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Management of Dry Flue Gas Desulfurization By-Products in Underground Mines

Topical Report
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EXECUTIVE SUMMARY

This topical report summarizes the findings in materials handling and system economics research of coal combustion by-product transportation and handling in an overall research project entitled "Management of Dry Flue Gas Desulfurization By-Products in Underground Mines." The overall research project, conducted under cooperative agreement DE-FC21-93MC-30252 between the U.S. Department of Energy and the Southern Illinois University at Carbondale, has been active since October, 1993. It will be completed by March, 1998.

Disposal of coal combustion by-products (CCBs) in an environmentally sound manner is a major issue facing the coal and utility industries in the U.S. today. Approximately, 90 million tons of CCBs are generated annually by the electric utility industry in the United States. Currently, only 1/3 of the generated by-products can be utilized, the remaining 2/3 is disposed of in surface facilities or landfills near the power plants. The cost of surface disposal is rapidly increasing, especially in and around urban areas. Also, surface disposal may negatively impact land use, land values, and surface and ground water over time.

Disposal into abandoned sections of underground coal mines may overcome many of the surface disposal problems along with added benefits such as mitigation of subsidence and acid mine drainage. However, many of the abandoned underground coal mines are located far from power plants, requiring long distance hauling of by-products which will significantly contribute to the cost of disposal. For underground disposal to be economically competitive, the transportation and handling cost must be minimized. This requires careful selection of the system and optimal design for efficient operation. The materials handling and system economics research addresses these issues.

Transportation and handling technologies for CCBs were investigated from technical, environmental and economic points of view. Five technologies were found promising: (1) Pneumatic Trucks (PT), (2) Pressure Differential Rail Cars (PD-car), (3) Collapsible Intermodal Containers (CIC), (4) Cylindrical Intermodal Tanks (CIT), and (5) Coal Hopper Cars with Automatic Retractable Tarping (CHC). The first two technologies are currently being utilized in transporting by-products from power plants to disposal sites, whereas the next three are either in development or in conceptualization phases. In this research project, engineering design and cost models were developed for the first four technologies. The engineering design models are in the form of spreadsheets and serve the purpose of determining efficient operating schedules and sizing of system components. The cost models provide the "annualized costs" of the systems and "cost-per-ton" of material transported. The developed models were arranged in form of templates for the selected technologies to make their use as practical as possible.

In this report, a review of physical, chemical and engineering characteristics of CCBs is given along with current surface disposal practices. The operating scenarios developed for the selected technologies and the corresponding engineering design and cost models are described. Hypothetical cases applicable to southern and central Illinois are evaluated using the developed software, and the results are reported as a comparative analysis whereby

favorable operating ranges of each technology are determined in terms of distances and tonnage. Finally, a case study, involving the hydraulic and pneumatic placement demonstration, planned within the overall project, is described and the results of its engineering design and economic evaluation are reported.

Through the comparative analysis of the hypothetical cases, it was found that the cost of the PT transportation was very sensitive to distance but insensitive to tonnage, whereas, the opposite was true for the other technologies. When 50,000 tons of by-product was considered annually, it was found that the PT technology would give lower delivery costs up to approximately 70 miles compared to PD-Car and CIT, and up to 110 miles compared to CIC. At 100,000 tons, the PT technology would be better than CIT up to 45 miles, and better than CIC and CIT up to 65 miles. At 200,000 tons, the PT technology was better than the others only at distances of less than 30 miles. The delivery costs for all three tonnage are shown in Table 1 in terms of c/ton/mile.

Table 1. Cost of by-product delivery from power plants to mines using environmentally acceptable transportation technologies

Production (tons/year)	**Distance (miles)**	**TRANSPORTATION TECHNOLOGIES**			
		PD-car (c/ton/mile)	**PT** (c/ton/mile)	**CIC** (c/ton/mile)	**CIT** (c/ton/mile)
50,000	30	30.0	13.7	39.9	31.7
	100	7.41	9.34	12.37	11.08
	200	4.89	8.46	6.57	6.73
100,000	30	25.7	11.9	27.5	23.6
	100	9.28	9.01	8.64	8.64
	200	5.82	8.19	4.62	5.51
200,000	30	16.67	10.1	17.63	16.5
	100	6.46	7.71	5.66	6.41
	200	4.34	7.05	3.11	4.31

The cost of undergound placement was also determined for all three annual tonnage considered above. It was found that it will cost $2.48, $2.33, and $2.25 to place one ton of CCB when the annual tonnage is 50,000, 100,000, and 200,000 tons, respectively. The slight decrease in cost as the tonnage increases is explained by the effect of the economies of scale. The placement cost can be added to the transportation and handling cost to obtain the overall cost. For instance, when 100,000 tons of CCB is transported annually to a placement site 30 miles away, it will cost $3.57 (11.90 c/ton/mile x 30 miles / 100 c/$) to transport and $2.33 to place one ton of CCB, giving a total of $5.90/ton.

The results of the economic evaluations were examined for the shares of the capital and operating cost components in the overall costs. It was found that the CIC and CIT technologies are most capital intensive technologies where capital cost constituted approximately 70% of the cost-per-ton of CCB transported and placed. In contrast to these two technologies, the PT technology was found to be operating-cost driven, where the cost-per-ton was composed of approximately 75% operating cost and 25% capital cost. The CIT technology showed a balanced cost composition with 50% capital cost and 50% operating cost.

A case study was conducted for the Peabody No. 10 mine in Pawnee, Illinois, which was chosen for underground placement demonstration as a part of the overall research project. It was assumed that the project would have a life of 10 years, and that annually 100,000 tons of by-product for hydraulic placement would come from Dallman plant of City Water, Light, Power (CWLP) company in Springfield, Illinois, located 25 miles north of the mine. For pneumatic placement case, it was assumed that annually 100,000 tons of by-product would come from the Decatur plant of Archer Daniels Midland Company (ADM), located 65 miles northeast of the mine. The PT technology was chosen for the transport of the by-products since the distances of the plants to the mine remained within the favorable range of this technology. It was found that it would cost approximately $6.0 per ton to transport and hydraulically place the by-product from the CWLP Dallman plant. Similarly, it would cost about $8.0 per ton to transport and pneumatically place the by-product from ADM plant. The underground placement cost alone was found to be about $2.50 per ton in both cases, although pneumatic placement cost was slightly lower than the hydraulic placement. It was also found, in both scenarios, that the operating cost constituted almost 80% of the total cost.

The transportation and handling costs given above for the hypothetical cases are based on the system operating scenarios, cost estimates, and a number of assumptions. Also, the placement cost is calculated based on the assumption that 10,000 tons of CCB can be injected through a borehole. A better estimate of this tonnage will be available after the completion of the placement demonstration at the Peabody No. 10 mine as planned in the DOE-SIUC cooperative agreement. It is important to note that the capital and operating cost estimates of the underground placement system are the first time estimates, and the researches are currently working on the improvement of the system as well as on the cost estimates. Therefore, the results given in this report should be interpreted cautiously. The emphasis, however, should be on the software developed in this research. This software is general enough to be used in evaluating any transportation technology as long as that technology can be identified with one of the selected technologies. For instance, any type of truck transportation can be evaluated using the template developed for the PT system. Similarly, any rail car transportation can be evaluated using the template developed for the PD-car system.

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1.0 INTRODUCTION

Approximately, 90 million tons of CCBs (fly ash, bottom ash, scrubber sludge) are generated annually by the U.S. electric utility industry (ACAA, 1993). This amount is expected to increase significantly after 1995 due to Clean Air Act Amendment of 1990. Disposal of these by-products in an environmentally sound manner has become a major issue for the utility industry. Most of today's by-products are disposed of in surface facilities, or landfills, near power plants. Surface disposal is becoming more and more expensive, especially in and around urban areas, and also bears over time the potential to negatively impact not only land use and land values, but also surface and ground water quality. Disposal of by-products into abandoned sections of underground coal mines appears to be a promising alternative whereby most of the disadvantages of surface disposal could be overcome (Sevim et al., 1992). Furthermore, when fluidized gas desulfurization (FGD) by-products from advanced combustion processes are used in backfilling the voids, subsidence and acid mine drainage -- two major problems resulting from underground coal mining -- may be significantly reduced due to the cementitious characteristic and alkalinity of these by-products (Meiers et al., 1995).

Recognizing these potential advantages, on September 30, 1993, the U.S. Department of Energy (DOE) entered into a cooperative research agreement with Southern Illinois University at Carbondale (SIUC) to investigate the engineering, environmental, and economic feasibility of disposing of coal combustion by-products (CCBs) into abandoned sections of underground coal mines. Although the investigation focuses on the Illinois coal basin, the findings can easily be projected to other coal producing areas. The project has been progressing in six (6) branches since September, 1993, and is expected to be completed in March, 1998. The six branches are: 1) By-products and Mix Characterization, 2) Materials Handling and System Economics, 3) Underground Placement, 4) Environmental Monitoring and Assessment, 5) Health and Safety Issues and Permitting, and 6) Field Demonstration.

In this report, the findings and developments in Materials Handling and System Economics research are presented. The term "materials handling" includes loading, transporting, unloading, and temporary storage of the dry coal combustion residues for the purpose of placing them in abandoned areas of the underground coal mines in Illinois.

The objectives of the materials handling research are defined as follows: 1) Identify the systems that are technically, economically, and environmentally feasible in handling and transporting the coal combustion by-products (CCBs) from the power plant to the underground placement site, 2) Demonstrate the operation of one or two of the identified systems.

The objectives of the system economics research are defined as follows: 1) Develop a generalized "Engineering Design and Economic Evaluation" model that can be used in evaluating various types of materials handling and underground placement systems, 2) Conduct economic analyses of the selected materials handling systems along with the underground placement system using the developed model, and 3) Conduct a case study for the hydraulic and pneumatic underground placement demonstration which is planned as a part of the overall research project

Although underground disposal presents a potential solution to disposal problem, many of the abandoned underground coal mines are located far from power plants, requiring long distance hauling of by-products which will significantly contribute to the cost of disposal. For underground disposal to be economically competitive, the transportation and handling (T&H) cost must be minimized while maintaining strict environmental compliance. This requires careful selection of the T&H system and efficient design of its components.

A number of T&H technologies, existing and futuristic, were examined to isolate those that are environmentally friendly. Altogether, five technologies were found to be promising:

1. Pneumatic Trucks (PT),
2. Pressure Differential Rail Cars (PD-car),
3. Collapsible Intermodal containers (CIC^{TM}),
4. Cylindrical Intermodal Tanks (CIT), and
5. Coal Hopper Cars with Automatic Retractable Tarping (CHC).

The first two technologies are currently being utilized in transporting by-products from power plants to disposal sites. The third technology, CIC, was developed by SEEC, Inc. as a part of the overall DOE-SIUC cooperative agreement. A field demonstration of CIC technology was held at the Illinois Power Company's Baldwin Power Plant on November 17, 1994. A final topical report entitled "The Development and Testing of Collapsible Intermodal Containers for the Handling and Transport of Coal Combustion Residues" was submitted to USDOE in July 1995 (Carpenter and Thomasson, 1995). The fourth technology is still under investigation whereas the fifth is in the conceptualization phase.

To achieve the cost-minimization objective through an efficient design, computer models were developed for each of the first four T&H technologies cited above. At this time, a separate model could not be developed for CHC technology due to lack of design and cost information. The developed models are comprised of three units:

1. Engineering design computations,
2. Capital and operating cost computations,
3. Economic evaluation.

A data bank comprised of engineering design information, capital costs of system components, and operating cost items was compiled for each technology and stored permanently to support the computations and entries in the above three units.

The engineering design unit of the model was coded using Microsoft EXCEL software. This unit is a spreadsheet whereby operating schedules composed of plant schedule, transportation schedule between the plant and the mine, and mine schedule, are devised; and critical system parameters such as silo capacities, number of transportation units, loading rate, transloading rate, injection rate are calculated for a given case. The second unit, capital and operating cost computations, was also developed as a spreadsheet using Microsoft EXCEL software. It receives information from the first unit and subsequently feeds the computed values of the operating and capital cost items to the "economic evaluation" unit. The economic evaluation unit was based on the "Net Cash Cost" method and it was coded using FORTRAN language. In this unit, values of economic decision criterion such as annual equivalent cost and cost-per-ton are calculated.

The cost computation units and the economic evaluation unit were configured "under one roof" using a rapid application development tool called "Delphi". This configuration facilitated the development of interactive Windows applications for the first four T&H technologies mentioned above. Also, to help the user visualize the system operation, a sketch of the system was drawn using Microsoft Power Point software and made part of the Windows application.

Materials handling systems are divided into four modules as seen in Figure 1.1. The first two modules constitute the Primary Materials Handling Systems where the storage, handling and loading of the CCBs at the plant site, and their transportation from the plant to the mine site are addressed. The next two modules constitute the Secondary Materials Handling Systems where the unloading, storage and handling of the CCBs at the mine site and their transportation to the underground placement site are addressed. The integrated software developed in this project follows exactly these modules as will be seen in Section 5 entitled "Development of an Integrated Software" where the software is presented. The fifth module,

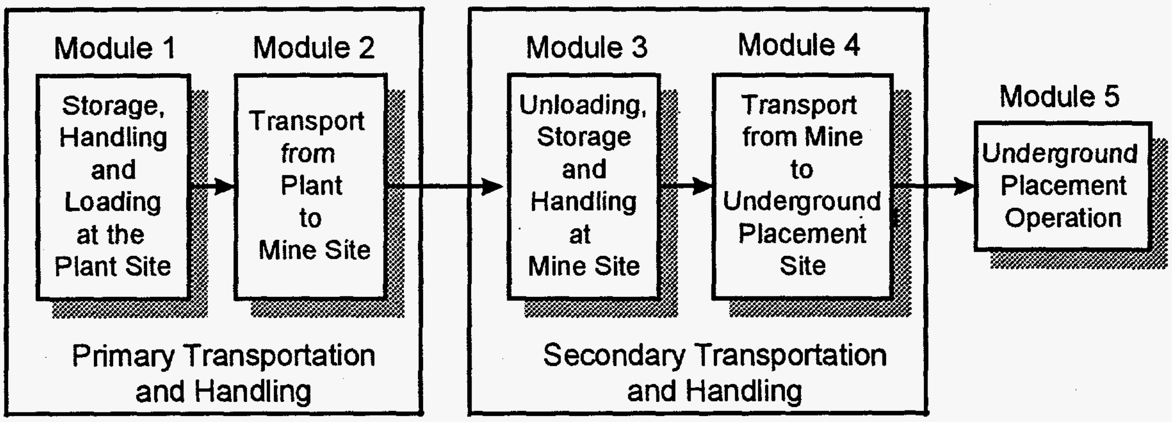


Figure 1. 1 Modules in transportation and handling of coal combustion by-products

underground placement operation, is being investigated by another group of researchers. However, the economics of the fifth module are made part of the integrated software.

The results of the materials handling research have been reported in different publications (Sevim and Gwamaka, 1995; Sevim, Lei and Gwakama, 1995; Sevim, Gwamaka and Lei, 1996; Sevim and Lei, 1996; Sevim, 1997). In addition to these publications, a master thesis entitled "Development of Simulation and Cost Models to Evaluate Coal Combustion Residue Transportation and Handling Systems" was completed (Gwamaka, 1996).

In this report, Section 2.0 covers a review of CCBs from materials handling point of view along with a review of the current surface disposal practices. The specific goals and objectives of the materials handling and system economics research are stated in Section 3.0. The T&H technologies suitable for long distance transportation and their environmental features are presented in Section 4.0. Those technologies that were found to be environmentally friendly are further elaborated for their operating scenarios developed in this research project. In Section 5.0, a brief description of the integrated software developed for the engineering design and economic evaluation of the selected technologies is given. Section 6.0 is devoted to the analysis of each environmentally friendly technologies using the operating scenarios and software specifically developed for them. As a natural extension of this section, a comparative analysis was conducted in order to reveal the favorable operating ranges of each technology in terms of distances and tonnage. In Section 7.0, a case study was conducted. This case study was considered in conjunction with the hydraulic and pneumatic placement demonstration that is planned in the overall research project. The demonstration will take place at the Peabody No. 10 mine near Pawnee, Illinois, during the summer of 1997. The by-product for hydraulic and pneumatic placements will come from the Dallman plant of City Water, Light, Power (CWLP) company in Springfield, Illinois, and from the Decatur plant of Archer Daniels Midland Company (ADM) in Illinois, respectively. Finally, in Section 8, a summary of the research results are given along with the conclusions.

2.0 GOALS AND SPECIFIC OBJECTIVES

The term "materials handling" in this research project includes loading, transporting, unloading, and temporary storage of the dry coal combustion by-products for the purpose of placing them in abandoned areas of the underground coal mines in Illinois. Materials handling systems have been analyzed in four consecutive modules: 1) storage, handling and loading of the by-products at the plant site, 2) transportation from the plant to the mine site, 3) unloading, handling and storage at the mine site, and 4) transportation from the mine site to the injection site.

The objectives of the materials handling research are defined as follows: 1) Identify the systems that are technically, economically, and environmentally feasible in handling and transporting the coal combustion by-products (CCBs) from the power plant to the underground placement site, 2) Demonstrate the operation of one or two of the identified systems.

The objectives of the system economics research are defined as follows: 1) Develop a generalized "Engineering Design and Economic Evaluation" model that can be used in evaluating various types of materials handling and underground placement systems, 2) Conduct economic analyses of the selected materials handling systems along with the underground placement system using the developed model, and 3) Conduct a case study for the hydraulic and pneumatic underground placement demonstration which is planned as a part of the overall research project

In accordance with the above stated objectives, several transportation and handling technologies for coal combustion by-products were investigated from technical, environmental and economic points of view. Five technologies were found promising: (1) Pneumatic Trucks (PT), (2) Pressure Differential Rail Cars(PD-car), (3) Collapsible Intermodal Containers (CIC), (4) Cylindrical Intermodal Tanks (CIT), and (5) Coal Hopper Cars with Automatic Retractable Tarping (CHC). Among these technologies, engineering design and cost models were developed for the first four technologies. The fifth technology (CHC) was not amenable for such developments due to lack of cost and engineering data at this time. The developed software were used in the evaluation of a number of hypothetical cases as well as a case study.

The third technology, CIC, was developed by SEEC, Inc. as a part of the overall DOE-SIUC cooperative agreement. A field demonstration of CIC technology was held at the Illinois Power Company's Baldwin Power Plant on November 17, 1994. A final topical report entitled "The Development and Testing of Collapsible Intermodal Containers for the Handling and Transport of Coal Combustion Residues" was submitted to USDOE (Carpenter and Thomasson, 1995).

In addition to the quarterly and annual reports, one of the tasks of this segment of the research project was to submit a topical report on "Materials Handling and Systems Economics", which is accomplished with this report. Another deliverable is a user's manual for the software developed for the selected technologies. This manual will be delivered to USDOE in August, 1997.

Another objective of this research project was to train a graduate student in the area of "coal combustion by-product handling and transportation". Accordingly, Mr. Samual Gwamaka was trained in the Department of Mining Engineering from 1994 to 1996. He completed a master's thesis entitled "Development of Simulation and Cost Models to Evaluate Coal Combustion Residue Transportation and Handling Systems", in January, 1996.

3.0 COAL COMBUSTION BY-PRODUCTS AND THEIR SURFACE DISPOSAL

Understanding the chemical, mineralogical, physical, and engineering properties of the CCBs is important in designing and selecting the handling, transportation, and placement systems. The composition of the by-product is not only a function of the composition of the feed coal but it is also a function of the factors such as combustion process, collection equipment, degree of pulverization of the coal and temperature during combustion. The major constituents of the coal are carbon, hydrogen, oxygen, nitrogen, and sulfur. These elements typically account for 70 to 97 percent of the total, and are present in varying quantities. All of the major elements form gaseous compound when burned. There is also silicon, calcium, aluminum, iron, magnesium, along with some trace elements in coal. These elements survive the burning process by either forming oxides such as Fe_3O_4, Fe_2O_3, CaO, MgO, or by melting and forming crystalline and non-crystalline alumino-silicates. Coal ash is formed by these elements.

3.1 THE CCBS OF INTEREST

In this research project four types of CCBs are targeted:

(1) Conventional fly ash
(2) Scrubber sludge
(3) Fluidized Bed Combustion (FBC) fly ash
(4) Spent-bed ash

3.1.1 Conventional Fly Ash

Conventional fly ash is formed in furnaces where pulverized coal is burned. In these furnaces, temperature exceeds 1500°C, fusing the mineral impurities which form the coal ash. Approximately, 20 % of the fused matter fall to the bottom of the furnace where it is collected as "bottom ash". The remaining 80 % is carried to low temperature area of the furnace where it solidifies and forms crystalline and non-crystalline glassy matters which are subsequently carried out of the furnace in the flue gas. This material is called fly ash and is trapped in a baghouse or in an electrostatic precipitator. Since it is formed in the conventional burners it is called conventional fly ash, or in short CFA.

The CFA contains large quantities of silica (SiO_2), alumina (Al_2O_3) ferric oxide (Fe_2O_3), and smaller quantities of various other oxides and alkalies. There are two classes of CFAs: Class F and Class C. When silica, alumina, and ferric oxide constitute more than 70 % of the total weight, the ash is classified as Class F ash. When these elements constitutes 50 to 70 % of the total weight along with significant amount of CaO, the ash is classified as Class-C ash. A bituminous coal will always produce Class-F ash, but a sub-bituminous coal or lignite can produce either Class-C or Class-F ash depending on the calcium content in their composition (Tishmack, 1996).

The main factors to be considered in the transportation and handling of CFA are particle size, reaction with water, moisture content, abrasiveness, and corrosiveness.

The CFA is composed of very fine particles; typically, 65% of the particles are less than 0.01 mm (10 micron). The scanning electron microscope (SEM) images of a Class-C and a Class-F ash are shown in Figure 3.1 and 3.2, respectively. As seen, the particles are very small and they are predominantly spherical shape.

Typically, western sub-bituminous coal and lignite produce fly ash that contain more than 20% CaO (Class-C fly ash). In presence of sufficient water, CaO reacts with silicious and alumino-silicious materials to produce a cementitious product. This phenomenon is known as pozzolonic activity and the ash possessing this property is widely used in the cement industry. The eastern and mid-western coals, on the other hand, produce low calcium ashes which do not react with water. The pozzolonic property is important in the long distance transportation of the ashes due to the fact that, if the ash is in contact with water it may harden in the transport vessel causing severe problems during unloading.

The CFA that will be transported to the mine site will be silo-stored CFA typically with an average bulk density of 60 lb/ft^3 and moisture content of 3 to 5 %. The CFA can be abrasive since it is formed by amorphous particles with a specific gravity of approximately 2.5. Corrosiveness is a function of the product pH whereby a pH of one to five is considered corrosive, five to seven mildly corrosive, and greater than seven generally non-corrosive. For CFA, corrosiveness will be of concern if the material is in contact with moisture. The CFA from CWLP (the ash to be used in the underground placement demonstration in the cooperative agreement) was tested at pH 12.26 indicating its non-corrosive nature (Chugh et al., 1994).

3.1.2 Scrubber Sludge

Scrubbing is the process of removing the sulfur oxide gaseous constituents of flue gases after they exit the furnace. Fly ash particles are also entrained in the scrubbing process. The by-product is called "flue gas desulfurization (FGD) by-product" and it is predominantly composed of calcium sulfite and calcium sulfate. This product is also known as "scrubber sludge". In scrubbing, an alkaline sorbent, usually lime, reacts with SO_2 to form calcium sulfite and calcium sulfate. The sludge is the slurry that carries the dissolved solids and suspended solids from the chamber called scrubber. As the slurry flows out of the scrubber, it contains 15 to 20 % solids by weight. For dry disposal purposes, the solids concentration is first increased to approximately 40 to 50% in thickeners and then to 65 to 75 percent in either vacuum filters, centrifuges, or cyclones. Sometimes, the sludge is mixed with conventional fly ash to improve its handling properties and to further increase its solids concentration before disposal.

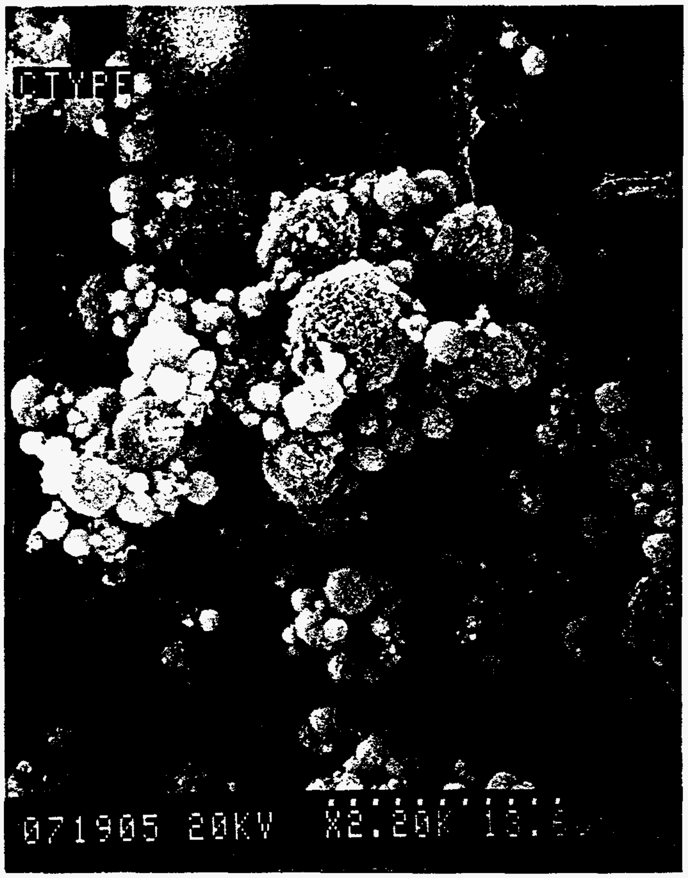


Figure 3.1 Scanning electron microscope image of a Class-C fly ash (Honaker and Paul, 1994)

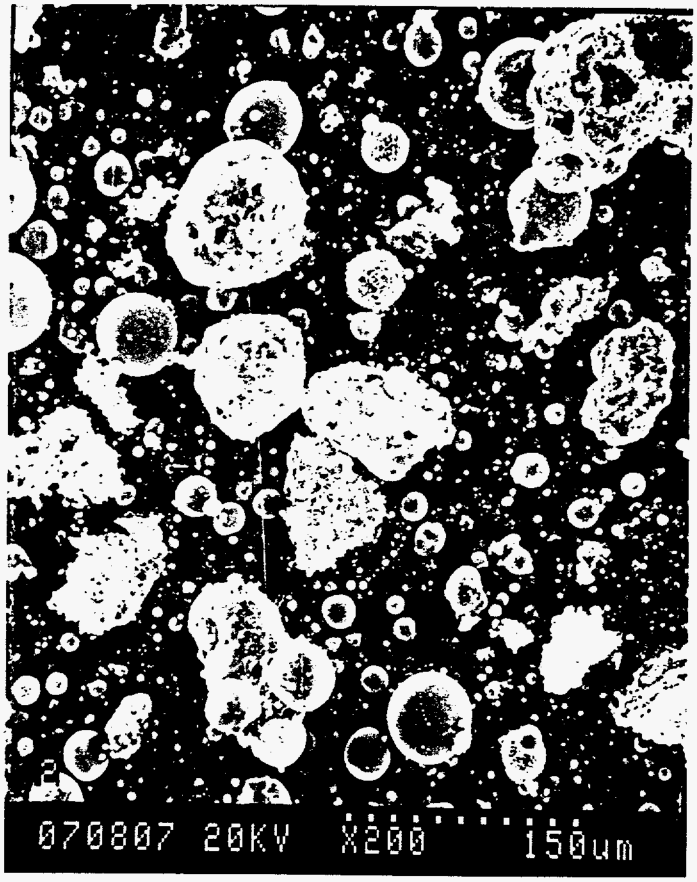


Figure 3.2 Scanning electron microscope image of a Class-F fly ash (Honaker and Paul, 1994)

The average particle size of FGD by-product ranges from 20 to 40 microns. The fly ash in the FGD sludge is similar in particle size, particle density and morphology to those of CFAs, but the sorbent reaction products have lower bulk densities due to differences in their chemical and mineralogical characteristics. The FGD by-products contain higher concentrations of calcium and sulfur, and lower concentrations of silicon, aluminum, and iron than CFAs (Tishmack, 1996).

The FGD by-product should have at least 75 % solids concentration by weight to qualify as a dry product to be transported economically in long distances. Besides the concentration, physical and chemical properties such as bulk density, angle of repose, angle of surcharge, flowability, temperature, corrosiveness, and abrasiveness must be carefully evaluated before selecting, or designing, T&H systems and equipment.

The bulk density of FGD sludge is a function of the solids percentage. Typically, a vacuum filtered product will have 53 to 80 percent solid which will correspond to a bulk density of 92.4 lb/ft^3 to 111.0 lb/ft^3 (Knight and Rothfuss, 1983). The angle of repose is dependent on the sludge composition, varying from virtually zero for sulfite sludge to values approaching 60° for dewatered sulfate sludge. Corrosiveness of sludge can be controlled by using protective coatings on equipment. However, when the sludge is also abrasive, the effectiveness of coating will decrease. A sludge will become more abrasive with increased fly ash in its composition. The sludge from CLWP (the sludge to be used in the underground placement demonstration in the cooperative agreement) was tested at pH 8, indicating of its non-corrosive nature (Chugh et al., 1994).

3.1.3 Fluidized Bed Combustion (FBC) Fly Ash and Spent-Bed Ash

The FBC is a relatively new technology whereby different fuels can be burned in a bed of fluidized sorbents such as limestone to remove the SO_2. Although the main fuel is crushed coal, other fuels such as petroleum coke, coal waste, wood chips and refuse derived fuels can be burned together with coal (Lees et al., 1988; Tishmack, 1996). Basically, two by-products form during the combustion; fly ash which is collected by either a fabric filter or electrostatic precipitator, and spent-bed ash which is withdrawn from the bottom of the boiler.

In the furnace, the fluidized bed is generated by jets of air where the limestone and coal particles mixes turbulently to form a pseudo-fluid. This pseudo-fluid allows the coal to burn at relatively low temperature (800 - 900°) without any loss in efficiency when compared to conventional coal fired boilers. In the combustion process, as much as 90 % of the SO_2 is absorbed by the sorbent along with other acid gases, virtually eliminating the need for post combustion cleaning. The shortcoming of this technology is that for every ton of coal burned typically 1/3 to 1/2 ton of limestone is added to the system which increases the by-product volume significantly (Tishmack, 1996).

The minerals in FBC fly ash and spent-bed ash are similar in composition, but they differ in proportions. The FBC fly ash is richer in silicon and iron oxides whereas the spent-bed is richer in anhydrite and lime. The low temperature of the boiler does not allow fusing of the coal ash, and therefore, glassy spheroidal particles do not form as in the conventional fly ash from pulverized coal burners. Typically, FBC fly ash consists of rather homogenous, irregularly-shaped particles smaller than 45 microns. The spent bed ash particles on the other hand are usually larger than 75 microns. The angular, irregular shape of particles can be seen from the scanning electron microscope image of an FBC fly ash given in Figure 3.3.

The major physical properties to be considered in the transportation and handling of FBC by-products can be listed as: abrasiveness, corrosiveness, hygroscopicity, mean particle size, size distribution, bulk density, specific gravity, and moisture content.

The abrasiveness of the FBC by-products have been verified through the wear and tear they cause on the plant equipment. These by-products were found to be as abrasive as the conventional fly ash. The corrosiveness, however, is mild due to rather high pH values. The pH of the FBC fly ash and spent-bed ash from ADM plant (by-product to be used in the underground placement demonstration in the cooperative agreement) were tested at pH 12.2 and 12.0, respectively, indicating their non-corrosive nature (Chugh et al., 1994).

From the published data, it can be concluded that the average particle size of FBC fly ash ranges from 10 to 20 microns, and that of the spent bed ash from 0.5 mm to 1 mm. The plots of the size distributions of these by-products generally give steep slopes, indicating uniform size distribution (Lees et al., 1988; Honaker and Paul, 1994, Chugh et al., 1994).

