Economic Efficiency

Management must to be able to consistently evaluate a mineral property based on sound engineering and economic practices to determine if the mineral prospect has any potential market value. One efficient way to determine a property's value is to conduct a laborious full cycle economic study that specifies costs associated with:

1. environmental licensing,
2. land acquisition,
3. royalty,
4. exploration,
5. definite and development drilling,
6. plant capital,
7. plant and wellfield operating expense,
8. groundwater restoration,
9. decommissioning and closure.

These nine headings constitute the major components that, when summed together, yield an expected total production cost. Knowing this value can provide comfort to the marketing group and customer whose fuel cycle is dependent on an assured supply of uranium. Conducting a full economic cycle study, or more frequently termed a feasibility study, will provide management with the expected length of time required to develop, produce and restore the project. Unknowns that could extend the time frame and add unit cost include: permitting delays, difficulties encountered in expanding the reserve base to meet future production demands, and unanticipated operating problems. These problems can be mitigated by garnishing political and public support through employee community involvement, management's frequent awareness to long term production goals, and employing an operational staff proficient in *in-situ leach (ISL)* technology.

A properly designed feasibility study will consider the ore's hydrology, geology, and leachability, frequently referred to as the decline curve, of the mineral. The hydrology will assist the economic engineer in determining the cost required to pump water from the subterranean to the surface. The volume of water that is capable of being produced from a single production well can establish the size of the surface facility. The mineral's geology contour establishes the type of wellfield pattern most efficient for mining. Finally, the leachability will determine the life expectancy of individual well patterns, and the need and timing for finished wells containing additional reserves needed to supplement production.

Land Budget

The Land Budget is usually the first budget that experiences any outflow of moneys. Payments to lease holders

Environmental Licensing.

The task to permit a mineral property in the United States is a very arduous process. For all the headings discussed throughout this technical report it is recommended that a standardize spreadsheet containing a detail list of common and specific descriptions be constructed. In this matter specific costs items, which easily could be overlooked, are presented in a thorough table for consideration.

The environmental budget for permitting should include funding for consultants to conduct field sampling, lab tests, hydrologic computer simulations, pump tests, socioeconomics studies, cultural and archeology research, regional geology and surface waters, vegetation and fauna, health physics, environmental justice, costs and benefits of proposed project, and the writings of the draft and final reports. It is always wise to set guidelines for consultants so they will be focused on the specific task at hand so that, in the end, there is are as few surprises to the company as possible. You, as the company representative, can negotiate fees and outside required labs services for your consultant as direct invoicing to the project. Consultants frequently send samples outside their domain for analysis and usually charge the client an “add-on” percentage of the outside lab fees for this service. You can pre-negotiate this arrangement with your consultant prior to its development.

Environmental permitting costs represents a major investment to any corporation. Be sure not to omit the obvious charges which include: permitting fees for processing and drafting permits by the regulatory agencies, travel and entertainment, telephone, printing, drilling and completing baseline wells, baseline water quality analysis, environmental equipment, and soil and air baselines assays.

Definite and Development Drilling

In other sections of this manuscript other authors have provided detail information on the how-to of wellfield drilling. An overall schedule must be prepared that makes many operating and technical assumptions which are utilized in forming the basis for the drilling plan. These assumptions include: an optimization drilling penetration rate expressed in feet/hr, drilling rig hourly cost if contracted, drilling mud and other additives costs and useages, down hole logging, drill bits and retipping charges, cement (bagged or bulk), casing, centrallizers, and specialized drilling components (underreamers, sub-assemblies, down-hole TV).

Formulating a drilling schedule that determines the number of new penetrations by month requires the engineer or geologist to make some assumptions. Knowing the number of reserves that need to be under wellfield for the project’s start-up and then working backwards based on the estimated reserves contained within one producing pattern, the technician can arrive at the required number of production and injection wells for start-up. Then based on this requirement a schedule of definite holes, holes that will further define the ore’s geology, can be predicted. Depending on the extend of prior exploration drilling and the difficulty of the geology it is usually predictable that between one to four definite holes may be required for each production well. The important part of this process is to then insure that these targets are met when development and definite drilling is in progress. There are a multitude of daily company and environmental bookkeeping chores that require constant update and involvement, and because of this excessive activity the drilling manager can easily lose sight of his budget status. Many a drilling program has fallen to excessive cost overruns because the individuals in charge either were unfamiliar or lost sight of the feasibility guide lines. Naturally the feasibility study is not casted in stone and should be altered as conditions change, but it is important that every consideration be attempted in complying with the budget criteria.

