ABSTRACT

The University of North Carolina at Chapel Hill is in the design phase for a replacement power plant incorporating two circulating fluidized combustion (CFC) boilers. CFC is state-of-the-art technology for combined control of sulfur dioxide and nitrogen oxide emissions which are precursors to acid precipitation. The trend toward requiring the removal of contaminants from the waste gas stream results in transfer of these pollutants to the solid waste stream.

The primary goal of this study was to provide the Vice Chancellor for Business and Finance of the University of North Carolina the alternatives for management of ash to be produced by the replacement power plant. This study satisfies Conditions 9 and 10 set forth in the Special Use Permit issued to the University by the Town of Chapel Hill for the development of this project.

Current and potential technological alternatives for the management of coal ash were surveyed in the technical literature and by conducting informal interviews with experts. The advantages and disadvantages of each alternative, including economic, technological and environmental considerations were discussed.

Characteristics that influence the handling of ash from a fluidized bed combustion (FBC) power plant, and more

specifically, from the new Circulating Fluidized Combustion (CFC) type of FBC technology are identified and discussed. A preliminary assessment is made based on data from similar plants of the environmental safety of ash from the new plant using the criteria of toxicity, leachability and corrosivity. Current and anticipated state and federal regulations regarding power plant ash are reviewed at length.

Three general approaches to ash management are discussed that fit into an integrated program. The first approach is to identify alternatives for ultimate disposal of the ash. A number of scenarios are presented for various ash disposal options. The second approach is to reduce the amount of waste to be managed. This will require modeling economic conditions and making appropriate decisions to achieve the lowest feasible level of ash production. The third and final approach is to divert ash from disposal into a resource channel. This approach requires a balance of research, development, and capital against incentives of profits as well as saved disposal costs.

The decreasing acceptability of landfilling as the catch-all approach to solid waste management, increasing stringency in regulation of landfill practices and the escalating cost of siting and operating a landfill will play an important part in attempting to manage the power plant waste stream.

ASH MANAGEMENT ALTERNATIVES:

UNC-CH POWER PLANT

CONTENTS

BACKGROUND

The University of North Carolina at Chapel Hill is currently in the design phase for the construction of a replacement boiler and cogeneration facility at the University power plant. The project design incorporates two circulating fluidized combustion (CFC) boilers, each capable of producing 250,000 pounds per hour of steam at 1300 psig and 900^{O}F.

The site for the replacement facility is on property currently controlled by the University and housing the existing power plant. Special constraints imposed upon ash handling methodologies are a reflection of the surrounding area land use, which is primarily residential. This necessitates the use of dust control measures for all stages of ash handling.

The existing UNC - CH power plant is generating approximately 6,000 tons of ash per year which is collected from the combustion chamber and baghouses and transported to an ash silo by pneumatic handling systems . The ash is then loaded into trucks, and transported, for the most part, to the Chapel Hill - Orange County landfill. Current practices also include the trucking away of 15-20 % of the ash by the city of Asheboro for use as a conditioning agent for the city's municipal waste water sludge.

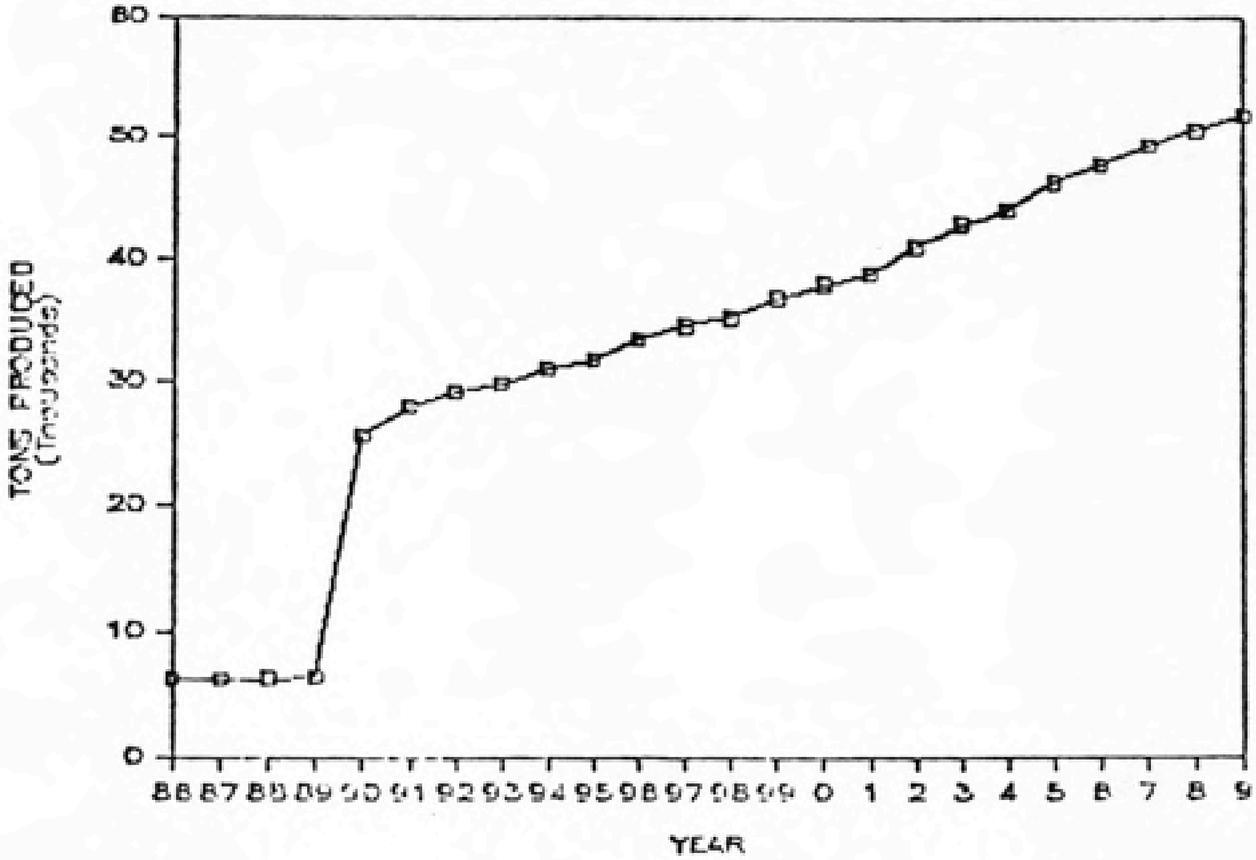
The university is currently a major user of local disposal facilities, with ash from the existing power plant comprising 25% of the University's total solid waste and 5% of the total waste stream going to the landfill.

The replacement power plant will, upon start-up in 1990, produce about 26,000 tons of ash the first year (about four times as much ash as is currently produced). Ash volume from the facility is expected to increase each year throughout the expected life of the plant to a maximum annual ash production of about 52,000 tons by 2009 (figure 1). The bottom ash and fly ash will be removed by a pneumatic ash collection system and are intended to be stored in a common silo prior to ultimate disposal (CRS Sirrine, Inc., 1985).

Chapel Hill, Orange County, and University Officials are evaluating the implications of this significant increase in the amount of ash over that presently generated. Like many other localities, Chapel Hill will soon exhaust its capacity at the current landfill site, and will face significantly increased costs for developing a new facility to meet expected new municipal solid waste landfill regulations.

Figure 1

ASH PRODUCTION



Prior to construction of the replacement facility, the University has agreed to meet special conditions set by the Town of Chapel Hill. These conditions include obtaining a Special Use Permit, a Zoning Compliance Permit, a Building Permit, approval of the Appearance Commission and meeting special design requirements. The special design requirements stipulate that the facility be designed such that all handling of coal, limestone and ash is done "within enclosed structures"(Town of Chapel Hill, 1986).

The University was granted the Special Use Permit (Town of Chapel HIll, Book 592, Page 362) on 23 June 1986 for the development of the university replacement power plant with attached special terms and conditions (Town of Chapel Hill, 1986). Condition 9 of the special use permit requires "that alternative methods of disposal (other than landfilling) for the spent lime/ash mixture be investigated and a report submitted to the Manager outlining the advantages and disadvantages of each alternative." Condition 10 requires that the leachability, corrosivity and toxicity of ash from a pilot or similar plant be determined. Results of these studies are to be reported to the Town Manager prior to issuance of the Zoning Compliance Permit for the project. These conditions are the basis for the current study.

CURRENT STUDY

The primary goal of this study is to provide the Vice Chancellor for Business and Finance of the University of North Carolina with a report on the alternatives for management of ash to be produced by the design power plant. This report satisfies Conditions 9 and 10 set forth in the

Special Use Permit issued to the University by the Town of Chapel Hill for the development of this project.

The objectives of this study are to:

(1) survey current and potential technological alternatives for the management of coal ash;

(2) identify and discuss characteristics that influence the handling of ash from a fluidized bed combustion (FBC) power plant, and more specifically, from the new Circulating Fluidized Combustion (CFC) type of FBC technology;

(3) discuss the advantages and disadvantages of each alternative, including economic, technological and environmental considerations;

(4) develop an information base and communication network for more detailed study of those alternatives meriting such.

(5) make a preliminary assessment of the environmental safety of ash from the new plant using the criteria of toxicity, leachability and corrosivity, based on data from similar plants.

REGULATORY CLIMATE

The primary factor affecting feasibility of alternative methods of ash disposal is the regulatory climate which determines which disposal methods will be permitted at all and how much they will cost to design and operate. These regulations are currently in a state of flux, and any alternatives favorably presented in this report and subsequently selected as alternatives of choice may be subject to modification in the future if more stringent regulations are put into effect. Following is a summary of current major laws and regulations applicable to the management of coal ash:

The activation of Clean Air Legislation has led to controls on emissions, including particles and noxious gases responsible for health problems and environmental degradation. The result of this cleansing of the waste gas stream from combustion processes is notably cleaner air, but also tons of material (up to 95% of the solids previously allowed to leave the stack) being retained in electrostatic and mechanical precipitators, bag houses, flue gas desulfurization (FGD) systems, and fluidized bed combustion systems.

Efforts to reduce air pollution by removing pollutants released when coal is combusted and collecting them for dry disposal can result in direct pollution of ground and/or surface waters if the resultant solids are not disposed of properly. This transfer of waste from one medium to another (in this case from the air to the land) can be referred to as cross-media pollutant transfer or intermedia pollution. These materials must now be managed as solid wastes.

The Resource Conservation and Recovery Act (RCRA) exhibited a clear consciousness of problems in intermedia pollution wherein it credits the Clean Air Act and other laws dealing with public health and the environment for the creation of "greater amounts of solid waste (in the form of sludges and other pollution treatment residues) ...." An objective of the act is to promote "...solid waste management, resource recovery and resource conservation systems which preserve and enhance the quality of air, water and land resources...." RCRA further gives a directive to EPA to integrate the Act with other laws dealing with environmental protection (Entman, 1980).

