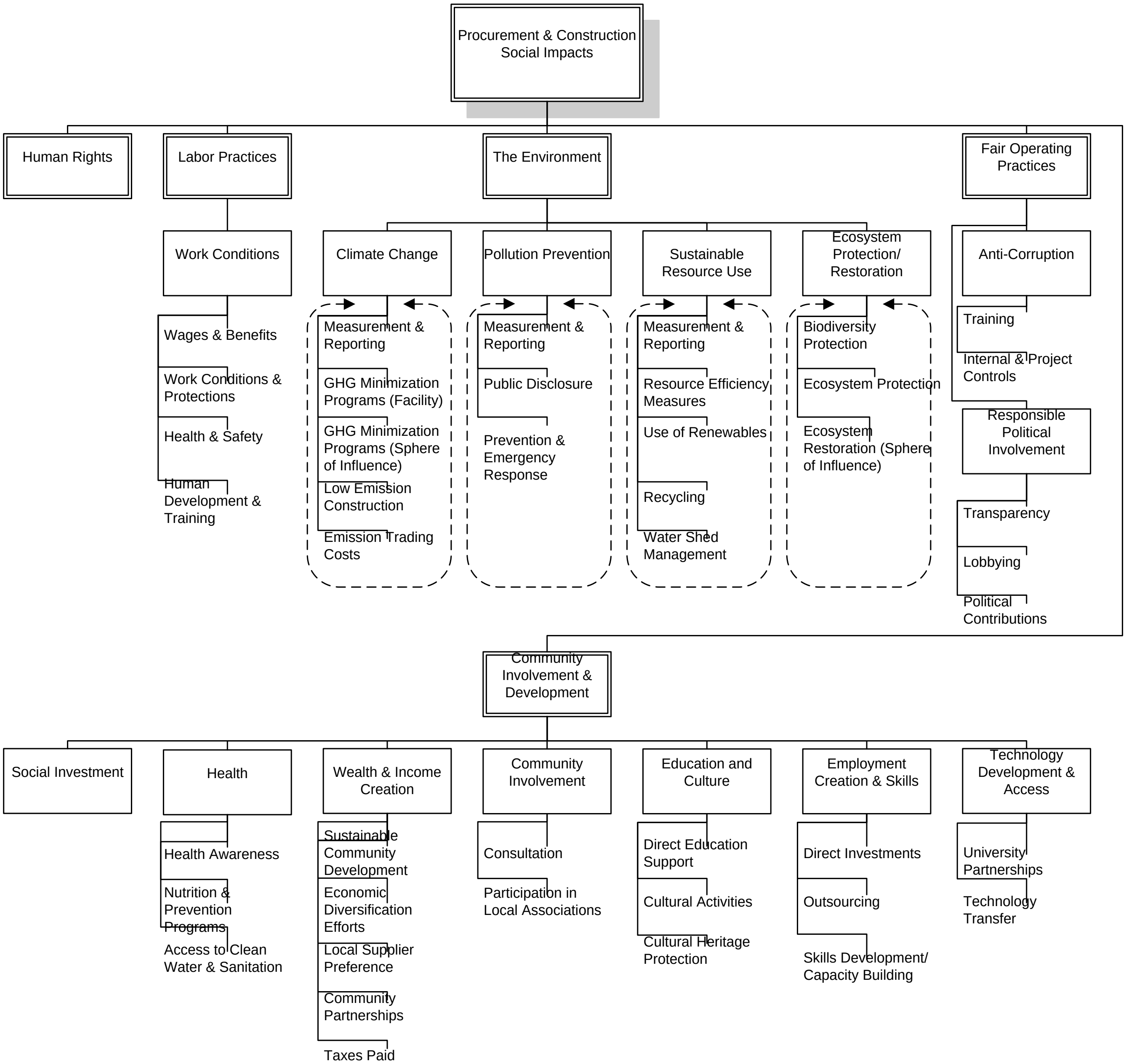
The procurement and construction phase may be seen as an organized set of activities as illustrated below.



From an environmental bottom line perspective (the second of the "Triple Bottom Lines"), the procurement and construction phase would appear as follows:



From a social bottom line perspective (the third of the "Triple Bottom Lines"), the procurement and construction phase might appear as follows. Activities that go beyond what is directly required for delivery of the facility are included but other social activities inherently part of project delivery must also be considered in "tallying" up the benefits and impacts in the social dimension. Similar social impacts are expected throughout the balance of the facility life cycle but are not repeated later in this paper.



Looking at each major category of life cycle costs in turn, we may see some of the factors affecting procurement costs in the following table.

Procurement Factors Typically Considered in a Capital Asset Life Cycle Analysis
Labor Costs associated with professional services including market surveys, supplier outreach, procurement services, related legal services, vendor and shop inspection and other quality related services.
Labor Costs associated with logistics and other supply chain related services including expediting, trafficking and documentation
Benefits realizable through use of prepositioned supplier relationship agreements for equipment, materials and services
Duties and taxes, both import and export related, including consideration of jurisdictional variations, subsidies and export control or embargo related costs and time
Materials management costs including labor, facilities cost, and security related costs
Cost of Time (related to procurement durations, potential impacts of procurement protests or litigation, transportation times both surface and maritime, customs and quarantine durations, manufacturing or other supply related durations)
Value of Risk (procurement risk; supplier risk; currency and sovereign risks including duty, quarantine and embargo; logistics risks; subcontractor and other vendor supply chain risks)
Procurement estimate uncertainties (estimating based; management model driven; rework based on late inputs or owner driven changes)
Embedded greenhouse gases in procured equipment, materials and associated transport.
Water footprint of procured equipment, materials and associated transport.
Other hazardous releases to the environment from procurement activities.
Direct and indirect jobs created at facility location
Total direct and indirect jobs created

Turning now to construction related costs to be considered in the life cycle analysis we see five major groupings of cost:

- Preconstruction and temporary construction
- Non process infrastructure or NPI
- Construction support costs
- Intermediate construction costs (prefabrication and modules)
- Facility construction costs