Plant Capital

The surface treatment facility represents a long term investment. And as such the project manager should select good equipment when he plans the project. Far too often, the person in charge of selecting the equipment that goes into building the plant is not the same person who's responsibility it is to operate it. This represents a conflict of interest. It does not cost much more to go "first class" on equipment selection especially if that equipment's downtime or outage will result in a loss in production. Equipment that is depended upon to operate greater than 70% of the time should be of higher quality and if connected to a motor should have a high efficiency motor to operate it. Solution mining depends heavily on the use of pumps and the motors that run them.

Electrical - *Efficient Motors*

In the industrial sector of the U.S. economy, loads driven by motors account for about 70 percent of the total use of electricity. In the mining industry, this percent is over 90 percent. It is then imperative that major attention be paid to efficiency, particularly in integral horsepower, three phase AC induction motors.

With as little as a 3.8 percent improvement in motor efficiency, a 200 horsepower motor can save between $2,000 and $5,000 per year depending on the cost of electricity and cycle frequency. The payback for investing in a high efficiency motor usually is less than a year. Many such motors can have an expected life from between 10 or 15 years, so the savings quickly mount. The cost difference between standard motors and energy efficient motors is generally in the range of 15 to 30 percent more for the energy efficient motor. The energy cost saved within the first year usually pays for the initial capital difference. See the Figures 1 and 2.

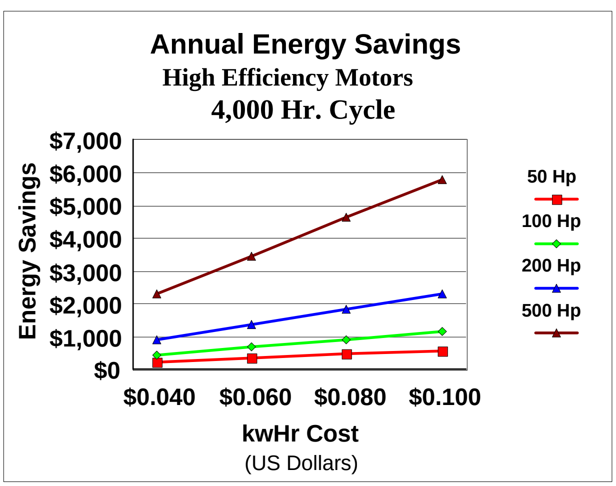

Figure 1.

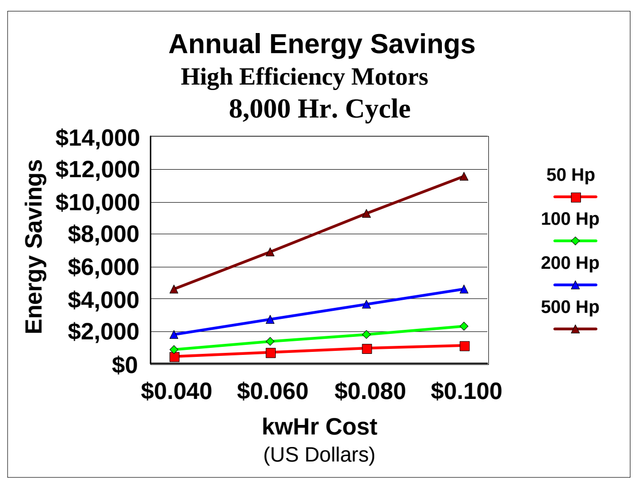

Figure 2.

The 15-30 percent added front end cost for a high efficient 200 Hp motor can usually be recouped within a year if kwhr costs are greater than $.05/kwhr.

These often overlooked savings result from the fact that energy efficient motors run cooler than their standard counterparts, resulting in increased motor life, insulation and bearing life. Other benefits derived from more efficient motors include: extended lubrication cycle, better tolerance to thermal stresses, an ability to operate in higher ambient temperatures, and more resistance to abnormal operating conditions such as undervoltage, overvoltage or phase imbalance.

These benefits derive from the fact that energy efficient motors are built using copper instead of aluminum in the windings. Also they are designed with increased conductor wire size which lowers a motor's I^2R losses and thermal buildup, improved fans and bearings, reduced air gaps between stator and rotor, and closer machining tolerances. Because of their inherent superiority, high efficient motors, in general, are a more reliable motor. There are fewer winding failures and forced outages which can limit production.