The reported "poured" bulk densities for FBC fly ash range from 23.1 to 34.3 lb/ft^3 and those of the spent bed ash range from 53.5 to 88.2 lb/ft^3. The average specific gravity of both by-products have been reported to be approximately 2.6 (Lees et al., 1988).

The FBC by-products do not contain any free moisture, but they have great affinity for water. Contact with moisture will cause hydration reactions with calcium oxide and sulfate. This reaction could harden the by-product and develop relatively high heats of hydration. Also, these by-products generally contain high levels of caustic, anhydrous quicklime which may be irritating if inhaled or in direct contact with skin. Therefore, transportation should be in enclosed or covered vehicles to prevent fugitive dust and contact with water (Lees et al., 1988).

3.2 CLASSIFICATION OF SURFACE DISPOSAL FACILITIES

Surface CCB disposal facilities can be classified as either impounding or non-impounding. In impounding facilities, the CCB is disposed of in slurry form behind or within the embankment, forming the impoundment. In non-impounding facilities, the CCB is disposed of in dry form, containing small percentage of water, or water is added during disposal to condition the material and to minimize fugitive dust. A number of facility configurations are practiced. Schematics of these impounding and non-impounding configurations are shown in Figure 3.4 and 3.5, respectively, and a brief description of them are given below. It is noted that these

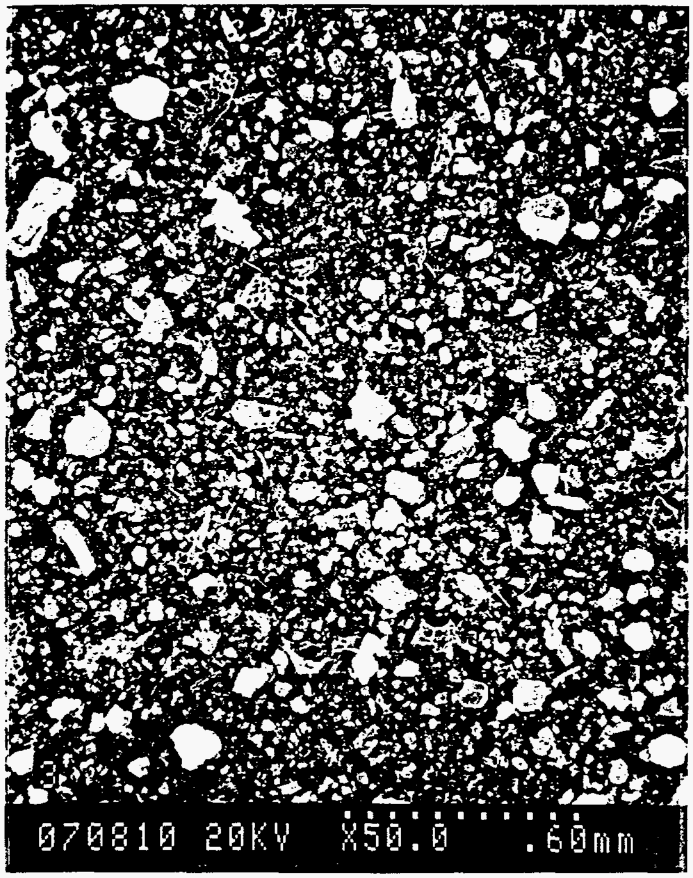


Figure 3.3 Scanning electron microscope image of a FBC fly ash (Honaker and Paul, 1994)

configurations are also widely used in the disposal of coal refuse from coal preparation plants and co-disposal of preparation plant refuse and CCBs (D'Appolonia, 1974; Sevim, 1994). The major factors to be considered in the design of these facilities can be listed as follows (Lees at al., 1988):

- Containment of by-products and associated leachate.
- Long-term stability of the disposal area.
- Maximization of by-product quantities placed in a disposal area.
- Minimization of by-product handling problems.
- Minimization of fugitive dust emissions.
- Limitation of operator/equipment hazards.
- Utilization of the disposal area (reclamation).

3.2.1 Configurations in Impounding Facilities

The descriptions of the following facility configurations are adapted from D'Appolonia, 1974; Knight and Rothfuss, 1983; and Lees et al., 1988.

Cross-Valley: This type of impounding facility is used in hilly terrain. The embankment crosses a valley. It is similar to a regular water dam. The facility is designed not only to store the CCB disposed in slurry form but also to control and discharge water that may inflow from the watershed of the facility.

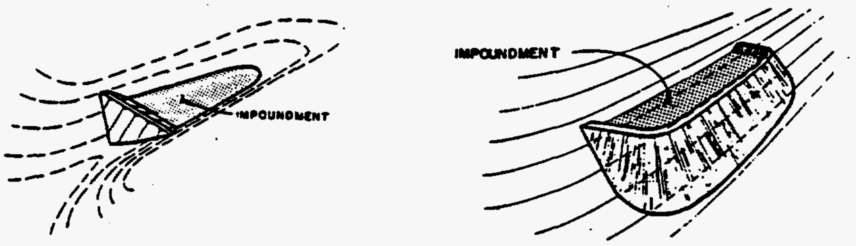
Side-Hill: This type of facility is also used in hilly regions. The embankment of the facility lies along the side of a hill or valley but does not cross the bottom of the valley. It has diked edges or a contoured surface to impound slurry.

Diked Pond: These facilities are usually constructed in regions of nearly flat terrain. The embankment is an enclosed dike which contains a pond. The pond is formed almost entirely above the original ground level. The dike may be constructed of materials excavated from below the ground level if the ground water or bedrock is not at shallow depths. If so, it may be constructed of materials from borrow sources.

Incised Pond: This type of facility is also constructed in regions of nearly flat terrain. It is basically a pond in an excavation below the original ground level. The spoil from the excavation is usually deposited around the periphery of the excavation. This configuration is suitable where groundwater and bedrock will not be encountered during excavation.

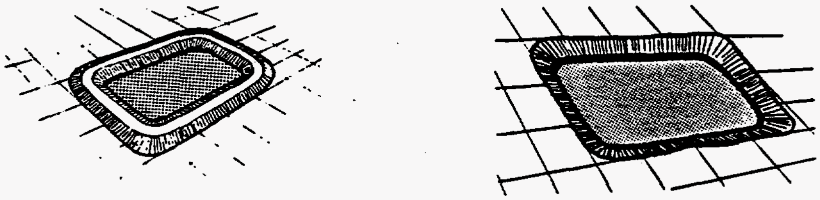
3.2.2 Configurations in Non-Impounding Embankments

Valley-Fill: This configuration is well suited for hilly regions. The embankment fills a valley. Usually, filling begins at the upstream end and progresses downstream. Alternatively, a cross-valley structure can be constructed first, and the area behind the structure can be filled in



1. Cross-Valley

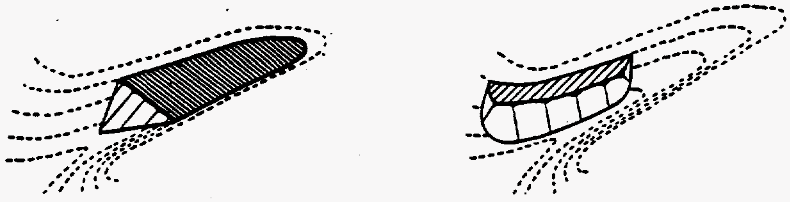
2. Side Hill



3. Diked Pond

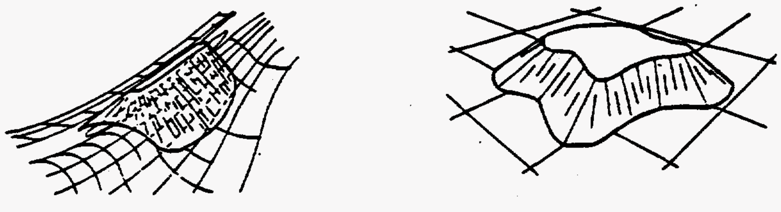
4. Incised Pond

Figure 3.4 Impounding facility configurations for by-product disposal (D'Appolonia, 1974)



1. Valley-Fill

2. Side Hill



3. Ridge

4. Heaped

Figure 3.5 Non-Impounding facility configurations for by-product disposal (D'Appolonia, 1974) subsequently, progressing the embankment upstream. Since valleys are natural avenues of surface runoff, control of surface water and groundwater is necessary. It is important to direct surface runoff water under and around the facility to avoid impounding water and to help control erosion and surface runoff contamination. The surface of the fill is continuously sloped or graded to eliminate the possibility of ponding.

Side-Hill: The embankment lies along the side of a hill or valley. As in valley-fill, the surface of the embankment is graded to prevent ponding. When designed properly, side-hill fills may blend with the existing terrain and may provide valuable property after reclamation.

Ridge: The embankment straddles the crest of a ridge, and by-product is disposed of along both sides of the ridge. This configuration too, is well suited for hilly regions.

Heaped: The embankment is a mound, lying upon a relatively flat surface which may be horizontal or moderately inclined. Grading is closely observed to prevent ponding. Problems such as groundwater pollution, slope stability and site preparation are not as serious when compared to other configurations. However, a heaped fill does not blend well with the surrounding flat terrain and will be highly visible.

3.2.3 Disposal into Surface Mines

Disposal of CCBs into active surface mines is an attractive alternative. The ideal situation is when the mine is "captive" and the generating station is a "mine-mouth" operation requiring only very short distance of by-product transportation. However, even distant mines may be economically feasible if either land for near-plant disposal facility has been exhausted or land value has significantly increased. As a matter of fact, in today's competitive coal market, coal producers who are quite a distance away from the generating plants are offering the spaces available in their mines for CCB disposal as an incentive to sell their coals.

In the USA, the surface coal mines can be listed under two mining methods: area surface mining and contour surface mining. The former is practiced in the West and Midwest where the terrain is relatively flat and the coal seams are at shallow depths, whereas the latter is practiced in the hilly regions of eastern coal basins. Two different practices of by-product disposal in area surface mining are schematically shown in Figures 3.6 and 3.7.

In Figure 3.6, by-product is placed on the bottom of the pit where coal has been extracted. Problems associated with this type of disposal are; fugitive dust, increased in-pit traffic, and possible disruption of groundwater discharge. With proper precautions and design, however, these problems can be reduced or eliminated.

In Figure 3.7, by-product is disposed of in the vee-notch troughs of the spoil bank. The advantage of this practice is that it reduces the regrading of the spoil bank when the bank is reclaimed, and it eliminates congestion in the pit. The disadvantage, however, is the necessity to built roadway within the spoil bank for by-product haulage trucks (Lees et al., 1988).

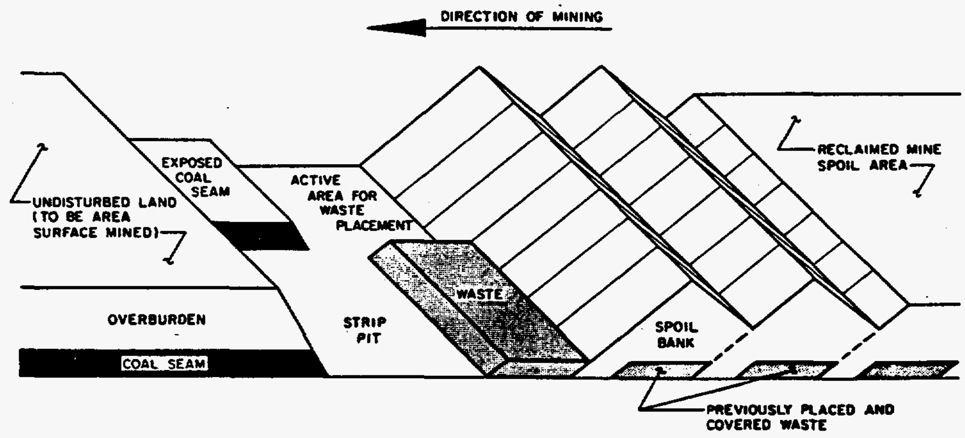


Figure 3.6 Pit-bottom disposal of by-products in area surface mine (Lees et. al., 1988)

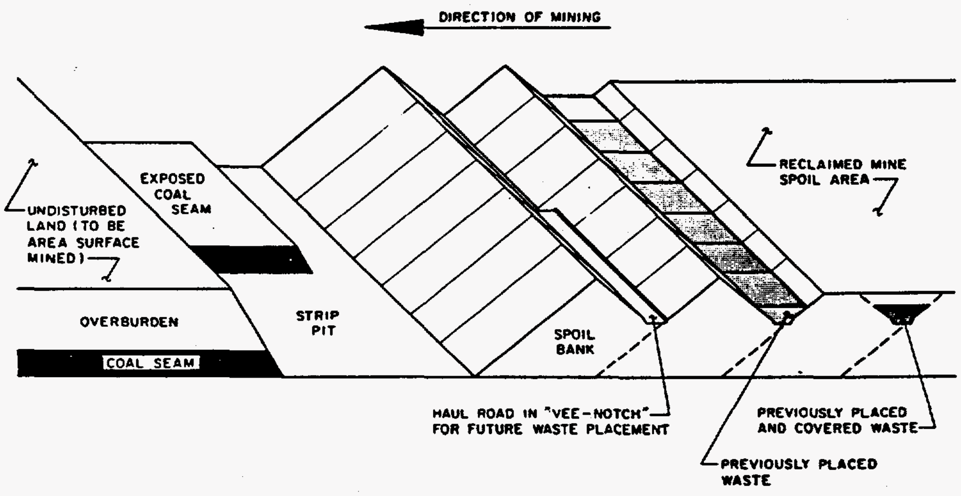


Figure 3.7 Vee-Notch disposal of by-products in area surface mine (Lees et. al., 1988)

The disposal into mines operating under contour surface mining method is schematically shown in Figure 3.8. As seen, the by-product and the overburden are placed concurrently into spoil bank. This application will be practical in mines where the overburden is hauled to the spoil bank by trucks and the roads are already in place.

Disposal of by-product in inactive or abandoned surface mines are also practiced. In most cases though, the disposal of CCB is associated with the remediation of the abandoned lands in terms of acid mine drainage mitigation and land value improvement. In a number of projects in the Midwest, researchers have successfully neutralized acid drainage from abandoned mines with alkaline FGD and FBC by-products (Bryenton et al., 1996; Giles, 1995; Hamric, 1995; Mafi, 1996; Paul, 1996). Economically justified, abandoned surface mines may provide vast lands for disposal in the Midwest and East since there are thousands of abandoned-mine acres.

3.3 TRANSPORTATION OF CCBs

There are a number of alternatives in transporting the CCBs from power plants to surface disposal areas. The most commonly used alternatives are:

- Truck
- Belt conveyor
- Pipeline
- Rail
- Barge

Trucks are the most widely used alternative in the transportation of all types of CCBs. Either dump trucks or pneumatic trucks can be used. Trucks offer more flexibility than any other alternative; they can easily reach the changing dumping point, capacity can be easily adjusted, and breakdown of a truck in the fleet does not interrupt transportation. The disadvantages of the truck transport are relatively high operating cost (labor and fuel) and public visibility. Especially for large operation, increased number of trucks may cause dust, noise and traffic on roads and highways which may not be welcomed by local residents.

Dump trucks may be more feasible when fly ash can be conditioned with water at the plant and transported a <u>short</u> distance to disposal site. For long distances, conditioning with water may trigger the hardening process. Dump trucks must be covered with tarps to prevent fugitive dust in long distance transportation, otherwise, pneumatic trucks should be used. When transporting FGD sludge, the product should be dewatered to a solid concentration of at least 75% before loading onto trucks. Dump trucks are suitable for sludge transport, and since the product is not dry, trucks do not have to be covered. Pneumatic trucks can transport only dry by-products.

Belt conveyors can conveniently be used for transportation of CCB for distances less than a few miles. They are suitable for dry by-product transportation; however, conditioning the by-

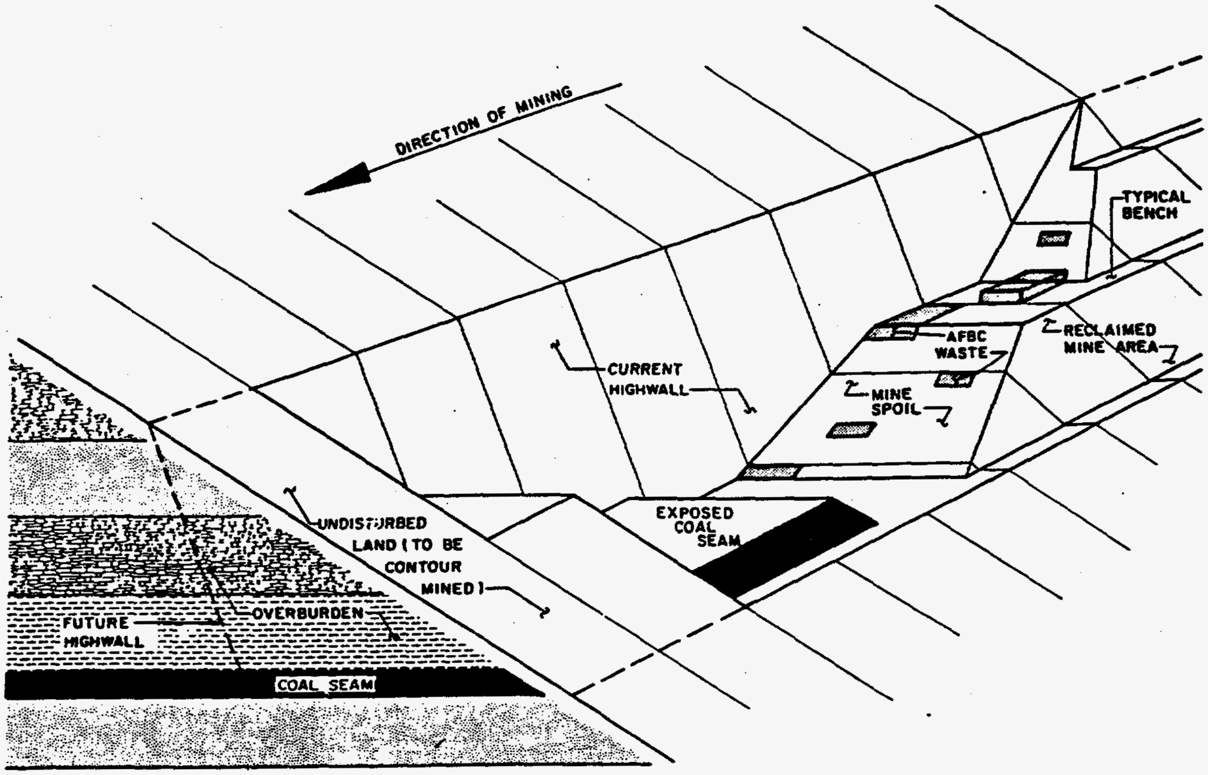


Figure 3.8 Disposal of by-products in the spoil banks of contour surface mine (Lees et. al., 1988)

product with water may be useful in preventing fugitive dust. Hooded belt conveyors may be used when dust is a serious problem. When transporting FBC fly ash, it is important that the ash is cooled below 300° F before loading onto the belt. Belt conveyors are quite practical when the by-product transportation is continuous and the loading point is fixed. They usually have long life and low operating cost. However, the capital cost can be substantial, and once constructed they are relatively inflexible.

Pipeline transport is another commonly used system where ash is mixed with water and pumped into an ash pond. Usually, solids concentration is kept around 10 to 15% and slurry velocity around 10 fps. The water from ash pond can be transferred into settling pond where the fly ash particles in suspension settles and the decant water is returned to the plant through another pipeline system for reuse. In the application of pipeline system, fly ash must not possess hardening property. For this reason, Class C and FBC fly ashes are not suitable for pipeline transportation. Fly ash which is known to be quite abrasive may cause serious wear and maintenance problems in pipeline systems. Most common pipes are either steel or cast iron. Sometimes, abrasive resistant coating of pipes may payoff in the long-term even though it may increase the initial capital cost significantly.

Rail transport may be very attractive especially for cases where there is a dedicated unit train between the plant and the mine and the CCB is returned back to the mine that supplies the coal. A unit coal train usually is composed of 100 coal cars pulled by two or three locomotives, but the number of coal cars may be as low as 50. This mode of operation may provide substantial savings due to reduced backhaul charge. However, the application of rail transport is not very practical because it requires loading facility at the plant and unloading facility at the mine site. Secondary handling of fly ash at the mine site will inevitably increase the cost of disposal. Also, to prevent fugitive dust, rail cars must be covered or dust suppressants must be used.

Transportation of fly ash in pressure differential rail cars eliminate the necessity of tarping or use of suppressants. However, coal cannot be transported in these cars, and therefore, there is no reduced charge incentive. A successful application of pressure differential rail car transportation has been in operation between a co-generation plant in New Jersey and disposal site in Blacksville, West Virginia operated by the Greenon Coal Co. since 1994 (Chugh et al., 1995).

Barging is a convenient transportation mode for plants located very close to navigable waterways. It is a very reliable, high volume and low unit cost system, through which either wet or dry CCBs can be handled. The disadvantage of this system is in the necessity of special loading and unloading facilities and secondary handling to transport the CCBs to the disposal site when the site is not by the waterway.

3.4 CURRENT DISPOSAL PRACTICES

There are basically two methods of disposing CCB: dry and wet. The decision as to which method to apply is dependent on factors such as site topography, land availability, location, water availability, and engineering, physical and chemical properties of the by-product.

3.4.1 FGD Sludge Disposal

The majority of existing FGD sludge disposal systems are wet systems. However, wet disposal is not necessarily advantageous over dry disposal in all cases. In fact, both methods have relative advantages and disadvantages, and a decision as to which type of system is optimum in a given case will depend on the specific disposal situation.

The common factor in all wet disposal systems is that the sludge is transported and deposited into the final disposal site in a slurry form. The degree of sludge processing may vary considerably. In some systems, the scrubber bleed stream is piped directly to a disposal ponds, with the supernatant returned to the scrubber system for make-up water. In other systems, the bleed stream is treated prior to final ponding. Some systems use thickeners and/or interim settling ponds to reduce water content. This process reduces the size of the final disposal pond.

Another alternative is to incorporate a preliminary dewatering stage followed by the addition of a commercial fixation chemical (e.g. Calcilox) prior to placement in the disposal pond.

Wet disposal systems are applicable to all lime, limestone and alkaline fly ash wet scrubbing systems. The primary advantages of the wet system are the low operating cost and the reduced problems of noise, fugitive dust, and traffic. The primary disadvantages on the other hand, are the requirement of larger disposal volumes compared to dry disposal, necessity of construction dams and dikes requiring high capital cost, and relative inflexibility with regard to system modifications.

In dry disposal systems, the sludge is processed so that it may be deposited in a landfill site as a solid material, or as a material which will solidify rapidly enough that dams or dikes are not required. There are a number of dewatering, conditioning and blending processes practiced in the industry to prepare the sludge for dry disposal. The most common processes are:

1. Interim ponding of the bleed stream for dewatering.
2. Use of thickeners followed by interim ponding.
3. A two-stage dewatering process consisting of the use of a thickener followed by a vacuum filter or centrifuge.
4. A two-stage dewatering process followed by the stabilization of the sludge with dry fly ash.
5. A two-stage dewatering process followed by the fixation of the sludge with fly ash and lime.

6. Forced oxidation of scrubber sludge followed by a single or two-stage dewatering step.
7. Forced oxidation of scrubber sludge followed by stacking.

Dry disposal systems are usually most applicable in arid regions, or in systems with high ash/sludge ratios or high sulfate content, and/or where land is premium. What is an advantage for wet disposal is usually a disadvantage for dry disposal and vice-versa.

The fixation mentioned in item 5 is a chemical treatment of the sludge which involves the addition of lime or other reactive material, such as blast furnace slag, alkaline fly ash, or Portland cement, to result in cementitious-type reactions in the sludge. These reactions bind the sludge particles together, thus increasing shear strength and reducing permeability.

The forced oxidation mentioned in items 6 and 7 above is a process whereby the sulfite species are intentionally oxidized and transformed to sulfate so that gypsum is the primary solid component of the waste. Forced oxidation offers a number of advantages in obtaining a by-product with near optimum qualities for dry disposal. The resultant gypsum dewaters readily by either settling, thickening alone, with subsequent filtration, or centrifugation to about 80% solids. This reduces the volume of the product to be handled, the transport costs, the land area requirements, the land acquisition costs, and the disposal costs.

Dry fly ash is often mixed with scrubber sludge to stabilize the sludge for disposal. The possible benefits obtained by blending dry fly ash with scrubber sludge are:

- Reduced moisture content of the resultant waste
- Decrease in permeability
- Increased structural strength if the fly ash possesses any cementitious characteristics.

The unique particle morphology of fly ash affects the final waste product when it is added dry to scrubber sludge. The spherical shape of the particles is reported to decrease the viscosity of scrubber sludge. This would tend to improve the pumping characteristics of the sludge. Also, drainage is improved by the presence of particles larger than those in sulfite-sulfate sludge alone. On the other hand, alkaline fly ashes can decrease the permeability of a disposal mixture through hydration reactions which fill the pore spaces of a material. A decrease in permeability would result in less leachate (Knight and Rothfuss, 1983).

3.4.2 Conventional Fly Ash Disposal

As in the sludge disposal, the conventional fly ash can be disposed of either wet or dry. The trend, however, is toward dry disposal for two reasons: 1) Increased ash marketability, 2) Increasingly stringent environmental regulations for surface water and groundwater protection.

Fly ash is commonly collected dry from particulate removal systems and temporarily stored in hoppers. Upon filling these hoppers to a predetermined level, the fly ash is pneumatically conveyed to either a storage silo prior to dry transport, or to a mixing area where it is slurried for wet transport.

If the fly ash is removed from the flue gas stream by a wet collector, it may be sluiced directly to a pond for dewatering or disposal. If the fly ash has been collected by mechanical collectors, fabric filters or electrostatic precipitators, it must be transported to either a temporary storage silo or the ash sluicing area.

In wet ash disposal systems, the ash is transported hydraulically from the power plant to ash disposal ponds which function as large-scale sedimentation basins. Bottom ash and fly ash can be placed in the same pond, in different ponds, or sluiced to different areas of the same pond to enhance ash segregation.

The primary advantages of the wet disposal are: reduction of noise, dust and traffic at the site and along transportation routes, and low operating cost as compared to dry disposal. The primary disadvantages on the other hand, are: high site development cost, larger quantities of leachate and larger disposal site volume when compared with dry system, reduction in the value of fly ash for reuse, inflexibility of operation with regard to future changes, higher cost of site closure, limited distance of transportation when ash possesses self hardening property.

Dry disposal systems essentially entail landfilling of ash conditioned with a sufficient amount of water to aid placement. Bottom ash, normally sluiced from the boiler bottom to a dewatering bin or pond, is commonly transported separately from fly ash.

The primary advantages of the dry disposal are: lower site preparation cost since extensive dams and dikes are not required, more efficient use of disposal area and volume, possible reclamation of site for a specific land use after closure, flexibility in operation, reduced leachate quantities, and easier reclamation of ash for utilization than with wet disposal.

The primary disadvantages on the other hand, can be listed as: need to control noise and dust problems, increased visual impact along transportation routes, and relatively high operating cost (Bahor et al., 1981).

It should be noted that several combinations of wet and dry systems are also possible, depending on the characteristics and in-plant collection and handling systems. Following are two possibilities:

- Pump the ash slurry to a pond located at the power plant site. After dewatering, the ash can be excavated and transported to a dry site for final disposal.

- If the fly ash is very reactive it can be transported to the disposal site where it is mixed with water and deposited into ponds to cure and harden (Bahor et al., 1981).

3.4.3 FBC Fly Ash Disposal

The FBC fly ash is disposed of dry. The ash can be conditioned with water at the plant before it is discharged into transport vehicles. The added water may constitute 15 to 30 % of the product weight. Conditioning helps prevent fugitive dust during transportation and disposal. There are, however, two important issues with conditioning of FBC fly ash: 1) considerable temperature rise may be experienced when the ash reacts with water, 2) when transported long distances ash may begin to set up in the vehicle due to its pozzolonic property, causing severe problems of unloading at the disposal site. Therefore, even modest amount of water addition to FBC fly ash must be carefully evaluated (Lees et al., 1988).

4.0 TECHNICAL DISCUSSION

To attain the above stated objectives, several technologies were first evaluated from environmental point of view. These technologies can be classified under two categories:

1. Existing Technologies

    1. 1. Pneumatic Trucks
    1. 2. Pressure Differential Rail Cars
    1. 3. Coal Hopper Cars
    1. 4. Tarped Rear-Dump Trucks
    1. 5. Bottom-Dump Container Trucks

2. Adaptable and Futuristic Technologies

    2. 1. Collapsible Intermodal Containers
    2. 2. Cylindrical Intermodal Tanks
    2. 3. Coal Hopper Cars with Automatic Retractable Tarping
    2. 4. Intermodal Steel Containers
    2. 5. Covered Hopper Cars (Grain Cars)

The major environmental concern in CCB transportation is the fugitive dust due to extremely small size of the particles. For instance, in an earlier study, the particle size analysis conducted for three conventional type fly ashes and one FBC fly ash produced in Illinois power plants, indicated that approximately 25-30 % of the particles were less than 10 microns, and 60 - 65 % less than 25 microns as shown in Figure 4.1 (Honaker and Paul, 1994).

The first two technologies listed above under "Existing Technologies" are currently being utilized in a number of operations throughout the United States. They can be considered as fugitive dust free technologies if they are handled properly at the loading and unloading stations. Since these two technologies were found to be environmentally friendly, they will be further elaborated in the next section.

The third technology, Coal Hopper Cars, has found some application in CCB transportation, but the opinions have been mixed. Chemical sprays have been suggested and applied to the surface of the by-products to form a crusted layer to prevent fugitive dust while traveling. The major drawback in this alternative, even if the formation of a crust is successful, is the need of baghouses both at the loading and offloading points to prevent serious fugitive dust problem. Also, penetration of water or moisture through the crust, leading to heating or setting of the by-product, may cause severe problems. There have been a few cases where the crust had to be broken with jackhammers.

The forth technology, Tarped Rear-Dump Trucks, has also found application in CCB transportation. Currently, at least two fly ash disposal operations in Illinois utilize this

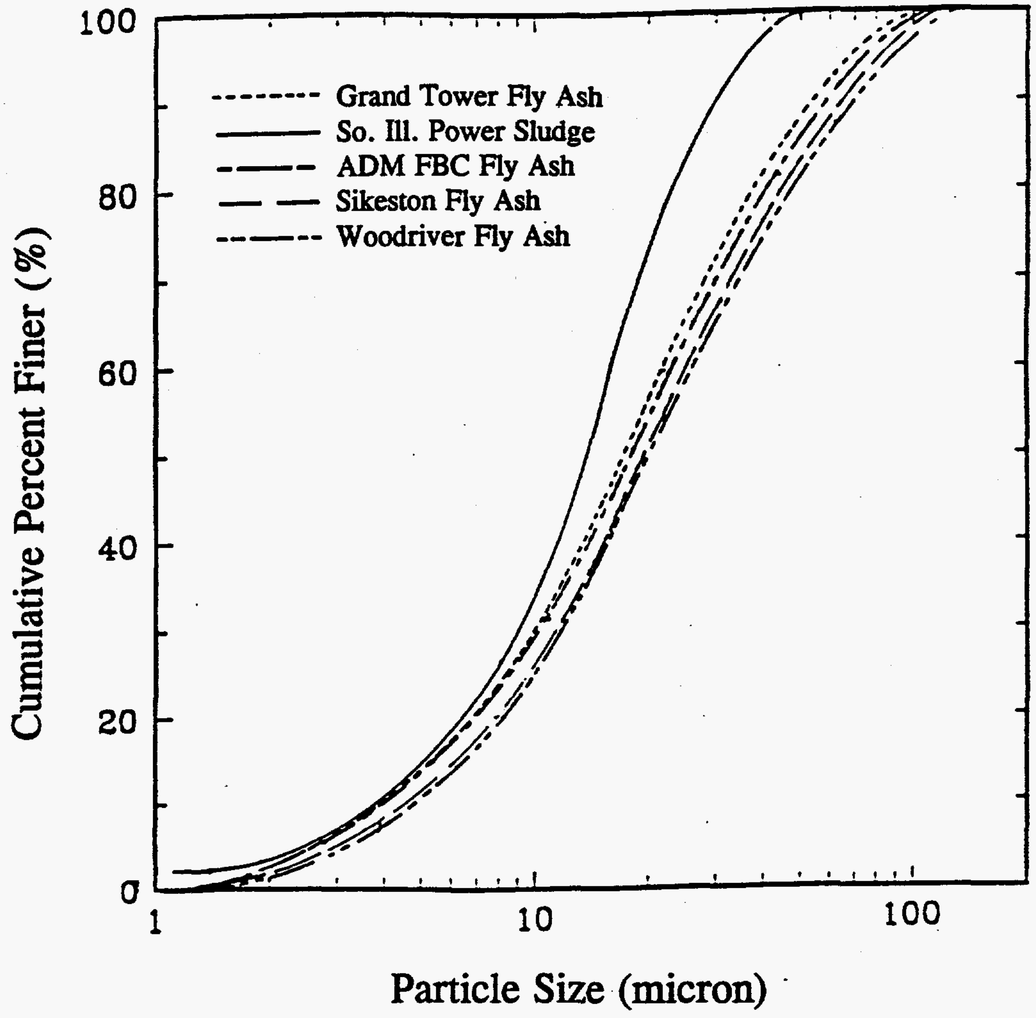


Figure 4.1 Particle size distributions of coal combustion by-products from different power generating plants (Honaker and Paul, 1994)

technology (Giles, 1995). The major concern with tarped trucks is again the fugitive dust during loading and offloading of the material. A technology that is an improvement over to Tarped Rear-Dump Trucks is the Bottom-Dump Container Trucks. These trucks are used to fronthaul coal from mine to power plant and backhaul ash from plant to mine. At the mine site, the truck is driven on an artificially created gentle slope and its content is dumped from the bottom while traveling at a very slow pace. This technique minimizes the fugitive dust problem. A bulldozer later spreads the material and compacts it in order to maintain the shape of the slope. These trucks will not be very convenient in underground placement because the by-product has to be offloaded directly from the tank into the injection hopper. With bottom dumping, there has to be a ramp arrangement for the truck to get to top of the hopper. These trucks, however, will be very convenient in surface disposal cases, especially when there is coal fronthauling.