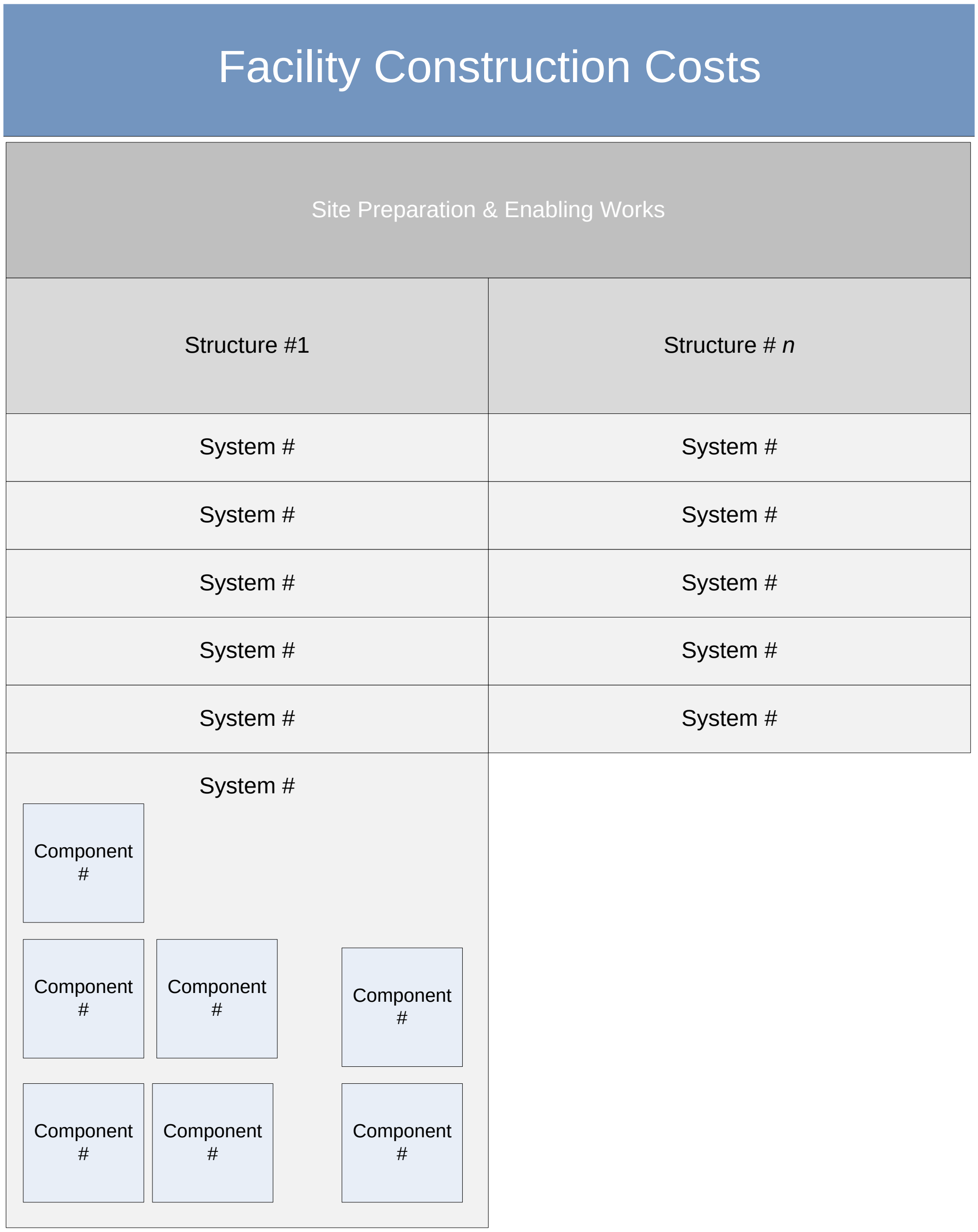
Preconstruction and temporary construction costs include costs related to construction related permits; professional services including design of temporary works and design efforts to take design to final completion under a design build delivery approach; general site improvements such as grading and drainage to allow construction operations to proceed; utility relocation or utilities to site based distribution points.

Non process infrastructure may include facilities essential to overall performance of the facility but not directly related to the facility operation at the site. Examples may include access roads; offsite rail links or required port improvements. Offsite power and water facilities required by the project may also be considered as NPI in some schemes.

Construction support costs can include early & enabling works (these may sometimes be considered as part of facility construction costs); specialized construction equipment such as marine vessels or custom designed cranes; construction power, water, wastewater and construction waste facilities. In addition construction camp and other construction related support facilities such as tank farms and maintenance facilities are included.

Intermediate construction costs resemble the suite of construction costs incurred at the final facility location. These costs include labor, materials of construction, equipment and miscellaneous construction services costs. The decision on the degree of prefabrication or modularization to be utilized can have a significant impact on overall first cost of the final facility.

Facility construction costs are all costs associated with the final installed facility not otherwise characterized. This can be conceptualized as a hierarchy of costs, encompassing all plant structures, systems and components as illustrated in the following figure.



Some construction factors considered in life cycle analysis are summarized in the following table.

Construction Factors Typically Considered in a Capital Asset Life Cycle Analysis
Construction related permit costs including those associated with occupancy, health & safety, labor, work permits and all other permits, licenses and registrations associated with facility construction including offsite construction activities related to NPI and prefabrication or modularization sites.
Labor Costs associated with design and other professional services related to design of temporary works and any design services required to take design to final completion.
Site improvement costs including grading, drainage, general site security, establishment of lay down or impoundment areas
Utility relocation or utilities to the site costs
Non process infrastructure costs including road, rail, port, transmission, water supply or treatment improvements and facilities included in the life cycle analysis but located off site.
Construction costs associated with early and enabling works including site stabilization, final grading, electrical or pipe chase construction
Specialized construction equipment including marine vessels, custom designed cranes, and erection gantries
Temporary power, water and waste water facilities including associated fuel and storage facilities; distribution networks including micro grids associated with temporary power dispatch and distribution; fuel depots; and construction waste related facilities including onsite landfills.
Labor costs associated with prefabrication and modular construction
Transportation costs of prefabricated and modular items of supply