Electrical - *Wiring*

Additional operating cost savings can be achieved by stepping up in wire size and conduit for those stationary circuits which will be operating for the life of the project. The loss of energy between the transformer and the motor as a function of resistance in the wire can be engineered to minimized power losses. Remembering that $\mathbf{I^2R}$ (I = amperage, R= resistance) represents the energy consumed within the *each* wire to transport the electrical current to the motor, the additional cost in stepping up in wire size can be paid back in energy savings within two years. For example a 25 Hp, off the shelf, 460 V, 3-phase, TEFC motor running at 75% load would require a No. 8 AWG (American Wire Gauge) circuit. By upsizing the wire gauge to No. 6 the resistance drops approximately 15% (#8 R=.49Ω/1,000ft., #6 R=.419Ω/1,000ft.). Another side benefit from using the larger wire size is the wire will run cooler than the smaller wire. That difference will be in the vicinity of 10°C, which result in even lower resistance in the larger wire, producing a small amount of additional savings that has not been accounted for in this example.

Filtration

Good filtration does not have to be expensive, but bad filtration always is. There is not a chemical process developed that does not entail some form of precipitation caused by changes in internal chemistry, inherent biological fouling, mechanical fouling due to invasion from foreign insoluble material, or transformations induced by eh-pH phase shifts of ionic species. All solution mining operations, to some extent, exhibit degrees of material fouling. If left unfiltered, these solids will find their way back into the injection interval where they will foul the zone containing the mineral. Mechanical fouling of the injection interval can impact ultimate recoveries while transferring a serious material handling problem downhole where it is more difficult to correct. To try to eliminate **all** solids is financially impossible as the added operational costs would require recovery yields much above that which is normally achievable just to compensate for the removal expense.

Some down hole fouling can be beneficial however if the formation exhibits high permeability (> 2 Darcy). In these circumstances the section of injection interval, which typically has received the magnitude of the flow by this time, may slowly seal allowing the resulting increase hydrologic pressure in the wellbore to force solution into the underlying zones. But left unchecked, the entire interval can be compromised which will require a costly well work over to remediate. Having insufficient positive back pressure at the wellhead can cause the majority of solution to flow through the most permeable sand zones. This has been observes in wells when running spinner surveys. A spinner survey is a device that is either mechanical in nature; i.e. a rotating propeller, or chemical: radioactive isotopes which can be detected with sophisticated electronic equipment that can determine the rate of injection between injection intervals.

Precipitation of calcium compounds ($CaSO_4$ and $CaCO_3$) will occur if the solubility factors are not closely scrutinized. Precipitation on the screened interval or on the formation face can result from the ensuing pressure drops induced by rapidly injected solutions. On the extraction side the process is further complicated with dissolved species of ferrous iron which easily oxidize to ferric compounds. Although many projects are designed as pressurized systems and theoretically not vented to the atmosphere, they all reinject oxygenated water to oxidize reduced uranium. You have to wonder what happens to the ferrous iron when the gaseous oxygen is added to the circulating waters. Over time there will occur a slowing of injection rates as the resulting ferric iron clogs the pore spaces adjacent to the screened interval. When the initial formation permeabilities are quite small (< .5 Darcy), the throughput rate of solution will gradually decline. The spotting of HCl hydrochloric acid will temporarily mediate the fouling as will an occasional pH lowering purge of CO_2 gas into the lixiviant. Operations that employ the downhole gaseous oxygen sparger can temporarily be piped into a separate CO_2 injection manifolds system. The use of the well's hydrologic head then aids in the solubility of the CO_2.

Elution of loaded IX resins typically are achieved by contacting the resin with a brine solution of elevated pH. If not thoroughly rinsed prior to being placed back in the loading circuit, moderate pH changes over short intervals of time will occur around the resin site. It is conceivable that some forms of precipitates could persist at this point that could find their way downhole blinding the opened injection interval.

Good filtration does not have to be expensive, but bad filtration always is. It is always prudent to install adequate filtration when considering any solution mining endeavor regardless as to whether the mining formation is unconsolidated sandstone or permeable rock. All of the fore mentioned occurrences consider with precipitates.

When transferring water from one location to another over extended distances great care should be exercised in engineering the necessary pipe diameter for the anticipated flows and pressures. It makes no sense to install valves downstream to throttle back line pressure when a properly designed pump and pipeline can save you energy costs.

In today's solution mining environment the use of high density polyproplyene (HDPE) is commonly used because of its pressure design ratings, chemical resistance, and ease of installation and repair. It has been the experience of several ISL operators to "cut and drag" large sections of HDPE pipe from regions of depleted wellfields to new areas where wellfields are being readied to be put online. The highest cost for most ISL projects is the cost for electricity. Time spent on engineering a piping system which utilizes low pressure pumps will correspondingly allow for thinner walled pipe. The lower front end capital cost for the pipe and the lower operating pressures to the wellfield will keep electrical costs to a minimum. It is in the wellfield that

and corresponding lower unit cost will reap dividends month upon month for as long as the installation is operated.