EPA received a Congressional mandate in the 1980 amendments to RCRA to determine whether or not the waste produced by coal combustion and by the air pollution control systems associated with coal combusting plants is hazardous. EPA is prohibited from regulating such wastes as hazardous until such a determination is made, in part because it was advocated that regulations of these waste streams would discourage use of coal and innovative use of coal ash as a resource. EPA is in the process of collecting data for making this ruling on waste classification of ash which will likely be proposed to EPA decisionmakers by the end of 1987 (Adler, 1987). It does not seem likely that ash will be classified as hazardous (Subtitle C under RCRA), but there is some indication that it will be treated as a special class of industrial waste requiring some special handling.

RCRA assigns control of coal ash (and other high volume utility waste) to states as non-hazardous (Strauss, 1987). As increased information is gathered, there exists the potential for classification of this waste such that it may need more specialized management. CFC ash is currently managed as a non-hazardous waste, with the burden of determining whether or not it possesses Resource Conservation and Recovery Act (RCRA) Subtitle C characteristics resting on individual plant owner/operator. North Carolina requires separate disposal operations (monofill) for high volume generators of coal combustion residues (Dover, 1987) and anticipates banning ash from landfilling with municipal waste in the near future.

FLUIDIZED BED TECHNOLOGY

Fluidized bed combustion (FBC) is currently receiving a great deal of research and development attention, especially by the Tennessee Valley Authority (TVA), Electric Power Research Institute (EPRI) and The Department of Energy (DOE), as a state-of-the-art technology for combined control of pollution by sulfur dioxide and nitrogen oxides (Princiotta, 1985).

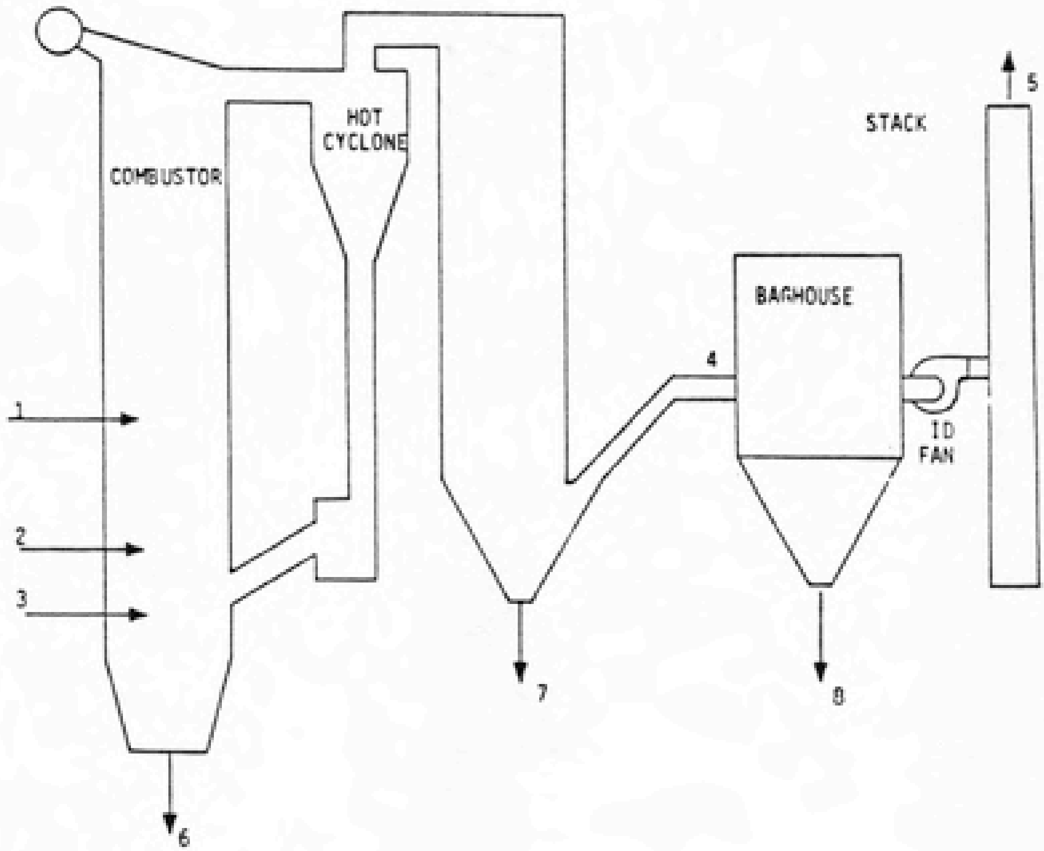
In the FBC process, crushed limestone, the sorbent for sulfur, is blown into the combustion chamber with pulverized coal. Combustion proceeds under conditions determined by the air supply and temperature which allow for the suspension of the coal - lime mixture such that it behaves much like a fluid. The process is one of the recent technological answers to the demand being placed on coal burning power generation facilities for reduction of emission of pollutants which are precursors to acid precipitation - sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Injected limestone in the FBC process decreases sulfur emissions directly by the absorption of sulfur released from coal combustion. Nitrogen oxide emissions are also decreased through operation at temperatures below those which are optimal for its formation.

Limestone eventually loses its absorptive capacity and is removed from the bottom of the boiler for disposal with the bottom ash, resulting in as much as a quadrupling in the amount of solid waste that needs to be disposed of. FBC has clear advantages over earlier technologies employing wet scrubbing techniques, in that less energy is used and the resultant waste is more stable for surface disposal. The ash resulting from FBC can be handled as a non-hazardous waste (Princiotta, 1985), and if properly managed, dry FBC ash is less likely to contribute to water pollution than ash from conventional plants.

Circulating Fluidized Combustion (CFC) technology is a type of fluidized bed combustion in which solids (fuel and limestone) circulate through the combustion chamber and cyclone until the particles become light enough to escape as fly ash trapped in fabric filters. CFC technology has been developed to more effectively remove pollutants from the waste gas stream before leaving the combustion chamber. In addition to gaseous emissions reductions, CFC allows for more efficient combustion and reduction in particulate emissions through the recycling of particles, including uncombusted carbon, from the cyclone back into the combustor (Figure 2).

Figure 2

CIRCULATING FLUIDIZED COMBUSTION



1. Combustion Air 64,041.6 ACFM @ 80° F
2. Coal 25,112 #/HR
3. Limestone 3,900 #/HR
4. Flue Gas - 107,000 ACFM @ 305° F; 5200 lbs/hr Particulate entering baghouse; 99.69% collection efficiency

5. 107,000 ACFM @ 305° F; particulate emissions to atmosphere - 16.16 lbs/hr
6. Bottom Ash Hopper Ash Discharge - 975 lbs/hr
7. Air Heater Hopper Ash Discharge - 325 lbs/hr
8. Baghouse Hopper Ash Discharge - 5,183.84 lbs/hr

ASH CHARACTERISTICS

Ash produced by the CFC process differs in important ways from ash produced by other types of combustion technology. A large body of technical literature is being developed currently on performance and operational characteristics which influence composition of the ash and options for its management. Differences in physical and chemical composition result in different considerations for determining what management alternatives might be environmentally acceptable or economically viable. Such characteristics may reduce the attractiveness of currently acceptable management alternatives for ash generated by other combustion processes, while at the same time may enhance or open up new options.

Chemical and physical characteristics of coal combustion residues require understanding, as they bear significantly on the management and marketing options. Ash, being the product of high temperature combustion is uniform in its physical structure, though ashes generated by different processes have different characteristics. For example, fly ash is different from bottom ash and ash from fluidized bed combustion differs from that produced by other combustion processes. Characteristics of FBC ash relevant to disposal options are superior to conventional power plant wastes making the ash more suitable for landfilling and surface applications (Gleick, 1980).

Important properties of ash which would help in determining the suitability of the specific ash for various disposal and marketing options and predicting its behavior under various situations include 1) moisture content 2) ash particle tension, 3) density 4) pozzolanic behavior, or how the alumina and silica of the ash mixture react readily with water to form hydrated compounds (Villaume and Ripp, 1986), and 5) proctor density, or compressibility. Chemical composition of the ash must be taken into consideration where management methodology allows for runoff or leaching into surface or groundwaters.

<ins>CONDITION 10</ins> of the Special Use Permit issued by the Town of Chapel Hill asks that appropriate tests "be conducted on the lime/ash mixture from a pilot or similar plant and the results submitted to the [town] manager...." In the event that the ash is considered to be hazardous, an alternative to landfilling the ash must be approved by the town."

For purposes of classification of waste as hazardous or non-hazardous based on toxicity, EPA has developed a procedure (EP Toxicity - Federal Register, May 19, 1980) intended to simulate precipitation trickling through a landfill for extracting potentially toxic substances from a solid waste sample. Levels of toxic substances present in the leachate (fluid collected after percolating through the sample) are determined analytically and compared to EPA criteria pollutants (Table I) applicable to power plant residues. Until EPA makes an industry wide determination of the classification of power plant residues, it will be necessary for each plant to show that its ash is non-hazardous based on these criteria. Such determination cannot, for obvious reasons, be made for the UNC plant until the plant is actually in operation and ash is being produced.

Toxicity

Very few CFC plants are in existence or operating in this country. A pilot plant in San Diego, CA operated by Pyropower, Inc., the manufacturer of the boiler for the University Power Plant, offers test burns in its facility for the purposes of providing data on the combustion of the fuel and ash composition from a sample load of coal and limestone taken from the mines under contract to the interested party. This theoretically provides the plant operator some idea of what to expect under similar conditions in the same type of boiler with the same coal and the same limestone. Their charge for this service is \$20,000 to \$25,000 per day of the burn (Brown, 1987). To go to such an expense to get test burn data was determined to be cost ineffective due to the likelihood that such a burn, even in an identical plant, would not produce ash representative of ash from the UNC Plant due to a number of variables, including:

1. Coal composition - can vary drastically in the metals content from shipment to shipment even within the same coal seam, and certainly, from mine to mine.

2. Limestone composition - like the coal, can vary from shipment to shipment and from mine to mine in absorptive properties which can influence the metals concentration in the ash.

3. Operating conditions - efficiency of the burn, air velocities, coal and limestone feed rates can all effect the metals concentration of the ash.

One alternative to a test burn is to examine sample analyses from a similar facility which burns similar coal with similar limestone and to project from this data to draw some assumptions about the replacement plant. Data provided courtesy of Central Soya, Inc which operates a Pyropower plant in Chatanooga, Tennessee similar to the one purchased by UNC, indicates that the ash from their plant is not hazardous based on EP Toxicity criteria. This is one of the few CFC plants in operation in the country, and the only one for which toxicity data could be obtained. The relatively low values of toxic metals in the Central Soya plant (Table I), which also burns eastern coal, suggests that this type of technology is not likely to produce EP toxic ash. Similar testing will have to be conducted at UNC after the plant is in operation.