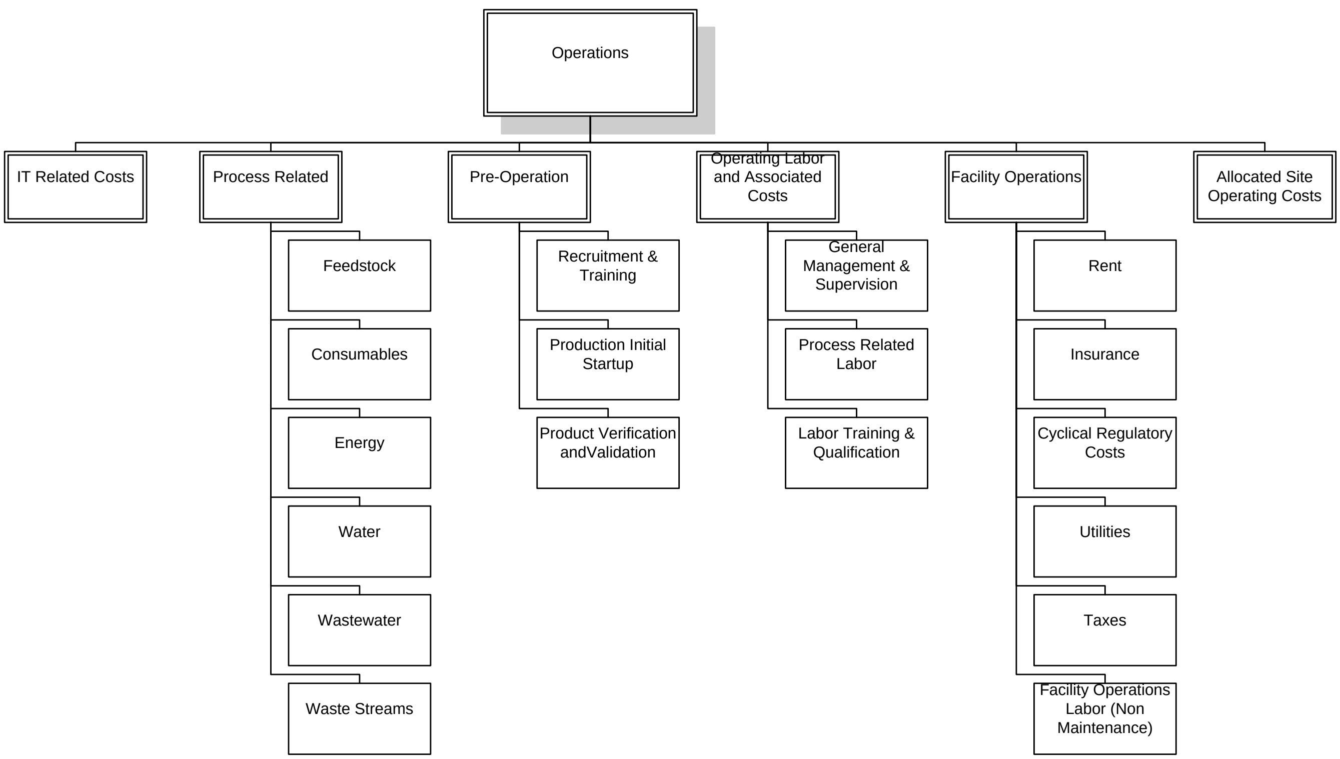
Mod yard costs, temporary facilities and miscellaneous construction related services
Cost of module equipment, materials and non-labor costs
Schedule related benefits realizable through use of prefabrication, modularization and additional construction fronts
Duties and taxes, both import and export related, including consideration of jurisdictional variations, subsidies and export control or embargo related costs and time associated with prefabricated or modular items of supply.
Labor costs associated with facility construction not otherwise characterized
Construction materials including consumables, equipment and miscellaneous services associated with facility construction not otherwise characterized.
Cost of Time related to construction durations and associated contingencies)
Value of Risk including construction risk; supply risk; currency and sovereign risks; cash flow risks; logistics risks; impacts of weather and other acts of god, labor disputes, and project disruption including impacts from subcontractor performance, safety performance, late design or owner changes or other foreseeable risks
Construction estimate uncertainties (estimating based; management model driven; rework based on late inputs or owner driven changes)
Taxes on construction materials and work
Greenhouse gas emissions from construction activities
Embedded greenhouse gases in procured equipment, materials and associated transport not included in procurement totals
Water footprint from construction activities
Water footprint of procured equipment, materials and associated transport not included in procurement totals
Other hazardous releases to the environment from construction activities
Direct and indirect jobs created at facility location
Total direct and indirect jobs created
Value of other social benefits created

Operation

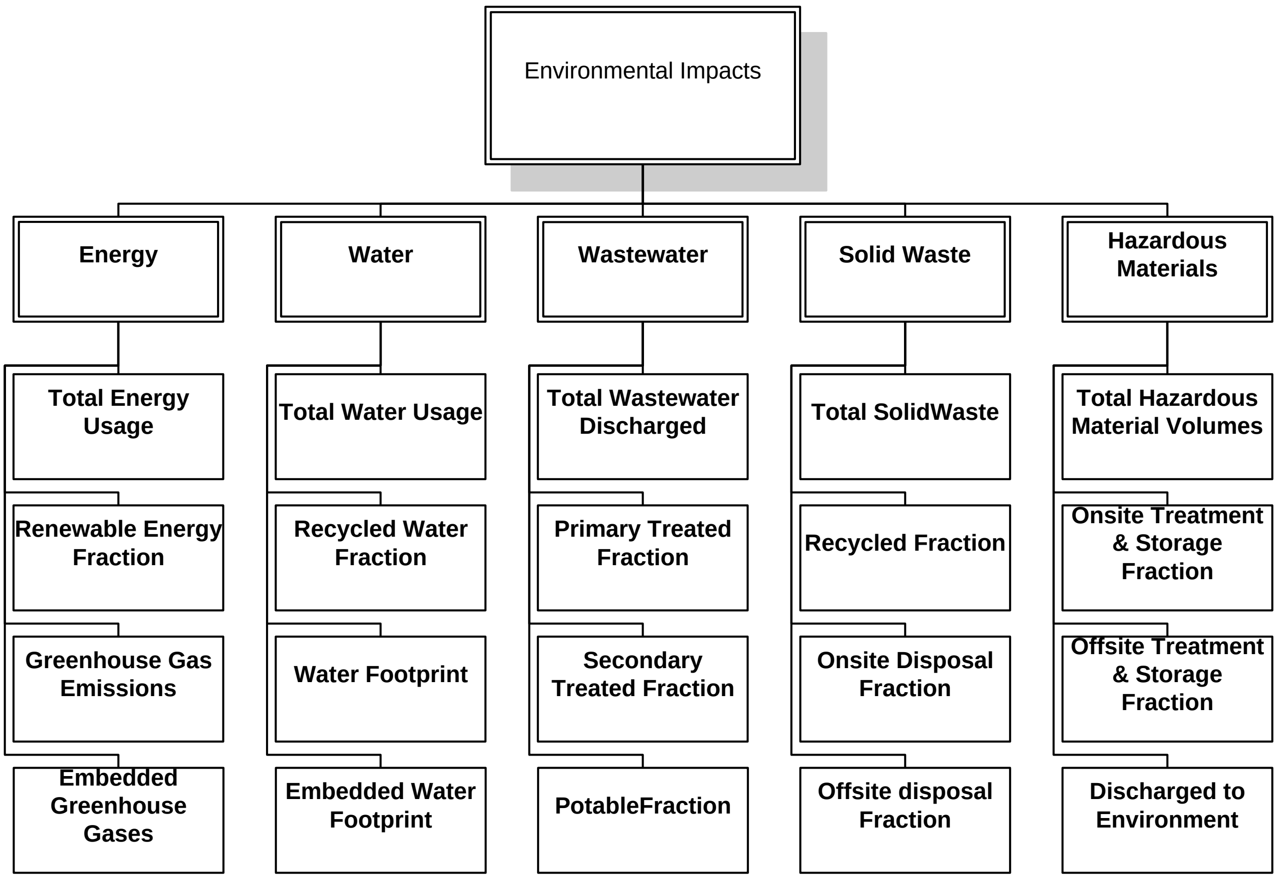
Operation costs cover the longest portion of the capital asset life cycle. Operating costs can be significantly influenced by plant design, selected technologies, energy and water usage, as well as waste streams. Principal categories of operating costs to be considered in a life-cycle analysis include:

- Pre-operation costs
- Process related costs
- Operating labor and associated costs
- IT related costs
- Facility operations costs
- Allocated site operating costs

These costs are reflected in the figure below.



