



# Facility Decommissioning and Adaptive Reuse

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## FACILITY DECOMMISSIONING AND ADAPTIVE REUSE

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### **ABSTRACT**

The objectives of facility management are changing. In many cases, changing operational directives or facility closures are dramatically modifying the current and future use of facilities. These changes can often be the catalyst for environmental investigation, possible remediation, equipment removal, and adaptive reuse. This paper presents an approach for investigating the current environmental conditions of a facility, taking an inventory of buildings and equipment, and evaluating the appropriate response actions for preparing the facility for its intended future reuse. Planned actions may include a combination of alternatives from environmental remediation and equipment dismantling, to total facility demolition. The suggested approach will be presented in a step by step outline and supplemented with case studies of previous projects performed by Roy F. Weston, Inc. (WESTON) to provide real world perspective.

### **INTRODUCTION**

Changing operational functions or complete closure affects the appropriate management directives for facilities. In some cases, the historical operations of a facility are being modified to reflect revised needs. In other cases, facilities are obsolete because of factors including age, design, location, or maintenance costs to name a few. Combinations of these factors lead to facilities becoming obsolete, but it is often the older facilities that are targeted for decommissioning. This is important from a sociological perspective because many older facilities are located in geographic areas that are heavily populated or near commercial districts. The facilities might have been originally constructed on the edge of a growing city but now are in the middle of an urban area. Many of these older facilities have operated for decades and there has been plenty of time for city sprawl to engulf them.

This proximity to the general public increases sensitivity to environmental discharges and noise. The airborne discharges, if any, can make a strong visual impact. Noise levels have been a contentious issue in some cases, especially when a facility operates on a continuous basis 24-hours per day. Additionally, many older industrial facilities are located adjacent to surface water bodies. As urban renewal efforts strive to focus public recreational opportunities around these water bodies, industrial operations may become an unwelcome neighbor.

The proximity of some facilities to an increasingly dense population center can result in citizen opposition to its continued or adapted operation. The argument that the facility was at the

location before the growth that followed typically does not sway the general public. Negative public sentiment toward an urban facility can have an impact on a company or government entity when they are making decisions about where to commit their limited funding for upgrades and modifications. This can accelerate the march toward the point in time when an urban facility becomes obsolete.

At the same time, the proximity of the obsolete or marginal facility to the urban center can make it a candidate for adaptive reuse. The term ‘adaptive reuse’ has been applied to situations where a facility or building is obsolete from the perspective of its original purpose but can be modified for a new function. If the facility has the right combination of location, architectural scale, and aesthetic or historical appeal, it can be an extremely attractive prospect for adaptive reuses that are oriented toward the general public. In some cases, adaptive reuse of old industrial facilities is being incorporated into urban renewal efforts. The opportunity to reuse obsolete facilities in the urban core supports sustainability and smart growth initiatives designed to focus redevelopment in inner cities in an effort to decrease urban sprawl.

Two very important factors in assessing the adaptive reuse potential of an obsolete facility are who currently owns it, and who or what is/are the driving force(s) behind creating a new use for the facility. The owners may want to convert the facility into an internal use such as offices or warehouse space. In other cases, the owner may be interested in selling the property for a profit. External parties that could be interested in an obsolete facility include economic development groups, museum committees, businesses, developers, or government entities such as municipalities.

When a facility has a significant change in operations or is going to be decommissioned, it is an appropriate time to assess environmental conditions and regulatory compliance. If an entire facility or buildings within a facility are going to be demolished, it is especially important to perform an environmental assessment. Proper planning and performance of an environmental assessment prior to facility dismantling/demolition can help avoid personnel exposure and environmental contamination migration issues during the dismantling phase of a project. After the initial investigation is performed, informed decisions can be made to assess the alternatives for an appropriate course of action and implement the selected course of action. The final plan may include modifications of the facility or building(s) so that it may be reused for a new function.

This paper presents a framework for performing these types of environmental assessments and for planning facility decommissioning work. Our overall approach can be broken down as follows:

- Initial Investigation
  - Environmental assessment
  - Regulatory review
  - Equipment inventory
  - Building inspection
- Evaluation of Alternatives

- Financial issues
- Environmental goals
- Engineering considerations
- Anticipated future use
- Facility Decommissioning
  - Environmental remediation
  - Equipment dismantling
  - Building demolition
- Adaptive Reuse

After each of these topics is discussed, two case studies will be provided to add perspective and details to the conceptual plan.