Resin Poisoning

Over time ion exchange resins are apt to contain ionic species or compounds that can chemically and mechanically foul the resin from being able to load uranium onto its functional exchange sites. For geologic deposition of uranium to occur requires that certain conditions be present for the oxidized uranium to precipitate. One such geological condition that encourages deposition of uranium is the presence of sufficient reducing agents; noteably H_2S compounds, sulfate reducing bacteria, or organic matter that are plentiful and in strong enough concentrations to alter the geochemical environment. When conditions are ripe, uranium will undergo a physical change and deposit onto sand particles or within organic matter.

Solution mining reverses the oxidation-reduction process that nature employed to position uranium in orebodies. Unfortunately the oxidant of choice, gaseous oxygen, is not always able to be solubilized in high sustaining concentrations to react completely with all the reduced minerals to completion. One such mineral is iron sulfide; FeS_2. Equation 1 describes the oxidation of iron sulfide.

$$FeS_2 + 4O_2 + 2H_2O = Fe(OH)_2 + 2SO_4^{-2} + 2H^{+2} \quad \text{-------} \quad \text{Equation 1}$$

In mining reservoirs where the presence of hydrogen sulfide can still be detected, the reaction depicted in Equation 1 is not taken to completion. Instead intermediate compounds of sulfur can exist. They are:

Thiosulfate $S_2O_3^{-2}$
Tetrathionate $S_4O_6^{-2}$
Pentathionate $S_5O_6^{-2}$
Polythionates $S_xO_6^{-2}$, $x \geqq 3$

Polythionates are known to adsorp on the anion exchange resins utilized in the recovery of uranium from solution. Their presence will poison the resin thereby reducing the resin's active exchange capacity. Continual exposure to any forms of polythionates will exascerbate the resin's condition.   Standard elution chemistries utilized within the industry to strip the resin of its uranium values will not displace any of the polythionates. Therefore a purification of the resin must be undertaken to recondition it back to, as near as possible, its original as-received state.

Humiates are sometimes presence in the mining aquifers as a reducing material. During the oxidation process if they too do not completely oxidize, and if left unabated, humic compounds can poison the ion exchange resins in much the same matter as polythionates. Additionally the negative charge composition of anion exchange resins used dominantly in the recovery circuits of uranium mills are an ideal electron food source for bacteria. Bacteria, like humiates and polythionates, will block pregnant solutions from penetrating within the resin bead increasing its loading ability. Instead bacteria will seal the pathways within the resin bead, and to make matters even worse, bacteria can multiply in-situ because all the ingredients for growth are present within the resin; electron source, carbon, oxygen, and phosphorus. Fortunately there is a recipe to cure these all fouling situations.

Contacting the resin with a 2 percent solution (20grams/liter) of NaOCl (sodium hypochlorite) for at least an hour will effectively oxidize and destroy all the aforementioned poisons. This rinsing should be conducted above a pH of 6.5 to limit the formation of chlorine gas from the decomposition of hypochlorite. Prolong or excessive oxidizing solution strengths will reduce the functionally of the resin and thereby reducing its overall loading capacity. In time the styrene matrix of the resin will soften making it useless. However brief encounters with mild oxidizing solutions will clean the resin bead and improve its loading characteristics. A simple, and yet effective way to clean the resin with NaOCl is to add it to the wash elute. But be careful when acid is added to the elate, it should be done in a well ventilated area due to the possible off-gasing of chlorine.

Resin can be poisoned by mechanical means too. In alkaline environments where the concentrations of FeS_2 in the ore is significant, the generation of amorphic $Fe(OH)_2$ solids can be a hindrance to the ion exchange process. Precipitating compounds can lead to mechanical fouling of the resin. Mechanical fouling requires a severe acid wash usually employing HCl (hydrochloric acid) at a sustained pH of 0.6. This has demonstrated to be effective in cleaning iron precipitates from within strong base resins. Further cleansing with mild oxidants should be conducted only after the acidified resin has been thoroughly washed and pH adjusted back to neutral otherwise there exists the probability that the oxidants will react and decompose if significant residual acid is present.

Ion Exchange Column Design

The selection of ion exchange reactors should be based on the host reservoir and geologic formation under consideration. What is standard equipment for one project may not be practical or advisable for another. When the host mineral exhibits very little pyrite and its derivative neighbors, marcosite and hemitite then consideration of downflow ion exchange vessels may be practical. However in certain areas of south Texas the iron compounds found within the mineral host are in sufficient concentrations (> 2% Fe) that run high and contribute to solid generation.