From an environmental bottom line perspective, the life cycle analysis would assess impacts along the following lines:



Some key operating factors considered in the life-cycle analysis are summarized in the following table.

Operations Factors Typically Considered in a Capital Asset Life Cycle Analysis
Pre-operation labor and other initial production and acceptance costs
Operating labor costs (staffing levels, labor types, shift labor and premiums, training and certification costs)
Labor related insurance and benefits (Workers comp, medical and other healthcare, social security, disability, retirement contributions or costs)
Facility rent or depreciation costs
Property, casualty and liability insurance costs
Cyclical regulatory costs including cost of monitoring, reporting, fines, permit and other regulatory fees, improvement and retrofit costs due to changed regulation
Facility energy costs (electric, gas, steam, oil, coal) for non process operations (lighting, heating, air-conditioning, security systems, vertical transportation)
Facility water costs for non process operations (cooling water for air conditioning, fire protection water, potable water, grey water applications such as landscaping)
Facility sewage and other wastewater costs
Facility related solid waste disposal costs
Telephone and data communication costs
Real estate and other facility related taxes
Facility Capacity and Capacity Factor
Product Mix and Volumes
Facility operating labor costs (reception; security; building management; facility power, boiler, HVAC plant)
Feedstock costs (materials incorporated into final product)
Consumables used in process operations (cleaning fluids and materials; catalysts; intermediate materials and chemicals; filters and filter media; tools)
Process power costs including purchase, transmission and distribution and conditioning costs(electricity,

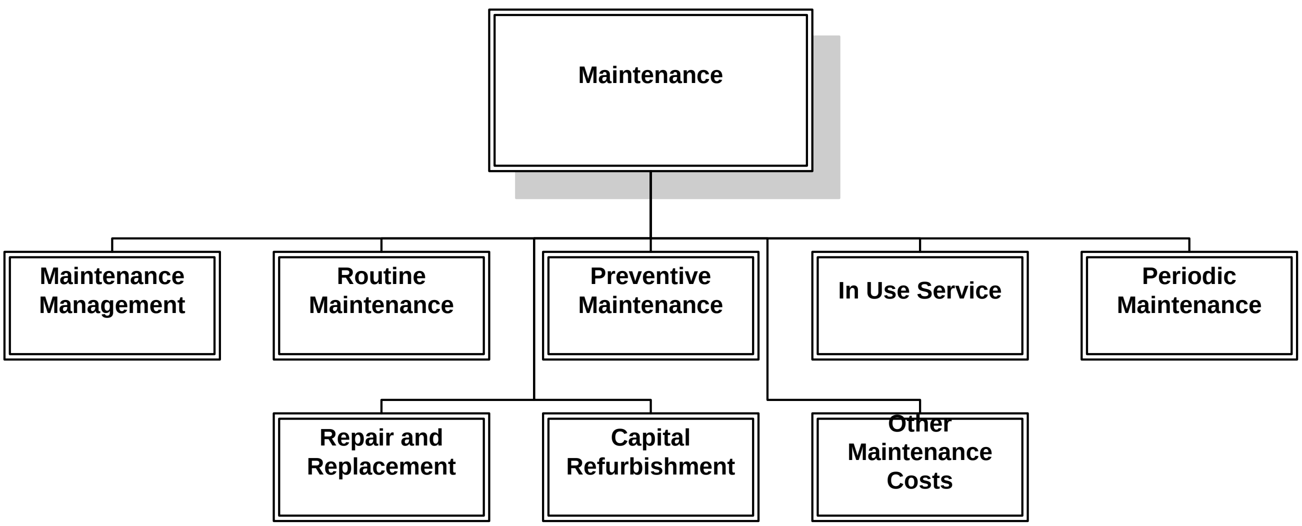
steam, direct combustion, renewables; energy recovery systems; storage)
Power supply credits (renewable sales to grid; cogeneration sales)
Process water costs (purchase cost, transmission cost, pretreatment and storage costs)
Wastewater costs (third party treatment costs, transmission costs, treatment prior to discharge, storage)
Hazardous or radiological material waste streams (collection, treatment, storage, transport, disposal costs)
Industrial waste streams (mixed waste, sludge, slag, non hazardous byproduct) costs (collection, treatment, storage, transport, disposal costs)
Solid waste costs
IT related costs - hardware (data center, servers, network, computers, printers, storage devices)
IT related costs – software (software purchase or license; software development)
IT related costs – labor (hardware and software support services including 3rdparty; data center and network operations)
Allocated general site operating costs (multi-facility sites) (site security; site transport; landscaping and site maintenance; site taxes; general and administrative costs)
Facility life time
Cost of Time (restricted operating hours; slow facility ramp up; reduced facility lifetime)
Value of Risk (risks to capacity factor; energy and water cost and availability risks; labor cost and availability risks; natural hazard risks; process technology risks; product liability risks)
Value of asset flexibility
Operations estimate uncertainties (estimating based; management model driven; late inputs or owner driven changes)
Greenhouse gas emissions from operations
Water footprint from operations
Direct and indirect jobs created at facility location
Value of other social benefits created

Maintenance

Maintenance costs generally coincide with the operating period of the facility and together with operating costs typically represent the most significant portion of facility life cycle costs. Maintenance costs are influenced by a range of design decisions, quality of construction and operating practices. Maintenance costs throughout the life-cycle are influenced by the levels of preventive maintenance activities undertaken.
Maintenance costs encompass:

- Maintenance management
- Routine maintenance
- Preventive maintenance
- Servicing of a facility or process asset in use
- Periodic maintenance of various facility and process assets
- Repair or replacement of worn or failed assets
- Capital refurbishment of major systems or assets

These costs are reflected in the following figure:



Some key operating factors considered in the life-cycle analysis are summarized in the following table.