## **INITIAL INVESTIGATION**

The first phase of a facility decommissioning and adaptive reuse project should include an initial investigation or assessment phase of work. This phase of the project is used to define the current conditions, regulatory requirements, areas of concern, and alternatives for future action. The initial investigation is very important because the future technical and financial project decisions will be based on the results of this initial work.

### **Environmental Assessment**

An environmental assessment should be performed to identify and determine the nature and extent of any hazardous building materials or environmental contaminants at the facility. This can be a costly and time-consuming effort, but there are methods to help make this more efficient and effective. Our recommended approach is to use existing information to direct the environmental investigation efforts rather than starting out with a widespread sampling program. The environmental sampling activities then can be directed toward the potential sources of concern and include the known or suspected materials of concern. This focused approach reduces sampling effort, laboratory analysis, and associated costs.

### ***Information Collection***

Available information sources should be reviewed as the first step of the environmental assessment. Potential sources of existing information that may be helpful to direct subsequent phases of the environmental assessment include:

- Current site conditions based on observations
- Process knowledge and operational reports
- Information regarding past maintenance practices
- Interviews with senior facility staff
- Historical aerial photographs and as-built drawings
- Previous environmental investigation and management reports
- Regulatory Agency inspections, reports and files

These sources can often provide valuable information about prior activities at a facility. Process knowledge and prior operational reports should describe the types of activities performed during the life of the facility. This information in turn can provide valuable insights about the potential types of environmental issues that may have been associated with those processes. For example, old electrical generation and distribution facilities often have mercury or polychlorinated biphenyls (PCBs) present. Operational reports may also give information about process upsets, chemical storage, spills, and any prior abatement activities. Building age and type of construction can provide insight into the likelihood of encountering asbestos and metals-based coatings. Past maintenance practices can provide insight into historical activities that may have impacted building materials or environmental media at the facility. For example, WESTON has worked on a power plant decommissioning project where we found out that maintenance staff used turbine lube oil on all rotating machinery in the facility and the oil was subsequently found to contain PCBs. These types of past practices can only be determined by interviewing senior facility personnel that have been around the operations for a period of time. These ‘old timers’ often have a wealth of institutional knowledge that will never be found in written records.

Historical aerial photographs that include the facility in question are often available. These photographs have proven to be valuable in confirming the recollection of facility staff or providing a catalyst for stimulating their recall. Aerial photographs also can be very useful for identifying outdoor storage areas, spills, and operations that are no longer current. At military installations, however, it should be noted that aerial photographs where the facilities were considered sensitive at a given time in history sometimes have been blocked out from photographs of the surrounding area.

Regulatory agency files can also be a source of historical information. Previous inspections, spill notifications, and operations reports contained in these files can provide insight into historical operations and potential environmental concerns.

### ***Environmental Sampling***

If known or suspected hazardous building materials or environmental constituents of concern are believed to be present based on the results of the information collection efforts, sampling should be performed to define the full nature and extent of these materials. The information collected about the historical operations and process knowledge should be used to direct this environmental sampling effort. This is especially valid for large facilities where investigation activities need to be focused in order to control costs. We recommend directing initial sampling efforts towards characterizing known or suspected building materials and contaminant source areas rather than starting out with widespread grid sampling of the entire facility. The investigation area can be expanded based on the results of this initial directed sampling approach if warranted. This approach has the advantage of focusing sampling efforts to optimize the amount of sampling and analysis performed. The disadvantage is that the iterative process inherent in this approach can take more time to implement.

Considerations for the differences between indoor and outdoor areas need to be made during planning for the environmental sampling activities. Some of these differences include items like the different media, depth of sample collection, types of sources, and sampling conditions such

as confined space entry. For example, investigation outdoors around an underground storage tank may require deep soil borings or groundwater sampling in contrast to inside a building where wipe samples or bulk samples of surface materials may be appropriate. It is also important to fully evaluate the potential for cross contamination between indoor and outdoor areas. For example, the potential for liquid spills indoors to have migrated through process drains to sanitary sewer systems or local outfalls should be evaluated.