TABLE I

EP TOXICITY OF ASH FROM PYROPOWER CFC PLANT

(Concentration in mg/L)

Parameter	pH Adjusted 18-00057	pH NOT Adjusted 18-00057	pH Adjusted Stoneman	pH NOT Adjusted Stoneman	Mininum Concentration for Characteristic of EP Toxicity	
Arsenic	≤0.001	≤0.001	≤0.001	≤0.001	5.0	(D004)*
Barium	0.11	0.10	3.74	0.28	100.0	(D005)*
Cadmium	≤0.005	≤0.005	0.023	≤0.005	1.0	(D006)*
Chromium	≤0.03	≤0.03	0.05	≤0.03	5.0	(D007)*
Lead	≤0.06	≤0.06	0.20	≤0.06	5.0	(D008)*
Mercury	≤0.0005	≤0.0005	≤0.0005	≤0.0005	0.2	(D009)*
Selenium	≤0.002	≤0.002	≤0.002	≤0.002	1.0	(D010)*
Silver	≤0.007	≤0.007	0.043	≤0.007	5.0	(D011)*

*EPA Hazardous Waste Number

(Commercial testing and Engineering, 1983)

Leachability

The absorptive properties of limestone that make it desirable for use in removing pollutants in the combustion process also enhance the binding and concentration of metals within the ash/limestone mixture. The alkaline nature and resultant buffering capabilities of the lime would tend to bind the metals more completely, and largely prevent their leaching into the groundwater in as high a concentration as would be expected in conventional power plant ash. This is partly owing to the fact that these metals are not as soluble, and therefore, not as leachable in the alkaline environment as they are in the more acidic environment of conventional coal ash. In addition, FBC ash tends to set up harder if it is moistened prior to disposal, and therefore to bind the metals more completely within the matrix of the cement-like mixture.

Corrosivity

Another characteristic which would require a waste to be managed as a hazardous waste, and that applies to ash from some power plants (particularly conventional plants), is corrosivity. RCRA defines corrosive materials as having a pH less than 2 or greater than 12.5, or being able to corrode steel at a rate of greater than one fourth inch per year. Conventional power plant ash is acidic to the extent of being able to corrode steel, but not likely at the rate set in RCRA. The nature of the CFC process virtually assures that the ash will not be hazardous on the basis of corrosivity, since the process involves the injection of large amounts of limestone which naturally buffers acidity released by coal combustion to a level expected to be well within the acceptable range. Again, final verification will have to be made following plant start-up.

ASH MANAGEMENT ALTERNATIVES

Management options were identified through this study as an attempt to encourage UNC to incorporate the most innovative ash management practices feasible under expected conditions.

Three general approaches should be integrated into a program for management of ash. The first approach is to identify alternatives for ultimate disposal of the ash (MODE I). This involves keeping abreast with regulations and identifying a suitable depository for the ash under whatever set of circumstances present themselves. The second approach is to reduce the amount of waste to be managed (MODE II). This will require modeling of economic conditions and making appropriate decisions to achieve the lowest feasible level of ash production. The third and final approach is to divert ash from disposal into a resource channel (MODE III). This will involve a balance of research, development, and capital directed against the potential market and saved disposal costs.

MODE I: DISPOSAL OF ASH

Independent of avenues through which UNC may be able to reduce or market its power plant residues, it is necessary to have provisions for assured disposal options for the total volume of ash to be produced at the replacement power plant. Whether it is managed contractually by an independent firm, or placed in a dedicated landfill, the ash must have some place to go. A first line consideration to assure this is determining the total volume of ash expected to be produced and the amount of fill void required to manage it acceptably.

The plant is expected to produce 26,000 tons of ash in the first year, with an average annual increase of about 5 % per year through the twentieth year of the plant's design usefulness. The total mass of ash to be produced through the life of the plant is estimated at 767,000 tons. The estimated density of the ash is 50 lbs/ ft^3. (~800 kg/m^3). At this uncompacted density, approximately 700 acre-feet (~869,000 m^3) of landfill volume would be required to handle the worst case scenario of all the ash requiring secure landfill management.

Ash compacts to some degree simply by gravity and the weight of the overburden. Ash which is moistened to 15% moisture, however, occupies only about 50% of its original volume (Villaume, 1987). Optimally compacted, then, the UNC power plant ash could be expected to require approximately 350 acre-feet (~435,000 m^3). These estimates do not take into account any cover volume which might be taken up by periodically required earthen cover for dust (fugitive emissions) control. Such cover can be largely foregone if ash is moistened properly and compacted allowing it to harden (Leming, 1987; Labuz, et al., 1986; Rose, 1987).

WET SLUICING

At many coal fired power plants, settling basins are used for wet disposal by sluicing the ash in a slurry to the disposal site. In such cases the water drawn off the settled ash - the supernatant - receives the necessary treatment and is discharged to nearby surface waters. However, this technology is neither feasible of desirable for the UNC facility. Wet sluicing of ash requires completely different handling and disposal technology and nearby settling basins sufficient to handle the amount of ash produced. Groundwater protection measures including liners and groundwater monitoring are also required in most cases. The resultant settling basins are physically unstable and environmentally unacceptable relative to any of the other land disposal methods mentioned here. Trends in recent years have been toward dry disposal of the ash, owing partly to increasing stringency in discharge standards and emphasis on more conservative land use practices (Labuz, et al., 1987).

The University has, upon occasion, sent ash to the Chapel Hill landfill in a slurry state (Heflin, 1987). Landfilling of ash in a slurry, not to be confused with the moistening of ash to 15 % moisture after it has been placed in a landfill, is contrary to RCRA ban of liquids from landfills, and causes a number of serious problems. Ash slurry has too much water content to be compactable by usual methods, and causes ponding in the landfill which can result in undesirable illegal and potentially hazardous leachate formation. Disposing of ash slurry in a landfill is not an acceptable practice.

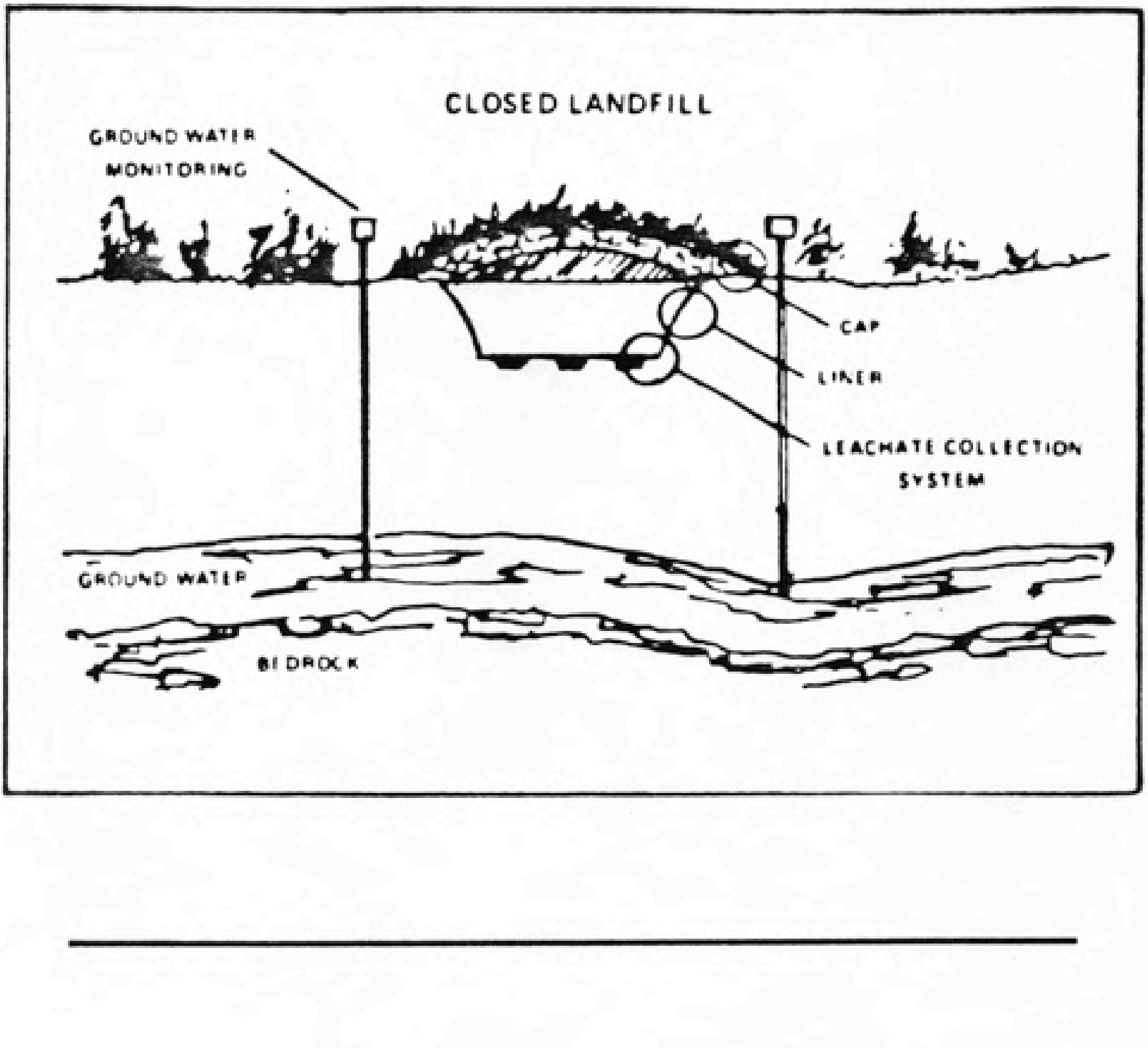
LANDFILL

Physical and chemical characteristics indicate that dry ash, particularly that from FBC plants with the relatively high free calcium content associated with it, if at optimal moisture content and mechanically compacted, is physically stable in a landfill, either as a sole component waste stream or as a stabilizing agent for other less stable waste. These characteristics impart to CFC ash a potential value in a landfill as replacing all or part of the cover material. Chapel Hill is currently studying the feasibility of using ash for mounding over existing landfilled waste (Heflin, 1987). This practice would have the benefit of increasing landfill capacity and providing a low permeability cap over the landfill which can then be revegetated and assist in diversion of rainfall off the site, hence decreasing the potential for leachate formation.

The potential for leaching of toxics (selenium, iron, etc) may prompt the federal government or the states to regard all general purpose disposal landfills as potentially hazardous to the environment - a determination that would result in requirements for increased testing, protective linings, and groundwater monitoring (Strauss, 1987). Such a decision would have a major impact on Chapel Hill solid waste disposal options as a whole, not only ash disposal. The primary net effect, especially on large volume users such as the University, will likely be a significant increase in disposal costs (tipping fees). A number of scenarios are presented in the following for various ash disposal options.

SCENARIO I: MUNICIPAL LANDFILLS, if allowed to continue to receive residues from small power plants such as the University's replacement plant, will do so under conditions of increasing stringency in regulations concerning those landfills. Anticipated groundwater protection standards will force even non-hazardous solid waste (Subtitle D under RCRA) facilities to include impervious liners, leachate collection and treatment systems and groundwater monitoring (figure 3).