Among the technologies cited in the second category above, the first, Collapsible Intermodal Containers, was developed as a part of this research project by SEEC Inc. This technology will be elaborated in the next section.

There have not been serious attempts to look into the technical and economic feasibility of the second and third technologies (Cylindrical Intermodal Tanks and Coal Hopper Cars with Automatic Retractable Tarping). These technologies were found to be environmentally friendly and very much adaptable to by-product transportation, and therefore they are elaborated in the next section.

The fourth technology, Intermodal Steel Containers, is currently being investigated by another researcher as a part of the overall DOE-SIU cooperative agreement. These are 8x8x20 ft general purpose containers. The modifications considered for adaptation to by-product transportation are: a top gate to facilitate filling from ash silos, and a rear-end valve or gate arrangement to offload the content into the injection system hopper. Upon the completion of the investigation, a separate report will be submitted on this technology. It is noted that Norfolk Southern Corp. reported the use of these containers, called Coltainer, for coal transport from a mine in Berry, Alabama to Alabama Power's plant Gorgas. In this operation, coal is loaded into containers positioned atop flatcars, which move 24 miles by rail to an intermediate facility at Parrish, Alabama. There, piggy packers (also called sideloaders) transfer the containers to specialized chassis for truck delivery to the plant. The move by truck is eight miles to the plant (Norfolk Southern, 1995)

Finally, the last technology, Grain Cars, was also found to be adaptable to by-product transportation. The advantages of these cars are that they are abundantly available, and they can be loaded pneumatically or by gravity with minimal fugitive dust problem. However, they require an under-track bin at the mine site to dump the material. Rehandling of the residue from the under-track bin is not a desired feature. Offloading from these cars into pneumatic trucks is a possibility but retrofit for a fluidizing system may be costly. A solution to offloading problem, yet to be tested, could be the use of "portable direct rail-to-truck transfer unit" manufactured by Wilson Manufacturing and Design Inc., of Cecilia, Kentucky. Figure 4.2a depicts this unit in action between a pressure differential rail car and pneumatic truck.

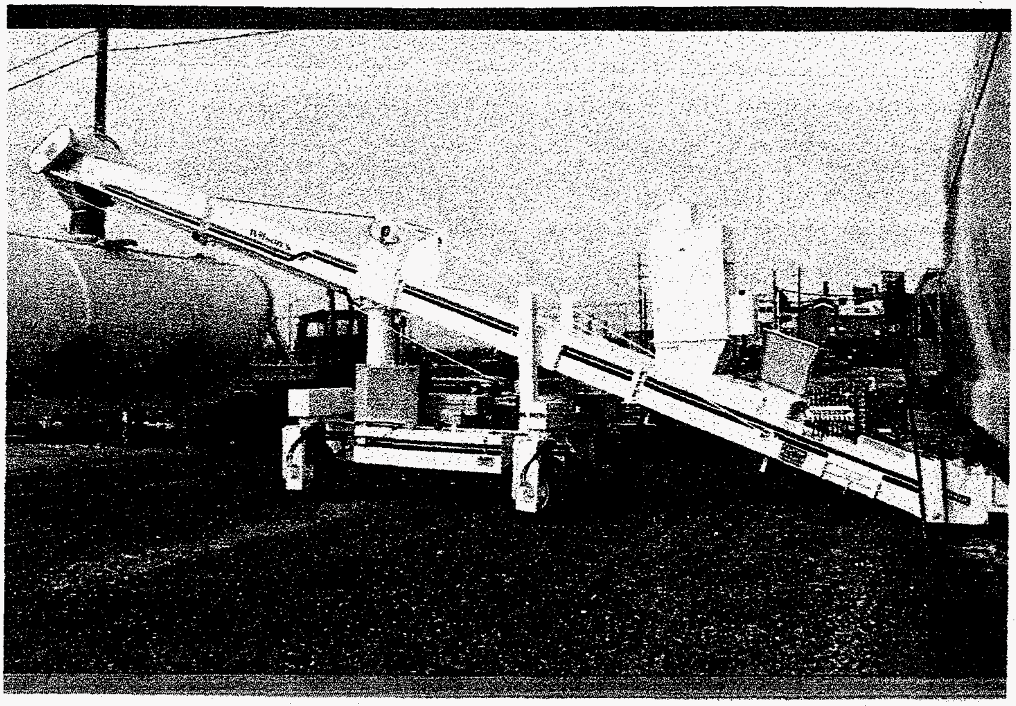


Figure 4.2a Wilson's articulating conveyor unit in action between a pressure differential rail car and a pneumatic truck (Wilson Manufacturing and Design, Inc.)

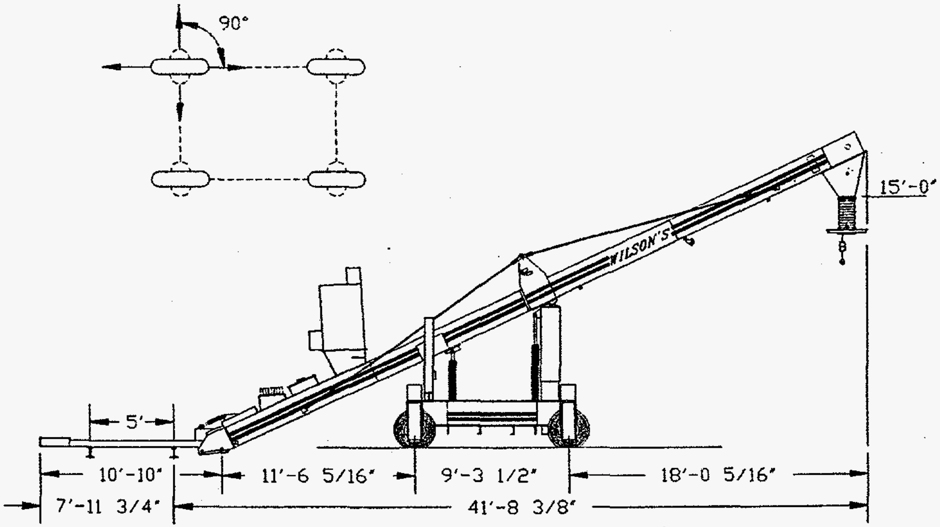


Figure 4.2b Dimensions of a Wilson's articulating conveyor unit (Wilson Manufacturing and Design, Inc.)

Figure 4.2b shows the dimensions of the unit. This is an articulated loader-conveyor system that can engage to rail car's gate with a large gasket and transfer the powdered product through its enclosed chain (or screw) conveyor into a pneumatic truck. The capacity of the unit may range from 60 to 160 tph depending on the type of material conveyed. It has been reported that several types of powdered material have been successfully transferred by this unit (Wilson Manufacturing).

During the evaluation of the T&H technologies, it was found that the technical and economic feasibility of the mode of transportation of the FGD materials from an existing plant to a mine site depends on the following factors:

- Dusting, corrosion, abrasion, sticking, hardening, flowability and heat generation of the material,
- Particle size of the material, bulk density, angle of repose, angle of surcharge and moisture content,
- Volume of the material,
- Transportation distance,
- Profile of the haulage road,
- Possibility of backhauling the material,
- Possibility of contracting the haulage,
- Presence or absence of railway facilities,
- Presence or absence of waterway facilities,
- Existing handling facilities at the plant and the mine site, and
- Remaining life of the operation

4.1 ENVIRONMENTALLY FRIENDLY TECHNOLOGIES

The first four technologies described below were found to be environmentally friendly and ready to be applied. They were studied extensively, and as a result, operating scenarios, engineering design and cost models were developed for each of them. The last technology, Coal Hopper Cars with Automatic Tarping, was also found to be environmentally friendly, but it is at a conceptualization phase and not readily applicable.

4.1.1 Pneumatic Trucks (PT)

Pneumatic trucks, also referred to as bulk tank trucks, are widely used in transporting low density dry flowable powder and granular materials as well as high density materials such as cement, limestone and fly ash. A pneumatic truck is composed of three main components: (i) tractor, (ii) tank trailer, and (iii) blower. These main components and all other accessories of a typical pneumatic truck are shown in Figure 4.3. The most common method of loading the material is gravity feeding from a silo by a collapsible spout which engages to the gate on top of the tank. The tank is air tight when the lids of the gates are closed. During offloading, the material flows through the piping below the tank due to pressure difference created by the blower. Figures 4.4 and 4.5 show a pneumatic truck loading dry bulk material from a pressure differential rail car at Illinois Central Bulk Transfer Terminal at Harvey, Illinois.

The J&L Tank Co., a major manufacturer of the aluminum tanks for pneumatic conveying, specifies that 400 cfm air supply from a blower will be sufficient to pneumatically convey fly ash from the tank if the tank pressure is about 15 psig and a 4” line with 100-150 feet total unloading distance is used. The loose bulk density of fly ash is noted as 50-60 lbs/ft^3 and the maximum particle size as 300 microns. It is also noted that all J&L Pneumatic Dry Bulk Aluminum trailers are designed with a 160 °F product temperature limitation. Aluminum conducts heat very well, but it has a relatively low melting point as compared to other metals used in the construction of bulk trailers. To increase the temperature rating, the shell thickness has to be increased to assure structural integrity which would of course add to the cost and weight of the trailer.

The PT transportation scenario for this project is schematically shown in Figure 4.6. The trucks are loaded from the fly ash bin of the plant and they deliver the material directly to the underground placement point at the mine site. There, the pressure necessary for offloading the fly ash into the placement hopper is supplied by the blower mounted on the truck. These trucks are approximately 20-25 tons in capacity and can offload in about 20-25 minutes (Freitag et al., 1991). The preliminary testing at the demonstration site at Peabody No. 10 mine, however, indicated that the unloading can be accomplished in 30 to 40 minutes.

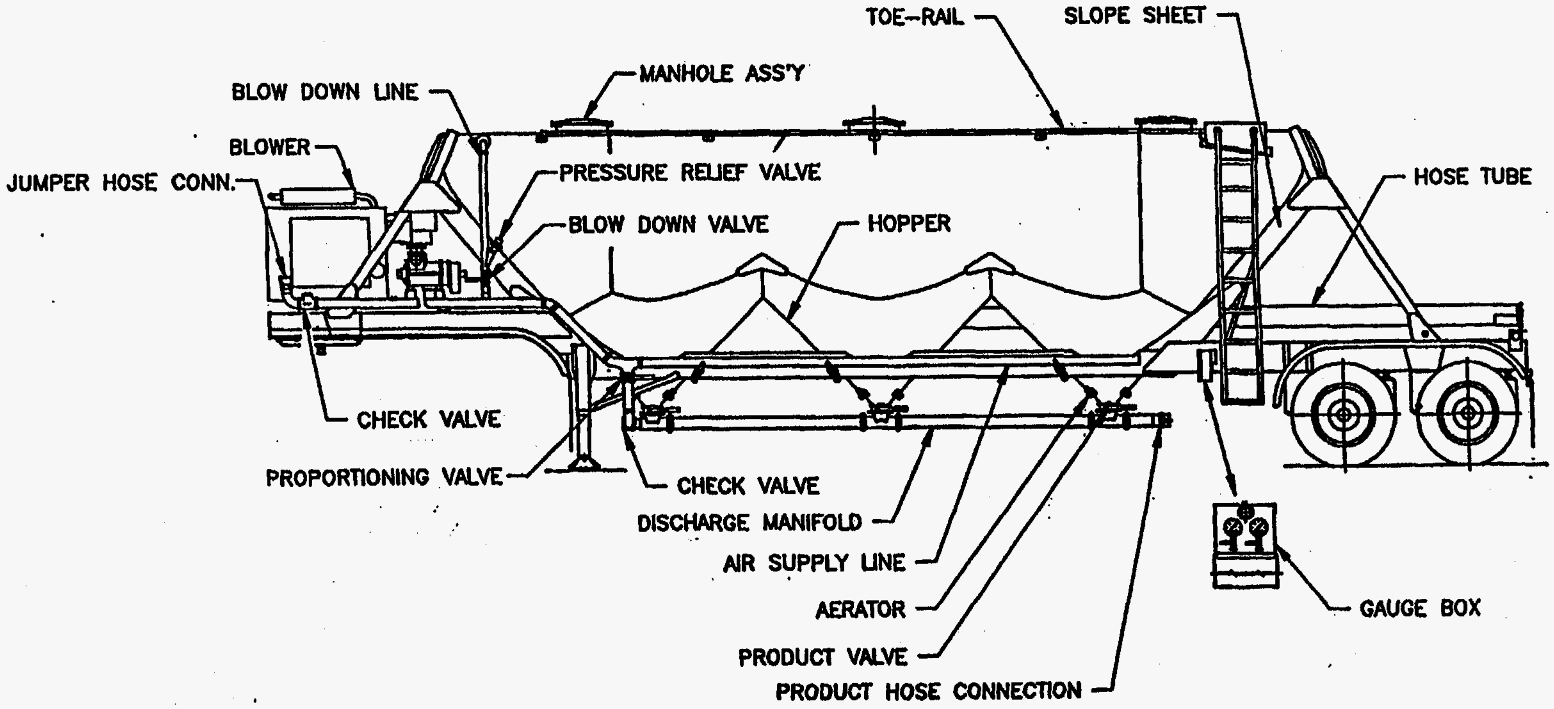


Figure 4.3 Schematic view of a typical pneumatic truck (J & L Tank)

Figure 4.4 Side view of a pneumatic dry bulk transport tank loading from a pressure differential rail car

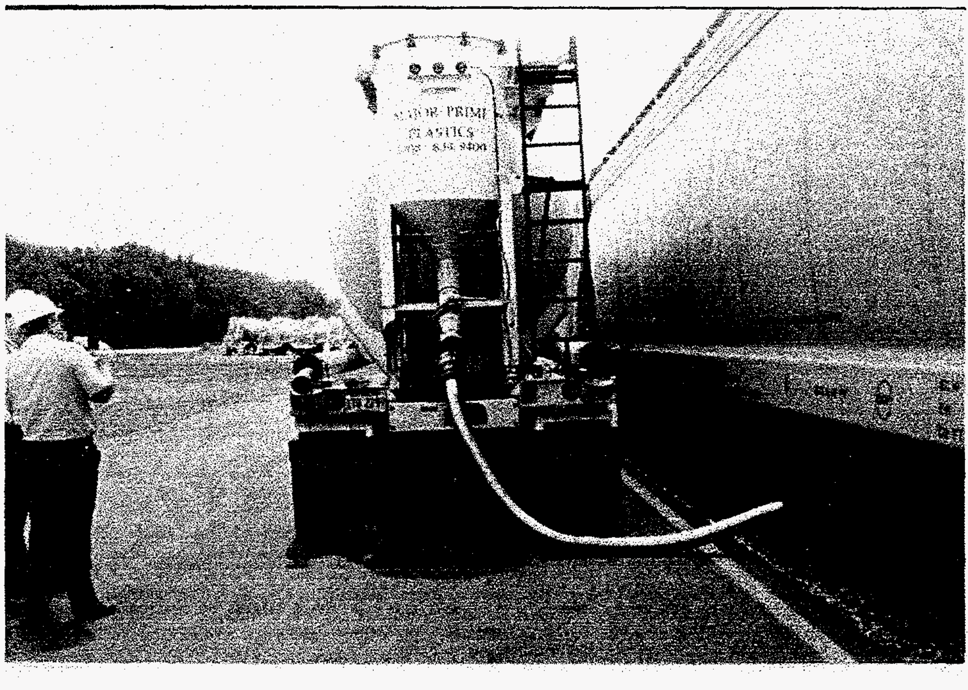


Figure 4.5 Back view of a pneumatic dry bulk transport tank loading from a pressure differential rail car

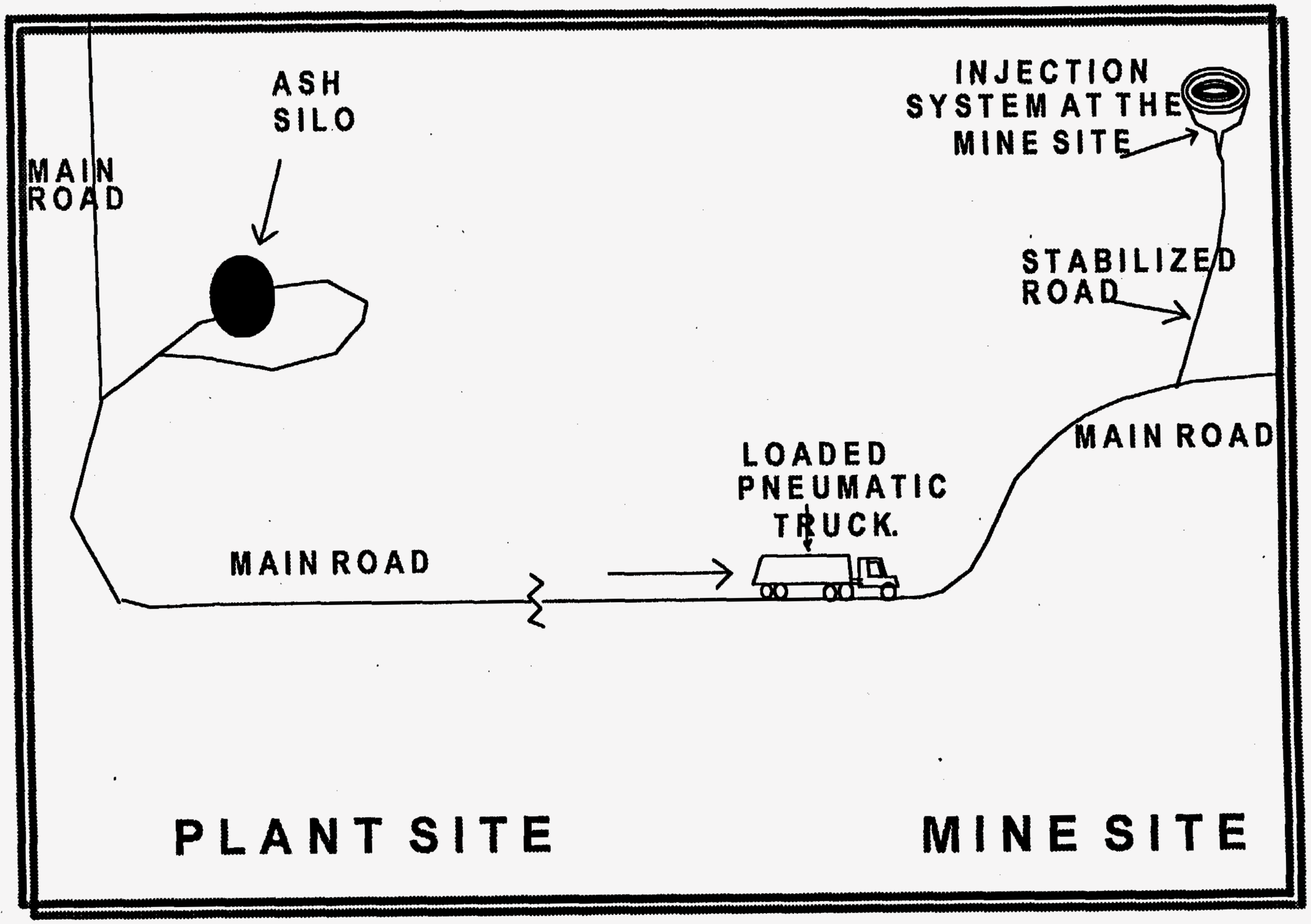


Figure 4.6 Dry FGD by-product transportation by Pneumatic Trucks

4.1.2 Pressure Differential Rail Cars (PD-car)

These are special type of rail cars used to handle powdered materials. They are operated under the principle of pressure differences between the car and the container to which the product is discharged. As seen in Figures 4.4 and 4.5, normally PD cars are complemented with pneumatic trucks at rail terminals to deliver the material to the final destination. When a PD car is pressurized to about 5 psi or more, the outlet valves are opened to form a steady flow of material into the truck until all the material in the compartment is cleared. Figure 4.7 shows pressure differential rail cars parked at the Illinois Central Bulk Transfer Terminal at Harvey, Illinois.

The PD-car transportation scenario is schematically shown in Figure 4.8. As seen, one set of cars is being filled at the power plant while the other set is being emptied at the mine. When all the cars at the plant are filled, either a "local train" or a "unit coal train" will take them to the mine. Similarly, the empty PD cars will be delivered to the plant for another round. At the mine, the product in the PD cars will be transloaded into a silo with the aid of a stationary blower. Delivery from the silo to the injection site can be done either by pneumatic trucks, or by regular dump trucks if the silo is equipped with a pugmill to wet the by-product to prevent fugitive dust.

This system has been in practice, with the exception of the underground injection, at a landfill operation in Blacksville, West Virginia, since 1994. This site is operated by Greenon Coal Co. The fly ash is loaded into 100-ton PD cars at a co-generation plant in New Jersey. In each trip, about 10 to 15 PD cars are attached to the unit train returning empty to West Virginia coal mines. At the Greenon facility, the PD cars are pushed to the emptying station, two at a time, by a track mobile (a tractor that can move both on rails and on road). At the station, the PD-car is hooked up to two sets of a pair of pressurized air lines; a 5 inch line to pressurize the car at about 13-15 psi, and an 8 inch line to provide the drag to transport the ash about 60 feet horizontally and 90 feet vertically to the top of a 240-ton silo. This silo is equipped with a baghouse to prevent fugitive dust. It takes about 45 minutes to empty a 100-ton PD-car. From the silo, fly ash is loaded into a 30-ton dump truck which delivers the load to the surface disposal area. To prevent fugitive dust, fly ash is treated with water in a pugmill before it is loaded into the truck (about 52 gallons of water is used for every ton of ash). At this operation, approximately 70,000 tons of fly ash was handled and disposed of during 1994.

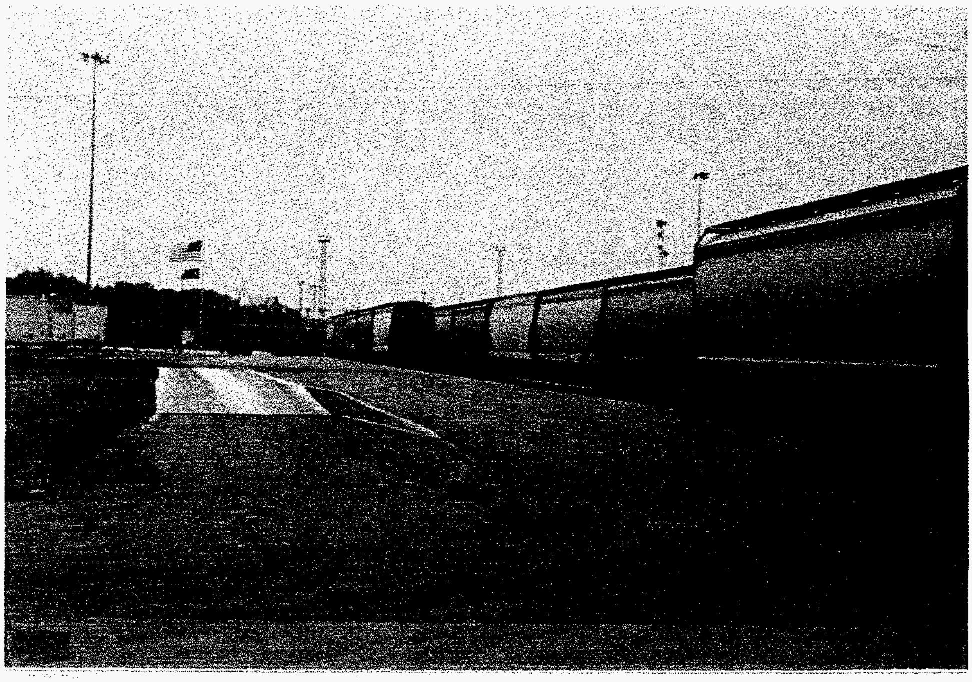


Figure 4.7 Pressure differential rail cars parked at a terminal

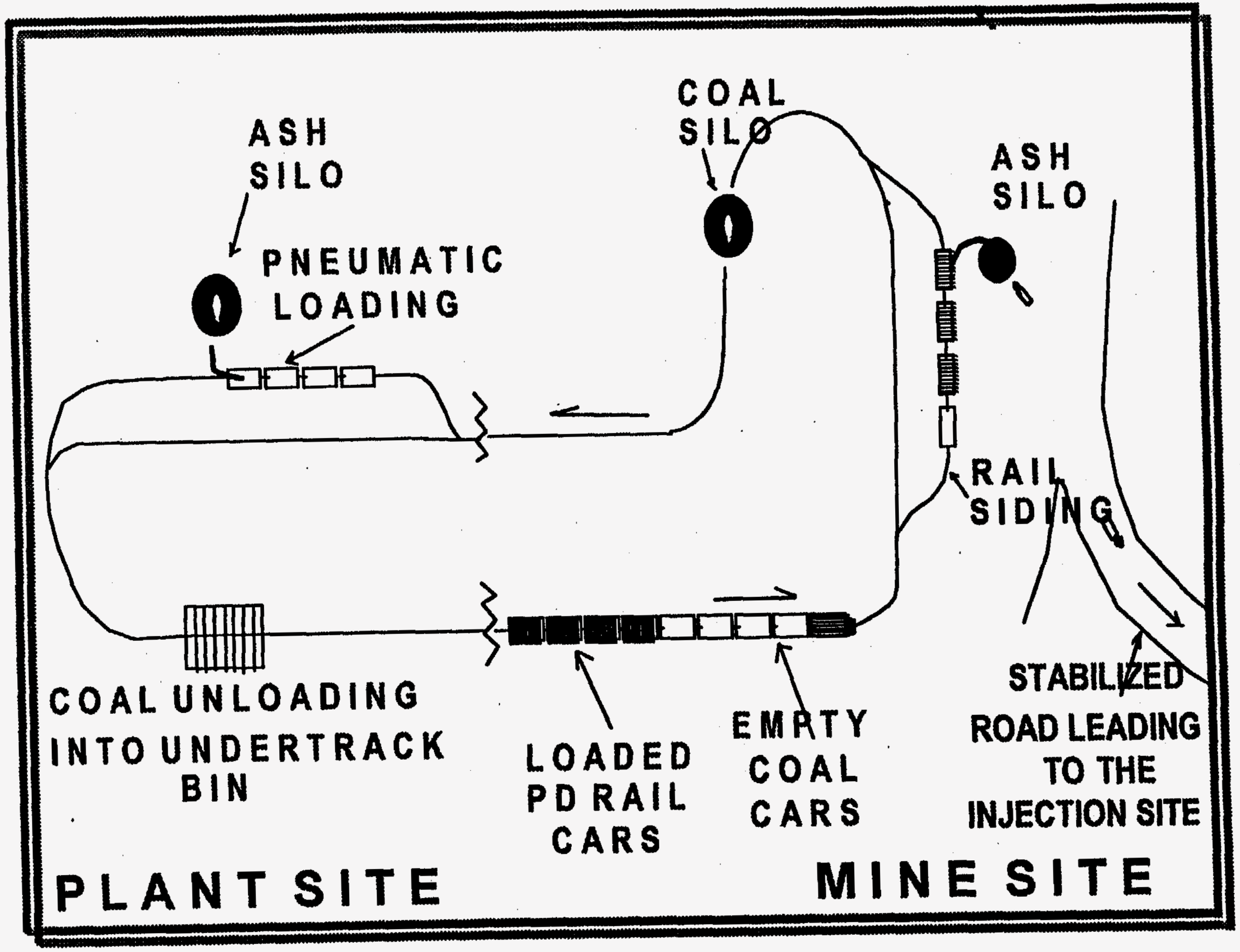


Figure 4.8 Dry FGD by-product transportation by Pressure Differential Rail Cars

4.1.3 Collapsible Intermodal Containers (CIC^{TM})

These containers are made of rubber coated aramid and nylon fabric with polyester webbing. They are patented by SEEC^{TM} Inc., one of the research partners in the DOE-SIUC cooperative agreement. The CICs are collapsible storage bins that are portable and intermodal - designed to ride inside coal cars, barges and trucks. Those CICs made to transport fly ash by riding in coal cars have a height of 120 inches, diameter of 110 inches and a 19-inch filling port. For ash of 60 lb/ft^3 bulk density, the CIC capacity is about 20 tons. These containers are extremely durable and provide fully encapsulated transport, eliminating fugitive dust problems (Carpenter and Thomasson, 1995). Figure 4.9 shows a 20-ton CIC being lifted by an overhead crane.

The CIC transportation scenario is shown schematically in Figure 4.10. The coal train arrives at the plant and offloads coal into an under-track bin. Next, the CICs which have already been filled with fly ash and staged along the rail are lifted, one at a time, by an overhead crane and placed into the bays of the empty coal cars. Two specially designed lifting brackets mounted on both sides of the CIC facilitate lifting and placement by the crane into the bay of the car. Three or four CICs occupy a car, each taking one of the bays of a typical coal car. The overhead crane is on rubber tires and travels along the rail track looking inside the cars. When all the CICs are loaded, the train leaves for the mine.

At the mine site, an overhead crane lifts the CICs, one at a time, and places them on the concrete pad along the rail track. When all the CICs are offloaded, the train pulls under the silo for coal loading. After filling all the hopper cars, the train leaves for the power plant. The CICs are then loaded on tote trailer(s) by the same crane and transported to the underground placement site. There, the ash is offloaded into the hopper of placement system by the use of a vacuum system designed specifically for the CICs. The empty CIC can be transported back to the rail site on the same trailer. At the rail site, the empty bag is lifted with a small forklift, carried into a baghouse where the air trapped in the CIC is extracted. The collapsed bag is then retrieved by the forklift and hung like a vest onto the rail guides of a covered trailer. After collecting 25-40 empty CICs, the trailer is transported back to the plant.

At the plant, the tractor leaves the filled trailer, takes the empty trailer and drives back to the mine. The empty CICs are retrieved from the trailer with the help of a small forklift and placed, one at a time, on a specially designed trailer and pulled under the fly ash silo by a tractor. There, it is filled by gravity similar to filling a pneumatic truck. Then, the CIC is transported back to the rail site, where the trailer pulls under the overhead crane, and it is lifted and staged along the track and kept there until the coal train comes back from the mine.