### **Regulatory Review**

A regulatory review is another component of the initial investigation phase of work that should be performed concurrent with the environmental investigation activities. The regulatory review should identify applicable regulations relating to the constituents of concern, required analytical methods and minimum detection levels for sampling, and target cleanup levels for any required remediation. The regulatory review should include applicable federal, state, and local requirements as these can differ between various regulatory authorities. It is helpful to know the intended future use of the facility and factor this information into the evaluation of applicable regulatory requirements. For example, target cleanup levels typically would be different for a future industrial use or limited exposure scenario versus the more stringent requirements for public use or a planned use with an unlimited time of exposure.

### **Equipment Inventory**

An equipment inventory is another component of the initial assessment as it is important to determine the equipment and materials present inside a building before it can be decommissioned. This applies to all facilities, whether the building houses industrial process equipment or medical appliances and furnishings. This equipment inventory can support the development of process knowledge, and it is also a consideration for remediation and dismantling from both a cost and logistical perspective.

The level of detail for an equipment inventory can vary greatly, from a simplistic assessment describing that there is a building of a certain size filled with a particular type of equipment, to a detailed listing of every piece and size of item in place. This information should be incorporated into the cost evaluation for the decommissioning options so a greater level of detail in the inventory is beneficial for the accuracy of the cost comparisons. This is especially true if the equipment and materials have reuse or scrap value. This type of information is also helpful when included in contractor bidding specifications. In the case of two power plant decommissioning projects on which we worked, a cost estimating engineering company prepared a detailed equipment inventory of all of the equipment and piping in the plants. They used the inventory and their cost estimating computer program to then estimate the cost of various dismantling scenarios.

### **Building Inspection**

A building inspection is another component of the initial assessment that also can provide valuable information for deciding on alternatives for future use. Inspection of the facility design, materials of construction, and current condition can provide useful information to help direct

other portions of the environmental assessment. The structural integrity of the building is an important factor to consider in evaluating whether the buildings should be reused or demolished. The architectural design of the building may also be a factor. For example, many old power plants have been converted into museums because the large open spaces inside the building in areas like the turbine hall readily lend themselves to adaptive reuse as exhibit space.

## **EVALUATION OF ALTERNATIVES**

An evaluation of alternatives should follow the initial investigation phase of work. In this phase of the project the results of the initial investigation are used to develop alternative response actions with their associated estimated costs. The assessment of the alternative response actions then leads to the selection of the desired approach and formulation of the plan for its implementation in the following phase. The general alternatives for decommissioning a building are:

1. Mothball – take no further action and leave the facility in place, as is. Hazardous building materials and environmental contaminants, if any, would be left in place to be dealt with at a later time, possibly during a future demolition project.
2. Remediate and Mothball – remediate the immediate environmental concerns and leave the rest of the building as is.
3. Remediate and Dismantle Equipment – this includes remediating all the environmental concerns and dismantling all the equipment inside the building leaving the shell of the building.
4. Demolish – this would result in the complete demolition of the building to what is often referred to as a “greenfield” condition. This type of demolition typically includes removal of the building and all associated infrastructure to a depth of two or three feet below grade. Environmental remediation may also be required. The option exists to send contaminated building debris to the appropriate landfill in lieu of cleanup or decontamination of those building materials. Depending on the level of existing contamination and the extent of remediation, this approach may result in a “brownfield” rather than a greenfield condition.

The environmental requirements, building decommissioning alternatives, cost estimates, and desired future use of the building should all be considered in selecting the desired course of action. The demographics and local setting of the facility are also important considerations. Politics and public interest can also be significant factors in selecting the appropriate course of action for a facility.

The alternative of no action should be approached cautiously. In some cases, owners view this as the least cost approach with minimal impact on their continued operations and budget. This can be a false impression if environmental liabilities exist or the building is in disrepair. Not addressing environmental contamination can lead to undesirable results such as migration of

contamination, more severe environmental impacts, regulatory enforcement actions, bad publicity, and more costly cleanups at a later date. Abandonment of buildings or deferred maintenance can lead to an exacerbation of small issues, animal infestations, and safety hazards because of structural deterioration or hazardous materials exposure. Uncontrolled or abandoned buildings also can become a target for transients and homeless people.