Figure 3


CLOSED LANDFILL
GROUND WATER
MONITORING
CAP
LINER
LEACHATE COLLECTION
SYSTEM
GROUND WATER
BEDROCK

Under this scenario, tipping fees of $5.00 per ton will be a thing of the past. In order to develop new landfill capacity and manage new solid waste programs, municipalities such as Chapel Hill will have to increase either general fund subsidies or landfill tipping fees. Under this scenario, the University can conservatively estimate its disposal costs at $10.00 to 25.00 per ton of ash to be landfilled by 1991, the projected start-up date. It is impossible at this time to reliably predict what the cost actually will be at start-up or what it might be by the time the plant has aged ten or twenty years. Even assuming a per tonnage tipping fee of only $10 by the start-up of the plant, a modest rate increase of 5% per year and ash production projections based on projected energy demand, the University could be paying along a schedule similar to the one in Table II for landfilling the power plant ash as a part of the local solid waste stream.

TABLE II

COST SCHEDULE: LANDFILL SCENARIO I

YEAR	ASH (TONS)	* DISPOSAL COST($)/TON	* DISPOSAL COST($)/YR
1990	25,800	10.00	258,000
1991	28,200	10.50	296,100
1992	29,300	11.02	322,886
1993	30,000	11.55	346,500
1994	31,200	12.16	379,392
1995	31,900	12.77	407,363
1996	33,500	13.41	449,235
1997	34,600	14.08	487,168
1998	35,300	14.78	521,734
1999	36,800	15.52	571,136
2000	38,000	16.30	619,400
2001	38,800	17.11	663,868
2002	41,100	17.97	738,567
2003	42,900	18.87	809,523
2004	44,000	19.81	871,640
2005	46,300	20.80	963,040
2006	47,700	21.84	1,041,768
2007	49,300	22.93	1,130,449
2008	50,700	24.08	1,220,856
2009	52,000	25.28	1,314,560
TOTAL	767,400 Tons		$13,413,185

PROJECTED AVERAGE LIFE CYCLE COST PER TON = $17.48

PROJECTED AVERAGE LIFE CYCLE COST PER YEAR = $670,659.00

* all costs are nominal dollars, without discounting to present value.

The validity of the above schedule is based on a number of assumptions, none of which is guaranteed. First, it is assumed that the full cost of managing the waste is not transferred to the University but that tipping fees continue to attempt to recover only operating costs. Under this assumption, some of the hidden costs such as amortization and capital outlay are subsidized (Heflin, 1987). An example of what this difference might mean is the case of New Hanover County, North Carolina which charges $22.50 per ton for tipping fees, but the estimated actual cost of landfilling is about $35.00 per ton (Dover, 1987). This represents a 36 % subsidy of disposal costs over user charges.

Second, this schedule is calculated with the assumption that business at the Chapel Hill landfill will go on as usual. However, it is estimated that by 1991 waste will begin going to the new site, located south of the existing site off of Eubanks Road. By this time, it is realistic to predict that regulations will require the new landfill to be constructed with a liner, leachate collection and treatment system and groundwater monitoring wells (Figure 3). This will be up-front capital expenditures which will have to be recovered in some manner. Costs for the liner itself can be upwards of $100,000 per acre. This could mean a cost of $35 million to line sufficient space for the UNC ash alone.

A third assumption is that projections of the total solid waste picture in Chapel Hill, Carrboro, and Orange County are an indication of real conditions. A significantly lower volume waste stream than that which is projected and planned for would likely necessitate higher user charges to cover operating costs (Heflin, 1987).

SCENARIO II: The second scenario cost schedule (Table III) is a modest estimate of a more realistic set of circumstances. This schedule uses $25.00 per ton as a first year estimated tipping fee with a 5% per year increase throughout the life of the plant. Though these estimates are still nowhere near the worst case (California power plant operators are currently paying as much as $58 per ton for disposal rights in local landfills) and might not even sufficiently cover expenses of the liner, it will at least give a picture which begins to recognize unpaid costs (which would be real if the University were required to landfill ash on its own) and anticipates upcoming regulations.

TABLE III

COST SCHEDULE: LANDFILL SCENARIO II

YEAR	ASH (TONS)	*DISPOSAL COST($)/TON	*DISPOSAL COST($)/YR
1990	25,800	25.00	645,000
1991	28,200	26.32	742,224
1992	29,300	27.70	811,610
1993	30,000	29.16	874,800
1994	31,200	30.69	957,528
1995	31,900	32.31	1,030,689
1996	33,500	34.01	1,139,335
1997	34,600	35.80	1,238,680
1998	35,300	37.68	1,330,104
1999	36,800	39.67	1,459,856
2000	38,000	41.75	1,586,500
2001	38,800	43.95	1,705,260
2002	41,100	46.27	1,901,697
2003	42,900	48.70	2,089,230
2004	44,000	51.26	2,255,440
2005	46,300	53.96	2,498,348
2006	47,700	56.80	2,709,360
2007	49,300	59.79	2,947,647
2008	50,700	62.94	3,191,058
2009	52,000	66.25	3,445,000
TOTAL	767,400		34,559,366

PROJECTED AVERAGE LIFE CYCLE COST PER TON = $45.03

PROJECTED AVERAGE LIFE CYCLE COST PER YEAR = $1,727,968

* all costs are nominal dollars, without discounting to present value.

<u>SCENARIO III COOPERATIVE DEDICATED LANDFILL (MONOFILL)</u> facilities are those that are designed for and accept only one type of waste. Monofilling of power plant residues is common practice in the utility industry, where in the face of uncertainty, internally imposed controls are stricter than currently required by regulation as an attempt to avoid expensive retrofitting (which could involve digging up a waste pile to install a liner under it). The possibility of UNC entering into a cooperative arrangement with a nearby utilities company to "piggyback" the relatively low volume UNC residue stream for disposal at their facilities was met with firm negatives.

There is a tendency for states to adopt solid waste management criteria adopted by EPA (40 CFR 257, Sep 13, 1979), requiring location, design, and operation with minimal undesirable discharges. Location of a landfill site is governed by ground and surface water conditions, geology, soil, topographic features, economic and social factors. Some states (eg, Tennessee) are anticipating the upgrading of solid waste management regulations under RCRA and are writing regulations which involve classification of components of the non-hazardous solid waste stream and segregation of these components for final disposition which matches the need (Victory, 1987).

These actions tend to confirm the predictions by EPA Office of Policy Analysis staff that even though it is unlikely that ash will be regulated as a hazardous waste (due largely to the volume of residues produced in the combustion of fossil fuels in this country), it is quite realistic to anticipate that regulations will require handling ash as a special class of industrial waste, and may ban it from municipal solid waste landfills. Disposal of ash in a monofill facility would likely be under design standards similar to those listed under scenario I (ie, liner, leachate collection and treatment system, and groundwater monitoring). One option being studied by Chapel Hill to anticipate this change is a separate monofill cell within the landfill to accept ash.

SCENARIO IV LANDFILLING IN A MONOFILL under the conditions of an independent venture by the University will bring the hidden costs and subsidies to the surface so that the full cost of all phases from siting through operation and closure would be figured into the schedule. Considering the factors, it would be reasonable to predict that the cost to the University would be double what is seen in Scenario II. The capital commitment to construct and operate a facility for these purposes could also have the deleterious effect of providing an incentive to send all the residue to the landfill rather than to find alternative, beneficial uses for the ash.

A number of other variables do come into play under this scenario which have forced at least one group of analysts to drop it from consideration as a viable alternative (Norman, 1987). For the University to operate its own dedicated landfill would require going through the siting and permitting process. Siting of any type of landfill is meeting sharply increasing opposition by local citizens. There is a significant backlog of permit applications waiting for action at the Solid and Hazardous Waste Management Branch. It is certainly possible that even if the University started the process today, there would still not be a suitable, approved site ready for receiving wastes upon startup of the plant. Economy of scale would probably increase the per ton cost of landfilling over cooperatively utilized facilities of similar design. Liability for the site would necessarily be shouldered by the University. An important concern is the impracticality and obstacles barring the University from going into landfill business on its own.

SCENARIO V: CONTRACTING TO A PRIVATE WASTE DISPOSAL FIRM for disposing of the ash under monofill conditions would have associated costs higher than if the University carried out the operation internally. The most obvious increase in costs would be the profit margin under which the firm operates. A reasonable cost schedule for comparison is

Scenario III schedule plus 10 % profit. No such firm has been identified through the course of this study.

<u>SCENARIO VI: HAZARDOUS WASTE LANDFILLS</u> could potentially become the required receptor of power plant residue. This would hinge on the determination by EPA to classify these wastes in general as hazardous, or alternately, for the state Solid and Hazardous Waste Branch to decide to regulate the waste as hazardous. Such a determination on the federal level does not seem likely owing largely to the lack of consistent data to confirm that it poses a threat to groundwater through leaching of the metals, but perhaps more influential is the pressure being applied by lobbyists for the utility industry to discourage it. A regulation in North Carolina requiring ash to be managed as hazardous is prohibited under the Hardison Amendment if EPA makes a determination that it is non-hazardous, unless the North Carolina General Assembly were to require such a regulation by legislation, which also seems unlikely.

<u>SCENARIO VII: RETURN TO MINE SITE</u> is an option that is receiving considerable attention by waste management authorities, power plant operators and mining operators. The Surface Mine Control and Reclamation Act (SMCRA) requires reclamation of mine sites, as nearly as possible,

to their original character. Coal ash has been used with success in a number of different operations, from experimental to emergency in nature. There are several basic approaches to this type of management, based on the role the ash is playing:

1. Mine stabilization is required under SMCRA where the existence of tunnels, shafts, voids and depressions poses an imminent hazard. Ash has been mixed with cement and injected into deep mines to successfully stabilize the area (Daughtery, 1987). Mine sites qualified for this remedial action are prioritized from state inventories on a case by case basis. The last site identified under this program in North Carolina is currently in design phase. This option is limited to opportunities available and handled on a contractual basis.

2. Mine fire extinguishing has incorporated the use of ash. This is limited to emergency situations and would be a useful recruitment of ash were the opportunity to present itself.

3. Acid mine tailings neutralization has been accomplished employing ash as a neutralizing agent. FBC ash would be particularly amenable to this type of remedial activity for which opportunities may exist. A single project in

Pennsylvania employed the use of about 26,000 tons of ash (predicted first year ash production from UNC plant) to neutralize acidic mine wastes or spoils (Daughtery, 1987).

4. Surface mine reclamation plans are required of operators under SMCRA. Ash is currently considered suitable for filling the depression, improving the soil texture, and water bearing capacity, and for stabilization of the soil if mixed in the right proportions. This last approach, when put in the context of returning the ash to the coal mine of origin seems to have some promise as an ash management alternative with benefits to both the mine operator and the power plant operator, and is discussed further in the following.

Returning ash to the mine site has been looked at actively by a number of coal suppliers, power plant operators and consultants. This approach, involving active mining operations, is being permitted and practiced in a number of states, including Iowa, Virginia, West Virginia, California, and Pennsylvania. (Rasmussen, 1987; Huiser, 1987; Sears, 1987; Demirel, 1987; Norman, 1987; Desko, 1987). Individuals studying the problem at Iowa State University and at a commercial facility in California have chosen this alternative as the primary management approach (Norman, 1987; Rasmussen, 1987).