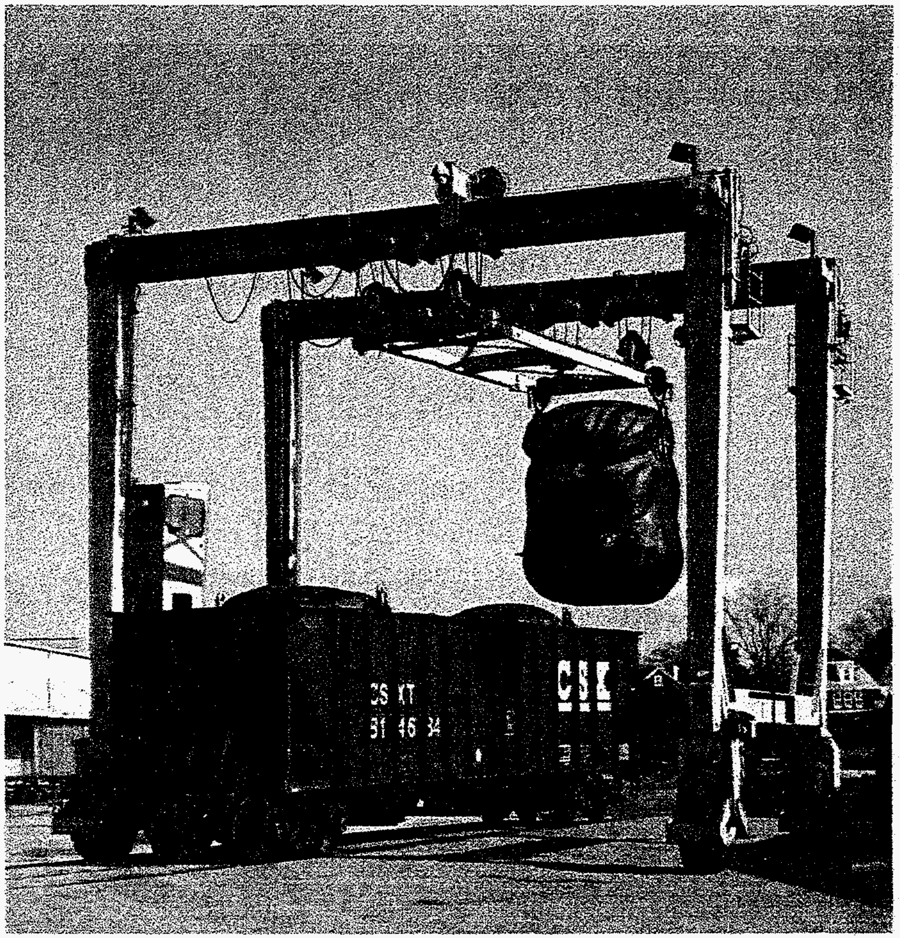


Figure 4.9 A 20-ton CIC™, filled with fly ash, is being lifted by an overhead crane (SEEC™, Inc.,)

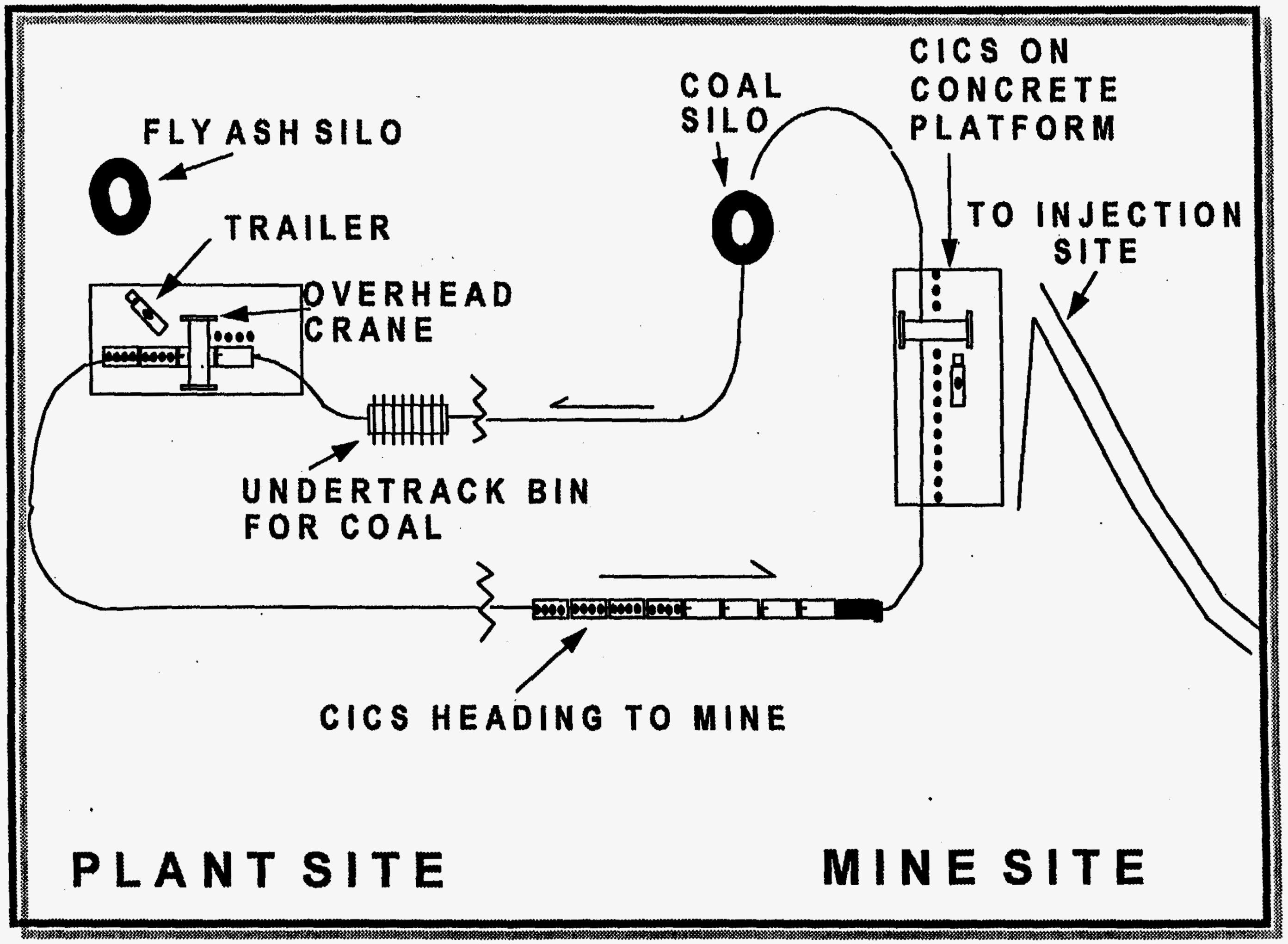


Figure 4.10 Dry FGD by-product transportation by Collapsible Intermodal Containers

4.1.4 Cylindrical Intermodal Tanks (CIT)

These tanks are made of either steel or aluminum and have a volume of approximately 6400 gallons. They are currently being used in transporting liquids and liquefied gases. The capacity of a tank will be approximately 20 to 25 tons assuming an average density of 60 lbs/ft^3 for coal combustion by-products. Since they are cylindrical, the bridging and sticking problems that occur in rectangular containers when handling powdered material like fly ash, or damp material like scrubber sludge, can be eliminated. These tanks may be mounted in steel frames to facilitate handling as shown in Figure 4.11.

The CIT transportation scenario is shown schematically in Figure 4.13. At the plant, an empty tank will be placed on a trailer with the aid of a piggy packer (a specialized crane) and shuttled to by-product storage silo where it will be filled like a pneumatic truck. Figure 4.12 shows a piggy packer in action, placing a container on a trailer. At the rail siding, the piggy packer will lift the filled tank and stage it along the railroad on a concrete pad. When the train arrives, the piggy packer will lift these tanks again one by one and place them on flat-bed rail cars. The length of these rail cars are suitable to handle 3 of these tanks on one car.

At the mine site, the tanks will be lifted again by a piggy packer and placed on the concrete pad. After the unloading is completed, the same packer will lift the tanks one by one and place them on a trailer to be taken to the injection site. The unloading of the residue into the injection hopper will be done by elevating the head of the tank with the aid of a hydraulic jack mounted on the trailer. The gate of the tank will then be opened and the content transferred into the injection system hopper. If emptying the tank through a flop gate creates unacceptable levels of fugitive dust, they can be designed to be emptied like a pneumatic truck with the aid of a portable blower attached to the injection hopper.

The empty tanks will be staged at the rail siding and will be waiting for the train to pick them up. After delivering the empty tanks to the plant another cycle will begin.

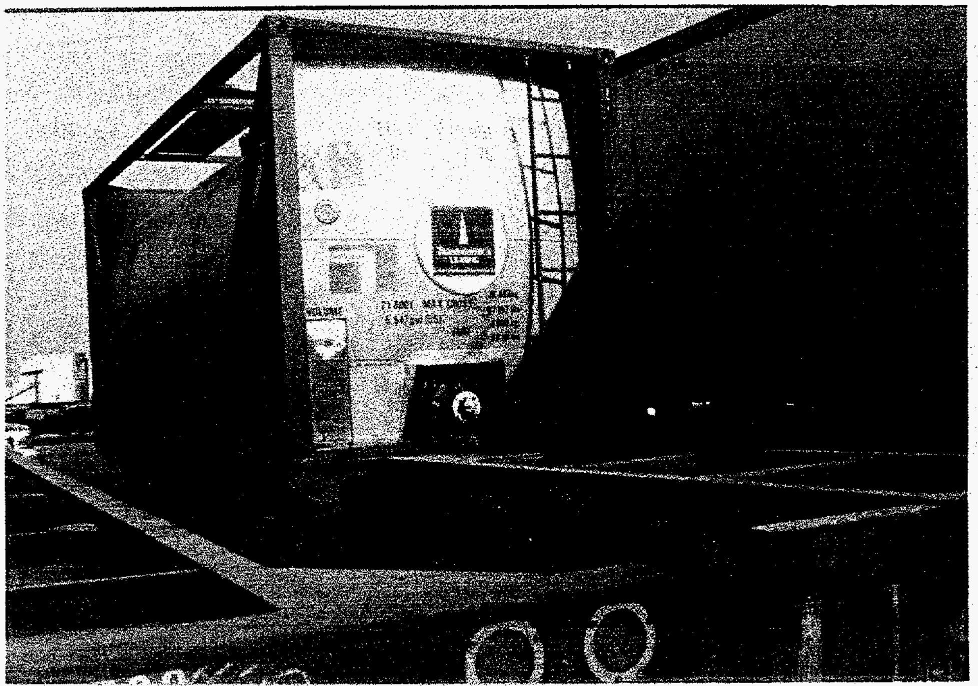


Figure 4.11 A 20-ton cylindrical aluminum tank mounted in a steel frame and placed on a trailer chassis

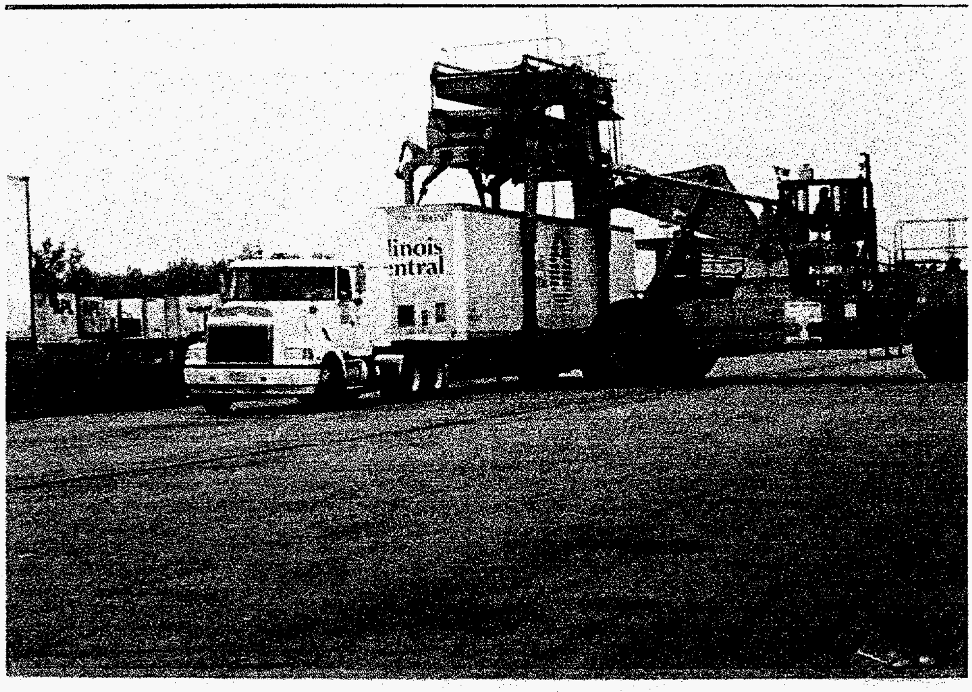


Figure 4.12 A piggy packer placing a container on a trailer

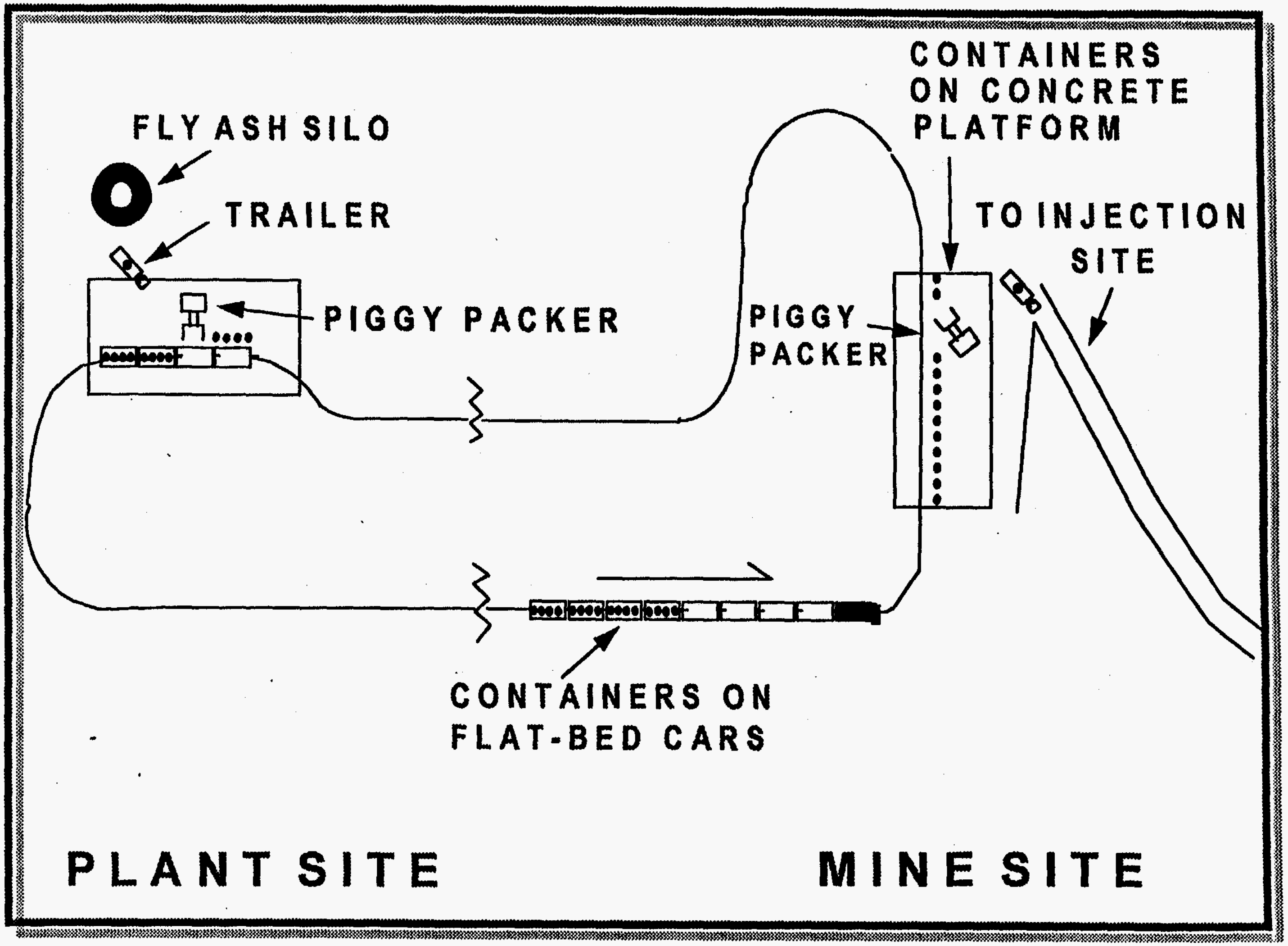


Figure 4.13 Dry FGD by-product transportation by Cylindrical Intermodal Tanks

4.1.5 Coal Hopper Cars with Automatic Retractable Tarping (CHC)

This system will be very convenient when the by-products are disposed of into abandoned section of the mine that supplies the coal to the plant. This way, coal cars will not go back empty but will transport by-product. The rate that the railroad would charge to transport by-products might be significantly less than the fronthaul rate. The retractable tarp will be push-button operated, and when it is activated it will seal all around the car to eliminate any fugitive dust and to prevent the effects of adverse weather conditions. This will be true both ways, that is, while transporting coal in fronthaul and by-product in backhaul.

The development of automatic tarping of coal hopper cars has been recently considered by Illinois Central Railroad, but to date, no reports have been available on the progress. The disadvantages of this system is that it requires a baghouse at the plant to prevent fugitive dust while loading, and an under-track bin at the mine to bottom dump. Despite the disadvantages, this system may prove to be economical especially for long-term contracts.

5.0 DEVELOPMENT OF AN INTEGRATED SOFTWARE

Figure 5.1 shows the software developed for all four T&H technologies. As seen, the evaluation of any of the selected T&H technologies is done in three steps:

1. Engineering design computations,
2. Capital and operating cost computations,
3. Economic evaluation

The engineering design computations are performed on spreadsheets. These spreadsheets are accessed independently and the results are fed in the cost computation software. The economic evaluation software is common to all technologies. A Windows application was developed for the second and third steps covering the cost computations and economic evaluation. A brief description of the methods used in the computations, and the software developed to facilitate these computations are given in the following sections. In Section 5.4 cost computations for underground disposal system is presented.

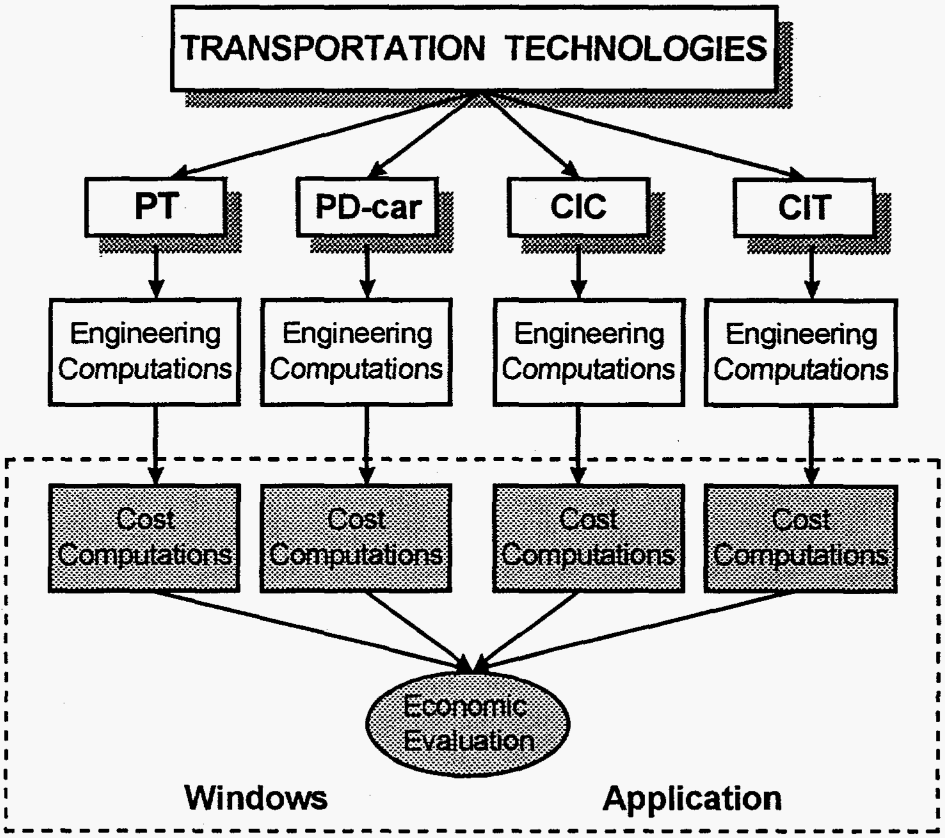


Figure 5.1 Software developed for the selected transportation technologies

5.1 ENGINEERING DESIGN COMPUTATIONS

To perform the engineering design computations, a spreadsheet was developed using Microsoft EXCEL software for each selected T&H technologies. In these spreadsheets, operating schedules composed of plant schedule, transportation schedule between the plant and the mine, and mine schedule, are devised; and critical system parameters such as silo capacities, number of transportation units, loading rate, transloading rate, and injection rate are calculated for a given tonnage-distance combination.

The spreadsheet developed for CCB transportation using pneumatic trucks is shown in Table 5.1. It is noted that this spreadsheet can actually be used for any type of truck transportation - tarped or open rear-dump trucks, bottom-dump container trucks, trailer mounted containers, etc. In Table 5.1, the first two blocks of data are user defined. The first block - line 1 to 3 - defines the operating schedule, whereas the second block - line 5 to 11 - defines values of operation parameters. The third block, printed in bold letters, exhibits the values of the design parameters calculated using the input data from the first two blocks.

For example, for a tonnage-distance combination of 100,000 tons and 100 miles (second column), the cycle time of a truck is found to be 133.3 minutes by adding loading time (line 5), travel time loaded (line 13), unloading time (line 8), and travel time empty (line 14). Another important parameter is the "maximum number of trucks without queuing". This is the maximum number of trucks in a fleet that would operate without waiting in line at either end of the operation. It is obtained by dividing the cycle time to the greater of the unloading time or loading time (133.3/20 in this example). The "required number of trucks" (line 20) to deliver the targeted tonnage, on the other hand, is calculated by dividing the "required number of trips per day" (line 18) to "maximum number of trips per truck per shift" (row 19). If the "required number of trucks" is smaller than the "maximum number of trucks without queuing," the scenario receives a "yes" (line 23) for its feasibility. Otherwise, the unloading time is decreased (line 8), or equivalently, the injection rate is increased (line 21) and the new scenario is re-tested for feasibility. It is noted that the upper limit for increased injection rate is assumed to be 2 tons/minute. Any scenario that requires more than 2 tons/minute to become feasible should be rejected.

The plant silo capacity is shown in lines 24 and 25. Assuming two idle shifts on Saturday and no work on Sunday, total fly ash accumulation hours at the plant adds up to 40 hours. This translates into an accumulation of 457 tons when the annual production is 100,000 tons. If the plant does not have a silo to accommodate this accumulation, either the operating schedule has to be changed or extra storage capacity has to be built in the system.

An important point in the determination of the truck fleet size should be mentioned here. The "required number of trucks" calculated in the engineering design spreadsheet will in most cases fall short of transporting the annual production due to the fact that the availability of a truck will always be less than 100 %. For instance, in the 100,000 tons - 100 miles combination, the required number of trucks was calculated to be 10.21 as seen in Table 5.1. This number was rounded to 10 and entered in the cost computation spreadsheet where it was subjected to "availability" concept. It is assumed that each truck in the fleet will have a 90 % availability.

With ten trucks, the availability of the fleet will be 0.9^{10}, or simply 0.348 (approximately 35 %). This is an unacceptable level of availability. Therefore, it is resolved in this design that the fleet availability must be at least 85 %. The number of trucks that would provide such an availability is then calculated by the use of the Binomial probability distribution. This number was found to be 12 for the above combination. The Binomial probability distribution and the computation of the number of trucks for the above case are given in the Appendix.

Table 5.1 Engineering design computations in CCB transportation by PT technology

1	*Annual Production (tons)*	*100000*	*100000*	*100000*
2	*Distance (miles)*	*30*	*100*	*200*
3	*Shifts per day*	*1*	*1*	*1*
4				
5	*Loading time (min)*	*10*	*10*	*10*
6	*Average speed loaded (mph)*	*45*	*45*	*45*
7	*Average speed empty (mph)*	*45*	*45*	*45*
8	*Unloading time (min)*	*29*	*29*	*29*
9	*Duration of a shift (min)*	*480*	*480*	*480*
10	*Work days per year*	*312*	*312*	*312*
11	*Truck payload (tons)*	*20*	*20*	*20*
12				
13	**Travel time loaded (min)**	**40.0**	**133.3**	**266.7**
14	**Travel time empty (min)**	**40.0**	**133.3**	**266.7**
15	**Cycle time (min)**	**119.0**	**305.7**	**572.3**
16	**Maximum number of trucks without queuing**	**4.10**	**10.54**	**19.74**
17	**Required number of trips per year**	**5000**	**5000**	**5000**
18	**Required number of trips per day**	**16.03**	**16.03**	**16.03**
19	**Maximum number of trips per truck per shift**	**4.03**	**1.57**	**0.84**
20	**Required number of trucks**	**3.97**	**10.21**	**19.11**
21	**Injection rate (tpm)**	**0.69**	**0.69**	**0.69**
22	**Injection system capacity (tph)**	**41**	**41**	**41**
23	**Feasible scenario?**	**Yes**	**Yes**	**Yes**
24	**Max. ash accumulation time (hrs)**	**40**	**40**	**40**
25	**Max. ash accumulation (tons)**	**457**	**457**	**457**

The spreadsheet developed for CCB transportation using PD cars is shown in Table 5.2. This spreadsheet is divided in two sections; plant site and disposal site. The first block in plant site (lines 1 to 7) corresponds to user defined data, whereas the second block (lines 9 to 17), marked in bold letters, corresponds to calculated values of the design parameters for the operations at the utility plant site. An important value in the user defined block is "the number of trips per week" (line 4) which is a determining factor of the number of PD-car needed in the system (line 11). Obviously, the more the trips per week the less the number of PD cars, and consequently, the less the capital investment in expensive PD cars (approximately $80,000 a piece). However, the number of trips that can be scheduled depends on the location of the plant and the mine, as well as the flexibility of the rail company operating within the area.

Another important value is the silo capacity at the plant (line 16). As seen on line 15, for 100 miles transportation distance, the train cycle time is estimated to be 28.4 hours. During this time period, the CCB produced in the plant has to be stored. At a continuous flow rate of 0.191 tpm (line 9), a silo of 326 tons (line 16) is needed. Since an existing silo of only 100 tons is reported by the user (line 5), a warning is given on line 17 to "increase" the silo capacity. If for any reason this extra capacity can not be provided, then the operating schedule must be changed.

The first block of the second section is again for the user defined data, whereas the second block is for the calculated values of the design parameters pertaining to disposal site. Here, the calculated transloading rate from the PD-car into the silo (line 32) is based on 480 minutes of continuous operation (line 23) in a shift. Similarly, the injection rate of 0.89 tpm (line 34) is based on 360 minutes of continuous operation (line 24). If these times are not realistic, they should be changed. Finally, in the last line of this block it is seen that three trucks will be sufficient to transport 100,000 tons annually from the silo to the injection point. In another operating scenario, however, silo may be totally omitted at the mine site, and that pneumatic trucks can be used between the PD cars and the injection system where the PD cars themselves will play the role of a silo. It is noted that, if desired, this spreadsheet can also be used for rail cars other than PD cars.

The spreadsheet developed for CCB transportation using CIT technology is shown in Table 5.3. The content of this table is very much similar to that of the PD-car table, except that there is an extra operation of container transfer and container loading at the plant site, which requires the determination of the right number of tote trailers (line 25). If, however, the facility provides direct loading of the containers from the silo while they are on the flat-bed rail car, this extra operation can be avoided. As in the first two spreadsheets discussed above, this spreadsheet too, can accommodate any type of intermodal container system.