After the appropriate response action is selected, it is time to develop an implementation plan for that action. This may include formulation of engineering specifications, bid documents, work plans for submittal to regulatory agencies, and revised engineering cost estimates. This phase of the project may also need to include meeting with regulatory agency staff to negotiate or confirm cleanup requirements if the environmental considerations are complex. In some cases, regulatory agency authorization is required prior to proceeding with remediation. The environmental work plan is a tool for communicating the planned approach to the facility owner, other interested parties, and regulatory agencies.

Specifications often are needed to describe the scope of the required remediation or dismantling. Typically these specifications are used to define the project and are a portion of the bidding package used to select and hire a contractor. The level of detail in the specifications can vary significantly. If the work is not complex, is performed with internal resources or is performed under an existing contract with an external company, it may make sense to provide a simple framework to define the scope of work and desired outcome. A detailed specification is often in the best interests of the facility owner if the work is complex, costly, has regulatory implications such as sensitive environmental issues, or is going to be bid out for external contractors. Simple specifications have the advantage of being easier to develop and easier for potential contractors to review. The disadvantage is that the lack of detail could leave gaps in information or requirements that will come back to haunt the implementation team during project execution. Detailed specifications are more time consuming and costly to develop, and more difficult for contractors to evaluate. However, they provide a greater level of specificity for the contractor to fully understand their assigned scope of work and provide protection for the owner when issues arise during project execution.

Another variable in developing specifications is to decide whether to provide performance-based or method-based specifications. For the performance-based approach, the desired end results are specified and the contractor is allowed to use their expertise to implement the best approach for achieving the desired goals. In a method-based specification, the ways and means of doing the work are directed and the contractor is responsible for properly implementing those methods while the owner retains responsibility for the outcome. In both approaches the applicable regulatory requirements and client preferences are also specified to provide a basis for monitoring and controlling the work, and maintaining compliance.

One item that is very important to include in specifications for environmental remediation, equipment dismantling, or facility decommissioning is a maximum project duration. This provides a tool for contractually managing the project schedule and provides protection for the owner. The owner is at a disadvantage on projects where no maximum duration is specified and the work falls behind schedule. One example we observed was where a dismantling contractor

looked like they were trying to extend the project duration in order to have additional time for scrap metal values to increase.

After the work plan has been approved, any applicable regulatory approvals obtained, desired response action selected, and specifications developed to define the desired implementation plan, it is time to bid the project and hire a contractor. This process is very client specific but typically includes developing the bid package, identifying interested and qualified contractors, issuing the bid package, conducting on-site prebid meetings, collecting and evaluating contractor responses, and selecting the desired firm. Although a contractor is typically selected for these types of projects based on the lowest bid, it very important to require minimum levels of technical qualifications and experience with the bid package in order to screen the applicants and eliminate unqualified bidders. Accepting low bids from firms without the minimum qualifications and experience to perform the work could result in problems during project execution. This is especially true in cases where the specification of the work is performance-based and the selection of the methods for achieving the project goals are left up to the contractor.

## **FACILITY DECOMMISSIONING**

The facility decommissioning phase of the project can finally begin once all of the assessment and planning activities are completed. Facility decommissioning may include a combination of environmental remediation, equipment dismantling, or building demolition based on the results of the initial investigation and the selected response action. At this stage of the project, the selected contractor performs the specified field activities to achieve that desired result of the decommissioning project. This process can take a few months to several years depending on the required scope of work. The result of this phase of the project is that the building or facility is ready for its adaptive reuse.

Engineering oversight should be performed during this phase of the project to document the performance of the fieldwork and achievement of regulatory compliance requirements. The environmental portion of the work, if any, may need to include verification sampling and reporting to the applicable regulatory agency. All waste streams should be monitored and documented on behalf of the owner. Equipment dismantling or building demolition also need certain levels of documentation. If an adaptive reuse is contemplated, it is beneficial to document the final conditions of the facility and any remaining liabilities, issues, or operating restrictions.

## **ADAPTIVE REUSE CASE STUDIES**

After a facility has been decommissioned, the reuse process can begin. If the facility or building was completely demolished, the remaining property may be suited for new construction or open space. If the shell of the original building remains, it is now ready for modifications to prepare it for its new intended use. The choice of the new function is highly case specific depending on the combination of factors discussed previously including the location, architectural design, demographics, public interest, and available funding. Two examples of adaptive reuse projects follow.