Coal suppliers to UNC have indicated a willingness to provide this service to UNC. The rates they would charge vary from no charge (Desko, 1987) to $1.00 per ton for disposal, provided that coal was also being purchased from the firm. Under best case conditions, the cost to the University will be only the cost of transporting the ash to the site. If the mode of transportation chosen for the ash matched that utilized for the coal, there would be the added benefit of preventing a dead haul back (truck or train car returning to point of origin empty) which is often rewarded by reduced rates over delivery, especially by truck (Desko, 1987; Lisk, 1987).

There are two circumstances peculiar to the UNC facility that might pose a problem in opting to return the ash to the mine of the coal supplier. First is the problem of transportation of the ash to the mine site. Trucking seems to be the most economical means for returning ash to the locations where contracted coal is commonly mined, mostly because it presents fewer handling problems at the mine site (Sears, 1987; Desko, 1987). Ash is currently trucked away from the power plant site, however, the daily delivery of coal so as to obtain reduced rates on return transport of ash would require the passage of ten times as many trucks through a residential area that is already sensitive to the impact of the power plant. This may be more of a nuisance than would be tolerated. The neighborhood location of the plant and the fact that coal unloading facilities are geared for rail tend to induce inelasticity into what the University might pay for rail transport of the ash.

Rail transport has been the method of choice for delivering the coal to the plant, but has significant handling problems associated with utilizing it for the ash. Coal suppliers have indicated that they are not set up to unload rail cars full of ash at the mine site. While one representative indicated that they might be willing to construct the necessary equipment, both highly recommended trucking as being far easier. One coal firm indicated they would charge \$1 to \$3 per ton handling fee at the mine site for rail car unloading but none for truck. Of primary concern to the rail companies are the problems associated with preventing fugitive emissions from the cars losing ash to the wind, the problem of ash getting damp, and hence difficult to remove from the car, and the problem of contamination of the coal with the ash.

These problems can be remedied by a number of options, varying widely in complexity and cost. The cars carrying the ash could either have removable covers, or separate empty, enclosed hopper cars could be brought in for the ash (Heath, 1987; Gilbert, 1987; Snyder, 1987), meaning a dead haul to the plant for these cars. Specialized private equipment is another possibility which is being considered by a consultant to a power plant in California (Norman, 1987). One of their options includes specially designed ash containers that fit into the coal cars and are returned on the train after use loaded with coal. Cranes on site at both the power plant and the mine site lift and maneuver the containers into position for ash loading and unloading. Though this solves the problems of handling, the expense is large and in the judgment of one rail official is not warranted by the volume of ash to be handled at UNC (Heath, 1987).

Additionally, rail transport of ash carries a higher price than over the road transport, due in part to the rail transport industry practice of assigning higher percentages of fixed costs in rates formulae for commodities of high density and relatively few options for transport (Levin and Stram, 1981; Gilbert, 1987). Rail offers very little discount on a backhaul of ash compared to the rate for coal, while one truck line stated a willingness to provide a free backhaul of the ash to the mine site if they were transporting the coal. The economics of transportation deserves further attention as it relates to this option with the resulting data being at least in part applicable to other management alternatives. One alternative that would address the transportation cost differentials as well as mitigate handling concerns would be to construct a truck to train transfer station for coal coming into the power plant, thereby eliminating all trucks in the neighborhood with the exception of those hauling ash away from the plant. This would be feasible if it were done on University property and arrangements made with the rail line serving the spur of track.

The second peculiarity that may hinder the employment of back-to-the-mine disposal is the UNC practice of awarding contracts for purchase of coal. Short term coal contracts are awarded to the most competitive bidder, resulting in the potential for supplier switching from one year to the next, and hence, the loss of incentive by the supplier willing to supply the service of disposal. A solution to this problem could be found in awarding longer term contracts to establish a relationship with the supplier/ash handler. A more attractive alternative to accomplish the same end would be to send out requests for bids for the joint supply of coal and disposal services. If the provision for disposal were linked to the contract for supplying coal in this manner, it would ensure that an arrangement for handling the ash would not be lost to a pennies-per-ton lower bid for delivered coal.

Regulatory uncertainty surrounding the classification of coal ash impacts the availability of the option of returning the ash to the mine of origin of the coal by limiting arrangements that might be entered into with a willing operator to short-term contracts at best (Sears, 1987). Operators are showing varying degrees of willingness to provide this service, reflected in the price they would charge. Some of the coal companies have had some experience providing mine site disposal to customers.

SCENARIO VIII: SOIL STABILIZATION for the purpose of providing a sub-base under structures appears to be a suitable, beneficial land based option for bottom ash, provided the ash is not going to be used within protected watersheds or near wetlands or drinking water supplies. Properly prepared ash from FBC will likely provide substantial support for most types of structures, including roads, buildings, and airports. Ash mixed with water and sand and compacted will achieve up to 2000 psi load bearing strength (Leming, 1987). This option may not be available if the ash does not meet ASTM specifications for the intended use, or if the ash were determined to be hazardous. This option will likely provide sporadic channeling for small portions of the waste stream at best. Costs should be nominal, limited to transport costs if any at all. Further study is needed to determine the suitability of ash from the University power plant.

MODE II: REDUCTION OF ASH

The volatility of regulatory conditions which influence directly or indirectly the disposal of ash prohibits predicting with any reliability the costs which will be incurred under any disposal option. Costs for disposal of each ton of ash will be higher in the future, regardless of the approach taken. Reduction of ash volume has obvious benefits in saved handling, transportation, and disposal costs. Policy-level decisions will have varying degrees of impact on the volume of ash produced by the plant.

ENERGY IMPORTING

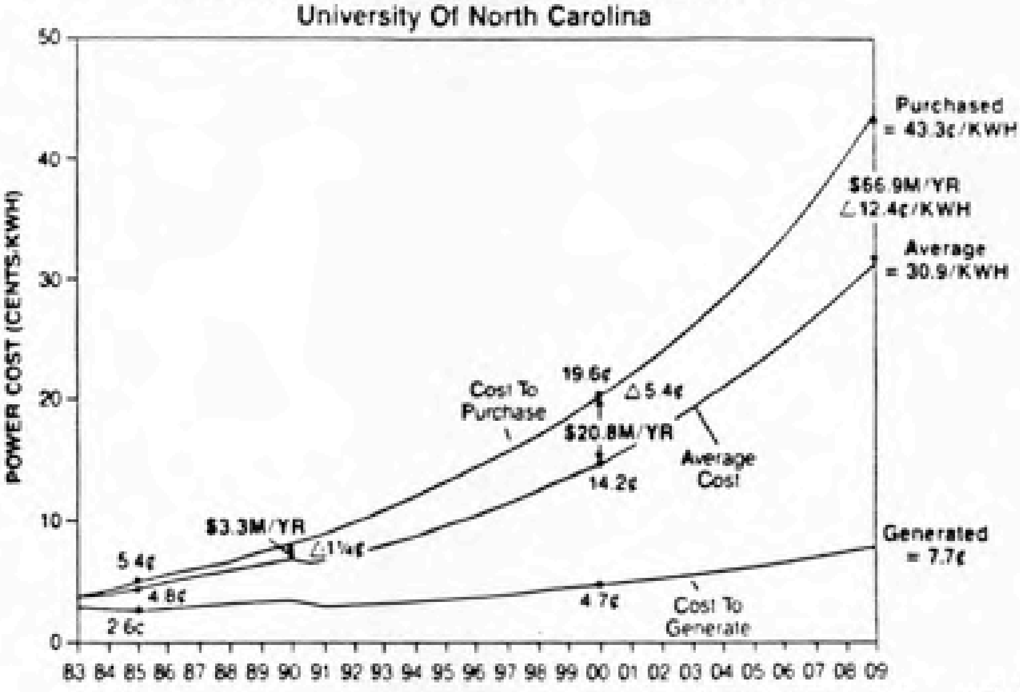
From the standpoint of this study, the most extreme ash reduction option for the University would be to eliminate the ash altogether. This can be viewed as one of the alternatives through opting to eliminate the project from further consideration. This option is not realistic at this phase in the project, and is not likely preferable in any case if examined more closely. For the sake of argument it will be included in the discussion here and receive cursory analysis.

The primary economic factors involved would be the cost differential to import energy for heating, cooling and electricity requirements over the cost of that which the University could generate (see Figure 4). The energy import cost is dependent upon its availability and rates set by the supplier. Immediately it becomes obvious that though this eliminates the ash disposal problem for the University it does little if anything toward addressing the overlying issue of solid waste in general, in that it is simply a transfer of waste and costs with the additional factor of lost efficiency in transmission and less optimal matching of energy types to end use (for instance, purchasing extra electricity to run air conditioners rather than co-generating steam at the UNC plant which could serve the same cooling functions with less net energy input).

Figure 4

Electric Power Cost — CFC Boiler

University Of North Carolina



(CRS Sirrine, 1986)

FUEL SWITCHING

Switching from coal to another type of fuel could have the effect of significantly reducing the ash load to a degree dependent on the fuel switched to. Switching to oil or natural gas would virtually eliminate the solid waste residuals.

The main drawbacks of switching to either of these as primary fuels are the much higher cost of acquiring the fuel and instability of prices of these fuels, and even their availability at required volumes under some circumstances. By the mid 1990's 50 to 60 percent of our oil could come from foreign sources, with so much uncertainty involved that predictions are meaningless. Current activity in the Persian Gulf may be responsible for natural gas price increases of as much as 30 percent, according to some energy analysts. One obstruction to the use of natural gas that would need to be overcome is the delivery of gas to the plant site. A new pipeline would have to be constructed before gas could be brought to the plant in sufficient quantities. The opportunity cost of designing and constructing a state-of-the-art coal combustion plant that does not get utilized, relative abundances of available American coal versus oil or gas, and the opportunity cost of the oil or gas are also factors that weigh against reliance on fuel switching as a waste reduction measure.

It has been stated policy of the Federal Energy Administration and the Federal Power Commission that "no new oil or natural gas fired base power plants can be constructed." A Bill introduced before the House of Representatives (National Energy Act, H.R. 8444, 95th Congress, 1st session, 1977) and President Carter in his National Energy Plan stated that "by 1990 no new or existing utility will be permitted to burn natural gas and that no new electric power plant shall use natural gas or petroleum as a primary energy source...."(Bernknopf, 1985). These policies reflect the perceived importance of utilizing coal in national security considerations, as well as the intention to reserve the less abundant oil and gas for uses for which coal is not suitable, such as refining and chemical manufacture.

COAL SWITCHING

The coal this plant was designed to burn is high ash/high sulfur eastern coal with fly ash typically being composed of quartz (SiO2), hematite (Fe2O3), gypsum ($CaSO_4.2H_2O$), and magnetite (Fe_3O_4) (Hanson and Helmke, 1979). Another option would be the use of coal from other sources (primarily western reserves) with characteristically lower ash and lower sulfur content. Western coal fly ash is typically composed of quartz , hematite , mullite (3Al2O3.2SiO2), anhydrite (CaSo4), periclase (MgO), Calcium Oxide (CaO), and thenardite (NaSO4). Coals with the characteristics listed in Table VI are assumed for purposes of comparison.