Finally, the spreadsheet developed for the CIC system is shown in Table 5.4. This spreadsheet is quite similar to CIT spreadsheet with the exception of a truck operation to transport the empty CICs from the mine to the power plant. The required number of truck trips shown on line 27 is obtained by dividing the number of containers to be transported on a weekly basis by

Table 5.2 Engineering design computations in CCB transportation by PD-car technology

	PLANT SITE:			
1	*Distance between the plant and the mine (miles)*	*30*	*100*	*200*
2	*Annual residue production (tons)*	*100000*	*100000*	*100000*
3	*PD car capacity (tons)*	*100*	*100*	*100*
4	*Number of trips per week*	*1*	*1*	*1*
5	*Existing silo capacity (tons)*	*100*	*100*	*100*
6	*Average speed of train (mph)*	*45*	*45*	*45*
7	*Time between delivery of filled cars and pick-up of the empties (hours)*	*24*	*24*	*24*
8				
9	**Continuous flow rate from plant into silo (tpm)**	**0.191**	**0.191**	**0.191**
10	**Weekly residue production (tons)**	**1923**	**1923**	**1923**
11	**Required number of PD cars per trip**	**19.23**	**19.23**	**19.23**
12	**Final number of PD cars per trip**	**19**	**19**	**19**
13	**Tonnage transported per trip (tons)**	**1923**	**1923**	**1923**
14	**Round trip time (hours)**	**1.333**	**4.444**	**8.889**
15	**Total time for train arrival at plant (hours)**	**25.333**	**28.444**	**32.889**
16	**Minimum required silo capacity at plant (tons)**	**290**	**326**	**376**
17	**Need to adjust the silo capacity?**	increase	increase	increase
18				
19	**DISPOSAL SITE:**			
20	*Number of working weeks per year*	*52*	*52*	*52*
21	*Working days per week*	*6*	*6*	*6*
22	*Shifts per day (100 tph inj. rate is max, so 100*6*6*52=187200t)*	*1*	*1*	*1*
23	*Transloading time per shift (minutes)*	*480*	*480*	*480*
24	*Injection time per shift (minutes)*	*360*	*360*	*360*
25	*Truck capacity (tons)*	*20*	*20*	*20*
26	*Truck travel time empty (minutes)*	*10*	*10*	*10*
27	*Truck travel time loaded (minutes)*	*10*	*10*	*10*
28	*Truck loading time from silo (minutes)*	*10*	*10*	*10*
29	*Truck unloading time into injection hopper (minutes)*	*20*	*20*	*20*
30				
31	**Truck cycle time (minutes)**	**50**	**50**	**50**
32	**Transloading rate from train to silo (tpm)**	**0.668**	**0.668**	**0.668**
33	**Silo capacity (one shift injection, tons)**	**321**	**321**	**321**
34	**Injection rate (tpm)**	**0.890**	**0.890**	**0.890**
35	**Injection capacity (tph)**	**54**	**54**	**54**
36	**Number of trucks in the fleet**	**2.226**	**2.226**	**2.226**
37	**Final number of trucks in the fleet**	**3**	**3**	**3**

Table 5.3 Engineering design computations in CCB transportation by CIT technology

	PLANT SITE:			
1	*Distance between the plant and the mine (miles)*	30	100	200
2	*Annual by-product production (tons)*	100000	100000	100000
3	*Container capacity (tons)*	20	20	20
4	*Number of trips per week*	1	1	1
5	*Existing silo capacity (tons)*	100	100	100
6	*Average speed of train (mph)*	45	45	45
7	*Time between delivery of filled cars and pick-up of the empties (hours)*	24	24	24
8	*Number of work weeks per year*	52	52	52
9	*Number of work days per week*	7	7	7
10	*Number of shifts per day*	1	1	1
11	*Duration of a shift (minutes)*	480	480	480
12	*Cycle time for filling one container (minutes)*	30	30	30
13				
14	**Continuous flow rate from plant into silo (tpm)**	0.191	0.191	0.191
15	**Weekly residue production (tons)**	1923	1923	1923
16	**Required number of containers per trip**	96.15	96.15	96.15
17	**Final number of containers per trip**	96	96	96
18	**Tonnage transported per trip (tons)**	1923	1923	1923
19	**Round trip time (hours)**	1.333	4.444	8.889
20	**Total time for train arrival at plant (hours)**	25.333	28.444	32.889
21	**Minimum required silo capacity at plant (tons)**	290	326	376
22	**Need to adjust the silo capacity?**	increase	increase	increase
23	**Storage and staging area (twice the area of containers - sq. ft)**	38400	38400	38400
24	**Total number of containers filled per shift per trailer**	16	16	16
25	**Number of tote trailers**	1	1	1
26				
27	**DISPOSAL SITE:**			
28	*Number of work weeks per year*	52	52	52
29	*Working days per week*	6	6	6
30	*Injection time per shift (minutes)*	360	360	360
31	*Shifts per day (100 tph inj. rate is max, so 100*6*6*52=187200t)*	1	1	1
32	*Tote trailer travel time empty (minutes)*	10	10	10
33	*Tote trailer travel time loaded (minutes)*	10	10	10
34	*Trailer loading time (minutes)*	5	5	5
35	*Container unloading time into injection hopper (minutes)*	5	5	5
36				
37	**Tote trailer cycle time (minutes)**	30	30	30
38	**Total number of containers transported per shift per trailer**	12	12	12
39	**Number of tote trailers**	2	2	2
40	**Storage and staging area (twice the area of all containers - sq. ft)**	76800	76800	76800
41	**Injection rate (tpm)**	0.890	0.890	0.890
42	**Injection system capacity (tph)**	53	53	53

Table 5.4 Engineering design computations in CCB transportation by CIC technology

	PLANT SITE:			
1	*Distance between the plant and the mine (miles)*	30	100	200
2	*Annual by-product production (tons)*	100000	100000	100000
3	*Container capacity (tons)*	20	20	20
4	*Number of train trips per week*	1	1	1
5	*Existing silo capacity (tons)*	100	100	100
6	*Average speed of train (mph)*	45	45	45
7	*Average speed of truck to transport empty CICs*	55	55	55
8	*Maximum ash accumulation time (hours)*	40	40	40
9	*Number of work weeks per year*	52	52	52
10	*Number of work days per week*	7	7	7
11	*Number of shifts per day*	1	1	1
12	*Duration of a shift (minutes)*	480	480	480
13	*Cycle time for filling one container (minutes)*	33	33	33
14	*Number of empty CICs delivered per truck trip*	30	30	30
15				
16	**Continuous flow rate from plant into silo (tpm)**	**0.191**	**0.191**	**0.191**
17	**Weekly residue production (tons)**	**1923**	**1923**	**1923**
18	**Required number of containers per trip**	**96.15**	**96.15**	**96.15**
19	**Final number of containers per trip**	**96**	**96**	**96**
20	**Total number of containers**	**144**	**144**	**144**
21	**Tonnage transported per trip (tons)**	**1923**	**1923**	**1923**
22	**Silo capacity (tons)**	**458**	**458**	**458**
23	**Need to adjust the silo capacity?**	increase	increase	increase
24	**Storage and staging area (3 times the area of containers - sq. ft)**	**22608**	**22608**	**22608**
25	**Total number of containers filled per shift per trailer**	**15**	**15**	**15**
26	**Number of tote trailers needed**	**1**	**1**	**1**
27	**Required number of truck trips per week**	**3**	**3**	**3**
28	**Time available for a round trip (hours)**	**19**	**19**	**19**
29	**Duration of a round trip (hours)**	**1.09090**	**3.63636**	**7.27272**
30	**Number of tractors needed**	**1**	**1**	**1**
31	**Number of trailers needed**	**2**	**2**	**2**
32				
33	**DISPOSAL SITE:**			
34	*Number of working weeks per year*	52	52	52
35	*Working days per week*	6	6	6
36	*Injection time per shift (minutes)*	360	360	360
37	*Shifts per day (100 tph inj. rate is max, so 100*6*6*52=187200t)*	1	1	1
38				
39	**Tote trailer cycle time (minutes)**	**38**	**38**	**38**
40	**Total number of containers transported per shift per trailer**	**9**	**9**	**9**
41	**Number of tote trailers needed**	**2**	**2**	**2**
42	**Storage and staging area (3 times the area of containers - sq. ft)**	**22608**	**22608**	**22608**
43	**Injection rate (tpm)**	**0.890**	**0.890**	**0.890**
44	**Injection system capacity (tph)**	**53**	**53**	**53**

the number of empty CIC that can be loaded into a truck trailer. For example, for the combination of 100 miles - 100,000 tons, the required number of truck trips per week is 3 (line 27). Furthermore, the time available for a round trip is 19 hours (line 28), and one round trip takes 3.64 hours (line 29). Since the duration of a round trip is smaller than the time available for a round trip, only one tractor can do the job (line 30). It is noted that, if the operating scenario is such that the empties are to be returned in coal cars rather than in trailers, the above mentioned section can be eliminated, and the design computations will be almost identical to those of CITs.

5.2 CAPITAL AND OPERATING COST CALCULATIONS

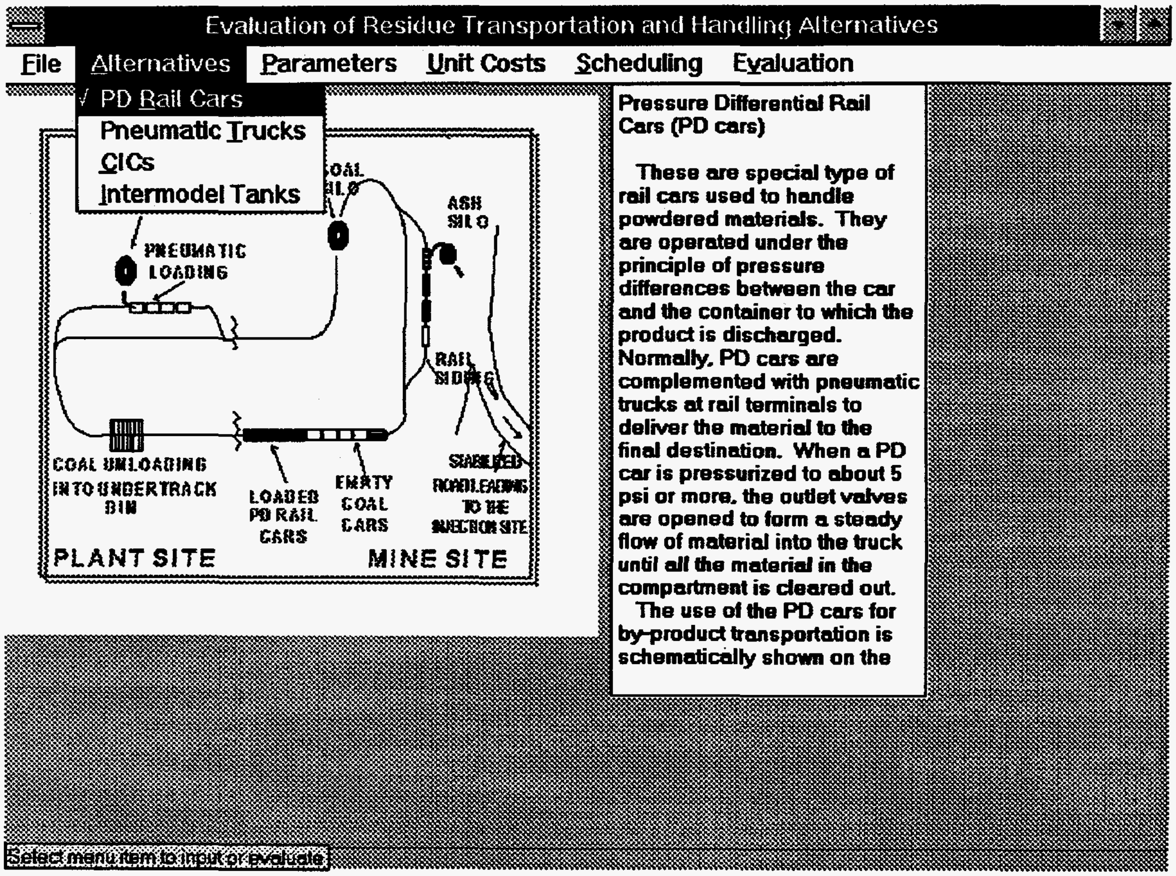
To perform capital and operating cost calculations a spreadsheet was developed for each selected T&H technologies using Microsoft EXCEL software. These spreadsheets were assembled "under one roof" using "Delphi", a rapid application development (RAD) tool. Under this roof, sketches of the systems and an economic evaluation model were also added. The sketches were drawn using AUTOCAD, and economic evaluation model was coded using FORTRAN language. The final product was a user friendly, interactive WINDOWS application.

In this WINDOWS application, the spreadsheets were converted into templates. When the user selects one of the technologies, the input data are presented to him in various dialog boxes. The source of a particular data entry can be retrieved by clicking on that entry. If the entry is not satisfactory, the user can overwrite it by typing in his own number. In other words, default values are provided for every entry in the template of the selected alternative.

With the organization of data in dialog boxes, the user can conveniently input parameter values and see the results of cost calculations right on the spot without the need to know the underlying structure. Helpful plots of system schematics and item explanations are shown on the screen as item-sensitive features. For instance, as shown in Figure 5.2, by selecting the "Alternatives" menu item from the menu bar, the user calls the sub-menu which shows the four technologies that were built in the software. When the user clicks on the PD car alternative, the software brings the sketch of the system to the screen. The description of the system operation appears on the box next to the sketch.

For convenience to the user, the input data and computations are organized in 9 categories as shown in Table 5.5. Although there are 9 categories, it can be easily seen that the primary and secondary materials handling modules shown in Figure 1.1 in the "Introduction" section have been preserved as the core of the developed software. The data given in Table 5.5 corresponds to a hypothetical PD-car transportation system delivering 100,000 tons of by-product per year to a mine 100 miles away from a power plant. As seen in this table, there are a number of data entries with a note in parenthesis that reads "from engineering design sheet." These are the calculated or fixed values of the parameters in the engineering design computations spreadsheet of that particular technology. The lines given in bold letters correspond to computations performed within the spreadsheet, whereas those in italic print correspond to input data.

After becoming familiar with the selected T&H system, the user can click on the "Parameters" menu item and activate the spreadsheet-like dialog box for entering the "General Parameters" values. The data under General Parameters are shown in Table 5.5. Next on the menu bar is the "Unit Costs". By activating this item, the user is supplied with equipment capital costs and various unit operating costs. Any question on the source of these unit costs can be answered by clicking on that unit cost, which will retrieve the information from the data bank and present it in a box. Should the user have better information on that unit cost, he can overwrite the default value by typing on that line. The unit operating and capital cost items for



Pressure Differential Rail Cars (PD cars)

These are special type of rail cars used to handle powdered materials. They are operated under the principle of pressure differences between the car and the container to which the product is discharged. Normally, PD cars are complemented with pneumatic trucks at rail terminals to deliver the material to the final destination. When a PD car is pressurized to about 5 psi or more, the outlet valves are opened to form a steady flow of material into the truck until all the material in the compartment is cleared out.

The use of the PD cars for by-product transportation is schematically shown on the

Figure 5.2 First window in the PD-car transportation technology

Table 5.5 An example of cost computations for pressure differential rail cars

GENERAL PARAMETERS:	
Distance between power plant and mine (miles)	*100*
Annual amount of by-product to be handled (tons)	*100000*
Project life	*10*
Pneumatic truck capacity (tons)	*20*
Rail car capacity (tons)	*100*
Average depth of the mine (feet)	*300*
CAPITAL COST ITEMS:	
Cost of a pneumatic truck	*120000*
Cost of a PD car	*80000*
Cost of rail siding ($/yard)	*570*
OPERATING COST ITEMS:	
Fuel consumption (gal/hour/unit)	*2.5*
Maintenance cost (% of capital cost - in decimals)	*0.02*
Overhead cost (% of operating cost - in decimals)	*0.1*
Tire cost per truck mile ($/truck/mile)	*0.06*
Contracted labor charge at the plant site ($/hr)	*25*
Wage for truck drivers and silo operator at the mine ($/hr)	*20*
Fuel cost ($/gallon)	*1.1*
Railroad charge (from chart in user's manual - $/ton/mile)	*0.0358*
Insurance cost (% of capital cost - in decimals)	*0.01*
Cost of road construction ($/sq. yd)	*5*
PD car maintenance cost (when they are leased) ($/mile/car)	*0*
Leasing cost of a PD car ($/month/unit)	*0*
Leasing cost of a pneumatic truck ($/month/unit)	*0*
Length of a PD car (yds)	*20*
Average cost of injection hole ($/ft)	*20*
POWER PLANT:	
Do we need silo (1 for yes, 0 for no)	*0*
Silo capacity (from engr. design sheet - tons)	*100*
Pneumatic rail cars required per trip (from engr. design sheet)	*19*
Number of PD car sets	*2*
Total number of PD cars required for the operation	*38*
Length of rail siding (yds)	**440**
Time to fill a PD car, including spotting (hours)	*1*
Contracted labor for loading the PD cars (hours)	**1000**
PLANT CAPITAL COST:	
Rail siding	**0**
Pressure differential rail cars	**3040000**
Silo	**0**
Total capital investment	**3040000**
PLANT OPERATING COST:	
Rail road charge	**358000**
PD leasing cost	**0**
PD car maintenance cost (when they are leased)	**0**
Insurance	**30400**
Maintenance	**60800**

Table 5.5 *Continued......*

Contracted labor at the plant	**25000**
Subtotal	**474200**
Overhead cost	**47420**
Total plant operating cost	**521620**
MINE SITE:	
Do we need silo (1 for yes, 0 for no)	*1*
Silo capacity (from engr. design sheet - tons)	*321*
Area of new road to be constructed (sq. yd)	*14000*
Number of working weeks per year (from engr. design sheet)	*52*
Number of working days per week (from engr. design sheet)	*6*
Duration of a shift (from engr. design sheet - hours)	*8*
Number of shifts per day (from engr. design sheet)	*1*
Length of rail siding (yds)	**440**
Number of trucks required (from engr. design sheet)	*3*
Number of ash silo operators per shift	*1*
Expected amount of by-product injected through one hole (tons)	*10000*
Number of injection holes to be drilled per year	*10*
Do we have hydraulic injection system (1 for yes, 0 for no)?	*0*
Do we have pneumatic injection system (1 for yes, 0 for no)?	*1*
Injection system capacity (from engr. design sheet, tph)	*55*
Operating cost of hydraulic injection system ($/ton)	**0**
Operating cost of pneumatic injection system ($/ton)	**1.97**
Injection system operating cost ($/ton)	**1.97**
MINE CAPITAL COSTS:	
Rail siding	**250800**
Silo	**123337**
Pneumatic trucks	**360000**
Hydraulic injection system	**0**
Pneumatic injection system	**122500**
Total mine capital investment	**856637**
MINE OPERATING COSTS:	
Leasing cost of pneumatic trucks	**0**
Road construction cost	**70000**
Insurance	**8566**
Silo operators wage	**49920**
Drivers wage	**149760**
Fuel cost	**20592**
Maintenance	**17133**
Injection system operating cost	**196885**
Cost of injection holes	**60000**
Subtotal	**572856**
Overhead cost	**57285**
Total mine operating cost	**630141**
TOTAL SYSTEM CAPITAL COST	3896637
TOTAL SYSTEM OPERATING COST	1151761
Operating cost per ton	11.52

the PD-car alternative are also shown in Table 5.5. "Scheduling" is the next item on the menu bar. Under this category, operating schedules at the plant and mine are devised. Figure 5.3 shows the spreadsheet-like dialog box for the plant site together with an information box giving the information on the "length of rail siding." The specific items in the scheduling of each site are shown in Table 5.5 under the subtitles of "POWER PLANT" and "MINE SITE."

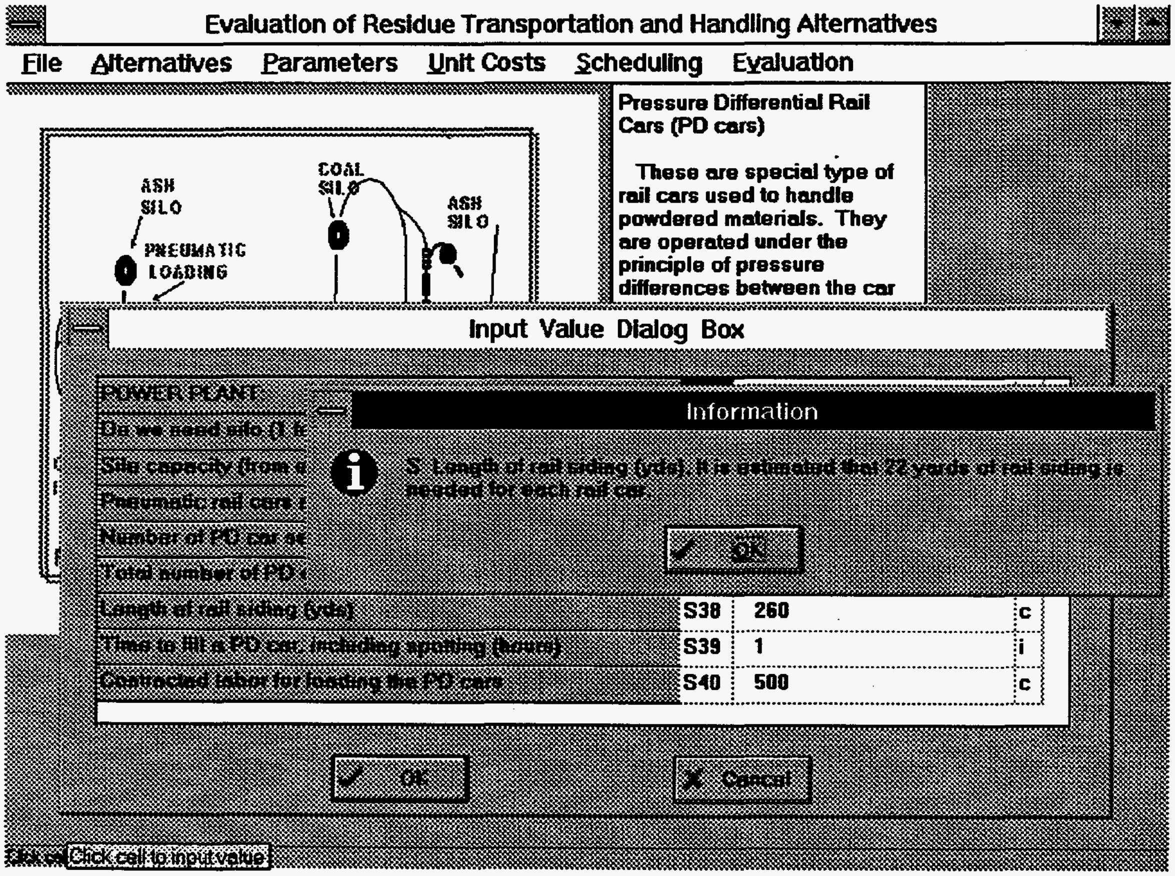
The last menu item is "Evaluation". When this item is clicked, three sub-items appear on the menu: 1) Cost Calculations, 2) Financial Data, 3) Start Evaluation. By invoking the Cost Calculations item, all operating and capital cost calculations are performed for both the plant and mine sites. In Table 5.5, these calculations are listed under PLANT CAPITAL COSTS, PLANT OPERATING COSTS, MINE CAPITAL COSTS, and MINE OPERATING COSTS.

Under "F inancial Data", the user is expected to enter the cost of each capital investment item, its depreciation life, the year it was invested, and its economic life as shown in Figure 5.4. The effective tax rate and the required rate of return (also known as the discount rate) are also entered under this item. After the item is completed, the user can invoke the "Start Evaluation" item which will run the "Economic Evaluation" model and will produce an output file. This file will contain the Net Cash Flows for each year of the project life, After-Tax Net Present Value, After-Tax Cost, and Before-Tax Price to be charged to the customer. The output file corresponding to the hypothetical case of transporting 100,000 tons of CCBs to a mine 100 miles away from the plant is given in the next section (Section 5.3).

It should be emphasized here that, with moderate knowledge of the software structure, the user can evaluate other T&H technologies. For instance, any intermodal tank transportation system can be evaluated using the template developed for the Cylindrical Intermodal Tanks. Similarly, any rail car transportation system can be evaluated using the template developed for Pressure Differential Rail Cars.

5.3 ECONOMIC EVALUATION MODEL

The economic evaluation model receives its input from the above mentioned templates. This model is coded using FORTRAN Language. The algorithm developed for this purpose is based on the principle of the "Net Cash Cost" (NCC) method, also known as "After-Tax Cost" method. The After-Tax method is preferred to Before-Tax method because, as stated by Stermole and Stermole (1990), "The effects of tax considerations often vary widely from one investment alternative to another, so it generally is imperative to compare the relative economies of investment alternatives on an after-tax basis to have a valid economic analysis."



Pressure Differential Rail Cars (PD cars)

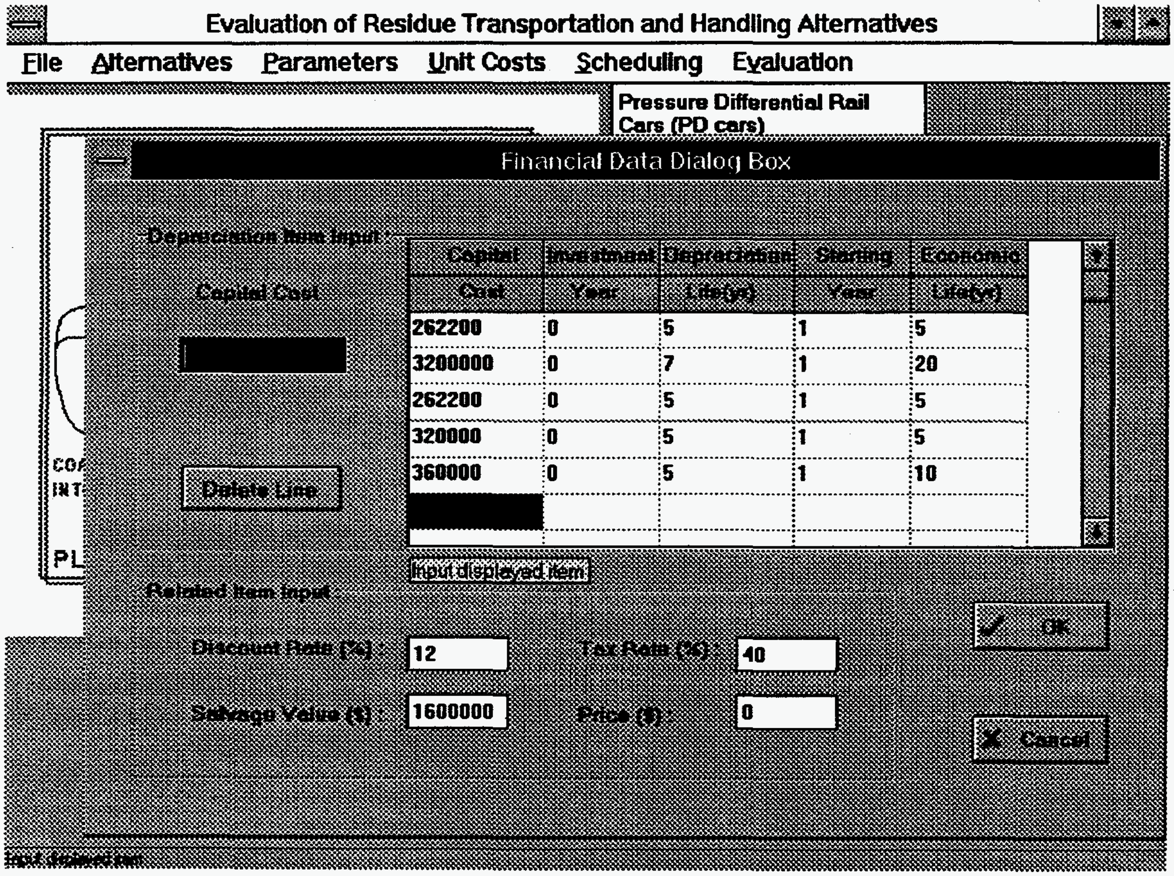
These are special type of rail cars used to handle powdered materials. They are operated under the principle of pressure differences between the car

S: Length of rail siding (yds). It is estimated that 22 yards of rail siding is needed for each rail car.

POWER PLANT			
Do we need silo (1			
Silo capacity (from			
Pneumatic rail cars			
Number of PD car se			
Total number of PD			
Length of rail siding (yds)	S38	260	c
Time to fill a PD car, including spotting (hours)	S39	1	i
Contracted labor for loading the PD cars	S40	500	c

Click cell to input value

Figure 5.3 Window for power plant scheduling in PD-car transportation technology



Capital Cost	Investment Year	Depreciation Life(yr)	Starting Year	Economic Life(yr)
262200	0	5	1	5
3200000	0	7	1	20
262200	0	5	1	5
320000	0	5	1	5
360000	0	5	1	10

Discount Rate (%): 12

Tax Rate (%): 40

Salvage Value ($): 1600000

Price ($): 0

Figure 5.4 Window for financial data in PD-car transportation technology

Table 5.6 exhibits a typical output of "Economic Evaluation" software. The case shown in the table is the same case given in the preceding section where a PD-car system transports 100,000 tons annually to a mine 100 miles away from the plant. It is assumed that the project life is 10 years, the effective tax rate is 40%, and the minimum required rate of return is 12%.

In each year of the project life, the NCC is calculated using Equation 5.1.

NCC = (Operating Cost + Depreciation) (1 - Tax Rate) - Depreciation + Capital Cost .... Eq. (5.1)

The depreciation allowances are calculated based on the "Modified Accelerated Cost Recovery System" MACRS. Also in this model, the "constant dollar" approach is preferred to the "escalated dollar" because it allows the use of "today's dollars" for cost estimations assuming that the cost escalation is equal to the inflation rate throughout the project life. This approach eliminates the complexity of estimating the future cost escalation (Stermole and Stermole, 1990).

As seen in Table 5.6, the net cash flows of years 1 to 10 are negative since only costs are involved in the analysis, and the objective is to find the price to be charged per ton of material delivered in order to make the minimum required rate of return. The net cash flow of year "0" simply reflects the initial capital cost invested in the project, which is $3,897,000 in this case. The NCCs calculated for each year are discounted to time "0" at the "minimum required rate of return" to obtain the Net Present Cost (NPC) of the project. The NPC is subsequently levelized (or annualized) over the project life using the same discount rate. The levelized cost is then divided by the annual tonnage of by-product transported to obtain the cost-per-ton value. Since this is an after-tax value, the "price to be charged" is obtained by dividing this value by (1 - tax rate).

In the example given above, the salvage value after 10 years of operation is estimated to be $869,000. Capital cost items in this project are assumed to be depreciated within 5 to 7 years. Hence, at the end of the project life all capital cost items were totally depreciated and the salvage was subjected to 40% capital gain tax, giving an after tax cash flow of $521,000. Again, as seen in Table 5.6, at 12% minimum required rate of return, the annual equivalent cost of the project is determined to be $1,161,000 indicating an after-tax cost per ton of $11.61. It is noted that this cost includes the injection cost too. At 40% effective tax rate, the $11.61 after-tax cost corresponds to a before-tax price of $19.36. In other words, the company who undertakes this project must charge $19.36 per ton in order to obtain a 12% rate of return on its investment. However, if the project is undertaken by either the company who owns the power plant or the mine, it will cost them $11.61 per ton, and this cost will be absorbed within the company as part of their overall operating cost.

There are a number of critical variables such as number of train trips per week, railroad rate, capital cost items, and wages and salaries that can affect the project economics. Sensitivity analyses on these variables are essential to reveal the project's merits. With the aid of the integrated software, these sensitivity analyses can be conducted in a short period of time.

Table 5.6 An example of economic evaluation of pressure differential rail cars (including injection system)

DISTANCE (MILES) ------------------------------ = 100
PRODUCTION (TONS/YEAR) ------------------------ = 100000
MINIMUM REQUIRED RATE OF RETURN (%) ----------- = 12
EFFECTIVE TAX RATE (%) ------------------------ = 40

Year	0	1	2	3	4	5
Revenue.........	0	0	0	0	0	0
-Oper. Cost.....	0	-1152	-1152	-1152	-1152	-1152
-Depreciation...	0	-584	-991	-690	-482	-360
Taxable Income..	0	-1736	-2143	-1842	-1634	-1512
-Tax............	0	695	857	737	654	605
Net Income......	0	-1042	-1286	-1105	-980	-907
+Depreciation...	0	584	991	690	482	360
-Capital Cost...	-3897	0	0	0	0	0
Net Cash Flow...	-3897	-457	-295	-415	-498	-547

Year	6	7	8	9	10
Revenue.........	0	0	0	0	0
-Oper. Cost.....	-1152	-1152	-1152	-1152	-1152
-Depreciation...	-333	-305	-152	0	0
Taxable Income..	-1485	-1457	-1304	-1152	-1152
-Tax............	594	583	522	461	461
Net Income......	-891	-874	-783	-691	-691
+Depreciation...	333	305	152	0	0
-Capital Cost...	0	0	0	0	0
Net Cash Flow...	-558	-569	-630	-691	-691

CAPITAL GAIN (OR LOSS) COMPUTATION ($1,000)

Salvage Value..................................	869
Book Value.....................................	0
Capital Gain (or Loss).........................	869
Tax Liability..................................	-347
After-Tax Capital Gain (or Loss)...............	521
Book Value.....................................	0
After-Tax Cash Flow Due to Cap. Gain (or Loss)..	521

AFTER-TAX NET PRESENT VALUE ($1,000) ....= -6562
AFTER-TAX ANNUAL EQUIVALENT COST ($1,000) ...= -1161
AFTER-TAX COST PER TON ($) ....= -11.61
BEFORE-TAX PRICE TO BE CHARGED ($/TON) ......= 19.36

Figure 5.5 shows such a sensitivity analysis which was conducted on the number of train trips per week. Originally, 1 (one) trip per week was selected, indicating the necessity of 38 PD-cars and a cost per ton of $11.61. As shown in this figure, when 2 trips per week was scheduled, the number of rail cars decreased to 20 and the cost to $9.46. Furthermore, when 3 trips per week was scheduled, the number of rail cars further decreased to 12 and the cost per ton to $8.50, providing significant reduction in cost.

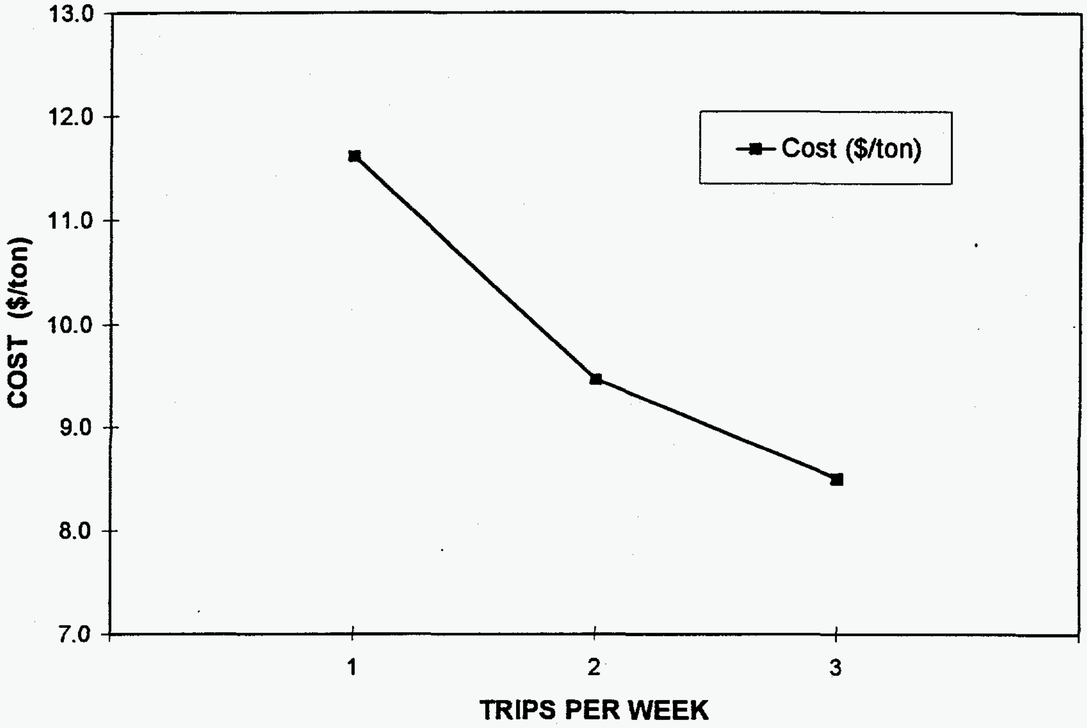


Figure 5.5 Sensitivity of cost to number of trips per week in PD-car technology

In the above example, it is assumed that the company which handles the by-products choose to purchase, and therefore capitalize, the system components such as PD cars and pneumatic trucks. If leasing of these components is a possibility, a leasing analysis can be conducted in addition to capitalization analysis so that a comparison can be made. The model has both options built in as can be seen from data entries in Table 5.5.