## Seaholm Power Plant



There are a number of attributes that old power plants have that make them attractive candidates for adaptive reuse. One of the major attributes of older power plants is that they were constructed with large turbine-generator “halls”. Unlike many new generating units that are based on combustion turbines and include minimal buildings or structures, old power plants were typically steam-cycle based and included large-scale buildings to cover the turbine-generator set(s) and control rooms. The boilers were also enclosed by structures in some cases. These very large open spaces represent significant opportunities for developing new functions on a grand scale. In many cases, the power plant buildings themselves were designed with a significant amount of style that makes them attractive today from an aesthetic or historical perspective.



Seaholm Power Plant Turbine Hall

In addition to their facility design, many of the older power plants represent adaptive reuse potential because of their relationship to the surrounding urban area, any recreational areas that have been developed around the cooling water bodies, and the infrastructure that often is connected to a power plant such as rail access. The architectural scale of many of these old power plants combined with their locations in urban areas and proximity to water make them attractive candidates for adaptive reuse.

The Seaholm Power Plant in Austin, Texas is an interesting project on which WESTON is working because the facility is currently in the middle of the equipment dismantling and environmental remediation phase, and, at the time of this paper, the future use of the facility is still undetermined. The Seaholm Power Plant main building was built in the 1950's using concrete and glass bricks in an Art Deco style. This main building has over 110,000 square feet of floor space with the turbine hall representing an estimated 27,000 square feet and a ceiling height of approximately 65 feet. The environmental considerations in decommissioning this facility are interesting and complex because there are PCB impacts on operating equipment and concrete floors, in addition to the typical asbestos, metals-based paint, and mercury issues.

The Seaholm Power Plant is also interesting because the driving force for its adaptive reuse has been a dedicated group of local citizens that see promise in converting the obsolete power plant into a new public use. This group sees the architectural style, scale, location, and ownership by the City of Austin Electric Utility as attributes toward adapting this facility for a new public life. The ultimate future public reuse for the Seaholm Power Plant has not been determined although all the most popular ideas center on an adapted public use. Leading examples include a museum, library, science and technology center, and a performing arts center. Other suggestions include a hub or station in the planned public transportation system, or an aquarium. There is a possibility of combining a number of these suggested uses. The process for making the ultimate selection is ongoing.

The adaptive reuse project at the Seaholm Power Plant presents an informative case study because the driving force for adaptive reuse has been the general public, the City Council has directed that the plant be decommissioned, and the future use has not been selected. The citizens group, 'Friends of Seaholm', prevailed in a campaign to get the Austin City Council to direct the City owned Electric Utility to decommission the plant. This decommissioning effort includes dismantling power-generating equipment and support systems, and addressing environmental concerns. Not knowing the future reuse of the facility, however, has created conflicts in the decommissioning process. For example, supporters of the idea for using the building as a Science and Technology center have expressed a desire to keep significant portions of the plant equipment on-site for display purposes. These requests have included retaining items ranging from gauges and chart recorders to a turbine generator set and the steam boilers. Other interested parties want the equipment totally dismantled and removed with only the "clean" shell of the building left remaining. Similarly, there was a great deal of debate about whether to demolish the boilers or develop an approach that would address the asbestos and metals-based paint while maintaining the aesthetic profile of the existing facility. All of these discussions occurred concurrently with the Electric Utility committing to be responsible to decommission the power plant while expressing their desire to eliminate their future potential liabilities at the facility, such

as leaving asbestos in place. This has created uncertainty during the execution of the decommissioning efforts.

Museums and similar public use activities are commonly the type of function to which old power plants are adapted. In other cases, restaurants, hotels or other hospitality-based businesses have been the selected use.

### **Hospital Buildings at Fort Sam Houston**



Known as the home of Army medicine, Fort Sam Houston houses numerous medical facilities such as the Army Medical Department Center and School (AMEDD), Brooke Army Medical Center and the Institute for Surgical Research. The former Brooke Army Medical Center and Beach Pavilion building complexes commonly referred to as BAMC and BEACH, were replaced with a modern medical center facility in 1994. These obsolete facilities have stood unoccupied since then, impacting the maintenance budget of Fort Sam Houston, restricting new construction, and not supporting of current missions.