Switching from high ash/high sulfur coal to lower ash/lower sulfur content coal would have the effect of reducing the volume of ash to be managed both directly and indirectly, through lower ash production and lower limestone demand because of more calcium and less sulfur in the coal (Villaume and Ripp, 1986). The cost of reducing ash produced in the boiler by switching to lower ash content coal has been calculated using the model coals with the characteristics and cost differential of $13.50 per ton, as identified in Table VI.

TABLE VI

COST OF COAL SWITCHING

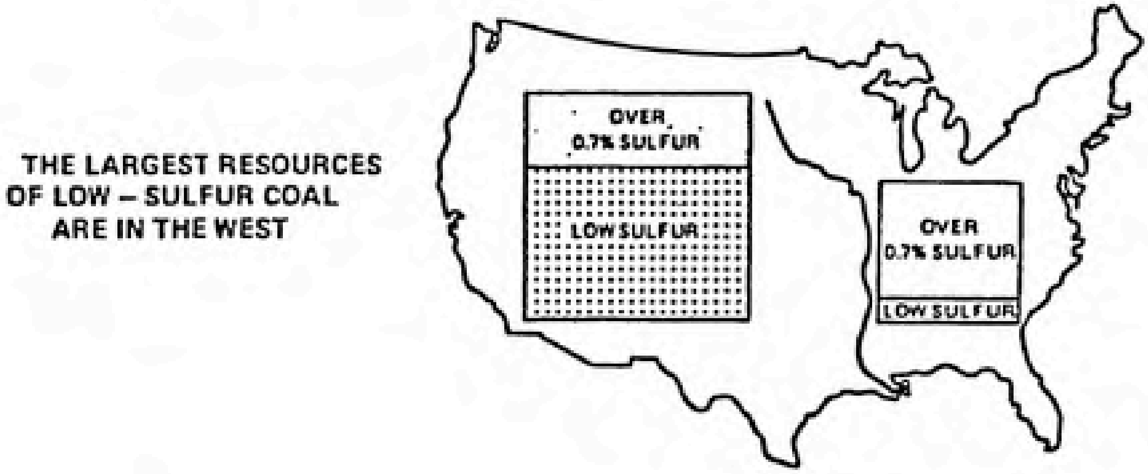
		high sulfur	low sulfur
Avg. coal heating value	=	12,600 Btu/lb	13,500 Btu/lb
Avg. coal sulfur content	=	2.0 %	0.7 %
Avg. coal ash content	=	13 %	6 %
Avg coal cost	=	\$32.50/ton	\$46.00/ton
Avg. cost / energy unit	=	\$1.30 /10^6 Btu	\$1.70 /10^6Btu
(1)**cost differential	=	\$0.40/10^6 Btu	
Avg. ash/energy unit	=	10 lb/10^6 Btu	4.4 lb/10^6 Btu
(2)**ash differential	=	5.6 lb/10^6 Btu	
(3)**ash differential cost from (1) & (2)	=	\$0.40/5.6 lb	
(3a)**	=	\$143.00/Ton	

****

Avg. limestone usage (@ 2:1 Ca to S)	=	12 lb/10^6 Btu	4 lb/10^6 Btu
(4)**limestone use differential	=	8 lbs/10^6 Btu	
Avg lime cost/energy unit (@ \$50.00/T 95% Ca)	=	\$0.30/10^6 Btu	\$0.10/10^6 Btu
(5)**lime cost differential	=	\$0.20/10^6 Btu	
(6)**energy consumption for (3a)	=	357 X 10^6 Btu	
(6a)**cost savings for (6)	=	357 X \$0.20 = \$71.4	
(6b)**lime savings for (6)	=	357 X 8 lbs = 1.4 Tons	
SWITCHING DIFFERENTIAL	=	\$143.00 - 71.00 / 1 + 1.4 Tons	
from (3a), (6a) & (6b)	=	\$30.00/Ton	

Burning the amount of model coals required to obtain a one ton differential of ash would result in a cost differential of $143.00, and given the characteristics of the model coal, a passive decrease of 1.4 tons of solid waste is obtained through lower limestone demand of the lower ash coal. At a limestone cost of $50.00 per ton, this nets a savings of $70.00 bringing the overall cost to reduce 2.4 tons of residue to $73.00 or $30.14 per ton of residue reduced. This value ($30.14) is taken to be the cost per ton of reducing ash through switching from the high ash to low ash coal. The same types of calculations could be performed for any available coal type at its current market value. This cost increase for burning low ash low sulfur coal over the cost of the high ash/high sulfur coal is due in part to the higher transport distances associated with the low sulfur coal, most of which is mined in western states (Figure 5). However, this low ash, low sulfur coal is also higher in price due to market imperfections caused by the number of consumers switching to this type of coal in order to comply with sulfur emissions standards in the clean air act. This demand for high quality "compliance" coal has led to prices higher than would be observed under truly competitive conditions (Bernknopf, 1985).

Figure 5



(from National Commission on Materials and Policy, 1973)

FBC is a technological advancement that has as one of its primary developmental incentives, the ability to meet clean air requirements without having to rely on burning low sulfur coal, and hence, can operate efficiently at over 90 % free of regulated emissions while burning any conveniently located fuel on the market. This speaks to the problem of curbing sulfur deposition without fueling the income distribution controversy.

The question of whether switching coal types is a feasible alternative for reducing the volume of ash requiring disposal is dependent on market conditions for coal as well as compares with the cost to landfill. Under current conditions, this is not an economically sound option. By monitoring the cost differential between the coal types, and comparing the cost to reduce ash at those market prices to the cost of disposing of ash by the best alternative, it can easily be determined if switching to low ash coal is economical. From the calculations in Table VI it can be assumed that if market conditions for coal are stable, switching to the coal type identified would not be a viable option unless the best alternative for managing the ash carried a price of $96.50 or higher. Under current practices of landfilling the ash at $5.00 per ton, the low ash coal would have to dip to $33.10 for switching to make sense economically. This type of analysis could be carried out on all available fuels with the result being a quick and easy index of cost effectiveness in reduction of ash through fuel switching.

SORBENT REGENERATION

A considerable portion of the residue from a CFC boiler is comprised of the limestone used as a sorbent for removing sulfur dioxide (SO_2)..The limestone is typically removed from the boiler after its sorbent capacity has been spent, or used up, however, regeneration of sorbent for FBC units has been shown to be feasible on a pilot scale, minimizing both the need for new sorbent for SO_2 removal and decreasing the spent sorbent disposal problem. The regeneration involves an additional process step, using known technology to remove the SO2 from the limestone sorbent (MITRE Corp., 1979). The general reaction is:

$$CaSo_4 + H_2 \dashrightarrow CaO + H_2O + SO_2 \quad \text{or}$$

$$CaSO_4 + CO \dashrightarrow CaO + CO_2 + SO_2$$

The operation is done in the bed by increasing bed temperature to about 1200o F while reducing the excess air to allow the bed to go to reducing conditions. The limestone is limited to only a few recycles, but one pilot plant was able to reduce the limestone input by a factor of about four during a continuous operating period of 5 days. More durable sorbents may be able to be developed.

ENERGY CONSERVATION

The amount of ash produced is directly proportional to the quantity of coal combusted in the boiler (assuming constant boiler and coal types), which in turn is directly proportional to the energy demand on the system and the efficiency with which that system supplies the energy demanded. Many operation and maintenance factors affect system efficiency. The incorporation of the usual screw-type ash cooler into the plant is but an example of the potential for gaining a calculable efficiency through recapturing some of the heat of combustion which would be lost to the environment under current design (Johnson, et al.).

UNC has already undertaken some measures to conserve energy including the incorporation of a new chiller plant, computerized automation of energy management, and the replacement power plant itself. Beyond these large scale measures, the cost of a university-wide energy conservation and efficiency program may pay for itself many times over through the life of the plant both directly through savings in fuel and indirectly by reducing maintenance of the system, and by reducing the amount of ash requiring disposal and hence the cost, both monetarily and environmentally.

Programs such as an energy education program to develop awareness of the benefits of conserving energy, and a uniform energy accounting system to be established in every building to identify the most and least efficient buildings (Garrett, et al., 1976) are just a few examples of the many little things which can lead to reduced energy consumption, and hence, less ash production. A one time expense per building per energy saving tactic results in long term reduced demand by that building, and therefore, less by way of a continuing commitment.

Energy saved through investments in energy conservative measures and replacing inefficient equipment with new efficient equipment which is readily available, often costs less than producing that amount of energy which was saved. Examples of such investments include replacing older refrigeration units with newer units requiring as little as one third as much electricity to do the same work and replacing inefficient incandescent light bulbs with new compact fluorescent bulbs. One program estimated the potential to save up to 80 percent of lighting energy in office buildings through conservative measures (Reisner, 1987).

MODE III: RECLAMATION OF ASH

Since the first Ash Utilization Symposium, held in March 1967 and sponsored by the Edison Electric Institute (EEI), National Coal Association (NCA) and the U.S. Bureau of Mines, the percentage of total ash produced which is utilized instead of disposed of with no utilization has increased from 7.9 (1966) to 23.5 (1985) percent for fly ash and 21.0 (1966) to 31.1 (1985) percent for bottom ash (ACCA, 1986; see Table VII) These figures show that fly ash realizes three times the reclamation potential as bottom ash. Additionally, the applications are far more numerous for fly ash than for bottom ash. The mixing of fly ash with bottom ash changes the characteristics of the resultant mixture sufficiently to eliminate many of the potential uses for either had they been maintained separately. Even applications suitable for mixtures are not as valuable or as widespread if there is no control over the mixture ratios or consistency. These considerations can only be met where separate handling and storage facilities are provided for qualitatively different ash stock intended for reclamation enabling separation from unusable ash destined for disposal.

Much research and development effort has gone into finding and implementing numerous means of reclaiming coal ash for productive use. The American Coal Ash Association (ACAA) was formed as a result of that symposium with the objective of promoting the use of ash, to transfer information on such and to generate a favorable climate for its acceptance as a resource.