Maintenance Factors Typically Considered in a Capital Asset Life Cycle Analysis
Pre-operation labor and other initial maintenance training and preparation costs not included in startup and commissioning activities
Maintenance management labor costs (staffing levels, labor types, shift labor and premiums, training and certification costs)
Labor related insurance and benefits (Workers comp, medical and other healthcare, social security, disability, retirement contributions or costs)
Maintenance facility and equipment rental, lease and depreciation costs
Property, casualty and liability insurance costs not otherwise included in operating costs
Cyclical inspection costs
Maintenance related energy costs including maintenance equipment and dedicated maintenance facilities and operations not included in operations costs
Maintenance related water costs for cleaning, flushing and other maintenance related activities
Maintenance related wastewater costs if not included in operations costs
Maintenance related solid waste disposal costs if not included in operations costs
Maintenance facility related taxes if not included in operations costs
Maintenance related facility downtime or reduced capacity
Maintenance labor costs (routine, preventative, in use servicing, periodic)
Maintenance materials costs (tools, consumables, disposal costs, fill and fluids, filters, lights)
Maintenance labor costs – repair and replacement
Design cost of repairs and replacements

Third party costs of repairs and replacements including special equipment rental, permits and inspections
Replacement part costs
Costs of capital refurbishment (management, labor, equipment, materials, third party design and inspections, permits and taxes)
IT related costs - hardware (data center, servers, network, computers, printers, storage devices) not included in operations costs
IT related costs – software (software purchase or license; software development) not included in operations costs
IT related costs – labor (hardware and software support services including 3rdparty; data center and network operations) not included in operations costs
Allocated general site maintenance costs not included in operations costs
Cost of Time (restricted operating hours; reduced throughput; reduced facility lifetime)
Value of Risk (risks to capacity factor; energy and water cost and availability risks; labor cost and availability risks; natural hazard resilience risks; environmental liability risks)
Maintenance estimate uncertainties (estimating based; management model driven; late inputs or owner driven changes)
Greenhouse gas emissions from maintenance activities
Water footprint from maintenance activities
Direct and indirect jobs created at facility location
Value of other social benefits created by maintenance sponsored activities

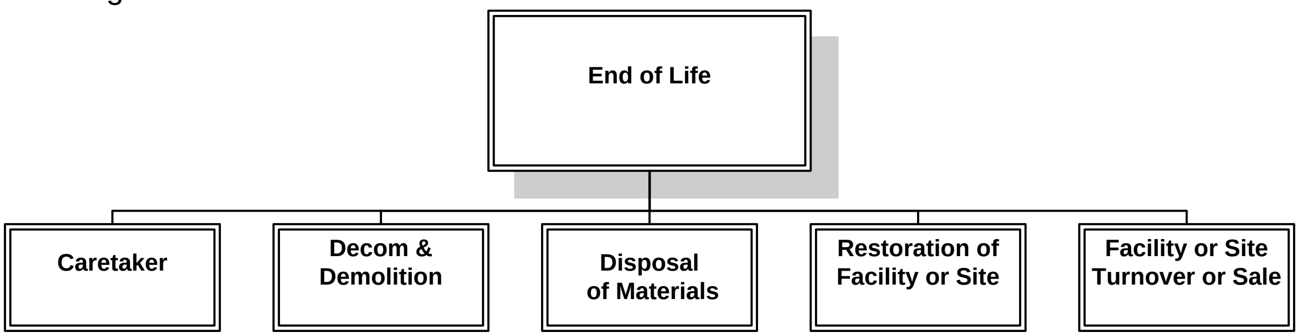
Decommissioning & Other End of Life

Decommissioning and other end of life costs can be significant costs and must be considered in life cycle analysis. An example of where these costs can be a driving factor in option selection is a nuclear power facility where waste disposal costs are meaningful and have long tail costs or in select defense facilities where site restoration time frames and costs can be significant.

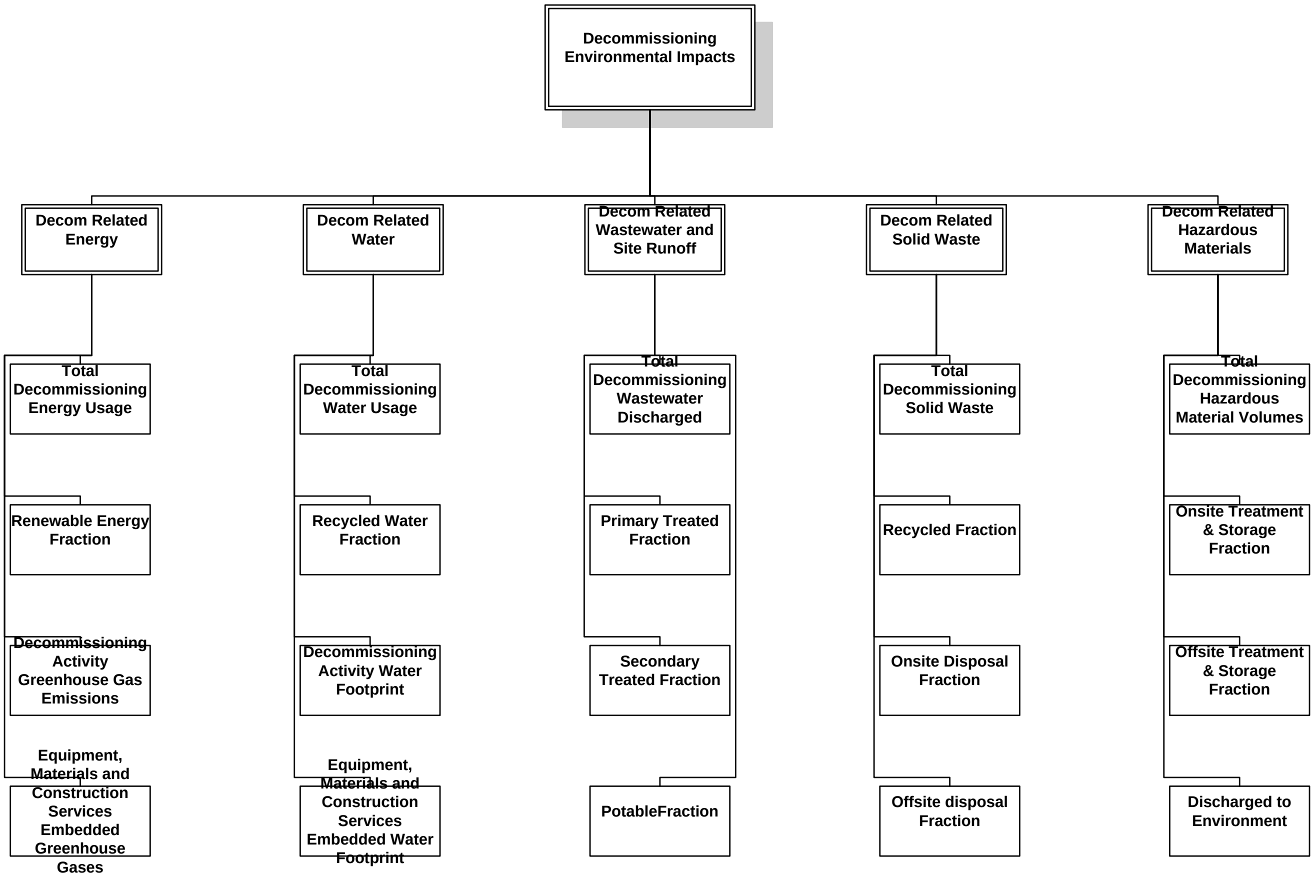
End of life costs encompass the period from when a facility ceases production operations until the facility or site are transferred to other use by the asset owner or disposed of. During this end-of-life period the facility may be sustained in a caretaker mode before being decommissioned and demolished if required. Materials that require permanent disposal or which must be removed from the facility either as a condition of its lease or as requirement for sale are stabilized and transferred during this period. Additionally, regulatory requirements may drive the nature, form and timing of site cleanup and disposition activities.