It should be noted that if the price to be charged is inputted to the developed model, the project becomes a revenue generating project, and its Net Present Value (NPV) becomes exactly equal to "0", securing a rate of return equal to the discount rate. For instance, in the

PD-car example given in this section, the price to be charged was calculated to be $19.36 per ton. This price was entered in the input data screen and the model reran. The resulting output file is shown in Table 5.7. As seen, the project becomes a revenue generating project, giving positive values in the first line of the table ($1,936,000); and the NPV of the project was equal to "0", indicating a rate of return of 12%.

Table 5.7 Demonstration of revenue generating project when a price per ton is given to the economic evaluation model (PD-car example)

```
DISTANCE (MILES) ------------------------------- = 100
PRODUCTION (TONS/YEAR) ------------------------- = 100000
MINIMUM REQUIRED RATE OF RETURN (%) ------------ = 12
EFFECTIVE TAX RATE (%) ------------------------- = 40
PRICE TO BE CHARGED ($/TON) -------------------- = 19.36

  Year                 0        1        2        3        4        5
-------------------------------------------------------------------------
 Revenue.........      0     1936     1936     1936     1936     1936
-------------------------------------------------------------------------
 -Oper. Cost.....      0    -1152    -1152    -1152    -1152    -1152
 -Depreciation...      0     -584     -991     -690     -482     -360
-------------------------------------------------------------------------
 Taxable Income..      0      200     -207       94      302      424
 -Tax............      0      -80       83      -38     -121     -169
-------------------------------------------------------------------------
 Net Income......      0      120     -124       57      181      254
 +Depreciation...      0      584      991      690      482      360
 -Capital Cost...  -3897        0        0        0        0        0
-------------------------------------------------------------------------
 Net Cash Flow...  -3897      704      867      746      663      615

  Year                 6        7        8        9       10
-------------------------------------------------------------------------
 Revenue.........   1936     1936     1936     1936     1936
-------------------------------------------------------------------------
 -Oper. Cost.....  -1152    -1152    -1152    -1152    -1152
 -Depreciation...   -333     -305     -152        0        0
-------------------------------------------------------------------------
 Taxable Income..    451      479      632      784      784
 -Tax............   -181     -192     -253     -314     -314
-------------------------------------------------------------------------
 Net Income......    271      287      379      470      470
 +Depreciation...    333      305      152        0        0
 -Capital Cost...      0        0        0        0        0
-------------------------------------------------------------------------
 Net Cash Flow...    603      592      531      470      470

      CAPITAL GAIN (OR LOSS) COMPUTATION ($1,000)

-------------------------------------------------------------------------
 Salvage Value..................................        869
 Book Value.....................................          0
-------------------------------------------------------------------------
 Capital Gain (or Loss).........................        869
 Tax Liability..................................       -347
-------------------------------------------------------------------------
 After-Tax Capital Gain (or Loss)...............        521
 Book Value.....................................          0
-------------------------------------------------------------------------
 After-Tax Cash Flow Due to Cap. Gain (or Loss)..       521
-------------------------------------------------------------------------


 AFTER-TAX NET PRESENT VALUE ($1,000) ........=         0
 AFTER-TAX ANNUAL EQUIVALENT COST ($1,000) ...=         0
```

5.4 ECONOMICS OF UNDERGROUND PLACEMENT SYSTEM

The underground placement system is being investigated by another group of researchers within the overall DOE-SIUC cooperative agreement. This group is working on the development of a hydraulic and a pneumatic placement system. Both systems are currently being tested at the Peabody No. 10 mine near Pawnee, Illinois. In these tests, the investigators are using the best CCB mixtures they have determined in a preceding study. In systems economic research, the capital and operating costs of the placement systems are expressed in terms of functions using the estimates obtained from the placement systems investigators. It is noted that these estimates are relatively crude, and that better estimates will be obtained through the experience gained in the demonstration project during the summer and fall of 1997. The placement cost also includes the borehole cost for which estimates were obtained from a few contractor operating in central and southern Illinois.

The capital and operating costs are expressed as a function of the system capacity. The system capacity is obtained in the engineering design computation spreadsheet as a function of the annual CCB to be placed, number of shifts per day to place the CCB, and number of operating hours. The cost computations are performed under MINE SITE in cost computation spreadsheets presented in Section 5.2.

Specifically, the following capital and operating cost equations were obtained:

- For the capital cost of the pneumatic placement system:

$$y = 113{,}333 - 200\,x + 6.67\,x^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Eq. (5.2)}$$

where:

y is the capital cost in \$
x is the system capacity in tph.

- For example, an underground placement system with 50 tph capacity will cost:

$$y = 113{,}333 - 200\,(50) + 6.67\,(50)^2 = \$120{,}000$$

- For the operating cost of the pneumatic placement system:

$$y = 2.0833 + 0.0025\,x - 0.0000833\,x^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Eq. (5.3)}$$

where:

y is the operating cost in \$/ton
x is the system capacity in tph

- For example, the operation of the underground placement system with 50 tph capacity will cost:

$$y = 2.0833 + 0.0025\ (50) - 0.000083\ (50)^2 = \$2.0/\text{ton}$$

- For the capital cost of the hydraulic placement system:

$$y = 16{,}667 + 5500\ x - 16.67\ x^2 \quad \dots\dots\dots\dots\dots\dots \quad \text{Eq. (5.4)}$$

where x and y are defined as in Eq. (5.2)

- For the operating cost of the hydraulic placement system:

$$y = 1.5833 + 0.0025\ x - 0.0000833\ x^2 \quad \dots\dots\dots\dots\dots \quad \text{Eq. (5.5)}$$

where x and y are defined as in Eq. (5.3)

6.0 DETERMINATION OF FAVORABLE DISTANCE AND TONNAGE RANGES

The software described in the preceding section were used to determine favorable operating ranges of each selected technologies in terms of distances and tonnage. In southern and central Illinois, annual by-product production range between 50,000 to 200,000 tons, and typically plants are 30 to 200 miles away from underground mines. Therefore, all evaluations were conducted for distance-tonnage combinations within these ranges. The criteria used in the determination of the favorable ranges was cost-per-ton of by-product disposed. This cost was calculated for hypothetical cases of 50,000 tons, 100,000 tons, and 200,000 tons annual by-product disposal. The distances of transportation considered for each annual tonnage were 30, 100, and 200 miles, respectively.

As described in Section 4.0, the secondary T&H operation differ from one technology to the other, requiring different equipment and infrastructure preparation, and therefore different capital and operating costs. It is of interest to find the costs of primary and secondary transportation separately in each T&H technology. To accomplish this task, two sets of runs were conducted for each technology; the first set included only the primary T&H - from the power plant to the mine site - and the second set included both the primary and secondary T&H where the secondary T&H is from the mine site to the underground placement site. Naturally, the difference of these two sets provided the cost of placement at each distance-tonnage combination for that particular technology. It is also of interest to find the underground placement cost alone. The cost of the placement system is a function of the tonnage placed irrespective of the T&H technology used to deliver the CCBs. Therefore, a placement cost was calculated by activating the placement unit of the developed software for each of the three tonnages considered for the hypothetical cases.

The results of the runs for 50,000 annual production for all four technologies are shown in Table 6.1. As seen, the secondary T&H cost in PT technology does not exist because trucks can drive from the power plant directly to the placement system without the need of secondary handling. The dip note to this table shows the cost of underground placement common to all T&H technologies. As indicated, when 50,000 tons is planned to be placed annually, the cost of underground placement was found to be $2.48 per ton. This cost is calculated with the assumption that 10,000 tons of CCB can be placed through a single borehole.

For 50,000 tons, the cost of primary T&H alone for varying distances are shown in Figure 6.1. As seen, the PT technology gave lower costs than the PD-car, and CIT technologies up to approximately 70 miles, and lower than the CIC technology up to 110 miles. The PD-car and the CIT technologies indicated almost the same cost for all distances, and they remained lower than the costs of CIC technology for all distances, though the difference was significantly reduced at 200 miles.

The total cost of delivery, including both the primary and secondary T&H, are shown in Figure 6.2. As seen, when secondary T&H cost is added, the PT technology improved its favorable range; it became better than the other three technologies up to a distance of approximately 125 miles. The costs in PD-car and CIT technologies remained almost the same as in Figure 6.1, but their advantage over the CIC technology were not as significant. As a matter of fact, the difference among these three technologies eroded after 150 miles.

Table 6.1 Cost of transporting 50,000 tons of CCBs annually from power plant to underground placement site using four different technologies ($/ton)

Operation	**Distance (miles)**	**TRANSPORTATION TECHNOLOGIES**			
		PD-car	**PT**	**CIC**	**CIT**
primary transportation and handling	30	5.84	4.11	9.88	6.15
	100	7.41	9.34	10.28	7.72
	200	9.77	16.92	11.05	10.09
secondary transportation and handling	1	3.16	-	2.09	3.36
total transportation and handling	30	9.00	4.11	11.97	9.51
	100	10.57	9.34	12.37	11.08
	200	12.93	16.92	13.14	13.45

** Underground placement cost: $2.48/ton

The reason for the PT technology to improve its favorable range was the absence of the seondary T&H in this technology. The operating scenario developed for this transportation mode indicates that trucks will bring the by-product to the placement site and directly hook up to the hopper of the placement system eliminating all equipment and infrastructure needs for handling the CCB between the mine site and the placement site. As seen on the second block of Table 6.1, while the secondary T&H cost is $0.0 per ton for PT technology, it is $3.16 for PD-car, $2.09 for CIC, and $3.36 for CIT technologies.

The steeper slope of the PT cost line, both in Figures 6.1 and 6.2, is due to longer cycle time of trucks as distance increases, which imposes additional units for the fleet in order to handle the same 50,000 tons annual by-product. To illustrate how each cost in Table 6.1 is obtained, sample outputs are given here for the case of delivering 50,000 tons annually by pneumatic trucks to a placement site 100 miles away from the power plant. The engineering design computations, the cost computations and scheduling, and the results of economic evaluation are shown in tables 6.2, 6.3, and 6.4, respectively. It is noted that the $11.82/ton after-tax cost shown at the bottom of Table 6.4 includes the cost of primary and secondary T&H as well as the underground placement cost. The $9.34/ton cost shown in Table 6.1 in the cell corresponding to 50,000 tons and 100 miles is the difference between $11.82/ton total cost and $2.48/ton placement cost.

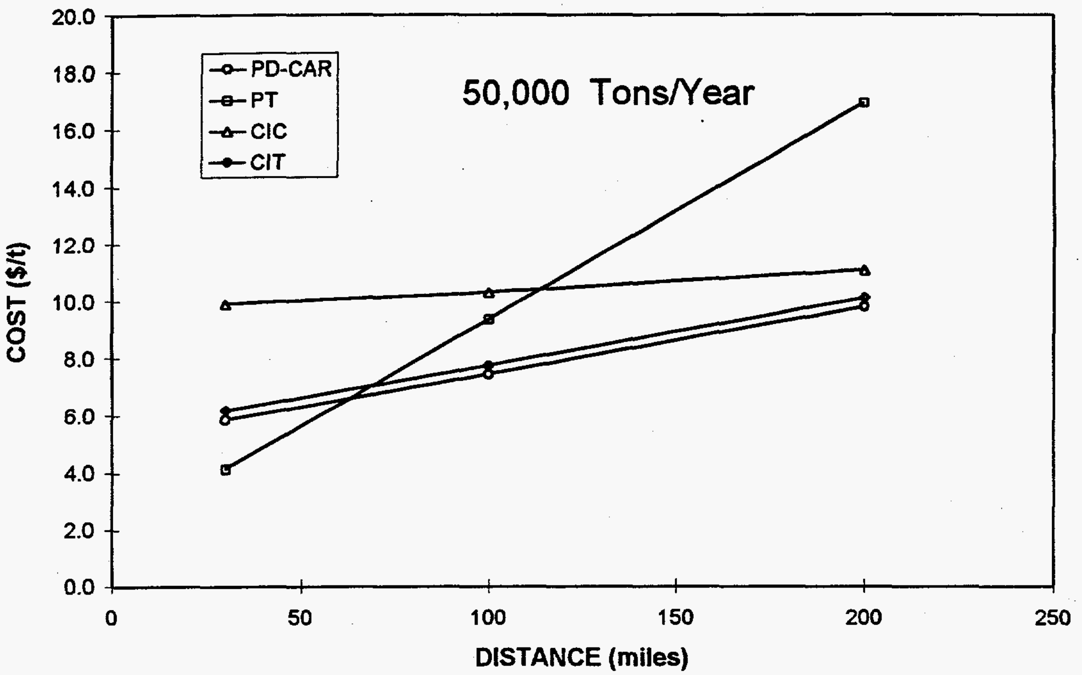


Figure 6.1 Cost of transporting 50,000 tons of CCBs annually from power plant to mine site using four different technologies (primary T&H)

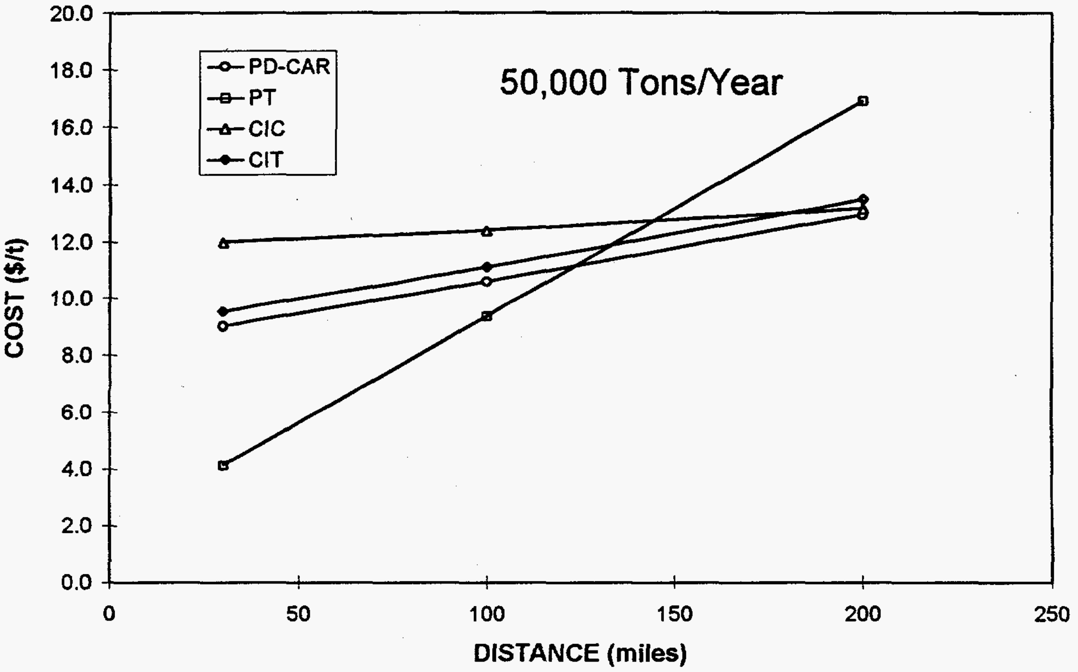


Figure 6.2 Cost of transporting 50,000 tons of CCBs annually from power plant to underground placement site using four different technologies (primary and secondary T&H)

Table 6.2 Engineering design computations in CCB transportation by Pneumatic Trucks (50,000 tons annually)

1	*Annual Production (tons)*	*50000*	*50000*	*50000*
2	*Distance (miles)*	*30*	*100*	*200*
3	*Shifts per day*	*1*	*1*	*1*
4				
5	*Loading time (min)*	*10*	*10*	*10*
6	*Average speed loaded (mph)*	*50*	*50*	*50*
7	*Average speed empty (mph)*	*50*	*50*	*50*
8	*Unloading time (min)*	*25*	*25*	*25*
9	*Duration of a shift (min)*	*480*	*480*	*480*
10	*Work days per year*	*312*	*312*	*312*
11	*Truck payload (tons)*	*20*	*20*	*20*
12				
13	**Travel time loaded (min)**	**36.0**	**120.0**	**240.0**
14	**Travel time empty (min)**	**36.0**	**120.0**	**240.0**
15	**Cycle time (min)**	**107.0**	**275.0**	**515.0**
16	**Maximum number of trucks without queuing**	**4.28**	**11.00**	**20.60**
17	**Required number of trips per year**	**2500**	**2500**	**2500**
18	**Required number of trips per day**	**8.01**	**8.01**	**8.01**
19	**Maximum number of trips per truck per shift**	**4.49**	**1.75**	**0.93**
20	**Required number of trucks**	**1.79**	**4.59**	**8.60**
21	**Injection rate (tpm)**	**0.80**	**0.80**	**0.80**
22	**Injection system capacity (tph)**	**48**	**48**	**48**
23	**Feasible scenario?**	**Yes**	**Yes**	**Yes**
24	**Max. ash accumulation time (hrs)**	**40**	**40**	**40**
25	**Max. ash accumulation (tons)**	**228**	**228**	**228**

Table 6.3 Capital and operating cost computations in CCB transportation by Pneumatic Trucks (50,000 tons annually, 100 miles, including pneumatic placement system)

GENERAL PARAMETERS:
Distance between power plant and mine (miles) = 100
Annual amount of by-product to be handled (tons) = 50000
Project life (years) = 10
Truck capacity (tons) = 20
Availability of a truck (in decimal) = 0.9
Number of front tires = 10
Number of rear tires = 8
Front tire replacement frequency (miles) = 75000
Rear tire replacement frequency (miles) = 150000
Average depth of the mine (feet) = 300

CAPITAL COST ITEMS:
Cost of a tractor = 70000
Cost of a tank trailer = 45000
Cost of a blower = 5000
Total cost of a truck (tractor-trailer-blower) = 120000

OPERATING COST ITEMS:
Truck leasing cost ($/year) = 0
Fuel consumption (miles per gallon) = 5
Fuel cost ($/gallon) = 1.1
Insurance cost per truck = 7500
Licence cost per truck = 2222
Annual highway tax per truck = 550
Tire cost (each) = 325
Maintenance cost ($/mile) = 0.14
Wage for truck drivers ($/hr) = 20
Wage for silo operator ($/hr) = 20
Overhead cost (% of other operating costs - in decimal) = 0.1
Cost of road construction ($/sq. yd) = 5
Average cost of injection hole ($/ft) = 20

POWER PLANT:
Do we need silo (1 for yes, 0 for no)? = 0
Silo capacity (from prescheduling sheet - tons) = 867
Truck cycle time (from prescheduling sheet - minutes) = 275
Number of working days per year (from prescheduling sheet) = 312
Number of shifts per day (from prescheduling sheet) = 1
Duration of a shift (from prescheduling sheet - hours) = 8
Number of trips per day (from prescheduling sheet) = 8.01
Number of trucks required (from prescheduling sheet) = 4.59
Number of trucks required (rounded) = 5
Number of trucks to have at least 80% fleet availability = 6
Actual fleet availability = 0.89
Number of drivers required = 5
Number of silo operators per shift = 1
Total number of silo operators = 1

PLANT CAPITAL COSTS:
Trucks = 720000
Silo = 0
Total plant capital cost = 720000

Table 6.3 *Continued ....*

PLANT OPERATING COSTS:	
Leasing cost for pneumatic trucks	= 0
Fuel	= 109961.28
Insurance	= 45000
Licence for tractor-trailer	= 13332
Highway tax	= 3300
Front tire replacement	= 21659
Rear tire replacement	= 8663
Maintenance	= 69975.36
Driver wages	= 249600
Silo operators wages	= 49920
Subtotal	= 571410.64
Overhead cost	= 57141.06
Total plant operating cost	= 628551.7

MINE SITE:	
Do we have silo (1 for yes, 0 for no)	= 0
Silo capacity (tons)	= 0
Area of new road to be constructed (sq. yd/year)	= 7000
Expected amount of by-product injected through one hole (tons)	= 10000
Number of injection holes to be drilled per year	= 5
Injection system capacity (from prescheduling sheet, tph)	= 50
Do we have hydraulic injection system (1 for yes, 0 for no)?	= 0
Do we have pneumatic injection system (1 for yes, 0 for no)?	= 1
Operating cost of hydraulic injection system ($/ton)	= 0
Operating cost of pneumatic injection system ($/ton)	= 2
Injection system operating cost ($/ton)	= 2

MINE CAPITAL COSTS:	
Hydraulic injection system	= 0
Pneumatic injection system	= 119999.75
Silo	= 0
Total mine capital cost	= 119999.75
MINE OPERATING COSTS:	
Road construction cost	= 35000
Injection system operating cost	= 100000
Cost of injection holes	= 30000
Subtotal	= 165000
Overhead cost	= 16500
Total mine operating cost	= 181500
TOTAL SYSTEM CAPITAL COST	= 839999.75
TOTAL SYSTEM OPERATING COST	= 810051.7
Operating cost per ton	= 16.2

Table 6.4 Economic evaluation of CCB transportation by pneumatic trucks (50,000 tons annually, 100 miles)

DISTANCE (MILES) ----------------------------- = 100
PRODUCTION (TONS/YEAR) ------------------------ = 50000
MINIMUM REQUIRED RATE OF RETURN (%) ------------ = 12
EFFECTIVE TAX RATE (%) ------------------------ = 40

Year	0	1	2	3	4	5
Revenue.........	0	0	0	0	0	0
-Oper. Cost.....	0	-810	-810	-810	-810	-810
-Depreciation...	0	-168	-269	-161	-97	-97
Taxable Income..	0	-978	-1079	-971	-907	-907
-Tax............	0	391	432	389	363	363
Net Income......	0	-587	-647	-583	-544	-544
+Depreciation...	0	168	269	161	97	97
-Capital Cost...	-840	0	0	0	0	0
Net Cash Flow...	-840	-419	-378	-421	-447	-447

Year	6	7	8	9	10
Revenue.........	0	0	0	0	0
-Oper. Cost.....	-810	-810	-810	-810	-810
-Depreciation...	-48	0	0	0	0
Taxable Income..	-858	-810	-810	-810	-810
-Tax............	343	324	324	324	324
Net Income......	-515	-486	-486	-486	-486
+Depreciation...	48	0	0	0	0
-Capital Cost...	0	0	0	0	0
Net Cash Flow...	-467	-486	-486	-486	-486

CAPITAL GAIN (OR LOSS) COMPUTATION ($1,000)

Salvage Value................................	0
Book Value...................................	0
Capital Gain (or Loss).......................	0
Tax Liability................................	0
After-Tax Capital Gain (or Loss).............	0
Book Value...................................	0
After-Tax Cash Flow Due to Cap. Gain (or Loss)..	0

AFTER-TAX NET PRESENT VALUE ($1,000) ....= -3338
AFTER-TAX ANNUAL EQUIVALENT COST ($1,000) ...= -591
AFTER-TAX COST PER TON ($) ....= -11.82
BEFORE-TAX PRICE TO BE CHARGED ($/TON) ......= 19.69

The results of the runs for 100,000 tons of annual production for all four technologies are given in Table 6.5. The cost of primary T&H alone for varying distances are shown in Figure 6.3. As seen, the PT technology gave lower costs than the CIT technology up to a distance of approximately 45 miles, and those of the PD-car and CIC technologies up to a distance of 65 miles. The cost line of the CIT technology remained parallel and slightly below the PD-car. The advantage of these two latter technologies over the CIC technology disappeared after approximately 100 miles.

For 100,000 tons, the total cost of delivery, including both the primary and secondary T&H, are shown in Figure 6.4. As in the 50,000-ton case, when secondary T&H was added, the PT technology improved its favorable range. It gave lower costs than the other three technologies up to approximately 90 miles. There were no significant difference between the other three technologies up to a distance of 120 miles, after which the CIC technology gave lower costs than the CIT and PD-car technologies. This phenomenon is explained by the fact that the CIC technology benefits from the backhaul rail charge which is assumed to be substantially lower than the fronthaul charge. If this assumption is not correct, however, the advantage of the CIC technology in distances longer than 120 miles will not hold. The undergound placement cost was found to be $2.33 per ton when 100,000 tons of CCB is planned to be placed.

Table 6.5 Cost of transporting 100,000 tons of CCBs annually from power plant to underground placement site using four different technologies ($/ton)

Operation	Distance (miles)	TRANSPORTATION TECHNOLOGIES			
		PD-car	PT	CIC	CIT
primary transportation and handling	30	5.55	3.57	6.70	4.61
	100	7.12	9.01	7.09	6.17
	200	9.48	16.38	7.68	8.54
secondary transportation and handling	1	2.16	-	1.55	2.47
total transportation and handling	30	7.71	3.57	8.25	7.08
	100	9.28	9.01	8.64	8.64
	200	11.64	16.38	9.23	11.01

** Underground placement cost: $2.33/ton

The results of the runs for 200,000 tons annual production are shown in Table 6.6. The cost of primary T&H alone for varying distances are shown in Figure 6.5. As seen, the advantage of the PT technology over the others disappeared at 200,000 tons annual production. The difference among the other three technologies were insignificant up to approximately 140 miles, after which the CIC became better, again due to assumed low backhaul charge. When the secondary T&H cost is added to delivery cost, the PT technology regained its advantage over the other three for distances up to 65 miles (Figure 6.6). The CIC technology gave lower costs than the PD-car and CIT after 100 miles. The undergound placement cost was found to be $2.25 per ton when 200,000 tons of CCB is planned to be placed.

When the cost lines are compared simultaneously in Figures 6.1, 6.3, and 6.5, or in Figures 6.2, 6.4, and 6.6, it can be seen that significant cost reductions occur in PD-car, CIT, and CIC technologies as the annual tonnage increases. This, however, is not true for the PT technology, which remains almost unchanged for all production rates. This is an indication that the economies of scale is favoring all three technologies, except the PT technology. Also, in all figures, the slopes of the cost lines remain relatively flat, except the ones for the PT technology. Therefore, it is concluded from these observations that the PT technology is sensitive to distance but insensitive to tonnage, whereas the opposite is true for the other three technologies.

The underground placement costs were $2.48, $2.33, and $2.25 per ton for annual placements of 50,000, 100,000, and 200,000 tons, respectively. The decrease in cost as the annual tonnage increases is explained by the economies of scale. It should again be emphasized, that the placement costs are based on the assumption that 100,000 tons can be placed through a single borehole, and that the capital and operating cost estimates for both pneumatic and hydraulic injection systems are relatively crude. Therefore, these costs must be interpreted cautiously.

Table 6.6 Cost of transporting 200,000 tons of CCBs annually from power plant to underground placement site using four different technologies ($/ton)

Operation	**Distance (miles)**	**TRANSPORTATION TECHNOLOGIES**			
		PD-car	**PT**	**CIC**	**CIT**
primary transportation and handling	30	3.20	3.03	4.00	2.96
	100	4.66	7.71	4.37	4.42
	200	6.87	14.09	4.92	6.63
secondary transportation and handling	1	1.80	-	1.29	1.99
total transportation and handling	30	5.00	3.03	5.29	4.95
	100	6.46	7.71	5.66	6.41
	200	8.67	14.09	6.21	8.62

** Underground placement cost: $2.25/ton

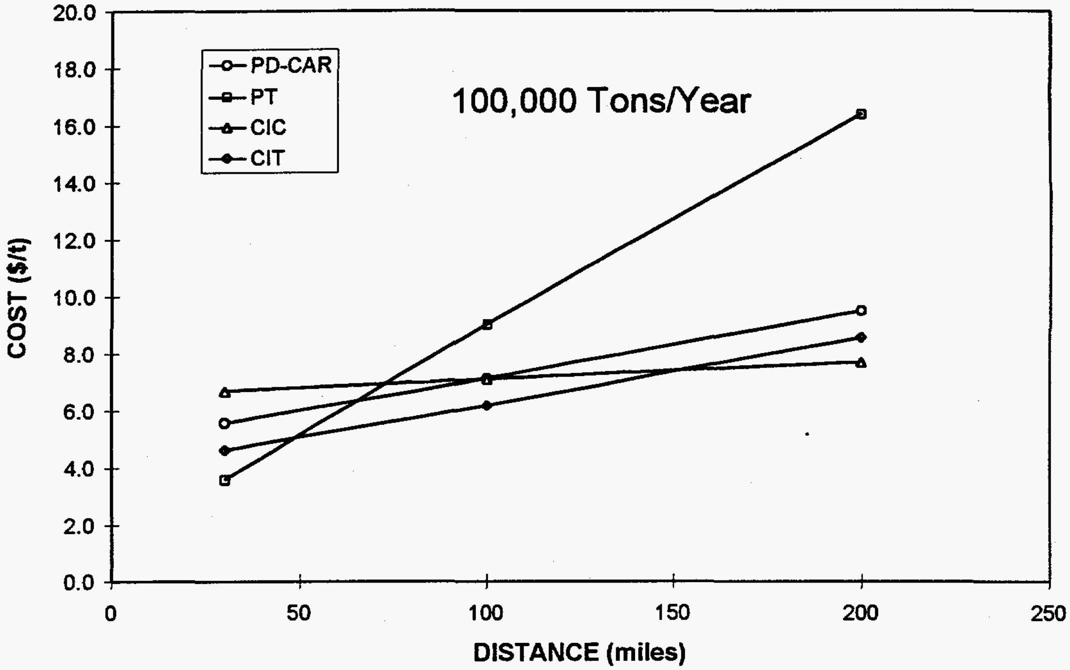


Figure 6.3 Cost of transporting 100,000 tons of CCBs annually from power plant to mine site using four different technologies (primary T&H)

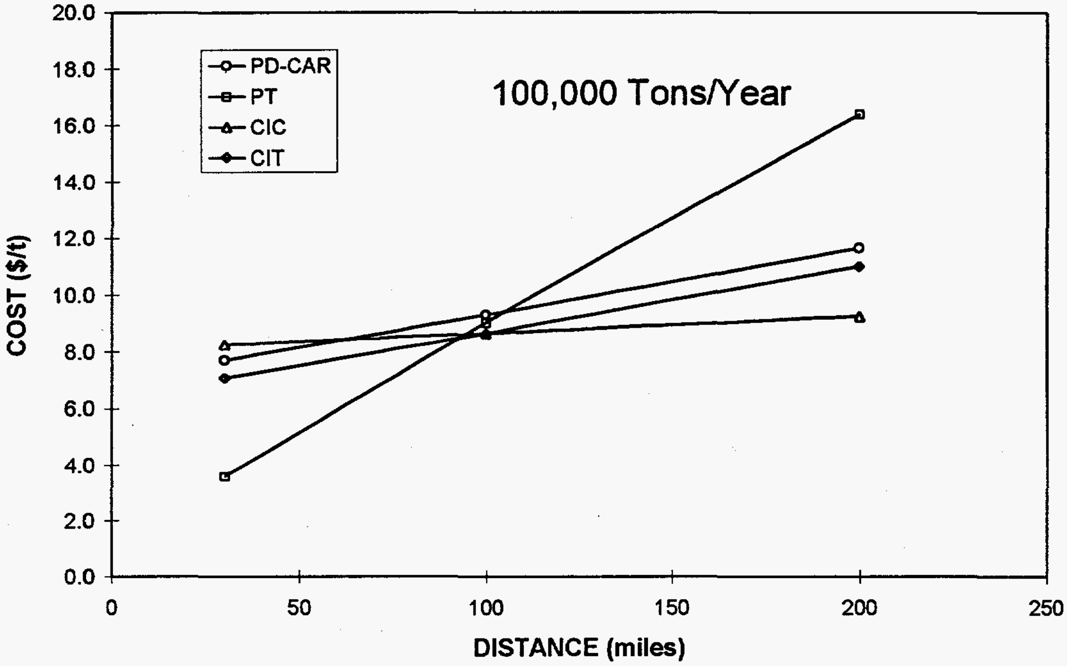


Figure 6.4 Cost of transporting 100,000 tons of CCBs annually from power plant to underground placement site using four different technologies (primary and secondary T&H)