TABLE VII

ASH PRODUCTION/ASH UTILIZATION

	*1966	1980	1981	1982	1983	1984	1985
Ash Produced							
Fly Ash	17.1	48.31	50.26	47.91	47.15	51.32	48.31
Bottom Ash	8.1	14.45	12.87	13.13	12.73	13.62	13.15
Boiler Slag	-0-	3.64	5.18	4.37	3.94	4.21	3.65
TOTAL ASH PRODUCED	**25.2**	**66.40**	**68.31**	**65.41**	**63.82**	**69.15**	**65.11**
Ash Utilized							
Fly Ash	1.4	6.42	9.41	7.95	7.52	10.43	11.39
Bottom Ash	1.7	4.26	4.07	3.63	2.76	2.96	4.10
Boiler Slag	-0-	1.75	2.93	1.97	2.53	2.65	2.38
TOTAL ASH UTILIZED	**3.1**	**12.43**	**16.41**	**13.55**	**12.81**	**16.04**	**17.87**
Percent of Ash Utilized							
% Fly Ash	7.9	13.3	19.0	16.6	15.9	20.3	23.5
% Bottom Ash	21.0	29.5	32.0	27.6	21.6	21.7	31.1
% Boiler Slag	-0-	48.1	57.0	45.1	64.2	62.9	65.2
PERCENT OF TOTAL ASH UTILIZED	**12.1**	**18.7**	**24.0**	**20.7**	**20.0**	**23.1**	**27.4**

*First year that data was taken

1967-1979 data omitted from tabulation because of space limitation

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8 1 86

Even with the availability of recovered fly ash, rallying by interest groups, and increased knowledge of its performance, there is no market for ash unless there is a use. Prices that can be expected from sale of ash depend on the economics of the material resources it is replacing, state of technology, and the attitude of the government and public towards recycling of waste (National Commission on Materials Policy, 1973). In many areas there may be market saturation from competing ash producers resulting in low prices or even no receptor for the ash at all. In any event, there is a realizable direct benefit in donating the ash to a willing receptor, particularly one who is willing to haul it away free of charge.

The Federal Government has taken the initiative to encourage the use of ash from coal combustion as a resource. A rule of the Federal Highway Administration (Federal Register, January 28, 1983) that went into effect in 1986 has had a marked effect on the acceptance of ash in highway construction. All states now have revised specifications in place to allow its use, with one state (Alabama) actually requiring its use (Vandenberg, 1987). Additional incentive was keyed into this year's Highway Bill passed by Congress which attaches a 5 % bonus in highway assistance funds for use of fly ash in concrete.

The suitability of fly ash as an additive in portland cement mixes has been known since 1914 (Boles, 1987). Fly ash affects concrete mixtures in a number of beneficial ways. Of primary consideration is the reaction between fly ash (and other pozzolanic materials) and the lime of hydration (calcium hydroxide) in portland cement mixtures resulting in increased strength as the concrete cures (Boles, 1987; Hatfield, 1987).

Pozzolanic character is a chemical property of fly ash of great interest to researchers and of extreme importance in determining the suitability of ash as structural material. Pozzolanic (lime-base) reactions in ash are the result of water coming in contact with the ash and reacting with the alumina and silica to form insoluble compounds. Ash from FBC has enhanced pozzolanic characteristics due to the presence of higher concentrations of unreacted or free Calcium, input as limestone for absorption (Leming, 1987). The chemical reactions involved in this process occur on the surface of the ash, and hence the pozzolanic activity of the ash increases with increased surface area to volume ratios - i.e. smaller particle size ash (Smith and Raba, 1980). Because of the recycling feature of the CFC type of plant, fly ash from these plants is generally of smaller particle size distribution than from conventional plants before it can escape the cyclone. Particle size distribution can be controlled in these systems by controlling air flow rates, and subsequently pressure within the cyclone, which is the determining factor for what size particle passes out to the baghouses.

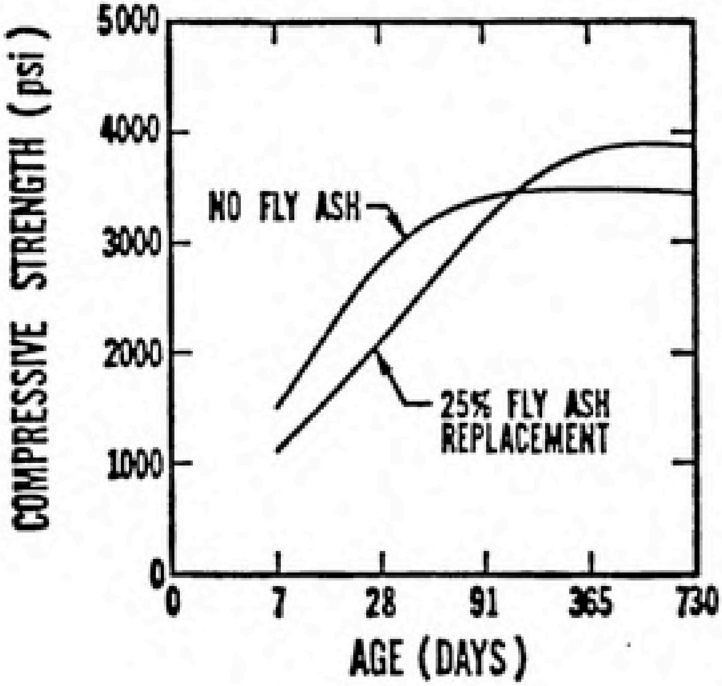
Carbon content and variability of the fly ash are problems associated with its use in a pozzolanic mix design (Smith and Raba, 1980). The carbon content is measured by the amount of ash lost on ignition and has a strong inverse relationship to the degree of air entrained in a fly ash - concrete mix. The carbon is in the form of unburned coal or inorganic carbon, and by absorption of the air-entraining agents during transport of the concrete can have the effect of changing original specifications of the mix. This has no detrimental effect on the concrete other than to dilute the pozzolanic material (Smith and Raba, 1980), and through modifications in combustion conditions can be altered to desirable specifications. These changes can be made without additional process or refining equipment. They involve approaching the production of byproduct to intentionally enhance the recyclability while designing out potentially hazardous materials (Jacobs, 1987).

The applications of fly ash as an additive to replace portland cement in concrete mixtures include: 1.) Ready-mix concrete, 2.) precast concrete products, 3.) aerated insulating concrete, and 4.) lightweight concrete. There are a number of advantages to be gained directly by adding fly ash to a mix design:

HIGHER ULTIMATE STRENGTH is imparted to concrete mixes by the addition of fly ash over those mixes with equivalent water to cement ratios, but without fly ash (Figure 6). The ultimate strength will be determined by the nature of the ash and the amount of ash added. Fineness or surface area of the ash (particle size) has perhaps the greatest effect on the strength of the mix. Concrete seems to have lower compressive strengths initially due to the rates of reactions, but properly designed and cured fly ash cement will exceed the strength of non-fly ash cement over time (Smith and Raba,1980)

Figure 6

EFFECT OF FLY ASH ON COMPRESSIVE STRENGTH

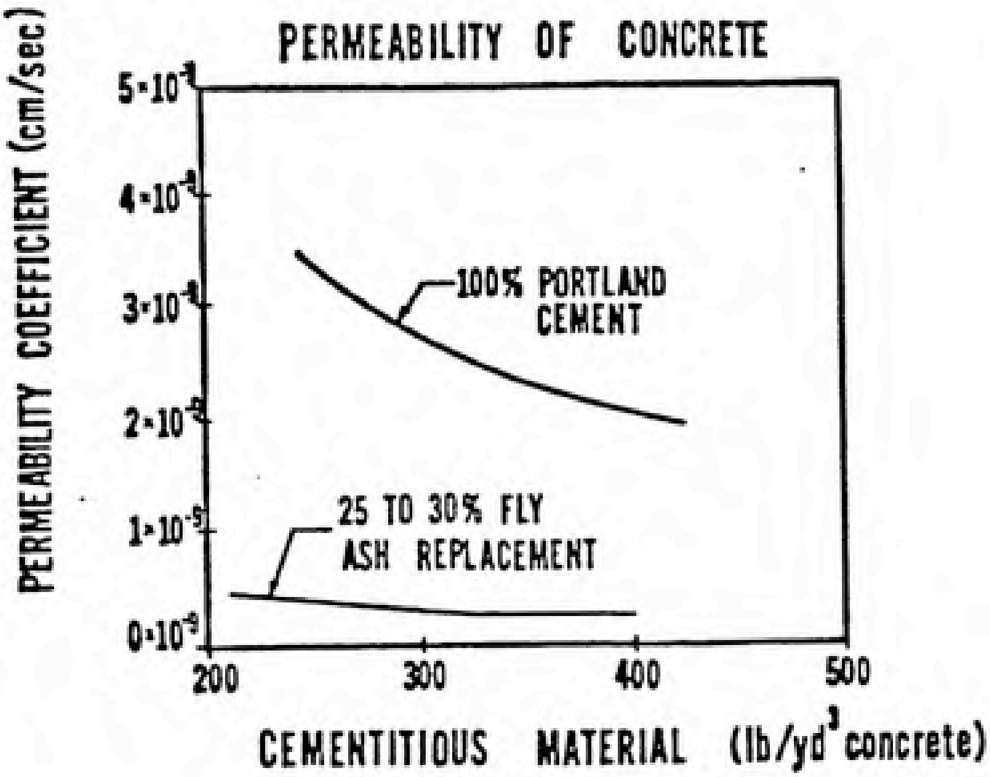


REF. TUTHILL, L.H., 1978

INCREASED RESISTANCE TO CHEMICAL ATTACK is achieved by adding 20 to 30 % of a good pozzolan (eg. fly ash) which reacts with the free lime to form an insoluble lime silicate. Lime in standard concrete readily dissolves in water which can result in the deterioration of the cement structure, particularly under conditions of an acidic environment (Smith and Raba, 1980).

LOWER PERMEABILITY is important where chemical attack (sea water, soil solutions, sewage, acid precipitation) on the structure is a consideration. The pozzolanic reaction tends to seal of the pore structure of the concrete, with the degree of permeability being proportional to the fineness of the fly ash (see Figure 7).

Figure 7



REF. NICKERSON, E.C., 1962

IMPROVED WORKABILITY is gained in fly ash concrete mixes owing to the increased plasticity of the mix resulting from the spherical shape of the ash particle. The lower water requirement of the fly ash cement results in less cracking and shrinkage. The spherical particles also allow the concrete to more completely fill voids and forms increasing the architectural versatility of the cement (Smith and Raba).

LOWER HEAT OF HYDRATION of cement with fly ash as additive is an important consideration in major pours such as dams and bridges, in that it dries more regularly, requires less artificial cooling and results in less cracking and shrinkage. Decrease in heat of hydration is dependent on the quantity and quality of fly ash used.

REDUCED ALKALI-AGGREGATE EXPANSION is an important benefit of adding fly ash which combines with the alkalies in the cement making them unavailable for reacting with the aggregate. Increased fineness of the ash increases its ability to decrease expansion of this type (Smith and Raba, 1980).