In some instances, the facility and associated site may be required to be restored to some prior state (beginning of lease period; greenfield equivalent). The final stage in end of life activity may result in an accrual of economic value from turnover or sale of the site.

These major cost categories can be seen in the following figure and further developed in the following table.



Similar to the construction and operations phase, the end-of-life stage can carry significant factors as it relates to the second of the "Triple Bottom Lines". Considerations at this stage that relate to this environmental bottom line are reflected below.

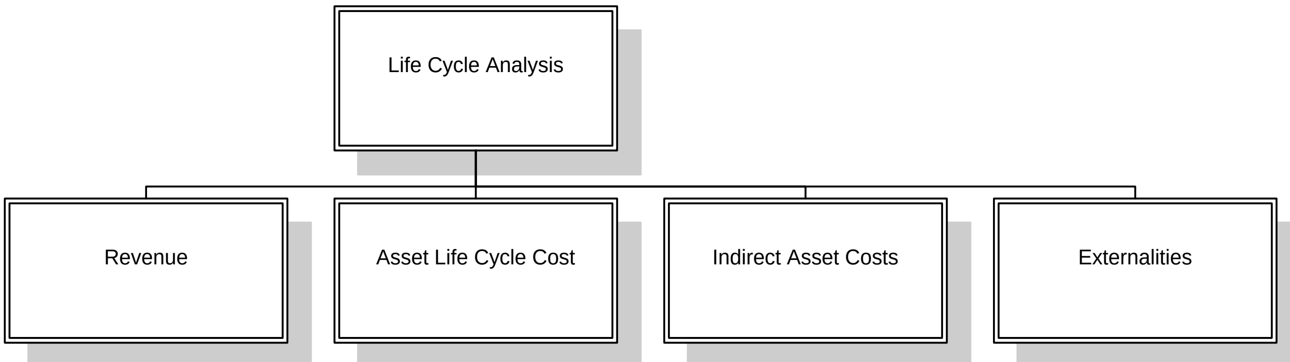


Decommissioning and End of Life Factors Typically Considered in a Capital Asset Life Cycle Analysis
Decommissioning related permit costs including those associated with occupancy, health & safety, labor, work permits and all other permits, licenses and registrations associated with facility Decommissioning including offsite construction activities related to processing and disposal sites.
Labor Costs associated with design and other professional services related to design of temporary works and any design services required to take treatment and disposal facility or site design to final completion.
Site improvement costs including grading, drainage, general site security, establishment of lay down or impoundment areas required as part of facility decommission and closure activities
Utility relocation or removal costs

Decommissioning costs associated with site stabilization, final grading, electrical or pipe chase relocation and removal
Specialized decommissioning equipment including vessels, custom designed cranes, and protective structures and impoundments
Temporary power, water and wastewater facilities including associated fuel and storage facilities; distribution networks associated with temporary power; fuel depots; and decommissioning waste related facilities including onsite landfills.
Schedule related benefits realizable through use of prefabrication and modularization
Duties and taxes, including consideration of jurisdictional variations and export control related costs and time
Labor costs associated with decommissioning not otherwise characterized
Construction materials including consumables, equipment and miscellaneous services associated with facility decommissioning not otherwise characterized.
Cost of Time related to decommissioning durations and associated contingencies)
Value of Risk, including decommissioning and construction risk; logistics risks; impacts of weather and other acts of god, labor disputes, and project disruption including impacts from subcontractor performance, safety performance, owner changes, regulatory changes or other foreseeable risks
Decommissioning estimate uncertainties (estimating based; management model driven; rework based on late inputs, regulatory changes or owner driven changes)
Taxes on construction materials and work
Greenhouse gas emissions from decommissioning activities
Embedded greenhouse gases in procured equipment, materials and associated transport
Water footprint from decommissioning activities
Water footprint of procured equipment, materials and associated transport
Other hazardous releases to the environment from decommissioning activities
Direct and indirect jobs created at facility location from decommissioning activities
Total direct and indirect jobs created
Value of other social benefits created

Indirect Asset Costs

The previous sections cover revenue contributions to life cycle analysis as well as those associated with life cycle costs. Two remaining categories must be considered in a comprehensive life cycle analysis – indirect asset costs and other externalities.



In this section we will consider indirect assets costs and their contribution to life cycle analysis.

Indirect asset costs include factors such as land usage, applicable tax regime or financing structures available under different asset configurations. Common financial factors affecting multiple pieces of the life cycle analysis, such as inflation, may be separately assessed and tracked as an indirect asset cost to allow inflation neutral analysis of options as well as modeling that considers such financial factors and their behavior over extended time frames.

Assessment of land use contributions to life cycle analysis must consider the following factors for location of the facility at a specific site:

- Concurrent availability – that is the site is available on some basis for use by other facilities. This becomes an important consideration when evaluating large program design or asset portfolio design. Concurrent availability may be either:
    - Constrained or limited
    - Unconstrained or unlimited (except with respect to limiting attributes of the site independent of the facility's presence at the site)

- Concurrent unavailability – the site is not available for other current use due to the facility's presence at the site.

- Loss of optionality – site use, post facility closure, is limited because of the prior presence of the facility

- Permanent unavailability – use of the site, post closure, is not reasonably possible

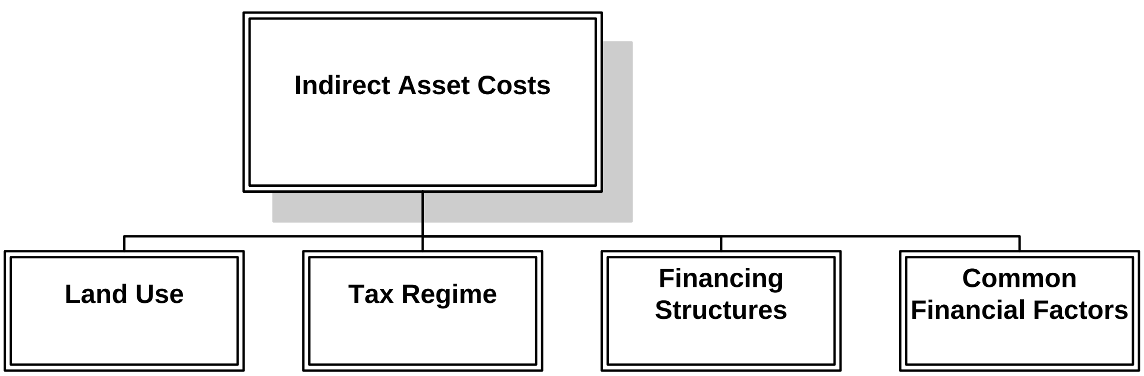
Each of the factors above will affect residual site values and any ultimate disposal value to be considered in the life cycle analysis.