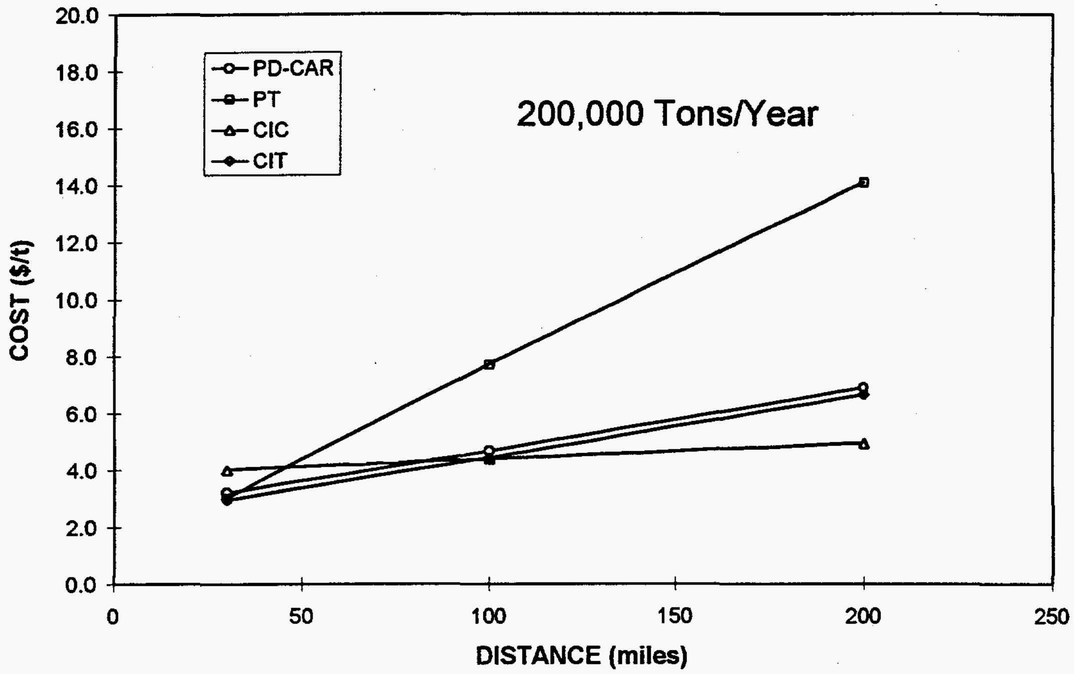


Figure 6.5 Cost of transporting 200,000 tons of CCBs annually from power plant to mine site using four different technologies (primary T&H)

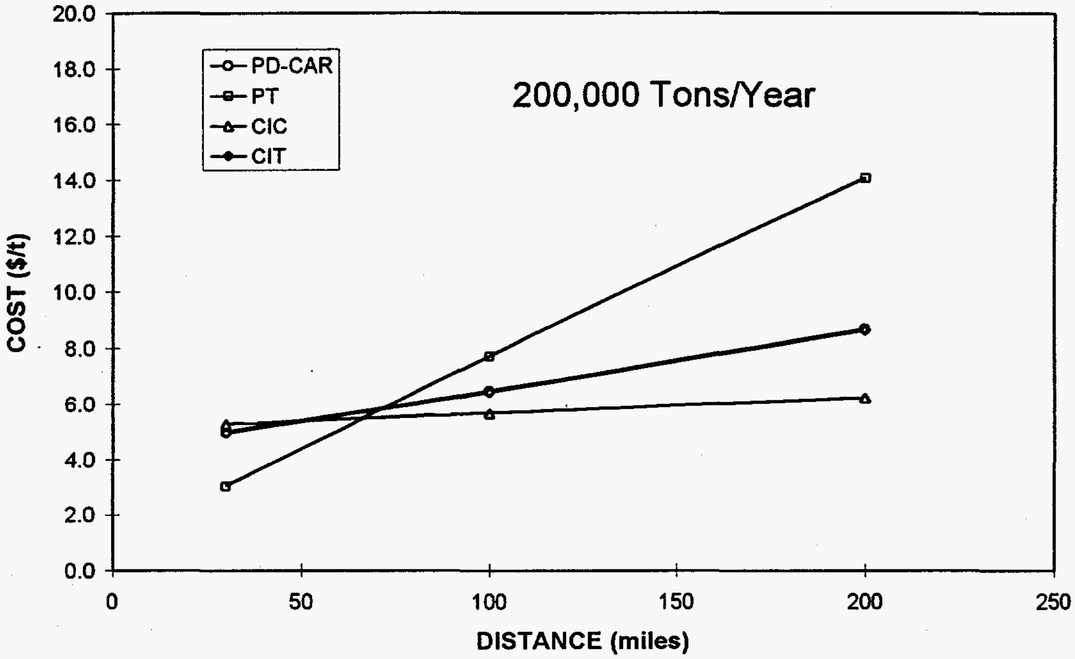


Figure 6.6 Cost of transporting 200,000 tons of CCBs annually from power plant to underground placement site using four different technologies (primary and secondary T&H)

7.0 CASE STUDY

Under the cooperative research program, Peabody No. 10 mine in Pawnee, Illinois, is the site for underground placement demonstration. To enhance this demonstration, it is decided to use the developed software to conduct an engineering design and economic evaluation specifically for this site.

Peabody No. 10 mine, located approximately 20 miles south of Springfield, Illinois, was opened in the 1950s and operated until August, 1994. Room-and-pillar mining method had been employed utilizing continuous miners to mine Herrin (No. 6) coal seam in this mine. The mine is about 350 feet deep with a seam thickness varying from 6 ft to 8 ft.

Pneumatic and hydraulic placement systems developed in the cooperative research program will be demonstrated at this site. The source of FBC fly ash and spent-bed ash for the pneumatic placement will be the Archer Daniel Midland Company's (ADM) power generating plant at Decatur, Illinois. The source of scrubber sludge and fly ash for the hydraulic placement will be City Water, Light and Power (CWLP) Company's Dallman power station in Springfield Illinois. The locations of these two plants and the Peabody No. 10 mine are shown in Figure 7.1 below. As seen, the mine is about 25 miles south of Dallman Plant and 65 miles southwest of ADM Plant.

7.1 BY-PRODUCT HANDLING AT DALLMAN POWER STATION

The fly ash handling system in Dallman Plant is a wet system. The fly ash is mixed with water and pipelined to the settling pond by gravity. Currently, the company is considering of building a dry storage system so that the fly ash can be marketed.

The scrubber sludge from the drum type vacuum filter, which is 85% solids and 15% water by weight, is stacked in the open using a stacker conveyor. Before filtering, the sludge is 55% solids and 45% water. The forced oxidation used in the process produces sulfates that can be filtered to a solid-like material. Without oxidation, sulfides, instead of sulfates, form and do not allow filtration. In 1996, 75,000 tons of scrubber sludge was produced. Currently, this product is delivered, by rear-dump trucks, to two customers for utilization in cement and wallboard manufacturing. The Portland cement manufacturing company is in Hannibal, Illinois, approximately 100 miles away from the plant. The wallboard manufacturing plant is in New Orleans, Louisiana. To reach New Orleans, the product is delivered first by trucks to a barge loading station on the Mississippi river 60 miles away from the plant. It is then loaded into barges and delivered to the manufacturer.

The engineer in charge of materials handling is of the opinion that the scrubber sludge would create problems due to the fouling characteristics of the sludge upon slight compaction. It is expressed that the sludge will not settle like concrete, but will pack and stick. It hangs up on the dumper of the trucks. The truck drivers use shovel to scrape it off. Problems of this nature are not foreseen with fly ash.

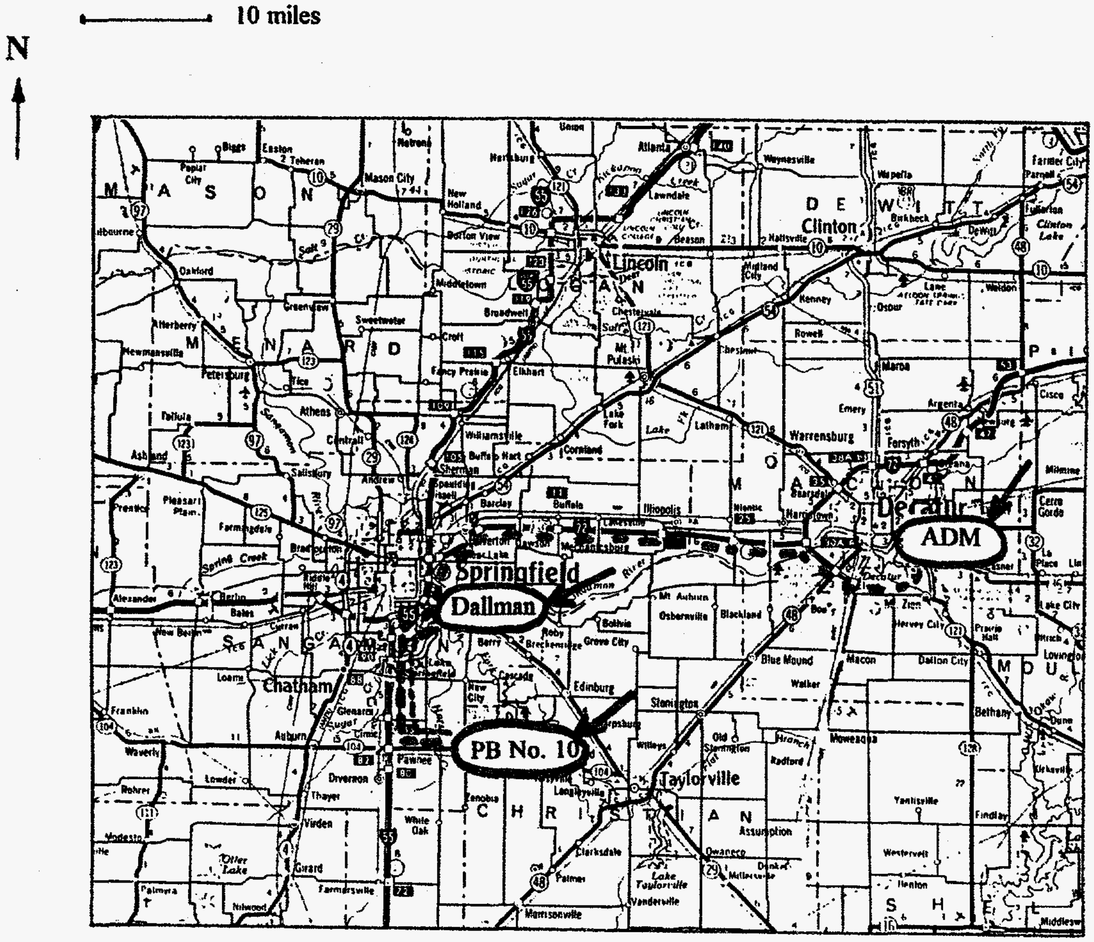


Figure 7.1 Location of Peabody No. 10 Mine with respect to ADM and Dallman plants

A total of 600,000 tons of coal with 10% ash and 3% sulfur is burned annually in the scrubbed unit (Dallman Unit 3) which has a generating capacity of 190 MW. The breakdown of ash in the burned coal is 80% fly ash and 20% bottom ash. This corresponds to an annual production of 48,000 tons of fly ash and 12,000 tons of bottom ash.

The transportation of coal into the plant is by trucks. A railroad spur exists in the plant, but not utilized. Reactivating the rail system requires an estimated $2 million.

7.2 BY-PRODUCT HANDLING AT THE ADM PLANT

The power plant at the ADM complex provides the necessary energy for the chemical processors utilized to produce ethanol and natural enzymes and grow lettuce in the greenhouse. The power plant has six fluidized bed combustion (FBC) type boilers with a capacity of 260 MW of electricity. An additional 120 MW is purchased from outside. Construction of the seventh boiler with a capacity of 74 MW was completed in late 1996. With the addition of this unit the power usage has increased to 454 MW from the current 380 MW.

In this plant, 1.5 million tons of coal and more than two million vehicle tires are burned annually. Coal is brought to the plant by either 25 ton frameless aluminum trucks or by rail cars. In either case, the dust prevention method is covering by tarp. The limestone is transported to plant the same way, that is, using trucks or rail cars. The consumption of Aglime (Agricultural quality limestone) is roughly 1500 tons/day. The amount of ash produced is about 2000 tons/day. The breakdown of ash is 75-80% fly ash (minus 300 mesh) and 20-25% bottom ash (small yellow balls that are about 1/16 inches in diameter).

The fly ash recovered at the baghouse is transported pneumatically to the fly ash storage bin by a negative pneumatic system. A similar system is used for the bottom ash. The ash is backhauled to Freeman Coal Conpany's Crown Mine #3 using the same type of 25-ton trucks that are used to haul the coal and the limestone into the plant. This mine is about 40 miles away from the plant. The trucks are covered by tarps to prevent fugitive dust. The tarp is covered and uncovered by a simple mechanism of sprockets. It is necessary to uncover the tarp to load the coal into the truck at the mine. The tarp is put back on after the coal is loaded. However, there is no need to remove the tarp to unload the coal. The truck backs into the dumping area and the back wheels are locked. Then, the front side of the bed is raised by a vertical hydraulic cylinder that causes the rear guard rail to open. The coal is unloaded by gravity. There is no need to remove the tarp to load the ash into the truck. There is a 12 inch diameter hole in the middle of the tarp. This hole is covered by a circular lid using a Velcro snapping system. To load the ash into the truck, the truck is parked underneath the storage bin so that the hole on the tarp and the collapsible nozzle from the silo are aligned. Then, the Velcro lid is removed and a 12 inch collapsible nozzle that is connected to the storage bin is guided into the hole on the tarp, and the truck is loaded by gravity feed. A tight fit between the nozzle and the hole prevents dust generation. After the truck is loaded, the Velcro lid is snapped onto the hole. The tarp is tightened by a special mechanism of handles on the guard rails of the dump truck and the load is backhauled to the mine.

7.3 ECONOMIC EVALUATION

The case study is conducted separately for pneumatic and hydraulic placements. For best results in pneumatic placement, the researchers in "Residues and Mix Characterization" group have found that the mix should be composed of 80% FBC fly ash and 20% spent-bed ash by weight. Similarly, the optimum mix for hydraulic placement should be composed of 55% scrubber sludge, 40% fly ash, and 5% lime waste. If lime is used instead of lime waste, only 0.5% of lime is found to be sufficient (Chugh et al., 1996).

The following assumptions were made:

1. The operation will be established for 10 years, at the end of which a salvage value will be obtained by liquidating the equipment.

2. Place pneumatically 100,000 tons of by-products per year. In accordance with the optimum mix, 80,000 tons of the total will be FBC fly ash and the remaining 20,000 tons spent-bed ash,

3. Place hydraulically 100,000 tons of by-products per year. In accordance with the optimum mix, 55,000 tons of the total will be scrubber sludge, 40,000 tons fly ash and 5,000 tons lime waste (or, 57,500 tons of scrubber sludge, 42,000 tons of fly ash and 500 tons of lime),

4. The by-product placed in the old workings will spread a distance of 300 feet from the injection borehole, amounting to 10,000 tons of by-product injection through a single borehole,

5. The placement work will operate one shift a day, 6 days a week, and 52 weeks a year, totaling to 312 days per year. This continuous work schedule had to be adopted in order to minimize storage requirements at the plant,

6. No silo will be needed at the mine site, and existing silo capacity at the plant site is sufficient,

7. The truck fleet availability should be at least 80 %,

8. In accordance with the findings on the favorable operating ranges of transportation systems considered in this report, truck transportation is preferred over others because CWLP Dallman Plant and ADM Plant are only 25 and 65 miles away from the mine,

9. The minimum required rate of return (discount rate) is 12 % and the effective tax rate 40 %.

First, hydraulic placement was conducted. It is assumed that scrubber sludge was brought from the Dallman plant by rear dump trucks, and fly ash by pneumatic trucks. First, scrubber sludge was dumped into the hopper of the hydraulic injection system. Then, fly ash and lime are added at predetermined percentages, and mixed thoroughly with sludge to form high density paste before placing it into the mine.

The engineering computations of Truck Transportation are shown in Table 7.1. In this table, the input data is shown in italic print whereas the computed values in bold. These computed values are then transferred into the Truck Transportation template together with other input data necessary for cost computations. The printout of the template for this case study is given in Table 7.2. It is seen in "POWER PLANT" section of this table that 5 trucks were needed to provide at least 80 % fleet availability. The actual availability of the fleet was calculated to be 92 %. The capacity of the hydraulic injection system was calculated to be 60 tph as seen in the "MINE SITE" section of the table. The operating cost of the system was $1.43 per ton. Two lines below, however, the placement system operating cost is given as $1.75 per ton. The incremental $0.32 is for the 10 pounds of lime added for each ton of paste injected.

The last three items in Table 7.2 indicate that the total system capital cost is $750,000, the annual operating cost is $834,870, and the operating cost per ton is $8.44. It is noted that this operating cost is before-tax and it is given here simply for information purpose. The meaningful unit cost, that is, the after-tax cost per ton of by-product placed in the mine, is calculated in the economic evaluation section of the software.

The outcomes of the economic evaluation is shown in Table 7.3. The initial investment and all ten years' net cash flows are shown in this table. As seen, these net cash flows are all negative because this is not a revenue generating project. The capital gain (or loss) computation which takes place at the end of the project life is shown at the bottom of this table. The last four lines summarize the project economics. The after-tax cost is found to be $5.98 per ton. It is noted that this cost will be absorbed by either the power plant or the coal company if the transportation, handling, and placement operation is handled by either of them or in cooperation. On the other hand, if a contractor is hired to undertake the project, the price that the contractor would charge would be $9.96 per ton, as seen in the last line, assuming that the contractor's minimum required rate of return is 12 %.

A separate run was made using the developed model to isolate the cost of transportation from that of the injection. The outcomes of the economic evaluation without underground placement is shown in Table 7.4. As seen at the bottom of this table, the after-tax cost per ton of by-product delivered from the Dallman plant to Peabody No. 10 mine is $3.29. The injection cost is, therefore, the difference between $5.98 and $3.29, which amounts to $2.69 per ton.

To reveal the effect of economies of scale on the cost of by-product transportation and underground placement in this case study, a sensitivity analysis was conducted on the annual production. Besides the 100,000-ton per year base case, two more runs were conducted for 50,000 and 150,000-ton per year, respectively. Furthermore, to isolate the transportation cost from that of the injection, "only transportation" scenarios were run for both production rates as it was done for 100,000 tons base case. The costs are summarized in Table 7.5. The numbers in parentheses reflect the "before-tax price to be charged" should the operation be undertaken by a contractor. The costs, both with and without placement system, are plotted in Figure 7.2. As seen, the cost decreases as the production rate increases. The placement cost at any production rate can be read as the difference between the two curves.

Table 7.1 Engineering design computations in truck transportation of sludge and fly ash from Dallman to Peabody No. 10 mine

1	*Annual Production (tons)*	*100000*
2	*Distance (miles)*	*25*
3	*Shifts per day*	*1*
4		
5	*Loading time (min)*	*10*
6	*Average speed loaded (mph)*	*45*
7	*Average speed empty (mph)*	*45*
8	*Unloading time (min)*	*20*
9	*Duration of a shift (min)*	*480*
10	*Work days per year*	*312*
11	*Truck payload (tons)*	*20*
12		
13	**Travel time loaded (min)**	**33.3**
14	**Travel time empty (min)**	**33.3**
15	**Cycle time (min)**	**96.7**
16	**Maximum number of trucks without queuing**	**4.83**
17	**Required number of trips per year**	**5000**
18	**Required number of trips per day**	**16.03**
19	**Maximum number of trips per truck per shift**	**4.97**
20	**Required number of trucks**	**3.23**
21	**Injection rate (tpm)**	**1.00**
22	**Injection system capacity (tph)**	**60**
23	**Feasible scenario?**	**Yes**
24	**Max. ash accumulation time (hrs)**	**40**
25	**Max. ash accumulation (tons)**	**457**

Table 7.2 Capital and operating cost computations in transporting 100,000 tons of sludge and fly ash annually by trucks from CWLP-Dallman plant to Peabody No. 10 mine

GENERAL PARAMETERS:
Distance between power plant and mine (miles) = 25
Annual amount of by-product to be handled (tons) = 100000
Project life (years) = 10
Truck capacity (tons) = 20
Availability of a truck (in decimal) = 0.9
Number of front tires = 10
Number of rear tires = 8
Front tire replacement frequency (miles) = 75000
Rear tire replacement frequency (miles) = 150000
Average depth of the mine (feet) = 350

CAPITAL COST ITEMS:
Cost of a tractor = 70000
Cost of a tank trailer = 30000
Cost of a blower = 0
Total cost of a truck (tractor-trailer-blower) = 100000

OPERATING COST ITEMS:
Truck leasing cost ($/year) = 0
Fuel consumption (miles per gallon) = 5
Fuel cost ($/gallon) = 1.1
Insurance cost per truck = 7500
Licence cost per truck = 2222
Annual highway tax per truck = 550
Tire cost (each) = 325
Maintenance cost ($/mile) = 0.14
Wage for truck drivers ($/hr) = 20
Wage for silo operator ($/hr) = 20
Overhead cost (% of other operating costs - in decimal) = 0.1
Cost of road construction ($/sq. yd) = 5
Average cost of injection hole ($/ft) = 20

POWER PLANT:
Do we need silo (1 for yes, 0 for no)? = 0
Silo capacity (from prescheduling sheet - tons) = 0
Truck cycle time (from prescheduling sheet - minutes) = 97
Number of working days per year (from prescheduling sheet) = 312
Number of shifts per day (from prescheduling sheet) = 1
Duration of a shift (from prescheduling sheet - hours) = 8
Number of trips per day (from prescheduling sheet) = 16.03
Number of trucks required (from prescheduling sheet) = 3.23
Number of trucks required (rounded) = 4
Number of trucks to have at least 80% fleet availability = 5
Actual fleet availability = 0.92
Number of drivers required = 4
Number of silo operators per shift = 1
Total number of silo operators = 1

PLANT CAPITAL COSTS:
Trucks = 500000
Silo = 0
Total plant capital cost = 500000

Table 7.2 *Continued........*

PLANT OPERATING COSTS:	
Leasing cost for pneumatic trucks	= 0
Fuel	= 55014.96
Insurance	= 37500
Licence for tractor-trailer	= 11110
Highway tax	= 2750
Front tire replacement	= 10836
Rear tire replacement	= 4334
Maintenance	= 35009.52
Driver wages	= 199680
Silo operators wages	= 49920
Subtotal	= 406154.48
Overhead cost	= 40615.45
Total plant operating cost	= 446769.93

MINE SITE:	
Do we need silo (1 for yes, 0 for no)	= 0
Silo capacity (tons)	= 0
Area of new road to be constructed (sq. yd/year)	= 14000
Expected amount of by-product injected through one hole (tons)	= 10000
Number of injection holes to be drilled per year	= 10
Injection system capacity (from prescheduling sheet, tph)	= 60
Do we have hydraulic injection system (1 for yes, 0 for no)?	= 1
Do we have pneumatic injection system (1 for yes, 0 for no)?	= 0
Operating cost of hydraulic injection system ($/ton)	= 1.43
Operating cost of pneumatic injection system ($/ton)	= 0
Injection system operating cost ($/ton)	= 1.75

MINE CAPITAL COSTS:	
Hydraulic injection system	= 250000
Pneumatic injection system	= 0
Silo	= 0
Total mine capital cost	= 250000
MINE OPERATING COSTS:	
Road construction cost	= 70000
Injection system operating cost	= 221000
Cost of injection holes	= 70000
Subtotal	= 361000
Overhead cost	= 36100
Total mine operating cost	= 397100
TOTAL SYSTEM CAPITAL COST	= 750000
TOTAL SYSTEM OPERATING COST	= 843869.93
Operating cost per ton	= 8.44

Table 7.3 Economic evaluation of CCB transportation from CWLP-Dallman plant to Peabody No. 10 mine (including hydraulic placement system)

DISTANCE (MILES) ---------------------------------- = 25
PRODUCTION (TONS/YEAR) ---------------------------- = 100000
MINIMUM REQUIRED RATE OF RETURN (%) ------------ = 12
EFFECTIVE TAX RATE (%) ------------------------ = 40

Year	0	1	2	3	4	5	6	7	8	9	10
Revenue.........	0	0	0	0	0	0	0	0	0	0	0
-Oper. Cost.....	0	-844	-844	-844	-844	-844	-844	-844	-844	-844	-844
-Depreciation...	0	-150	-240	-144	-86	-86	-43	0	0	0	0
Taxable Income..	0	-994	-1084	-988	-930	-930	-887	-844	-844	-844	-844
-Tax............	0	398	434	395	372	372	355	338	338	338	338
Net Income......	0	-596	-650	-593	-558	-558	-532	-506	-506	-506	-506
+Depreciation...	0	150	240	144	86	86	43	0	0	0	0
-Capital Cost...	-750	0	0	0	0	0	0	0	0	0	0
Net Cash Flow...	-750	-446	-410	-449	-472	-472	-489	-506	-506	-506	-506

CAPITAL GAIN (OR LOSS) COMPUTATION ($1,000)

Salvage Value....................................	68
Book Value.......................................	0
Capital Gain (or Loss)...........................	68
Tax Liability....................................	-27
After-Tax Capital Gain (or Loss).................	41
Book Value.......................................	0
After-Tax Cash Flow Due to Cap. Gain (or Loss)..	41

AFTER-TAX NET PRESENT VALUE ($1,000) ....= -3377
AFTER-TAX ANNUAL EQUIVALENT COST ($1,000) ...= -598
AFTER-TAX COST PER TON ($) ....= -5.98
BEFORE-TAX PRICE TO BE CHARGED ($/TON) ......= 9.96

Table 7.4 Economic evaluation of CCB transportation from CWLP-Dallman plant to Peabody No. 10 mine (excluding hydraulic placement system)

DISTANCE (MILES) ------------------------------- = 25
PRODUCTION (TONS/YEAR) ------------------------- = 100000
MINIMUM REQUIRED RATE OF RETURN (%) ------------ = 12
EFFECTIVE TAX RATE (%) ------------------------- = 40

Year	0	1	2	3	4	5
Revenue.........	0	0	0	0	0	0
-Oper. Cost.....	0	-447	-447	-447	-447	-447
-Depreciation...	0	-100	-160	-96	-58	-58
Taxable Income..	0	-547	-607	-543	-505	-505
-Tax............	0	219	243	217	202	202
Net Income......	0	-328	-364	-326	-303	-303
+Depreciation...	0	100	160	96	58	58
-Capital Cost...	-500	0	0	0	0	0
Net Cash Flow...	-500	-228	-204	-230	-245	-245

Year	6	7	8	9	10
Revenue.........	0	0	0	0	0
-Oper. Cost.....	-447	-447	-447	-447	-447
-Depreciation...	-29	0	0	0	0
Taxable Income..	-476	-447	-447	-447	-447
-Tax............	190	179	179	179	179
Net Income......	-285	-268	-268	-268	-268
+Depreciation...	29	0	0	0	0
-Capital Cost...	0	0	0	0	0
Net Cash Flow...	-257	-268	-268	-268	-268

CAPITAL GAIN (OR LOSS) COMPUTATION ($1,000)

Salvage Value..................................	45
Book Value.....................................	0
Capital Gain (or Loss).........................	45
Tax Liability..................................	-18
After-Tax Capital Gain (or Loss)...............	27
Book Value.....................................	0
After-Tax Cash Flow Due to Cap. Gain (or Loss)..	27

AFTER-TAX NET PRESENT VALUE ($1,000) ....= -1859
AFTER-TAX ANNUAL EQUIVALENT COST ($1,000) ...= -329
AFTER-TAX COST PER TON ($) ....= -3.29
BEFORE-TAX PRICE TO BE CHARGED ($/TON) ......= 5.48

Table 7.5 Cost of CCB transportation from Dallman plant to Peabody No. 10 mine

Tonnage (tons/year)	Cost with placement ($/ton)	Cost without placement ($/ton)
50,000	6.58 (10.96) **	3.81 (6.35)
100,000	5.98 (9.96)	3.29 (5.48)
150,000	5.03 (8.38)	2.77 (4.62)

** Numbers in parentheses represent "price to be charged per ton of CCB"

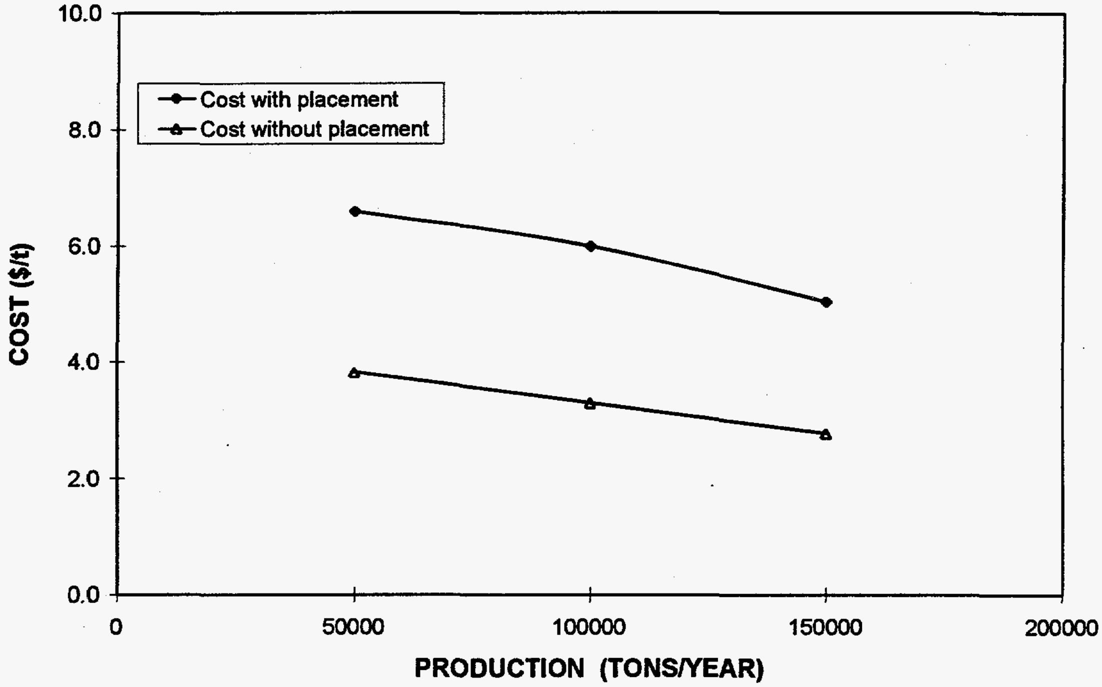


Figure 7.2 Cost of by-product transportation from Dallman plant to Peabody No. 10 mine

The above procedures of system evaluation were also followed for pneumatic placement case. It is assumed that the FBC fly ash and spent-bed ash will be delivered from the ADM plant to Peabody No. 10 in pneumatic trucks of approximately 20-ton capacity. The content of a truck will be directly transloaded in to the hopper of the pneumatic injection system and subsequently pumped into the old mine workings.

The engineering computations of Truck Transportation for this scenario are shown in Table 7.6. As seen, the cycle time of a truck has increased to 203 minutes for a round trip of 130 miles (including loading and transloading times) as compared to 97 minutes for a round trip of 50 miles in the Dallman-Peabody No. 10 case. The outcomes of the engineering design computations are then transferred into the Truck Transportation template. The input data and the outcomes of scheduling and cost computations performed in the template are shown in Table 7.7. As seen in the "POWER PLANT" section of this table, eight trucks were needed in the fleet to provide a minimum fleet availability of 80 %. The total capital investment for this project is estimated to be approximately $1 million whereas the annual operating cost $1.142 million.

The outcomes of the economic evaluation is shown in Table 7.8. As seen at the bottom of this table, the after-tax annual equivalent cost, which includes the operating as well as the capital cost, is $813,000. Since 100,000 tons of by-product are placed annually, the after-tax cost per ton of by-product transported from ADM plant to Peabody No. 10 mine and placed into the mine is $8.13.