LOWER COST OF PRODUCTION of concrete can be achieved through adding fly ash, which usually sells for a third to half the cost of Portland cement. This can result in a savings of $1 TO $2 per cubic yard of concrete and the value of conserving virgin Portland cement (Boles, 1987)

In addition to use in cement mixtures, there are a number of construction/structural applications suitable for utilization of fly ash as a partial or complete substitute which depend upon some or all of the above characteristics to determine the suitability. These uses include the use of fly ash as a material in the manufacture of materials such as brick, block, portland cement, mineral wool insulation, and grouting. Old standards limited the addition of fly ash to about 40 % of the total mix (Leming, 1987), but recent research and testing at the Kentucky Energy Cabinet and TVA have shown that these limits are not necessary. These researchers have used fly ash and spent bed material from FBC to completely replace portland cement and river sand in a "cementless concrete" mix which compares favorably with standard concrete regarding hardness and surpasses standard concrete in a number of other qualities (Bland, et al., 1987)

Quality of fly ash is related to the operational characteristics of the plant. Modern power plants seem to generate consistently high quality fly ash. A number of organizations set specifications for fly ash to be used in concrete materials, including Association of Standards for Testing Materials (ASTM), (ANSI), Corps of Engineers (COE), Bureau of Reclamation (Water and Power Resources Service), state highway departments, and individual projects such as dams and nuclear power plant projects. Parameters which are most frequently specified are fineness and loss on ignition, as they effect product performance most significantly. Some chemical characteristics and performance indicators are also specified in some instances (Smith and Raba, 1980)

A study by EPRI (1984) of seven coal samples indicates that pozzolanic activity, and hence the attractiveness of ash as a construction material, are related to a number of variables including:

1. coal source and furnace type
2. calcium content of coal (other chemical constituents had little or no influence.
3. particle size distribution
4. combustion efficiency
5. carbon content

Ash may be suitable as a structural fill for some applications listed in Table VIII dependent on the quality of the ash and specifications of each job. For more information on applicability of this alternative see the Fly Ash Structural Fill Handbook prepared by the Electric Power Research Institute (EPRI, 1984). The extent of the market for any of these applications will be dependent upon the volume of growth and development (including highway construction) at any particular time, and on the availability of alternate sources of suitable material.

This can not be predicted with any certainty, but it seems that the potential does exist in this region of the state for at least the first few years of the plant operating life.

TABLE VIII

STRUCTURAL FILL/STABILIZATION APPLICATIONS OF ASH

AGGREGATE
- HIGHWAY SUBGRADE STABILIZATION
- ROAD BASE
- LIGHTWEIGHT AGGREGATE

FILLER
- ASPHALTIC CONCRETE
- PLASTICS

BACKFILL MATERIAL
- STRUCTURAL FILL
- CONTROLLED DENSITY BACKFILL

Researchers within the utilities industry are continuously searching for other new directions for diversion of ash from landfill disposal. Some of the newest applications with correspondingly little information as to their suitability, particularly for CFC ash, are listed in Table IX. The options involve only a small percentage of the total ash produced, and may be unacceptable environmentally or on the basis of the quality of ash. No recommendation is made to pursue any of these without more information. They are provided here to complete the survey of options. These options all involve limited, specialized opportunities. Though none could be relied on for long term arrangements and/or large quantities, some exhibit some promise and the potential for the opportunity to divert some portion of the waste from more expensive disposal options. These probably do not represent marketing options, but more likely would involve donation of the material with the derived benefit being reduction of disposal costs relative to the amount diverted. Limitations for each are based on one or a combination of the three factors listed in the last column: environmental acceptability (E), information deficit (I) or marketing limitations (M).

TABLE IX

MISCELLANEOUS INNOVATIONS IN ASH UTILIZATION

OPTIONS	POTENTIAL	LIMIT
RESOURCE RECOVERY		
METAL RECLAMATION	LIMITED	M
SOURCE OF CENOSPHERES	LIMITED	M
WASTE TREATMENT OR STABILIZATION		
OIL SPILL ABSORBANT	LIMITED	E,I
INSULATING OIL FILTRANT	POOR	E
SLUDGE DEWATERING AGENT	HIGH	E,M
LANDFILL COVER/LINER	HIGH	E,M
SULFATE SLUDGE FIXATIVE	LIMITED	I,M
OTHER APPLICATIONS		
MOLDING SAND ADDITIVE	LIMITED	M
SOIL AMELIORATION	MEDIUM	E,M,I
MINE FIRE EXTINGUISHER	LIMITED	M
MINE SUBSIDENCE	HIGH	M

The number of applications for reclamation of good quality fly ash is continuing to increase as more and more is produced and as standards allowing its use are loosened. Most applications, especially any that involve a market return of the ash, require that the ash meet quite stringent quality control specifications. The general rule is that bottom ash and mixtures of bottom and fly ash do not meet these requirements, due either to chemical composition or particle size. The UNC power plant is designed to handle the bottom and fly ash with the same system and store it in a single silo. This essentially eliminates this ash from utilization in most of the applications addressed to this point. There are, however, a limited number of applications for bottom ash and mixtures of bottom and fly ash. These are listed in Table X with a notation regarding the applicability to bottom or mixes.

Coal bottom ash has been used in unknown quantities for increasing road traction on snow and ice covered roads. Though this may be a readily available material for this application, CFC ash would be less suitable for this application due to its smaller particle size, and therefore lowered ability to impart traction enhancement. From an environmental standpoint, this is a careless method of scattering the ash subject to being readily washed off into surface waters with potential contamination of those waters by the metals. This is an option which would be restricted seasonally and very limited in the southeast.

TABLE X

BOTTOM/MIXED ASH UTILIZATION OPTIONS

APPLICATION	BOTTOM	MIX
COLD MIX ASPHALT AGGREGATE	X	
PORTLAND CEMENT HIGHWAY BASE AGGREGATE	X	
BITUMINOUS HIGHWAY BASE INGREDIENT	X	
GRIT FOR ICE-COVERED ROADS	X	X
FILTER MATERIAL	X	
STRUCTURAL FILL	X	X

The number of uses for fly ash and bottom ash continues to attract research attention to determine the suitability of ashes from FBC units in conventional ash applications as well as new ones.

MARKETING ARRANGEMENTS

The range of options for how ash management is handled, particularly marketing options include management in-house or through a broker. The broker is an individual or firm functioning as the marketing specialist for the byproduct, through developing, assessing and utilizing information about the characteristics of the applicable markets (Jacobs, 1987). It becomes the broker's responsibility to stay abreast of the local, state and federal regulations which apply to the waste.

Many large utility companies and some of the smaller generators of coal ash have entered into contractual arrangements with ash brokerage firms. These ash brokers contract to take the ash from the generator and pursue the potential market for ash as a resource, and store or dispose of that amount of ash which is not marketable for quality considerations, or for reasons relating to demand. The same functions could be carried out by trained in-house staff. The benefits include the potential of a contractual arrangement for all or some of the ash for a set time period, and the elimination of the need to employ or train UNC staff to operate essentially as a broker. The cost is the loss to a broker any potential profit from marketable ash and quite likely, a higher cost to employ a broker than staff to perform the same operation. Brokerage firms may not even be interested in UNC ash due to the low volume, and almost certainly would not be interested if the mixed handling and storage were utilized.

For some reclamation options, the prospective receptor of the ash may be very willing to perform necessary testing and assume responsibility for handling and transporting the ash. In such a situation, donation of the ash will still result in a net profit to the University through reduced handling, transportation, and disposal costs.

CONCLUSIONS

The trend toward managing ash as a resource has as an incentive profits as well as saved disposal costs. Growth in this field is evident in the formation of The American Coal Ash Association (ACAA), to promote the innovative reuse of ash. The economic incentive is sufficient for the spread of brokers specializing in ash. The level of involvement the University can hope for in this arena is dependent on the way the next set of questions are addressed.

Ash management alternatives, most of which are identified in this report, are numerous and diverse. Based on the specifics of this plant and peculiarities of the University system, a number of options drop out of the picture. Many more depend on a very few decisions. The following conclusions can be made at this time regarding ash management alternatives, and specific requirements of the University regarding ash from the replacement power plant:

Ash management should follow three simultaneous modes of focus. The first line of approach is to assure that ultimate disposal is available and feasible. The second is to reduce the volume of ash to whatever degree is practical. The third approach is to channel into resource pools any portion of the ash for which there is a market.

RCRA REGULATION

EPA is prohibited from regulating coal ash as hazardous until they make an industry wide determination whether or not to classify power plant wastes as hazardous. EPA Office of Policy Analysis staff predict that ash will not be regulated as hazardous waste. UNC will need to test ash for hazardous characteristics after the plant is in operation.

Buffering capabilities of the lime used in the boiler would tend to bind the metals more completely to the ash, and inhibit leaching into the groundwater relative to conventional power plant ash. The nature of the CFC process virtually assures that the ash will not be hazardous on the basis of corrosivity.

STATE REGULATION

Management will require proceeding with the understanding that the next few years could bring significant change to the way this issue is viewed. North Carolina currently requires monofill operations for high volume generators of ash, and anticipates banning mixed landfilling of ash and municipal waste. Internally imposed controls stricter than current regulations avoid retrofitting.

DISPOSAL

Some assured disposal option is needed for the ash generated throughout the life of the plant. Sluicing is not an acceptable or feasible practice for the UNC facility. Disposing of ash slurry in an unlined landfill is not an acceptable practice.

Return to mine site seems to be the most attractive option for ultimate disposal of the non-recoverable portion of the ash. Coal suppliers to UNC have indicated a willingness to provide mine site disposal service. The UNC contracts for coal supply could be modified to include mine site disposal linked to the supply contract.

Physical and chemical characteristics indicate that dry ash, particularly that from FBC plants, would be physically stable for landfilling. There is increasing evidence that ash is valuable for stabilization of other landfill waste. Landfilling costs are expected to rise sharply requiring municipalities to increase general fund subsidies or landfill tipping fees.

The University is currently a legitimate patron of solid waste disposal facilities offered to the community in general. Characteristics of power plant ash may require special handling for which the University should expect to defray the costs.

AVOIDED DISPOSAL

Cost for disposal of each ton of ash will be higher in the future, regardless of the approach taken. Reduction of ash volume has benefits in saved handling, transportation, and disposal costs.

Many potential options exist for reclamation of ash as a useful resource. The market for ash is volatile and will provide opportunities to use variable amounts of the ash at various times. Marketing options include management in-house or through a broker. Donation of ash results in a net benefit through reduced handling, transportation, and disposal costs.

It is with these thoughts in mind that the following recommendations are made to the University of North Carolina for the next level of preparation for putting the replacement power plant on line.

RECOMMENDATIONS

ONE: UNC should monitor EPA and NC Solid and Hazardous Waste Branch in order to anticipate changes in regulatory environment which might affect management strategy and implementation costs.

TWO: The University should develop the analytical capacity to enable the selection of an optimal mix of alternatives, variable with time, in order to maximize efficiency and diversion of waste from costly landfilling.

THREE: The University should employ a campus-wide energy conservation program, such as an educational agenda and building energy audits, to reduce energy consumption, and hence, ash production.

FOUR: UNC should develop the staff and resources necessary to anticipate regulatory and market conditions which affect the dynamics of reclaiming ash as a resource.

FIVE: UNC should incorporate opportunities for research into the planning, construction, and operation of the facility as a means to produce ash which is suitable for use as a resource.

SIX: UNC should incorporate into the design of the plant separate handling and storage facilities for keeping marketable quality ash separate from non-marketable ash.

SEVEN: UNC should pursue a cooperative arrangement with local public officials to include ash in future solid waste management planning.

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