Tax regime considerations include assumed income tax rates on profits and any production tax credits that may be available. Recognition that these rates may change over time is an important consideration in life cycle analysis. For example, some renewable energy production tax credits were only available for a defined period of time. Decisions on whether to utilize the production credits which would be realized over time or up front tax credits would shape facility design, construction approach and financial structure, providing different life cycle analysis results.

Financing structures considered in a life cycle analysis will be influenced by many factors including asset characterization, governing financial metrics (ROE, ROI, IRR, ROA), asset lifetimes before refurbishment or replacement, refinance periods, construction and operations cash flows, and residual value of asset.

Other common financial factors which would be modeled and potentially tracked as an indirect asset cost could include general inflation (as a function of time) and currency exchange rates where multi-currency factors are significant and vary over the facility life-cycle.

These various factors are displayed in the following figure.



Externalities

Other externalities are also considered in LCA which may include intangibles such as brand value, susceptibility to "Black Swan" type risks, and "strategic speed". This later factor addresses the owner's or a competitor's advantage to capture greater market share through quick response or first mover advantages. "Time to market" is especially important in IP driven facility needs where patent expiration effectively defines the most valuable portion of the life-cycle.

Potential "Black Swan" factors to be considered in life cycle analysis include:

- Financial factors – hyper inflation, deflation, uninsured portion of disasters (natural, manmade, or Natech)
- Environmental factors – climate change
- Social factors – change in user behavior, change in surrounding community behavior with respect to the facility

Regulatory taxes on negative externalities and subsidies for external benefits would be considered here.

Life Cycle Analysis

Life cycle analysis considers the totality of benefits and costs associated with a facility and better represent the totality of costs and benefits derived from the facility. It is very much an "owner's perspective" and one which the capital asset industry needs to reflect in its design, construction and O&M decisions. It differs from life cycle cost analysis in two principal ways:

- Range of costs considered in LCA is greater than those considered in life cycle cost (LCC) analysis.
    - Consistent cost and scope definition is an industry issue in LCC which is not encountered in LCA
- Benefits – financial, environmental, social- are explicitly considered

LCA cares about these benefits in ways that do not traditionally reflect themselves in a LCC analysis and thus provides greater focus and impetus to sustainability efforts.

The variation in the range of costs and benefits considered for the first of the Triple Bottom Line's can be seen in the table below.

Economic Bottom Line		
Cost Factor	**Life Cycle Analysis (LCA) (Whole Life Costing)**	**Life Cycle Cost (LCC)**
Revenue	Included	Excluded
Asset Lifecycle Cost	Included	Included
Indirect Asset Costs	Included	Limited to common financial factors
Externalities	Included	Limited to regulatory taxes or subsidies on externalities

Similarly, LCA cares very much about the phasing of a facility and its financing structure as represented in selected discount rates. The discount rate takes into account the time value of money (money available now is worth more than the same amount of money available in the future because it could be earning a return consistent with its risk posture, i.e., equity or debt) and the risk or uncertainty of the anticipated future cash flows (which might be less than expected). This time value of money is best captured in a net present value approach.

Decision Basis			
Variable	**Use**		**Methodology**
	LCA	**LCC**	
Real Cost	Limited use	Preferred when evaluating asset acquisition costs	Use current known information irrespective of when cost incurred
Nominal Cost	Used to prepare financial budgets	Used to prepare financial budgets	Real cost adjusted by inflation or deflation factor
Discounted Cost	Limited use	Used when phasing is an important consideration	Used to compare alternatives over the facility lifetime or analysis period. Real or nominal costs adjusted by a discount factor.
Net Present Value	Preferred, considering both benefits and costs	Normal measure, typically including costs only	Discounts future cash flows to base date

Let's take a closer look at how the various cost factors come together in life cycle analysis by starting with some of the characteristics associated with the individual cost factors that comprise the life cycle analysis.

C = Cost or benefit associated with:

- A given cost factor, n, that is a function of σ and PDF, where:
  - σ describes the uncertainty (standard deviation or minimum and maximum) of C_n, and a
  - probability distribution function, PDF, related to σ and described by a distribution type (normal, triangular, lognormal, etc.)
- in the time period, t
- with associated discount factor, q

A Monte Carlo analysis allows overall confidence levels to be ascribed to various summations of all cost factors. The various summations are described below, where $C_{Confidence}$ is indicative of the associated confidence level (C_{50}, C_{80}, C_{90}).

When Real Costs are used for LCA, they are associated with a confidence level, such that:

$$\text{Real Costs} = C_{Confidence} = {}^{All}\sum_{n=1} C(n(\sigma, PDF), \text{Base Period}, 1)$$

When Nominal Costs are considered, they also can be associated with a confidence level such that:

$$\text{Nominal Costs} = C_{Confidence} = {}^{P}\sum_{t=1} \left({}^{All}\sum_{n=1} C(n(\sigma, PDF), t, 1)\right)$$

Where P, is the analysis period of the LCA.

The value for a given cost factor in any time period, t, is the nominal cost associated with a real cost, as known for the base period. It is determined such that:

$$C(t) = C_{\text{Base Period Value}} * \text{Cumulative } EF(t)$$

Where Cumulative EF(t) is the cumulative escalation factor from the base period to the time period, t

Cumulative EF(t) = 1*(1+EF(1))*(1+EF(2))*(1+EF(3))………*(1+EF(t)), where:

- EF(t) is the escalation associated with the cost factor in time period, t

When EF(t) is constant Cumulative EF(t) = $(1+EF(t))^t$

The preferred methodology for LCA is net present value (NPV), which like Real Costs and Nominal Costs, can be associated with a confidence level. Different cost factors may be associated with different discount rates when multiple funding sources are used and as such cost factors are linked to various cost factors.

$$LCA_{NPV(Confidence)} = {}^{P}\sum_{t=1} \left({}^{All}\sum_{n=1} C(n(\sigma, PDF), t, q) * q\right)$$

where q is the discount factor

Finally, life cycle analysis comparisons can be made on one or more metrics used to facilitate comparisons between different options. These metrics can include:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Payback period
- Return on Investment (ROI)
- Return on Equity (ROE)
- Return on Assets (ROA)

Risk and Uncertainty in LCA

Risk and uncertainty are inherent characteristics of the delivery, operation and maintenance of any capital facility asset. So too are risks and uncertainties around likely future revenues and their timing. Comprehensive LCA must address both risk and uncertainty particularly in the comparison of significantly different facility phasing, operating periods and financing structures.