With infrastructure dating back to the 1930s, these historical structures have significant environmental impairments that require remediation prior to being used by any new occupant. Although safe in an infrastructure sense, the buildings are in disrepair. While not an area eyesore, windows are broken and there has been much scavenging/salvaging of structural materials over the years since closure. The facilities contain significant quantities of asbestos and lead-based paint, mercury-bearing lights, PCB electrical equipment, underground storage tanks and other potential environmental hazards. Laboratory and pathology areas, and associated exhaust stacks require cautious dismantling and demolition. The challenge is to develop an adaptive reuse to convert these buildings into marketable facilities within the current commercial marketplace.

WESTON was selected to work in partnership with the U.S. Army to develop a Business and Lease Plan for the redevelopment of historic property at Fort Sam Houston. This is a unique partnering opportunity, a first for a lease arrangement of this nature and magnitude.

The public-private partnership approach is being pursued by the Army as part of their overall strategy of increased leasing to the private sector to reduce redevelopment costs, fulfill mission requirements, and ensure stewardship of historic Army properties. As prime contractor, WESTON lead a San Antonio-based team that included a real estate development firm, a real estate brokerage firm and an historical architectural firm. The team's goal is to manage this effort with Fort Sam Houston in close partnership with the surrounding neighborhoods, other interested stakeholders and the greater San Antonio community. Involving the community early in the planning process was critical to the success of this project.

The team worked hand-in-hand with the Army and commercial sector experts to prepare a first of its kind lease document that merged current Army Corp's of Engineers standard real-property lease document language with best commercial practices to develop a comprehensive business and lease plan, and lease document. This effort included:

- Financial Plan: An economic plan detailing the costs of redevelopment for each building, including a 50 year Pro Forma and Income Statement.
- Marketing Plan: An analysis of current market conditions of the surrounding community.
- Infrastructure Plan: An assessment of the overall internal and external infrastructure of the buildings and a summary of the additions needed to construct BAMC and Beach into productive facilities including:
  - Mechanical and Plumbing Systems
  - Electrical
  - Fire Suppression Systems
  - Security Systems
  - Parking
  - Traffic Flow
  - Storm Water Management
  - HVAC Systems
  - Structural Systems
- Historical Plan: An overview of the required areas of preservation throughout the three buildings including:
  - Identification of Specific Historic Spaces
  - Historic Renovation Plan
- Environmental Plan: An assessment of the hazardous material contained in the buildings including remediation plans and cost estimates.
- Community Relations Plan: The promotion of the redevelopment project within the community addressing the benefits for the surrounding areas including outreach plans.
- Meeting Army Goals: Developing an economically feasible Business and Lease Plan consistent with the Army goals including:

- Reduction of Operating Costs
- Providing Stewardship for the Buildings
- Supporting the Ongoing Mission of Fort Sam Houston

The intended outcome of this effort is to perform environmental remediation and equipment dismantling at these facilities in order to prepare them for adaptive reuse as multi-tenant office space. This will provide an opportunity to transition the buildings from a vacant, unproductive state to a new function that benefits the Fort and the surrounding community. The benefits of this program are multi-faceted.

- The U.S. Army achieves the benefit of reduction in costs required to maintain unusable facilities, and avoid the considerable cost of remediation of environmental issues.
- Removal of these non-adaptable historic structures from the installation's overall square footage per person allocation enables development of new facilities that can support new state of the art missions.
- The Army and Fort Sam Houston receive additional direct financial benefit by return of a portion of the lease revenues from the adaptive reuse of the old facilities.
- Fort Sam Houston receives the intangible benefit of expanded facilities to house new mission support contractors, potential conference/training facilities, and reduced associated logistical support costs for transportation, housing, and services previously provided off-post.
- The City of San Antonio's economic development plan benefits from the enhancement of business in this development zone.
- The Army is relieved of the risk of project success or failure.

## **SUMMARY**

There is a great deal of change occurring in America's industrial infrastructure. As part of this change, some older facilities are becoming expendable or obsolete. Although these old facilities may be obsolete from the perspective of their originally intended use, they may have the potential for a new life that is unrelated. Many old, obsolete facilities are attractive candidates for adaptive reuse because of their scale, architectural style, location, and proximity to urban centers. There are numerous examples of successful projects where obsolete facilities have been converted into museums, libraries, office buildings, or commercial businesses such as restaurants. These projects can be performed most economically by following a focused assessment, planning, and implementation process such as has been described in this paper.