As in the Dallman case, a separate run was made using the developed model to isolate the cost of transportation from that of the placement. The outcomes of the economic evaluation without placement is shown in Table 7.9. As seen at the bottom of this table, the after-tax cost per ton of by-product delivered from the ADM plant to Peabody No. 10 mine is $5.77. The placement cost is, therefore, the difference between $8.13 and $5.77, which amounts to $2.36 per ton. This cost is slightly lower than the hydraulic injection cost due to lower capital outlay in pneumatic system.

Again, as in the Dallman case, a sensitivity analysis was conducted on the annual production by varying the base case of 100,000 tons by ±50,000 tons. Also, to isolate the transportation cost from that of the placement, "only transportation" scenarios were run for both production rates as it was done for 100,000 tons base case. The costs are summarized in Table 7.10 and plotted in Figure 7.3. The slight upward trend when production increases from 100,000 tons to 150,000 tons is due to an increase in the truck fleet size from 8 to 13 trucks. It is noted that the fleet size in Dallman case went up from 5 to 6 only due to short transportation distance of only 25 miles.

Table 7.6 Engineering design computations in FBC fly ash transportation by trucks from ADM to Peabody No. 10 mine

1	*Annual Production (tons)*	*100000*
2	*Distance (miles)*	*65*
3	*Shifts per day*	*1*
4		
5	*Loading time (min)*	*10*
6	*Average speed loaded (mph)*	*45*
7	*Average speed empty (mph)*	*45*
8	*Unloading time (min)*	*20*
9	*Duration of a shift (min)*	*480*
10	*Work days per year*	*312*
11	*Truck payload (tons)*	*20*
12		
13	**Travel time loaded (min)**	**86.7**
14	**Travel time empty (min)**	**86.7**
15	**Cycle time (min)**	**203.3**
16	**Maximum number of trucks without queuing**	**10.17**
17	**Required number of trips per year**	**5000**
18	**Required number of trips per day**	**16.03**
19	**Maximum number of trips per truck per shift**	**2.36**
20	**Required number of trucks**	**6.79**
21	**Injection rate (tpm)**	**1.00**
22	**Injection system capacity (tph)**	**60**
23	**Feasible scenario?**	**Yes**
24	**Max. ash accumulation time (hrs)**	**40**
25	**Max. ash accumulation (tons)**	**457**

Table 7.7 Capital and operating cost computations in transporting 100,000 tons of FBC fly ash annually by trucks from ADM-Decatur plant to Peabody No. 10 mine

GENERAL PARAMETERS:
Distance between power plant and mine (miles) = 65
Annual amount of by-product to be handled (tons) = 100000
Project life (years) = 10
Truck capacity (tons) = 20
Availability of a truck (in decimal) = 0.9
Number of front tires = 10
Number of rear tires = 8
Front tire replacement frequency (miles) = 75000
Rear tire replacement frequency (miles) = 150000
Average depth of the mine (feet) = 350

CAPITAL COST ITEMS:
Cost of a tractor = 70000
Cost of a tank trailer = 45000
Cost of a blower = 0
Total cost of a truck (tractor-trailer-blower) = 115000

OPERATING COST ITEMS:
Truck leasing cost ($/year) = 0
Fuel consumption (miles per gallon) = 5
Fuel cost ($/gallon) = 1.1
Insurance cost per truck = 7500
Licence cost per truck = 2222
Annual highway tax per truck = 550
Tire cost (each) = 325
Maintenance cost ($/mile) = 0.14
Wage for truck drivers ($/hr) = 20
Wage for silo operator ($/hr) = 20
Overhead cost (% of other operating costs - in decimal) = 0.1
Cost of road construction ($/sq. yd) = 5
Average cost of injection hole ($/ft) = 20

POWER PLANT:
Do we need silo (1 for yes, 0 for no)? = 0
Silo capacity (from prescheduling sheet - tons) = 457
Truck cycle time (from prescheduling sheet - minutes) = 203.3
Number of working days per year (from prescheduling sheet) = 312
Number of shifts per day (from prescheduling sheet) = 1
Duration of a shift (from prescheduling sheet - hours) = 8
Number of trips per day (from prescheduling sheet) = 16.03
Number of trucks required (from prescheduling sheet) = 6.79
Number of trucks required (rounded) = 7
Number of trucks to have at least 80% fleet availability = 8
Actual fleet availability = 0.81
Number of drivers required = 7
Number of silo operators per shift = 0
Total number of silo operators = 0

PLANT CAPITAL COSTS:
Trucks = 920000
Silo = 0
Total plant capital cost = 920000

Table 7.7 *Continued........*

PLANT OPERATING COSTS:
Leasing cost for pneumatic trucks = 0
Fuel = 143038.9
Insurance = 60000
Licence for tractor-trailer = 17776
Highway tax = 4400
Front tire replacement = 28174
Rear tire replacement = 11269
Maintenance = 91024.75
Driver wages = 349440
Silo operators wages = 0
Subtotal = 705122.65
Overhead cost = 70512.26
Total plant operating cost = 775634.91

MINE SITE:
Do we have silo (1 for yes, 0 for no) = 0
Silo capacity (tons) = 0
Area of new road to be constructed (sq. yd/year) = 14000
Expected amount of by-product injected through one hole (tons) = 10000
Number of injection holes to be drilled per year = 10
Injection system capacity (from prescheduling sheet, tph) = 60
Do we have hydraulic injection system (1 for yes, 0 for no)? = 0
Do we have pneumatic injection system (1 for yes, 0 for no)? = 1
Operating cost of hydraulic injection system ($/ton) = 0
Operating cost of pneumatic injection system ($/ton) = 1.93
Injection system operating cost ($/ton) = 1.93

MINE CAPITAL COSTS:
Hydraulic injection system = 0
Pneumatic injection system = 130333
Silo = 0
Total mine capital cost = 130333

MINE OPERATING COSTS:
Road construction cost = 70000
Injection system operating cost = 193333.33
Cost of injection holes = 70000
Subtotal = 333333.33
Overhead cost = 33333.33
Total mine operating cost = 366666.67

TOTAL SYSTEM CAPITAL COST = 1050333
TOTAL SYSTEM OPERATING COST = 1142301.58

Operating cost per ton = 11.42

Table 7.8 Economic evaluation of FBC fly ash transportation from ADM-Decatur plant to Peabody No. 10 mine (including pneumatic injection system)

```
DISTANCE (MILES) ------------------------------- = 65
PRODUCTION (TONS/YEAR) ------------------------- = 100000
MINIMUM REQUIRED RATE OF RETURN (%) ------------ = 12
EFFECTIVE TAX RATE (%) ------------------------- = 40


  Year                 0        1        2        3        4        5
 ----------------------------------------------------------------------
 Revenue.........      0        0        0        0        0        0
 ----------------------------------------------------------------------
 -Oper. Cost.....      0    -1142    -1142    -1142    -1142    -1142
 -Depreciation...      0     -210     -336     -202     -121     -121
 ----------------------------------------------------------------------
 Taxable Income..      0    -1352    -1478    -1344    -1263    -1263
 -Tax............      0      541      591      537      505      505
 ----------------------------------------------------------------------
 Net Income......      0     -811     -887     -806     -758     -758
 +Depreciation...      0      210      336      202      121      121
 -Capital Cost...  -1050        0        0        0        0        0
 ----------------------------------------------------------------------
 Net Cash Flow...  -1050     -601     -551     -605     -637     -637


  Year                 6        7        8        9       10
 ----------------------------------------------------------------------
 Revenue.........      0        0        0        0        0
 ----------------------------------------------------------------------
 -Oper. Cost.....  -1142    -1142    -1142    -1142    -1142
 -Depreciation...    -60        0        0        0        0
 ----------------------------------------------------------------------
 Taxable Income..  -1202    -1142    -1142    -1142    -1142
 -Tax............    481      457      457      457      457
 ----------------------------------------------------------------------
 Net Income......   -721     -685     -685     -685     -685
 +Depreciation...     60        0        0        0        0
 -Capital Cost...      0        0        0        0        0
 ----------------------------------------------------------------------
 Net Cash Flow...   -661     -685     -685     -685     -685


     CAPITAL GAIN (OR LOSS) COMPUTATION ($1,000)

 ----------------------------------------------------------------------
 Salvage Value..................................        95
 Book Value.....................................         0
 ----------------------------------------------------------------------
 Capital Gain (or Loss).........................        95
 Tax Liability..................................       -38
 ----------------------------------------------------------------------
 After-Tax Capital Gain (or Loss)...............        57
 Book Value.....................................         0
 ----------------------------------------------------------------------
 After-Tax Cash Flow Due to Cap. Gain (or Loss)..       57
 ----------------------------------------------------------------------


 AFTER-TAX NET PRESENT VALUE ($1,000) ........=     -4593
 AFTER-TAX ANNUAL EQUIVALENT COST ($1,000) ...=      -813
 AFTER-TAX COST PER TON ($) ..................=     -8.13
 BEFORE-TAX PRICE TO BE CHARGED ($/TON) ......=     13.55
```

Table 7.9 Economic evaluation of FBC fly ash transportation from ADM-Decatur plant to Peabody No. 10 mine (excluding pneumatic injection system)

DISTANCE (MILES) ------------------------------ = 65
PRODUCTION (TONS/YEAR) ------------------------ = 100000
MINIMUM REQUIRED RATE OF RETURN (%) ------------ = 12
EFFECTIVE TAX RATE (%) ------------------------ = 40

Year	0	1	2	3	4	5
Revenue.........	0	0	0	0	0	0
-Oper. Cost.....	0	-520	-520	-520	-520	-520
-Depreciation...	0	-184	-294	-177	-106	-106
Taxable Income..	0	-704	-814	-697	-626	-626
-Tax...........	0	282	326	279	250	250
Net Income......	0	-422	-489	-418	-376	-376
+Depreciation...	0	184	294	177	106	106
-Capital Cost...	-920	0	0	0	0	0
Net Cash Flow...	-920	-238	-194	-241	-270	-270

Year	6	7	8	9	10
Revenue.........	0	0	0	0	0
-Oper. Cost.....	-520	-520	-520	-520	-520
-Depreciation...	-53	0	0	0	0
Taxable Income..	-573	-520	-520	-520	-520
-Tax...........	229	208	208	208	208
Net Income......	-344	-312	-312	-312	-312
+Depreciation...	53	0	0	0	0
-Capital Cost...	0	0	0	0	0
Net Cash Flow...	-291	-312	-312	-312	-312

CAPITAL GAIN (OR LOSS) COMPUTATION ($1,000)

Salvage Value..................................	84
Book Value.....................................	0
Capital Gain (or Loss).........................	84
Tax Liability..................................	-33
After-Tax Capital Gain (or Loss)...............	50
Book Value.....................................	0
After-Tax Cash Flow Due to Cap. Gain (or Loss)..	50

AFTER-TAX NET PRESENT VALUE ($1,000) ....= -2395
AFTER-TAX ANNUAL EQUIVALENT COST ($1,000) ...= -424
AFTER-TAX COST PER TON ($) ....= -4.24
BEFORE-TAX PRICE TO BE CHARGED ($/TON) ......= 7.06

Table 7.10 Cost per ton of CCB transported from ADM plant to Peabody No. 10 mine

Tonnage (tons/year)	Cost with placement ($/ton)	Cost without placement ($/ton)
50,000	9.08 (15.13) **	6.52 (10.86)
100,000	8.13 (13.55)	5.77 (9.62)
150,000	8.31 (13.85)	6.02 (10.03)

** Numbers in parentheses represent "price to be charged per ton of CCB"

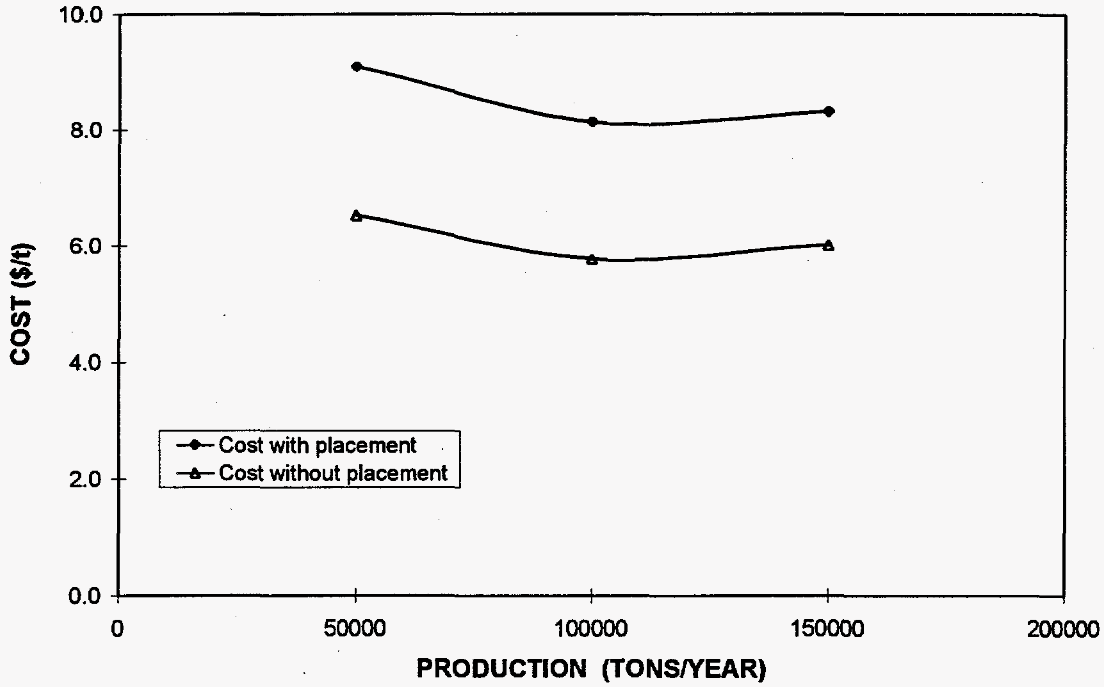


Figure 7.3 Cost of by-product transportation from ADM plant to Peabody No. 10 mine

8.0 SUMMARY AND CONCLUSIONS

One of the objectives in materials handling research of the DOE-SIUC cooperative agreement is to identify environmentally acceptable transportation and handling (T&H) systems to deliver coal combustion by-products (CCB) from the power plants to the underground coal mines for the purpose of placing these by-products into the old workings of the mines. To attain this objective several technologies were investigated, and five were found to be environmentally friendly. Of these five, four technologies, namely; Pneumatic Trucks (PT) , Pressure Differential Rail Cars (PD-car), Collapsible Intermodal Containers (CIC), and Cylindrical Intermodal Tanks (CIT) were investigated in depth. Integrated software, composed of engineering design and economic evaluation models, were developed for these technologies. Due to lack of engineering and cost data, models for the fifth technology, Coal Hopper Cars with Automatic Retractable Tarping, could not be developed at this time.

The software developed in this project were used to determine favorable operating ranges of each selected technology in terms of distances and tonnage. In these evaluations, the T&H operation is divided in two components: primary T&H from the power plant to the mine site, and secondary T&H from the mine site to underground placement site. In southern and central Illinois, annual CCB range between 50,000 to 200,000 tons, and typically plants are 30 to 200 miles away from underground mines. Therefore, all evaluations were conducted for distance-tonnage combinations within these ranges. Specifically, three annual by-product tonnage, 50,000, 100,000, and 200,000 tons, were considered, and each tonnage was evaluated for transportation distances of 30, 100, and 200 miles. The secondary T&H distance was assumed to be 1 mile. The results of the economic evaluation, for primary T&H alone, are summarized in terms of "c/ton-mile" in Figures 8.1, 8.2, and 8.3. It is noted that these figures are "c/ton-mile" versions of Figures 6.1, 6.3, and 6.5 given in Section 6.0 where the costs were expressed in terms of "$/ton".

At 50,000 tons per year (Fig. 8.1), the PT technology gave lower unit costs than the PD-car and CIT technologies up to approximately 70 miles, and lower than the CIC technology up to 110 miles. The costs in PD-car and CIT technologies were almost the same for all distances, and they remained lower than the costs of CIC technology for all distances. The unit costs in PD-car, CIC, and CIT technologies decreased significantly between 30 to 100 miles, and kept decreasing, though moderately, between 100 to 200 miles. In contrast, the unit costs in PT technology remained almost unchanged for all distances. This is an indication that the unit cost in PT transportation is insensitive to distance, whereas the opposite is true for the other technologies. It is noted that although the unit cost (c/ton-mile) in PT transportation is insensitive to distance, the total cost, expressed in $/ton, will be very sensitive to distance. Of course, the opposite will be true for the other three technologies.

At 100,000 tons per year (Fig. 8.2), the PT technology gave lower unit costs than the CIT technology up to a distance of approximately 45 miles, and those of the PD-car and CIC technologies up to a distance of 65 miles. The unit-cost curves of the CIT and PD-car technologies remained below that of the CIC technology up to approximately 100 miles, after which the differences became insignificant. It is noted that the reason the CIC transportation

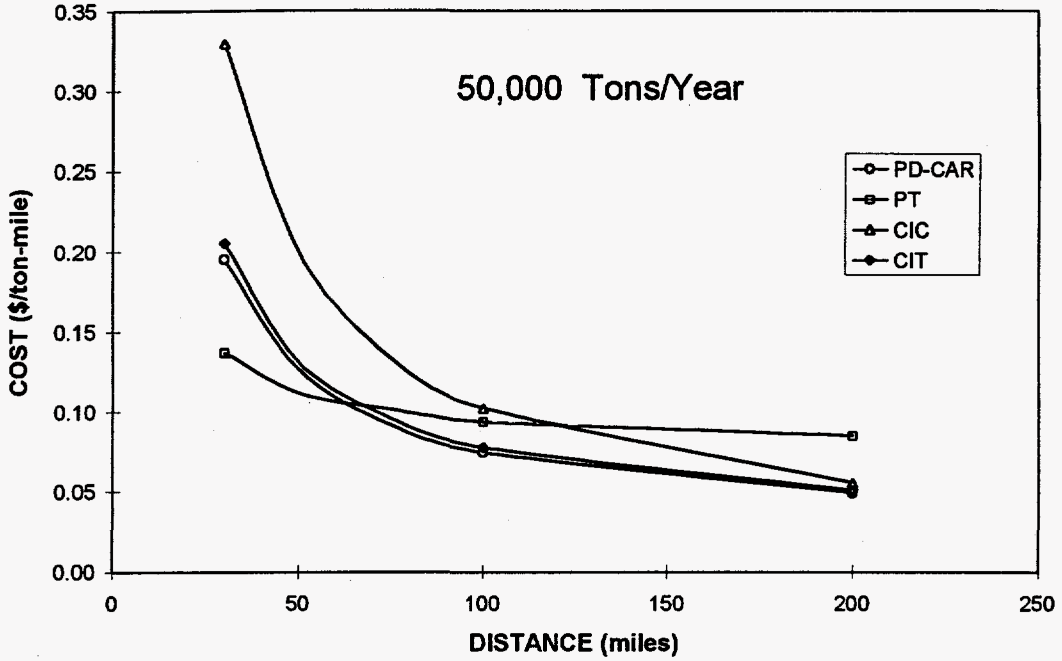


Figure 8.1 Unit costs in the transportation of 50,000 tons of CCB annually by four differnt technologies

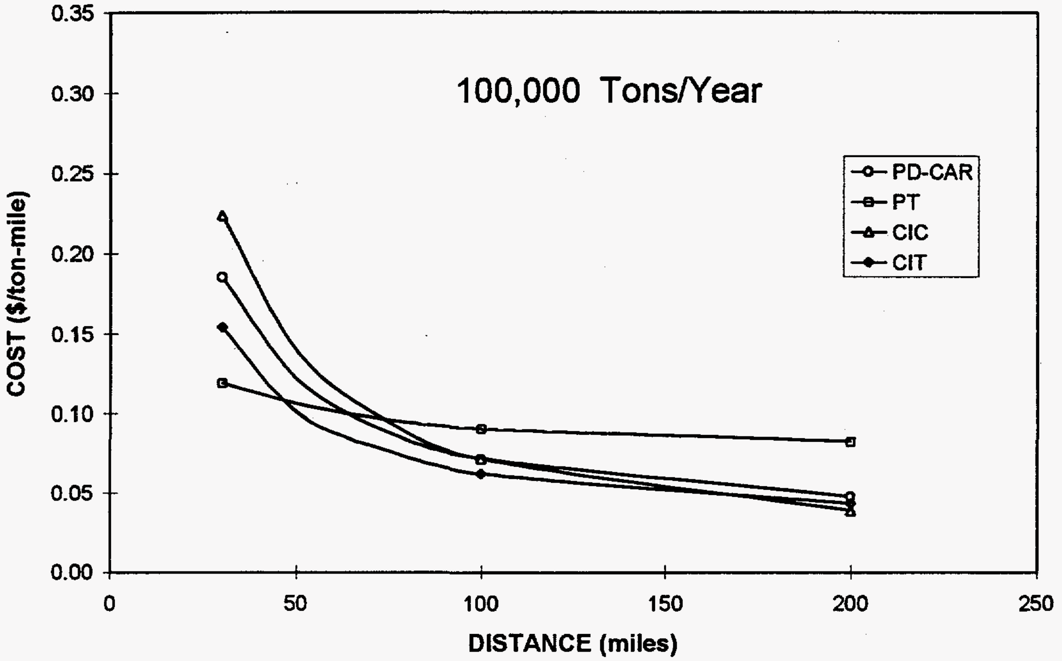


Figure 8.2 Unit costs in the transportation of 100,000 tons of CCB annually by four different technologies

closes the gap with others after 100 miles is the backhaul cost advantage associated with this system. Backhauling is defined as the transportation of CCBs in the "unit coal train" as the train travels empty to the coal mine. Railroad companies indicated that the backhaul charges may be considerably lower than the fronthaul charges. Accordingly, in the evaluations of the CIC system, the backhaul charge was assumed to be one fourth of the fronthaul charge. Should this assumption not hold, the unit cost in the CIC system would be higher than it is reported.

At 200,000 tons per year (Fig. 8.3), the advantage of the PT transportation over the others vanished. For a distance of 30 miles, the unit costs of the PT, PD-car, and CIT systems were almost equal, but lower than that of the CIC system. The cost of the CIC system started high at 30 miles, decreased quickly to match the costs of CIT and PD-car systems at around 75 miles, and became even better at 200 miles. Again, the CIC system gains its advantage due to reduced backhaul cost.

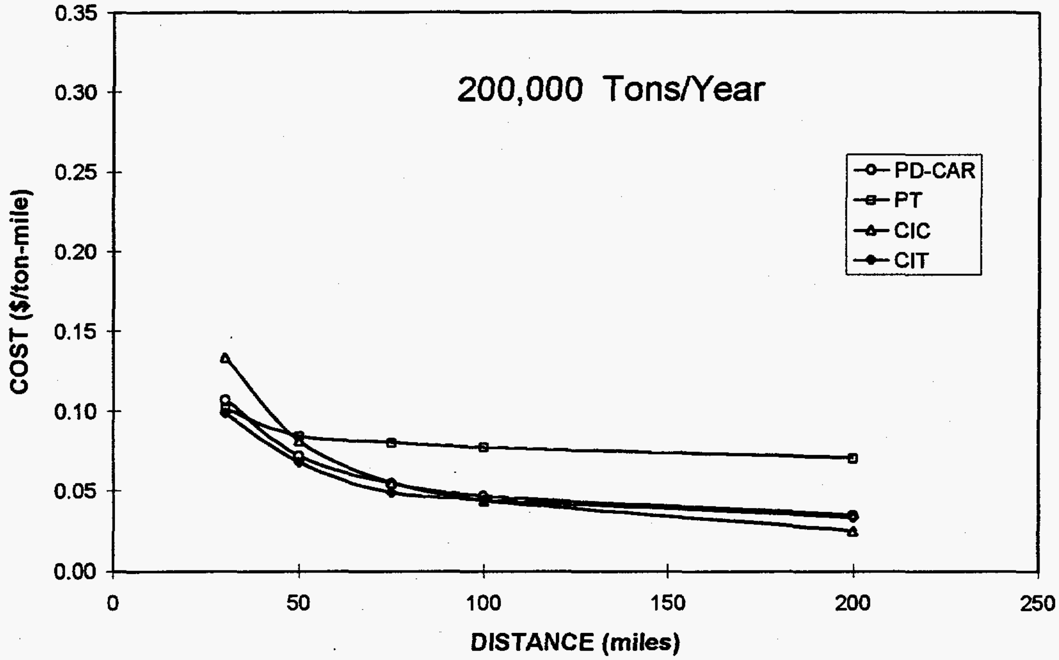


Figure 8.3 Unit costs in the transportation of 200,000 tons of CCB annually by four different technologies

As we move from Figure 8.1 to Figure 8.2, and then to Figure 8.3, we see significant decreases in unit costs in the PD-car, CIT, and CIC technologies. The decrease in unit costs in the PT technology, however, is very slight for all production rates. This is an indication that the economies of scale is favoring the PD-car, CIT and CIC technologies, but not the PT technology.

The secondary T&H costs for all technologies are summarized in Table 8.1 in terms of $/ton. As seen, the PT technology does not carry a secondary T&H cost since the trucks can transport the CCB directly from the power plant to the placement site. The other three systems require transfer at the mine site. As the tonnage increases from 50,000 to 200,000, the cost of secondary T&H decreases in all technologies due to economies of scale. The CIT and PD-car technologies bear relatively higher costs because of the additional infrastructure requirements and equipment needs.

Table 8.1 Cost of secondary transportation and handling of CCBs by four different technologies

Production (tons/year)	**TRANSPORTATION TECHNOLOGIES**			
	PD-car ($/ton)	**PT ($/ton)**	**CIC ($/ton)**	**CIT ($/ton)**
50,000	3.16	-	2.09	3.36
100,000	2.16	-	1.55	2.47
200,000	1.80	-	1.29	1.99

The underground placement system is being investigated within the overall DOE-SIUC cooperative agreement. The researchers are working on the development of a hydraulic and a pneumatic placement system. Both systems are currently being tested at the Peabody No. 10 mine near Pawnee, Illinois. In materials handling and system economics research, the placement system is investigated from the economics point of view. The developed integrated software embodies the underground placement module too. This module was used to determine the estimated costs of placement for the above tonnages. It is noted that the placement cost is a function of the annual tonnage only and it does not vary from one T&H technology to another.

The underground placement costs were $2.48, $2.33, and $2.25 per ton for annual placements of 50,000, 100,000, and 200,000 tons, respectively. The decrease in cost as the annual tonnage increases is explained by the economies of scale. It should again be emphasized, that the placement costs are based on the assumption of placing 100,000 tons through a single borehole, and that the capital and operating cost estimates for both pneumatic and hydraulic injection systems are relatively crude. Therefore, these costs must be interpreted cautiously. Better estimates of these costs will be obtained after the completion of the tests.

The shares of the capital and operating costs in the overall cost of CCB disposal were also determined in the economic evaluations of the nine cases presented above. It was found that the CIC and CIT technologies are most capital intensive technologies where capital cost constituted approximately 70% of the cost-per-ton of CCB transported and placed. In contrast to these two technologies, the PT technology was found to be operating-cost driven, where the cost-per-ton was composed of approximately 75% operating cost and 25% capital cost. The CIT technology showed a balanced cost composition with 50% capital cost and 50% operating cost.

It is clear from the above discussion that for a sound decision as to which transportation and handling technology should be selected for a given case, an engineering and economic analysis of the entire system, including the placement unit, must be conducted. The results summarized above are for hypothetical cases and are based on a number of cost estimates, system operating scenarios, and assumptions. Therefore, they must be interpreted cautiously. For instance, the existence of a rail siding at a mine site may change the economics, and therefore favor one alternative over the others. There are other important variables such as railroad charge, railroad schedule, and labor cost, which may significantly affect the results, and thus the selection of a technology.

Under the cooperative research program, Peabody No. 10 mine near Pawnee, Illinois, is the site for the demonstration of pneumatic and hydraulic placement systems developed in the cooperative-research program. To enhance these demonstrations, it is decided to use the developed software to conduct an engineering design and economic evaluation specifically for this site.

The source of FBC fly ash and spent-bed ash for the pneumatic placement will be the Archer Daniel Midland Company's (ADM) power generating plant at Decatur, Illinois. This plant is located approximately 65 miles northeast of the Peabody No. 10 mine. The source of scrubber sludge and fly ash for the hydraulic placement will be City Water, Light and Power (CWLP) Company's Dallman power station in Springfield, Illinois. This plant is located approximately 25 miles north of the Mine No. 10. The mine is about 350 feet deep with a seam thickness varying from 6 ft to 8 ft.

A case was developed by assuming that annually 100,000 tons of CCB will be transported from each plant and placed in the old workings of the mine over a period of 10 years. Furthermore, it is assumed that 10,000 tons of CCBs will be placed through each borehole, and that the discount rate and effective tax rate will be 12% and 40%, respectively. Consistent with the findings in "Favorable Range" study presented in Section 6.0, only truck transportation was considered since the distances of both plants to the mine favored truck transportation over the others. Also, rear-dump trucks were used in transporting scrubber sludge from CWLP plant since this product can not be transported in pneumatic trucks due to its 15 to 20% moisture content.

The economic evaluation of the case study indicated that the T&H cost from CWLP Dallman plant to Mine No. 10 will be \$3.29/ton with an additional underground placement cost of \$2.69/ton, giving a total cost of \$5.98/ton. Similarly, the cost of transportation and handling from ADM plant to Mine No. 10 will be \$5.77/ton with an additional underground placement cost of \$2.36/ton, giving a total cost of \$8.13/ton.

The integrated software developed in this research project can be adapted and used, with moderate knowledge of the software structure, in the evaluation of a number of other generic transportation and handling technologies. For instance, any intermodal tank transportation system can be evaluated using the template developed for the Cylindrical Intermodal Tanks. Similarly, any rail car transportation system can be evaluated using the template developed for Pressure Differential Rail Cars. Another important benefit of this software lie in its ability to provide a wealth of information on the selected transportation alternatives, to evaluate a number of alternatives in a short period of time, and to facilitate sensitivity analysis on important variables. Finally, the developed software can be used not only in the engineering design and economic evaluation of the transportation and handling of the by-products for the purpose of disposing them in underground coal mines but for disposal in surface mines and landfills as well.

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APPENDIX

USE OF BINOMIAL PROBABILITY DISTRIBUTION IN FLEET SIZE DETERMINATION

The probability distribution for a binomial random variable is given by:

$$p(y)=\binom{n}{y} p^{y} q^{n-y} \qquad (y=0, 1, 2, \ldots, n)$$

where:

p = Probability of a truck availability
q = Probability of a truck unavailability, (1-p)
n = Number of trucks in the fleet
y = Number of trucks working

$$\binom{n}{y}=\frac{n!}{y!(n-y)!}$$

Let us assume that in a truck fleet operation the overall fleet availability is desired to be 85 % (or 0.85). Engineering computations indicate that 10 trucks will be sufficient to do the job if each truck is 100 % available. What happens if truck availability is 90 %? The overall fleet availability is calculated as:

$$p\,(y=10)=\binom{10}{10} 0.9^{10}\, 0.1^{0} = 0.348$$

Clearly, 10 trucks are not sufficient to provide an overall availability of 85 %. Therefore, we must try a fleet of 11 trucks, and calculate the probability that at least 10 of them are in service at any time.

$$p\,(y \geq 10)=p(y=10)+p\,(y=11)=\binom{11}{10} 0.9^{10}\, 0.1^{1} + \binom{11}{11} 0.9^{11}\, 0.1^{0} = 0.697$$

As seen, adding one more truck to the fleet could not provide the desired 85 % availability. Next step is to increase the size by one more truck and recalculate the probability that at least 10 trucks are in service at any time.

$$p\,(y \geq 10)=p(y=10)+p\,(y=11)+p(y=12)=\binom{12}{10} 0.9^{10}\, 0.1^{2} + \binom{12}{11} 0.9^{11}\, 0.1^{1} + \binom{12}{12} 0.9^{12}\, 0.1^{0}=0.89$$

Since 0.89 is greater than 0.85 we conclude that 12 trucks were needed to ensure an 85 % overall fleet availability.