Here, risk is used to describe those factors where probabilities can be estimated. Uncertainty describes those factors where probabilities cannot be estimated.

The following table lists some of the risks and uncertainties that must be considered utilizing a statistical approach such as Monte Carlo. Selection of confidence levels must be appropriate for the intended use of the analysis.

Risks and Uncertainties to be Considered		
Quantitative/Estimate Uncertainties (quantity; unit price; productivity)	Inflation/deflation rate (over time; by cost category – general, labor, labor social and benefit costs, energy, water, feedstock)	Market Penetration Rate (associated with facility ramp up rate)
Duration Uncertainties	Refinancing timing	Revenue Levels Over Time
Sequencing or Timing Uncertainties	Refinancing Cost of Capital	Asset Availability
Capacity Factor	Tax Rates (over time)	Asset Lifetime
		Terminal Value

Triple Bottom Line Life Cycle Analysis

The prior section focuses on economic impacts or the first of the Triple Bottom Lines. Comprehensive triple bottom line impact assessment requires comparable consideration of the environmental and social bottom lines. Any direct economic factors would have been included in the economic bottom line analysis such that the analysis of the second and third bottom lines includes indirect economic factors (not directly affecting the financial performance of the facility) and non-economic factors.

Let's look at some examples:

- A carbon tax on facility greenhouse gas emissions directly impacts facility economics and would be included in the first bottom line life cycle analysis

- Tons of greenhouse gases emitted by the facility over a defined period (year, analysis period, lifetime) may have broader environmental impacts that may or may not be adequately captured through the carbon tax charge above. How these emissions behave under different facility configurations and operating regimes would be part of environmental bottom line analysis. Similarly, any mitigation measures taken to offset these greenhouse gas emissions would have been captured in facility costs but benefits may have no direct impact on the facility's economic bottom line. The benefits of those mitigation measures would be captured on the environmental bottom line.

- Building and operating a school in an education deprived community represents a social benefit to the local community and society more broadly. The benefits would be captured in the social bottom line while the costs incurred by the facility owner would be captured in economic life cycle analysis.

In some ways the bottom line analysis of the environmental and social bottom lines are similar to what one may experience in conducting a multi-currency economic life-cycle analysis where one or more of the currencies may not be readily convertible. In these instances, tons of carbon and acre-feet of water are not summable.

The following table highlights potential "currencies" to be considered in environmental and social bottom line analysis. One final point is that these currencies do not readily lend themselves to "discounting" so the notions of discounted impacts and benefits or NPV should be dissuaded.

Potential "Currencies" to be Considered in Environmental and Social Life Cycle Analysis	
Environmental	**Social**
Tons of greenhouse gas	Jobs
Acre-feet of water	Water-borne illnesses
Tons of hazardous waste	Cancers
Tons of solid waste	Deaths
Acres of natural lands/habitats	Quality of Life (living standards; access to education, health, infrastructure)

Summing the Parts

As illustrated in the discussion above on the "multi-currency" nature of environmental and social bottom line life cycle analysis, it is difficult to arrive at a singular value that defines the total benefit or impact from the whole life of a facility. Such a summing of the parts serves to mask the externalities associated with each potential facility program option.

From time to time such summing may occur, in effect placing value on a day lost to illness; a life; or the totality of impacts from a ton of carbon. In such instances it is essential that the respective "currency" values not be lost and that appropriate sensitivity analysis be performed to confirm that the selected "currency conversion" values are not distortional. We must remember that weighting involves value choices.

Conclusion and Recommendations

Life Cycle Analysis (LCA) or Whole Life Costing has grown in usage in the capital asset industry driven in part by government procurement programs focused on identifying "value for the money" and by owner's who are increasingly sensitive to life cycle costs related to energy, in particular. Despite this progress it still is underutilized as a decision and design tool and when employed is often focused on narrower component or system tradeoffs. Persistent emphasis on first cost often limits consideration of higher first cost lower life cycle cost options. This paper seeks to help provide owners with increased confidence in employing the broader perspective LCA requires. Improvements in application of LCA analysis would benefit the capital asset industry.

Importantly, the use of more comprehensive life cycle analysis, while employed in making many fundamental strategic business decisions, is not sufficiently used to select between various facility options and operating regimes. This represents a value adding role that facility designers in conjunction with facility operators can bring to the industry.
LCA analysis takes on growing importance as externalities and indirect asset costs grow in importance. Public sector projects employing alternate delivery models such as design-build-operate-maintain (DBOM) and Public Private Partnerships (PPP) drive increased attention to and implementation of LCA.

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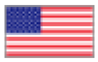
About the Author

Bob Prieto

Chairman & CEO
Strategic Program Management LLC
Jupiter, Florida, USA



Bob Prieto is a senior executive effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering and construction industries. Currently Bob heads his own management consulting practice, Strategic Program Management LLC. He previously served as a senior vice president of Fluor, one of the largest engineering and construction companies in the world. He focuses on the development and delivery of large, complex projects worldwide and consults with owners across all market sectors in the development of programmatic delivery strategies. He is author of nine books including "Strategic Program Management", "The Giga Factor: Program Management in the Engineering and Construction Industry", "Application of Life Cycle Analysis in the Capital Assets Industry", "Capital Efficiency: Pull All the Levers" and, most recently, "Theory of Management of Large Complex Projects" published by the Construction Management Association of America (CMAA) as well as over 750 other papers and presentations.

Bob is an Independent Member of the Shareholder Committee of Mott MacDonald. He is a member of the ASCE Industry Leaders Council, National Academy of Construction, a Fellow of the Construction Management Association of America, Millennium Challenge Corporation Advisory Board and member of several university departmental and campus advisory boards. Bob served until 2006 as a U.S. presidential appointee to the Asia Pacific Economic Cooperation (APEC) Business Advisory Council (ABAC), working with U.S. and Asia-Pacific business leaders to shape the framework for trade and economic growth. He had previously served as both as Chairman of the Engineering and Construction Governors of the World Economic Forum and co-chair of the infrastructure task force formed after September 11th by the New York City Chamber of Commerce. Previously, he served as Chairman at Parsons Brinckerhoff (PB) and a non-executive director of Cardno (ASX)

Bob serves as an honorary global advisor for the *PM World Journal* and Library and can be contacted at rpstrategic@comcast.net.